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Eugene Ch'ng
Vincent Gaffney
Henry Chapman *Editors*

Visual Heritage in the Digital Age

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Editors
Eugene Ch′ng
Vincent Gaffney
Henry Chapman
IBM Visual and Spatial Technology Centre
Digital Humanities Hub
University of Birmingham
Birmingham
UK

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Foreword

Digital Heritage: Agora and Agility

Subject disciplines are the building blocks of the academy. From the orderings of the trivium and quadrivium in classical antiquity, to the presence of divinity, natural philosophy, physick and law in the pre-modern era, and from the emergence of the classical sciences in the enlightenment, to the explosion of professional disciplines and the diversification of the humanities and social sciences in the twentieth century it is disciplinary communities—subject disciplines—that have been one of the most visible constituents of scholarship. Today, many of the academy's university curricula, library classifications, research council panels and learned societies retain and perpetuate the differentiations and demarcations of these individual subject disciplines. And, at their centre, each of these disciplines typically preserve their own canon of key works, their own common grammar of research questions, as well as core sets of methodologies and even shared protocols of publishing. Offering identity, community and intellectual equipment to their member scholars, academic disciplines remain, in effect, the tribes of scholarship.

So where does that leave a subject such as digital heritage, as well as the scholars who see themselves working within it? Is digital heritage a discipline? Does it need to be? And does it matter if it is not? There are, after all, no core sets of methodologies at the centre of digital heritage, no routine forms of evidence or data. Digital heritage scholars (most of the time) are not found in one place, and, in fact, are invariably located in an array of other subject disciplines across the arts and sciences. Similarly, with its investigations and investigators so varied, the outputs and publications of digital heritage (both in style and medium) are, likewise, eclectic. Moreover, as a young subject, relative to the rest of the academy, digital heritage has not built (many) organisational norms—be they formal institutions, honours, canonical reference points, pre-eminent journals or even textbooks. Consequently, we might think digital heritage does not satisfactorily meet the usual criteria of an academic discipline as commonly understood—at least not according to orthodox benchmarks. Instead, rather than being a discipline, digital heritage presents itself to us (progressively and excitingly) as something else. What we see instead is Digital heritage as a gathering of many different academics from many different fields. It occupies the space at the confluence of a number of different research trajectories and lines of thought. Instead of a 'discipline' digital heritage is, rather, an 'agora'.

Today, the agora of digital heritage has many notable characteristics. First, there is a fluidity to its shape. As technological invention changes (and with it, responsively, the professional agendas, government policies and funding opportunities) so the spotlight of interest and activity within digital heritage likewise shifts; the last 15 years alone have been testimony to some substantial alterations to the main headline discourse within the subject—from digitisation, to social media, to linked data, to mobile, to gameification, to augmented reality, to 3D printing, to the internet of things... One consequence of this moving story of digital heritage is the ebbing and flowing of the particular expertise drawn into its domain; rather than being permanently resident, experts might only pass through the agora of digital heritage, as and when their expertise becomes relevant.

Another characteristic of digital heritage is its openness to collaboration. Populated by multiple disciplines, and being as much about critical reflection as about practical and technical operation, the research partnerships between academics, as well as between academics and non-academic actors, have become a distinguishing mark of digital heritage activity. These are frequently partnerships not just between academic and heritage organisations, but also with commercial companies—if not the triple helix of all three. This culture of collaboration has also cultivated within the agora an extended definition of expertise. With no single centre to the subject area, and without the hierarchies that characterise some other academic disciplines, digital heritage projects operate in a professional landscape in which the principle of the ensemble thrives, in which (holistically) research and development relies upon mutual support and respect to achieve its goals. And it is digital heritage's culture of intellectual generosity that, in turn, allows approaches such as open publishing, open innovation and open data to flourish within it.

And yet, today, digital heritage (plastic, collaborative and open; an agora rather than a discipline) has the potential to develop further—in two areas in particular. First, digital heritage has the opportunity to be even more localised within its global community of research and practice. It can resist framing universal conclusions on technology and heritage, and instead acknowledge how much place, geography and cultural context matter. After all, the cultures of media usage vary internationally, as does (still) access to technology, and (not least) the relative position of heritage organisations around the world in their respective digital journeys. Research and practice in this area can display a sensibility to these contextual differences, being prepared—if necessary—to write a local theory of digital heritage.

Secondly, digital heritage has the opportunity to harness its own inherent agility. With no disciplinary etiquette to observe, no canonical practice to revere, no orthodox methodologies to reuse, digital heritage can respond, expand and (if necessary) contract to its world accordingly. With a confidence to be agile, digital heritage should be able to challenge itself, and even question its own function and role—especially as we enter a postdigital condition where technology is becoming more naturalised within our heritage organisation, to the point where it may even become inappropriate to reflect at all on something called 'digital'.

But whatever shape it takes next, whichever issues and ideas dominate its discourse, and whoever chooses to offer their expertise and disciplinary perspective to its activity, digital heritage offers a vision of the future of scholarship in the twenty-first century. Its intellectual agility and its place as an agora (rather than as closed discipline) position digital heritage as a maquette of what the wider academy can become.

Leicester, 2013 Dr. Ross Parry

Dr. Ross Parry is a Senior Lecturer in the School of Museum Studies and Academic Director for College of Arts, Humanities, and Law at the University of Leicester. From 2008 to 2011, he was elected Chair of the National Museums Computer Group, and in 2009 was made a Tate Research Fellow. He is currently Chair of Trustees for the Jodi Mattes Trust (for accessible digital culture), and sits on the national JISC Content Advisory Group. In 2012, he was Visiting Professor at the Danish Research Centre on Education and Advanced Media Materials at the University of Southern Denmark. He is the author of 'Recoding the Museum' (Routledge 2007), the first major history of museum computing, and in 2010 published 'Museums in a Digital Age' (Routledge).

Editors' Note

Heritage in the digital age is frequently a visual domain and access to visual interfaces, at a variety of sizes and scales, is often required to support the work and research of heritage practitioners. In this context, there is not surprisingly, a focus on visualisation in many of the contributions within the present volume. Whilst the collection of chapters presented here provides a rich source of visual materials for study, extra materials including videos or supporting imagery that could not be included within the printed text can be accessed through the SpringerExtras portal.

The chapter "Resolving the Carving: The Application of Laser-scanning in Reconstructing a Viking Cross from Neston, Cheshire" has associated images of the 3D scan of the Neston Cross from various positions, detailing the joining fragments, details of the damage to the stone fragments, cable moulding of the edges, a digitally decimated 3D model that demonstrate how the angling of light on the scanned surface changes the visible detail on the stone.

The chapter "Simulation and Visualisation of Agent Survival and Settlement Behaviours in the Hunter-Gatherer Colonisation of Mesolithic Landscapes" is accompanied by a video that demonstrates some of the agent behaviours outlined in the chapter. The video capture of the simulation and visualisation shows multiple views of agents roaming the landscape, leaving resource markers behind which indicates the availability of food and potential settlement areas based on the resource and settlement equations formulated in the text. In the latter part of the video, agents build houses after a settlement map has been constructed (within the 'memory' of the agents) at an area that has the highest score (safety, food and resources): they then collect resources from within the area. The second part of the video shows an interactive version of the software adapted from the simulation for The Royal Society Summer Science Exhibition at Carlton House Terrace, London, 3–8 July 2012.

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The editors gratefully acknowledge the support of IBM, Mechdyne and the FEI Visualization Sciences Group (Avizo team), who supported a decade of cutting-edge research at the Visual and Spatial Technology Centre. Sadly the space is not available to acknowledge the input of so many people over such a long period, although the frequent and widespread acknowledgement of the contribution of the group to digital heritage research, and specifically to archaeological computing, remains a testament to their achievements.

The establishment of the Digital Humanities Hub and the associated research at Birmingham, supported by the European Regional Development Fund, Michael Chowen, Mark Glatman, the Garfield Weston Foundation, Carol Kennedy, and The Leverhulme Trust provided the infrastructure and framework underpinning the world-class, cross-disciplinary research that made much of this book possible. The debt to these individuals and Institutions is gratefully acknowledged.

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Part IV Onwards and Upwards

Contributors

Dr. Graziana D'Agostino graduated in Building Engineering—Architecture (2008). In 2013 she obtained her Ph.D. in "Architectural, Urban and Environmental Design and Recovery" at University of Catania, with Ph.D. thesis entitled "The representation and survey's role in archaeology: from origins to the 3D Laser Scanner. The experience on Tricora of San Lorenzo Vecchio (SR)". Since 2004 she has been collaborating to the teaching's activity of "Drawing of Architecture I", "Drawing of Architecture II" and "Architectural Survey" at Faculty of Engineering (University of Catania). Since 2006 she has been collaborating to the research's activities of the Laboratory of Architectural Photogrammetry and Survey "Luigi Andreozzi" at University of Catania. The research involves the use of innovative digital technologies (Laser Scanner 3D, Photogrammetry) applied to the survey of architectural and archaeological heritage and their representation, conservation and documentation. She has attended several surveying campaigns: Roman Theatre, Odeon and Naumachie of Taormina, Greek Theatre, Dionisio's Ear and San Giovanni's roman Catacombs of Syracuse, Roman Amphitheatre of Catania.

Eamonn Baldwin is a Research Fellow in Remote Sensing at the IBM VISTA Centre in the Institute of Archaeology and Antiquity, Birmingham. He specialises in archaeological survey methods including: geophysical, topographical and terrestrial laser scanning surveys and standing building recording, as well as in the integration and management of spatial data in GIS and CAD systems for analytical purposes and heritage management. His research interests lie in the investigation, interpretation and presentation of archaeological landscapes through remote sensing technologies.

Dr. Vedran Barbarić grew up in Split in Croatia and graduated from the Department of Archaeology of the Faculty of Philosophy in Zagreb in 2004. He successfully finished his Doctoral study at the same Faculty with a Ph.D. thesis "Typology of Pottery from Late Bronze and Iron Age Dalmatia". Since 2005 he has worked in the Department of Art History in the Faculty of Philosophy in Split and has taken part in archaeological field work and excavations focusing on the prehistoric and Roman periods. His primary area of research remains the archaeology of the final millennium BC in Dalmatia and he has directed excavations on the hillfort site at Rat near Ložišća on the Island of Brač, Croatia since

2007. He has published extensively and contributes regularly to scientific conferences in Croatia and abroad.

Eugene Ch′ng is Innovations Director at the IBM Visual and Spatial Technology Centre and the Digital Humanities Hub, the University of Birmingham. He is also a visiting Professor at the Centre for Creative Content and Digital Innovation, University of Malaya. Ch′ng has formal education in a wide variety of fields (Fine Arts, Graphic Design, Interior Architecture, Computer Science and, Electronic, Electrical and Computer Engineering). His research has an overarching theme in Complex Systems Science research for studying and reconstructing physical, social and virtual landscapes. He specialises in advanced interactive Systems, enhanced Virtual Environments, Agent-based Modeling and Multi-Agent Systems requiring large computing clusters for processing of agent-interaction and computer graphics rendering. The fusion of 3D visualisation and complex systems modeling is a unique strength that is applicable to a wide variety of disciplines. His research focuses on a number of complex and interactive systems related to the reconstruction of terrestrial, social, political and virtual landscapes. He also applies cutting-edge technology for facilitating user experience and learning using emerging hardware and information computation in digital heritage. Ch′ng has over 40 peer-reviewed scholarly publications and is actively involved in editorial boards, technical and programme committees in international journals and conferences in his field. Ch′ng is a member of the IEEE Computer Society.

Keith Challis is a Research Associate in the Department of Archaeology at the University of York. For over 25 years he had worked in commercial archaeology in the East midlands and Yorkshire and in academia at the Universities of Nottingham, Birmingham and York. His research interests include airborne and satellite remote sensing, social media and the representation of landscape and heritage in digital media.

Dr. Henry Chapman is a Senior Lecturer in Archaeology and Visualisation and Co-Director of the University's new Digital Humanities Hub. He uses state-of-the-art technology and computers to visualize ancient landscapes and objects. He works closely with a number of museums, galleries and archives to enhance access to collections. One such recent project has been a 'virtual exhibition' of the Eton Myers collection of Ancient Egyptian artefacts currently on loan to the University, bringing access to these priceless treasures to the public at large. Henry's specific research interests focus on applying geomatic technology to model and understand a number of archaeological sites including Iron Age enclosures at Sutton Common (South Yorkshire), the late Neolithic Hatfield Trackway and Platform (South Yorkshire), and the Beccles Iron Age Triple Post Alignment (Suffolk).

Dr. Kevin Colls is a Professional Archaeologist and Researcher currently working for the University of Birmingham as a Research Fellow. He has directed and published archaeological projects throughout the United Kingdom and Europe and has widely travelled to sites across the world. His specialist subjects include island Archaeology, urban archaeology and forensic archaeology. His project portfolio includes major archaeological excavations in many of the UK's urban centres including London, Birmingham, Manchester and Bristol, archaeological survey and remote sensing on Scottish Islands, and rural archaeological surveys in central Greece. Of his current projects, the highest profile is the prestigious 'Dig for Shakespeare' Project in Stratford upon Avon. This globally important project focuses upon the excavation of the final residence of William Shakespeare (called New Place) and the house in which the Bard passed away. This project, and his work on the Scottish Islands, has led to two high profile appearances on television programmes for the BBC (Digging for Britain BBC2, and BBC Alba in Scotland) and Time Team (Channel 4). He works on a number of forensic research projects throughout Europe including sites of the Holocaust.

Dr. Chris Creed works on the ERDF funded Digital Heritage Demonstrator (DHD) project based at the University of Birmingham, UK. He has a Ph.D. in Computer Science and specialises in the area of Human Computer Interaction (HCI) with a particular interest in natural user interfaces. His Ph.D. research focused on the use of interactive avatars to help people improve their dietary habits over multiple weeks of interaction. Chris has also worked as a Research Fellow on a variety of HCI projects including the use of ancient manuscripts on multi-touch tables, creating interactive visualisations for military anthropologists (funded by the UK MoD), and developing a semi-autonomous video annotation system for journalists. His research has been published in several leading international HCI conferences and journals. Chris is currently working with a range of heritage partners through the DHD project (e.g. Birmingham Museum and Art Galleries, Ironbridge Gorge Museum Trust, The Library of Birmingham, and The Hive) to create digital products and evaluate their use "in the wild".

Dr. Simon Fitch took his undergraduate degree in Geology at Durham and a postgraduate degree in Landscape Archaeology and Birmingham. His Ph.D. was a study into the Mesolithic Landscape of the Southern North Sea and its population. He is currently a Research Fellow in Marine Archaeology at IBM VISTA, where Simon maintains an active interest in the use of visual and immersive technologies in the investigation of marine geophysical data. During his archaeological career he has worked on projects from as far as Oman in the Middle East to Fort Hood (Texas) where he worked as an Intern for the United States Military Archaeology Service. His current research interests are now focused upon the study of submerged prehistoric landscapes and marine archaeology worldwide and the impacts of environmental and landscape change upon human populations during prehistory. Simon's present research projects include studying the offshore landscapes of Wales as part of the 'West Coast Palaeolandscapes Project' and the NOAA funded 'Between the salt water and the sea strand' which comparatively studied the inundated marine landscapes of the North Sea and the Gulf.

Dr. Chris Gaffney is a lecturer in Archaeological Geophysics and Course Manager of the M.Sc. in Archaeological Prospection at the University of Bradford.

Prior to this recent appointment Chris worked in the commercial arena as co-owner of GSB Prospection for 18 years. He is the current Chair of ISAP (International Society for Archaeological Prospection) and has been the Editor of the journal Archaeological Prospection since 2005. He is particularly interested in rapid data collecting using low footprint devices as well as the archaeological interpretation of geophysical data. He is one of the investigators on the DART project.

Professor Vincent Gaffney is Chair in Landscape Archaeology at the University of Birmingham. Prof. Gaffney is also a Visiting Professor at the Centre for Creative Content and Digital Innovation, University of Malaya. After graduating from the University of Reading he worked in contract archaeology and museums before undertaking a Ph.D. He then spent several years in former Yugoslavia based at the University of Ljubljana (Slovenia) whilst carrying out survey on the Croatian island of Hvar. This work developed into the major international research collaboration—"The Adriatic Islands Project". Since then he has been involved in many other studies including survey at Roman Wroxeter and the world heritage sites of Cyrene and Diocletian's Mausoleum in Split. Other field projects have included work on the wetland landscape of the river Cetina (Croatia), fieldwork in Italy centred on the Roman town at Forum Novum and historic landscape characterisation at Fort Hood (Texas). Current research projects include mapping the inundated landscapes of the Southern North Sea, agent-based model of the battle of Manzikert (1071) in Anatolia and the "Stonehenge Hidden Landscapes" Project where he leads the UK team creating 3D and virtual imaging of the landscape through an extensive programme of geophysical survey of the largely unmapped landscape. In 2013 he was awarded the European Heritage Prize for his contribution to world archaeology by the European Association of Archaeologists.

Dr. Areti Galani is a Lecturer at the International Centre for Cultural and Heritage Studies, Newcastle University, UK. Her research concerns the use of participatory methodologies in the design of novel digital interventions, such as mobile applications, in museum and heritage settings. She is also interested in how user contributed content and especially photographs are accommodated in museum and heritage exhibition practice. Areti holds qualifications in Museology and Computing Science and has curated projects in Greece and the UK. Areti has led both knowledge transfer and academic research projects with museum and heritage partners and was the co-investigator on the Rock Art on Mobile Phones project.

Dr. Mariateresa Galizia is a graduate in Architecture (1995). In 2001 she got her Ph.D. degree in "Drawing and Survey of architectural heritage" (University of Rome "La Sapienza"). From 2001 to 2004 and from 2006 to 2009 she is lecturer at the Faculty of Engineering, at the Faculty of Mathematics, Physics and Nature of the University of Catania and at the Faculty of Architecture and Engineering of University Kore of Enna. In 2004, she was Researcher of Drawing at the University of Catania, Building Engineer and she is tenured professor in "Drawing of Architecture I" and "Drawing of Architecture II" since today. From 2008 to 2010 she was Member of Ph.D. School of "Architectural, Urban and Environmental design and recovery", Department of Architecture, University of Catania. In 2012 she was Member of Ph.D. School of "Structural and Geotechnical Engineer", Department of Civil Engineering and Environment-DICA, University of Catania. Since 1999, she has been collaborating with the research's activities of the Laboratory of Architectural Photogrammetry and Survey "Luigi Andreozzi" at University of Catania. Her research focuses on survey, knowledge, representation and preservation of architectural and archaeological heritage and historic urban.

Dr. Erlend Gehlken is a Physicist and Assyriologist. Erlend studied at the University of Heidelberg where he received a diploma in Theoretical Physics and a Ph.D. in Assyriology. In 2003, Erlend achieved Habilitation at the University of Marburg, and has since lectured in Assyriology at the Universities of Heidelberg, Frankfurt, Marburg and Birmingham (UK). Erlend is currently associated with the University of Frankfurt/Main, and is editor of a Babylonian temple archive from the ancient city of Uruk.

Dr. Helen Goodchild is Project and Fieldwork Officer in the Department of Archaeology at the University of York. Her research interests lie in the fields of archaeological geophysics, topographic and field survey, with a focus on computer modeling in landscape archaeology. She has worked on a number of landscape projects including the Wroxeter Hinterland Project, the Tiber Valley Project, the Cyrenaica Archaeological Project, and the Lochbrow Landscape Project. Helen's recent work has focussed more on integrated survey, working on various sites in Scandinavia as well as locally in the UK. She has also continued her interest in agronomic modeling using GIS, which she first carried out as part of her Ph.D. in using GIS to model Roman agricultural potential in Italy.

Dr. Stuart Jeffrey is Research Fellow for Heritage Visualisation at the Glasgow School of Art's Digital Design Studio and was formerly Deputy Director (Access) at the Archaeology Data Service. After graduating from the University of Glasgow in 2003, where he researched VR in Scottish Archaeology, his recent research has included major international projects on digital infrastructure, archive interoperability and the archaeological uses of Linked Open Data. He has published extensively on digital preservation and archaeological informatics.

Dr. Branko Kirigin studied Archaeology at the University of Belgrade, and was awarded a Doctorate in 2000 at the University of Split for research on the Greek colony of Pharos (Stari Grad, Hvar). After working at the Historical Institute of the Academy of Science and Arts in Dubrovnik, from 1972 to 1974, he moved to work as a keeper at the Archaeological museum at Split becoming Director from 1982 to 1887 and later Senior Keeper of Greek and Hellenistic Department from 1988 to 2012 when he retired. Since 2007 he has worked as deputy director of the Centre Studia Mediterranea at the University of Split. Kirigin has undertaken many archaeological field campaigns in Dalmatia and his interests in natives and Greek interaction in Dalmatia has directed much of his work towards study of the settlements of the Central Adriatic and especially with the Greek land division on the

Stari Grad Plain on the island of Hvar. More recently his main research has been connected with the discovery of a Diomedes sanctuary on the remote Adriatic island of Palagruža. He is the co-director if the international project "Adriatic Islands" and has published extensively and is the author and co-author of seven books and some 90 papers, of which many are published in foreign journals and editions.

Dr. Žiga Kokalj defended his Ph.D. in remote sensing in 2010 and is employed at the Scientific Research Centre of the Slovenian Academy of Sciences and Arts. His research interests lie in environment protection and management of protected areas. He is primarily involved in environmental studies using optical satellite imagery processing, Internet cartography, rapid mapping, lidar data processing and visualizing, spatial analyses, and natural processes modeling, especially from the viewpoint of how different human activities impact the environment. He is a member of the Aerial Archaeology Research Group and the International Union of the Prehistoric and Protohistoric Sciences. He regularly participates at scientific conferences and is involved in various national and international projects.

Andrew Lewis is a Ph.D. candidate at The Heritage and Cultural Learning Hub (do.collaboration) at the University of Birmingham and is currently working on a Leverhulme Trust funded research, exploring nature inspired methods for the semi-automatic and manual reconstruction of cuneiform tablets in virtual environments. With a background in Web design, coding, and journalism, Andrew's skill base also includes 3D scanning, additive manufacturing, and mechatronics. His work has been featured internationally in publications as diverse as O'Reilly Make magazine and The Guardian and Observer.

Michael Lobb is a Buildings Archaeologist and Archaeological Surveyor, who for the past 7 years has been applying terrestrial laser scanning (TLS) to the study of the historic environment. His specialisations are in the metric survey and recording of built heritage and the use of TLS and 3D modeling software. From 2005 to 2010 he worked at the VISTA Centre, University of Birmingham developing the use of TLS within both commercial and research archaeology. He is currently studying for a Ph.D. in Developing Terrestrial Laser Scanning of Threatened Coastal Archaeological Sites at the Department of Geography, University of Southampton.

Dr. Krištof Oštir received his Ph.D. in remote sensing in 2000. His main research fields are optical and radar remote sensing and image processing. In particular he has performed research in radar interferometry, digital elevation production, land use and land cover classification, post-processing and fuzzy classification. The applications of remote sensing range from hazard monitoring change detection, archaeological site analysis to paleo-environment and paleo-relief modeling. He is active in the development of small satellites for Earth observation. He is the author of the first Slovenian remote sensing monograph and of a number of papers on remote sensing, geographical information systems and computer engineering, and is a reviewer for the IEEE Transactions on Geoscience and Remote Sensing. He is employed at the Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Centre of Excellence for Space Sciences and Technologies, and as an associate Professor at the University of Ljubljana, where he teaches several courses on remote sensing and satellite image processing. He is the president of the Scientific Council of the Institute of Anthropological and Spatial Studies at the ZRC SAZU.

Dr. Deborah Maxwell is a member of the design team on the SerenA project (based at Duncan of Jordanstone College of Art and Design, University of Dundee) and a research fellow on the AHRC-funded Design in Action Knowledge Exchange Hub, Edinburgh College of Art, University of Edinburgh. Deborah is interested in the ways people interact with and reshape technology, and is investigating the ways in which interface design, storytelling and data visualisation can impact users' perceptions of quality, relevance and sense of engagement with content. Her research background includes work with rural communities and traditional storytellers, where digital technology is applied, but not viewed as a panacea.

Dr. Aron Mazel is a Senior Lecturer and Director of the International Centre for Cultural and Heritage Studies, Newcastle University, UK. Aron was the principle investigator on the Rock Art on Mobile Phones project (2010–2011). Before moving to the UK in 2002, Aron had a 25-year career in archaeological research and heritage and museum management in South Africa. Posts he held in South Africa included Assistant Director of the Natal Museum (1994–1997) and Director of the South African Cultural History Museum (1998–2002). Between 2002 and 2004, Aron undertook the Beckensall Northumberland Rock Art Website Project, which won the 2006 Channel 4 ICT British Archaeological Award. Aron's research interests include the management and interpretation of tangible and intangible heritage; museum history; the construction of the hunter-gatherer past; dating of rock art; and Northumberland rock art. Recent book publications include Tracks in a Mountain Range: exploring of the history of the uKhahlamba-Drakensberg (2007, with John Wright), Art as Metaphor: The Prehistoric Rock-Art of Britain (2007, co-edited with George Nash and Clive Waddington), and uKhahlamba: Umlando wezintaba zoKhahlamba/History of the uKhahlamba (2012, with John Wright).

Dr. Ante Milosević Born and raised in Sinj, Croatia. Milosević studied Archaeology and the History of Art at the Faculty of Philosophy in the University of Split. Graduating in 1976 he also undertook postgraduate studies in the Department and was awarded a doctorate in 2005. From 1977 he was the Director of the Museum of the Cetina region in Sinj and then, from 1994 to 2005, was Director of the Museum of Croatian Archaeological Monuments in Split where he now works as a senior keeper. During this time he has published extensively in Croatian and international journals with much of his work being dedicated early medieval archaeology and art history. Milosević has published several books and has edited journals including *Zbornika Cetinske krajine* (1979–1989) i *Starohrvatske prosvjete* (1994–2004.), and organized or led more than 40 national and international symposia and two international projects. Most notable is his exhibition “Croatians and Carolingians” (2000) as part of the international project “Charles the Great—Creation of Europe”.

Helen Moulden is a Research Associate in Artefact Scanning, Modeling and Reconstruction for IBM VISTA at the University of Birmingham. She specialises in the application of 3D scanning technologies (both object and terrestrial), with particular focus on the convergence of 3D object representations and digital archiving as a means to enhance accessibility and research practices. Her project portfolio includes the Eton Myers Virtual Museum Project, the Jewel of Muscat Comparative Analysis Project and the Stabiaen Graffiti Project. Recent work involves the large scale 3D digitisation of Chedworth Roman Villa to inform research into site phasing.

Dr. Philip Murgatroyd is a Research Associate at the University of Birmingham, currently visualising large geophysical datasets as part of the GG-Top project. His Ph.D. was completed in 2012 as part of the Medieval Warfare on the Grid project and focussed on the use of agent-based modeling in the study of medieval military logistics, using the march of the Byzantine army to the Battle of Manzikert as a case study. He has previously excavated in, and produced 3D models of, Pompeiian houses as part of the Anglo-American Project in Pompeii and studied at the universities of York and Bradford. Prior to that he did almost every conceivable job within the computer industry. His research interests include simulation within archaeology, military logistics, 3D modeling, Roman domestic archaeology and data visualisation.

Kieron Niven is a Digital Archivist at the Archaeology Data Service. He has recently worked on a two-year project revising the ADS Guides to Good Practice and is editor of a forthcoming introduction to digital archiving in archaeology. He was the convenor of the Forum for Information Standards in Heritage (FISH) for several years.

Peter Pehani holds a B.Sc. in Physics and is employed at the Scientific Research Centre of the Slovenian Academy of Sciences and Arts. He was primarily developer of Web mapping applications based on the Internet GIS technology. He has prepared a publicly accessible Interactive map of Slovenia presenting the ZRC SAZU databases, interactive map of Karst region (in Slovene language only) as a part of Fabrica project, and a summary of archaeological reconnaissance in southeastern Campeche, Mexico. Other Web GIS-based applications he develops for specific needs of particular institutes or projects. Lately, he is involved in various phases of satellite data processing, from orthorectification to products development for the fields: disaster management, classification and visualization.

Eleanor Ramsey is a Research Associate at the IBM VISTA Centre in the Institute of Archaeology and Antiquity, specialising in GIS analysis and marine geophysical interpretation. She has a background in commercial archaeology, and her recent project portfolio includes the Humber Regional Environmental Characterisation, the West Coast Palaeolandscapes Project and the Southern North Sea/Qatar project funded by NOAA. Current projects include the Adriatic Islands Project and the Royal Society Summer Science Exhibition. Personal research interests include the use of GIS to analyse documentary and cartographic sources from the 19th century to explore urban development and industrial change.

Professor Julian Richards is Professor of Archaeology and Director of the Centre for Digital Heritage at the University of York. His direct involvement in archaeological computing began in 1980 when he started his Ph.D. research studying pre-Christian Anglo-Saxon burial ritual using the computing power of an ICL mainframe and an early Z80 micro-computer. In 1985, he co-authored the first textbook in archaeological computing for Cambridge University Press, and has subsequently written numerous papers and edited a number of books on the applications of information technology in archaeology. Since 1996, he has been Director of the Archaeology Data Service and Co-Director of the e-journal *Internet Archaeology*. He is a member of the Board of Directors of Digital Antiquity, in the United States. Apart from computer applications his research interests focus on Anglo-Saxons and Vikings. He has directed excavations of Anglo-Saxon and Viking settlements at Wharram Percy and Cottam, and of the Viking cemetery at Heath Wood, Ingleby, and he is currently co-directing a project to investigate the site of the winter camp of the Viking Great Army at Torksey. He is author of *Viking Age England*, now in its third edition, and of OUP's *Very Short Introduction to Vikings*.

Dr. Cettina Santagati is Building Engineer (1997, University of Catania). In 2003, she got her Ph.D. degree in "Drawing and Survey of architectural heritage" at University of Rome "La Sapienza". Since 1999 she collaborates to the research's activities of the Laboratory of Architectural Photogrammetry and Survey "Luigi Andreozzi" at University of Catania. In the 2012–2013 academic years she is lecturer at Faculty of Architecture (University of Catania, site Syracuse) and at Faculty of Engineering (University of Catania). From 2010 to 2011 she holds a post Ph.D. research grant at Faculty of Engineering of University of Catania. Her research focuses on: Architectural and archaeological survey aimed at the knowledge, representation and preservation of built heritage; Graphical analysis of architecture; Survey of historic urban fabric and studies of historical and present maps; CAD and Descriptive Geometry. Since July 2012 she is the head of the Section "Innovative technologies for surveying and 3D reconstruction" of the Department of Communication, Interactive Graphics and Augmented Reality of IEMEST (Euro Mediterranean Institute of Science and Technology), Palermo. She is author and co-author of 60 scientific publications (books, book chapters, article in Journals and International proceedings) for the most part presented at International Conferences.

John Sear is both the co-founder of wallFour and Senior Technical Developer at University of Birmingham's Digital Cultural Heritage Demonstrator (DHD) Project. wallFour are internationally acclaimed for bringing technology from the videogame sector to live events. Their largest world to data Renga, a feature length 100 player experience for cinema, lies on the convergence between film and games and has been featured at South by Southwest, New York International Film Festival and the Toronto International film festival. DHD works with key heritage organisations and aims to demonstrate how collaborative projects exploring the use of digital technology with the Cultural and Heritage sector can develop new markets for business. Both of these roles require John to work with new technology in order to design and develop unique collaborative crowd experiences. John started his professional academic career at the University of Manchester where he combined teaching with research. He was a member of the High Performance Computing group studying for a Ph.D. in Computer Vision while also teaching at undergraduate level. From here he joined Codemasters where he worked on Massively Multiplayer Online Role-Play games. He returned to academia, combining both his industrial and academic backgrounds to develop a ground breaking degree course, specialising in the advanced software engineering required for large-scale triple-A game development. The course received recognition from industry for its focused approach to industry and employability. During his 7 years as Programme Leader, John also ran his own digital download games studio specialising in games for iOS devices.

Dr. Gareth Sears is Senior Lecturer in Roman History at the University of Birmingham. He works on Roman urbanism, particularly in North Africa, and the Christianisation of the city and society. He is the author of The Cities of Roman Africa and The City in the Roman West with Ray Laurence and Simon Esmonde Cleary. Most recently he has edited Written Space in the Latin West with Peter Keegan and Ray Laurence. He has co-directed projects in Cyrene, Libya and Dalmatia, Croatia.

Dr. Armin Schmidt is an Archaeological Geophysicist and IT pioneer, initially trained as a physicist. He has applied novel methods of geophysical prospection worldwide from Ecuador to Iran, Nepal and Japan, working as a researcher and UNESCO consultant. He is Founder of the International Society for Archaeological Prospection (ISAP), as well as co-founder of the Archaeology Data Service (ADS) and of the Bradford Centre for Archaeological Prospection (B-CAP). His specialisations are in near-surface geophysics for archaeological prospection and geoarchaeology; geodata processing; and computer applications in archaeology. He has written books on geophysical data in archaeology, and on magnetometer and earth resistance surveys for archaeologists. After obtaining a physics Ph.D. from the RWTH Aachen, Germany, he worked in the Department of Archaeological Sciences, University of Bradford (UK) from 1993 to 2010 as a Senior Lecturer. In 2010 he founded the company GeodataWIZ Ltd, which specialises in the advanced processing and visualisation of geodata. He holds honorary appointments with the archaeology departments of University of Bradford and Durham University.

Dr. Kate Sharpe is a Research Associate at Durham University, England. Her research focuses on prehistoric rock-art in the British landscape. She has also led community recording projects, resulting in the England's Rock Art database, and co-edited 'Carving a Future for British Rock Art. New directions for research, management, and presentation' (Oxbow Books, 2010).

Lawrence Shaw is the Heritage Mapping and Data Officer or the New Forest National Park Authority. Although heavily focused on the use of remote sensing to identify and manage archaeological monuments found in the National Park, Lawrence has always been interested in looking at landscapes as a whole and has been involved in a number of leading landscape projects including the Stonehenge Riverside Project and the Rapa Nui; Landscapes of Construction Project. His interest in modern technology, in particular that of mobile devices, led to his undertaking of master's dissertation at the University of Birmingham, the results of which can be seen in this book. To date he is currently looking at the use of tablet devices to aid with survey and LiDAR interpretation whilst undertaking ground verification work.

Joseph Sivell is a digital experience designer who has worked in museums and the heritage sector for many years. He specialises in creative concepts, digital storytelling and e-learning. His background covers both the technical and design side of digital media. He read engineering at Cambridge University and design and production of interactive multimedia cultural databases at Portsmouth school of design. After several years of working for digital media agencies in the tourism and heritage sector Joseph moved to the British Museum where he led the Educational Multimedia Unit for nine years. This multi disciplinary team was set up to devise innovative uses of new media for museum collections and to explore its potential for learning and audience engagement. Joseph subsequently set up The Field Unit, an umbrella for a group of digital creatives and consultants who work together in the wider heritage and education sectors. He is now Creative Director on the Digital Heritage Demonstrator project at the University of Birmingham. Current projects include touch tables for the Staffordshire hoard, Birmingham History Galleries and the Hive, Worcester.

Tom Sparrow is currently a research assistant at the University of Bradford working on the 'Digitised Diseases', a JISC funded project digitising human remains and 'Visualising Animal Hard Tissues', an AHRC funded project digitising animal hard tissues. He has worked in a variety of archaeological jobs both in the research and commercial sectors. He works as a data capture and processing specialist, working on many types of landscape and object-based data from many research fields ranging from geophysical data to CT data. He also designs and builds bespoke hardware and software set-ups for use in the capture of data and imagery.

Dr. Caroline Sturdy Colls is a Lecturer in Forensic Investigation at Staffordshire University and practicing Forensic Archaeological Specialist for various Police Forces across the UK. Her research focuses on the application of interdisciplinary approaches to the investigation of Holocaust landscapes and the establishment of a sub-discipline of Archaeology that solely examines this period of history. In particular, Caroline has developed a non-invasive methodology which allows the scientific, ethical and religious aspects associated with studies of this period to be upheld whilst allowing fieldwork, education, visualisation and dissemination to take place. Caroline has worked across Europe, including completing the first archaeological survey at the former extermination camp at Treblinka, Poland, as well as Alderney in the Channel Islands and the former Semlin Judenlager and Anhaltelager in Belgrade, Serbia. Caroline is also a member of the Scientific Advisory Council for Kamp Westerbork Archaeological Project in The Netherlands and an active member of a number of research groups in Holocaust and forensic archaeology, including Buried War Pasts, the Atlantic Wall Research Group and the Burial Research Group at Staffordshire University.

Professor Harold Thwaites is currently Consultant Professor at University of Malaya and Director of the Centre for Creative Content and Digital Innovation. Originally from Canada, he was a tenured Associate Professor of the Communication Studies Department at Concordia University in Montreal for 31 years and Dean of the Faculty of Creative Multimedia at Multimedia University, Malaysia from 2006 to 2012. He is now Adjunct Associate Professor. Thwaites has served as a government and industry consultant, while his research and teaching comprised media production, information design, digital heritage, biocybernetic research, and 3-D spatial media. He was the first overseas researcher at NHK Science and Technical Research Labs in Tokyo specializing in 3D HDTV, in addition to being the recipient of a Fellowship from the Telecommunications Advancement Organization of Japan. While in Montreal he was a founding member of the Hexagram Institute and was Research Director for Immersive Environments, VR and Audience. His most recent award is Honorary Senior Research Fellow, Department of Antiquity and Archaeology, at University of Birmingham, UK.

David Tomčík is a student at the Institute of New Technologies and Applied Informatics in the Technical University of Liberec. His research involves the application of novel technologies for design of 3D models with reference to their coordinate space. He is primarily interested in creation of processes for the creation of models and data conversions using freeware tools. David is currently working on his Ph.D. thesis although he is also working as a commercial IT analyst.

Dr. Roger H. White is an archaeologist who has worked for much of his academic life on the Roman town of Wroxeter in Shropshire. He has broad interests in the archaeology of the later Roman Empire and the early Middle Ages, and at the transition between the two. Since 2000, he has been Academic Director at Ironbridge Institute and has increasingly focused on heritage and its management as well as looking at the archaeology of the industrial age. He also has strong interests in material culture and its study. He has an active engagement in the archaeology sector through membership of the English Heritage Advisory Committee and his editorship of the journal *The Historic Environment. Policy and Practice*.

Dr. Sandra I. Woolley is a lecturer in the School of Electronic, Electrical and Computer Engineering at The University of Birmingham, U.K. She trained as a graduate apprentice engineer with Lucas Aerospace, U.K. and received the Ph.D. degree in Electronic Engineering from The University of Manchester in 1994 before working as a researcher at the National Institute of Standards and Technology (NIST), Maryland, U.S.A. She has lectured students in a variety of subjects, including microcontrollers, multimedia and computer networking. She has previously researched digital imaging and data storage, and her current research interests include aspects of e-health and, in particular, new applications in rehabilitation and assistive technology. She also works on multidisciplinary research in cultural heritage and has enjoyed contributing to two Leverhulme funded projects related to the digital heritage of cuneiform tablets.

Chapter 1
Seeing Things: Heritage Computing, Visualisation and the Arts and Humanities

Eugene Ch′ng and Vincent L. Gaffney

Abstract Digital technology and visualisation play an increasingly large role within the strategic framework of the Arts and Humanities. This is not in itself unexpected given the nature of research in these disciplines but the need to obtain and process large amounts of data, to gather this from disparate locations and then to link and disseminate this information in a manner that challenges researchers and informs the wider public which is both a challenge and an opportunity. Digital technology in Heritage is at the forefront of such a development through its relationship with large scale or pervasive visualisation and emerging human–computer interfaces with efficient algorithms for the processing, analysis and access of linked large-scale datasets. The "Big Data" worlds created by Arts and Humanities and Heritage research are proxies through which we may access the past and also make sense of the world in which we live. In this context therefore, the state-of-the-art applications presented in this volume provide a snapshot of our current position in this exciting new research landscape. The collection of chapters presents digital technology as part of an iterative process of investigation within Arts and Humanities, encompassing data capture, processing, analysis, interpretation and dissemination via interactive visualisation. The content of this book is inspired by the themes—objects, monuments, landscapes and behaviours and each chapter presents original research associated with the exploration and application of digital visual technologies within these research domains within. As a whole, the chapters demonstrate the diversity and scale of research in the discipline, and the utilisation of a wide range of digital technology to facilitate research on the frontiers of digital heritage.

E. Ch′ng (✉) · V. L. Gaffney
IBM Visual and Spatial Technology Centre, Digital Humanities Hub,
The University of Birmingham, Edgbaston, B15 2TT, UK
e-mail: e.chng@bham.ac.uk

V. L. Gaffney
e-mail: v.l.gaffney@bham.ac.uk

E. Ch′ng · V. L. Gaffney
Centre for Creative Content and Digital Innovation, Universiti Malaya,
50603, Kuala Lumpur, Malaysia

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> Trace Science then, with Modesty thy guide;
> First strip off all her equipage of Pride,
> Deduct what is but Vanity, or Dress,
> Or Learning's Luxury, or Idleness;
> Or tricks to shew the stretch of human brain,
> Mere curious pleasure, ingenious pain:
> Expunge the whole, or lop th' excrescent parts
> Of all, our Vices have created Arts:
> Then see how little the remaining sum,
> Which serv'd the past, and must the times to come!
> The proper study of Mankind
> ~ (Alexander Pope 1688–1744).

The role of computing and visualisation has rapidly been established as a strategic issue within the Arts and Humanities.[1] Such developments are not unexpected as the need to mine and process the increasingly large amounts of Arts data held in disparate locations, and the need to satisfy our increasingly complex academic aspirations, have inevitably pushed us towards the greater use of technology and a reliance on visualisation to make sense of the world in which we live.

The ubiquity of technology and its formative role in social and academic arenas is also driven by the increasingly Rabelaisian appetite of contemporary society for visual imagery, and again the role of visualisation has emerged as an integrating theme across the Arts and Sciences more broadly (Greengrass and Hughes 2008). This may be particularly clear in relation to heritage studies and the manner in which the past is being appropriated through the creation of vast, and increasingly interlinked, digital archives. Indeed, largely because of this, the pervasive nature of visualisation and, perhaps, the fetishisation of visualisation technologies have itself become a significant research issue. In both Social Sciences and the Arts there is an appreciation of the impact of technology on society and social agendas. These trends may also be encouraged by the increasing financial support for studying in these areas, driven within the UK at least, by research funding agencies who see the digital agenda as one in which they may demonstrate wider social impact.

The reasons for research interest in digital humanities may be complex but this does not deny the significance of these technologies for our society. We daily experience imagery that is cascaded as a proxy for reality (e.g., IMAX documentaries) or that are provided as explanatory guides to processes that transcend the capacity of individual comprehension, e.g. the MIT SENSEable City Lab's visualisation and tracking of 'senseable' household trash across the United States. We generate experiences and novel social groupings through gaming and

[1] See for example the scheme for the British Arts and Humanities Research Council's "Digital Transformations in the Arts and Humanities" and "Digging into Data" initiatives.

immersive environments (Cole and Griffiths 2007), experience elevated social status (Ducheneaut et al. 2006, p. 7), trade commodities and, in the case of the Bitcoin, and Second Life Linden$, even engage in parallel economies and currencies through these digital spaces (Jonas 2006). Increasingly our mediated world is visualised and interacted with via small and large digital displays that have penetrated the fabric of society to the extent that the boundary between the virtual and the real has become fuzzy, and, for better or worse, digital imagery has increasingly become a substitute for reality (Bugeja 2005; Yee 2006). For heritage, visualisation technologies provide powerful tools that can invoke the sense of presence (Lee 2004), a psychological state where, "virtual objects are experienced as actual objects in either sensory or nonsensory ways", or "a state of consciousness, the (psychological) sense of being in the virtual environment" (Slater and Wilbur 1997). In some sense, Baudrillard's "precession of simulacra" may have been achieved and experiential reality may now be deemed to have been realised without any prior basis in reality (Baudrillard 1983; Ch′ng 2009). It is no surprise, therefore, that understanding the position and significance of the virtual, via the proxy interface of visualisation, is increasingly recognised as a high priority for heritage professionals or that the wider theoretical content and significance of apparently abstract digital processes has been debated at disciplinary and social scales (Gregory 1994; Pickles 1994; Tilley 1994).

The process of visualisation itself, however, does not exist without a prior reality. Whether or not any existing data may be used as a visualisation, the act itself requires an increasingly complex mix of technologies to achieve verisimilitude or be applicable to heritage issues. As such heritage specialists must be concerned with how technology itself develops. Whilst it is widely appreciated that technological developments follow certain trends, for instance that observed by Moore (1998), there are other, equally important, "laws" linked with Gilders (2000) and Metcalfe (1995). The better known Moore's law suggests that the processing power of a microchip doubles every 18 months and, effectively, the price of a given level of computing power halves over a similar period. This has implications not only for processing speed, but also for other information storage devices—integrated circuits that stores millions of transistors and capacitors, such as the storage capacity of computer memory (Chip 2005)—and also imaging devices that deals with pixel data (Myhrvold 2006). Gilders's law states that the bandwidth of communications systems triples every 12 months—three times as fast as the growth of computing power suggested by Moore's law whilst Metcalfe's law asserts that the value of a network is proportional to the square of the number of connected users or nodes on the network. This means that the increase of nodes or users in a telecommunications or social network increases the value or usefulness of that network in terms of the ability to communicate and disseminate information.

The changes predicted by Moore, Gilders and Metcalfe will be of vital importance in heritage computing. As technology grows in a nonlinear fashion, our ability to gather and store large amounts of data and the capability to speed up the processing of information using parallel and distributed computing approaches, will grow at an exponential rate but bandwidth and the connectedness of networks will also change rapidly—and this will have significant impact on how researchers work and their links into wider digital communities. At the time of writing, the authors already collaborate using a Cloud service that manages the distribution and sharing of files—changes on an author's documents are instantly reflected on the computer of a collaborator. Mobile telecommunications coupled with GPS (Global Positioning Systems) and Web 2.0 features (O'Reilly 2007) are also providing the means to crowd-source using geolocation services, share and distribute information beyond the academic community, all within either a 2D or a 3D virtual world. The future of the connected Web will provide a host of services that will provide heritage information as personalised learning with meaningful subscribed content pushed to users via the Semantic Web (Antoniou and van Harmelen 2008). The Semantic Web (or Web 3.0) provides a base for intelligent software agents as service providers that learn our behaviours and automatically deliver collated information for users. As the establishment of hardware infrastructures matures, the software that sits on it will become increasingly intelligent and complex, it will enhance our user experience (Ch′ng 2013). At a practical level the significance of such developments can be gauged in the exponential change within the Birmingham computer group which, 15 years ago, was served by a local network of 26 PCs and a server that, eventually, boasted 4 gigabytes of storage and 64 megabytes of RAM. The capacity of much of that system could be replicated now in a single large workstation. The system today includes some 32 individual work stations, is supported by an in-house licence server, storage and render farm with 16 terabytes of storage, connectivity via 48 optic fibres including s dedicated link to the web and a 1Gbps link to the BlueBEAR cluster and *c.*150 terabytes of user disk space (BlueBEAR 2012). The theoretical peak performance of the compute nodes is 848 (cores) * 2.2 (GHz) * 8 (floating point operations/cycle), at 15 TFlop/s. The capacity of the current system has been transformed not simply by raw computing power but by connectivity and bandwidth. The top 500 High Performance Computing Systems of course, boasts greater computing power. As of writing, the world's fastest super computer–China's Tianhe-2 (Milky Way-2) operates at 33.86 petaflop/s, the equivalent of 33,860 trillion calculations per second, with a theoretical peak performance of 54.9 petaflop/s.

Having made this point, we must consider whether heritage studies actually need access to such powerful systems. Fortunately, such justification is relatively easy to provide. It is clear that many Arts disciplines operate at an interface with natural sciences and where this happens there is a natural propensity to generate large amounts of spatial/numeric data. Archaeology and its relation to landscape is an obvious example of a situation where a traditional arts discipline has been transformed by large-scale digital data sources, most notably generated by remote sensing, which have no existence other than in a digital format. The heterogeneous nature of Arts data also generates a requirement for data discovery and data mining at a monumental scale. Corpus linguistics can be cited as a discipline in which the whole of language may be considered an appropriate area of study. The requirement for a range of complex visualisation technologies for the purpose of representation, interpretation, restoration or aesthetic display increasingly demands high resolution modelling in areas such as architecture and art history which demand fidelity of representation. This cascades for many Arts disciplines that have an almost constant engagement with the general public, the media and creative sectors at a visual level. Ultimately, real-time exploration and the complex nature of individuals, societies, agency or action cannot be performed without such support. Human existence always carries the notion of a "being in the world" and the implication of a complex entanglement of relations between people, objects and environment (Dreyfus 1990; Hodder 2012). Such studies are infinitely complex and, usually, only one act within a larger, iterative process of collection, selection and manipulation of data that never actually ends (Fig. 1.1). Data and interpretation now cascade in a manner that was never realised previously and these networks will merely expand as computer systems become more powerful and, perhaps more importantly, all data becomes interlinked. The process of heritage computing is therefore a highly complex act and no individual part of the process, from data collection to interpretation, is independent. The debate, within archaeology at least, concerning the legitimacy of visualisation as an isolated output emphasises such a position (Exon et al. 2000; Gillings 2001; Wheatley and Gillings 2002) (Fig. 1.2).

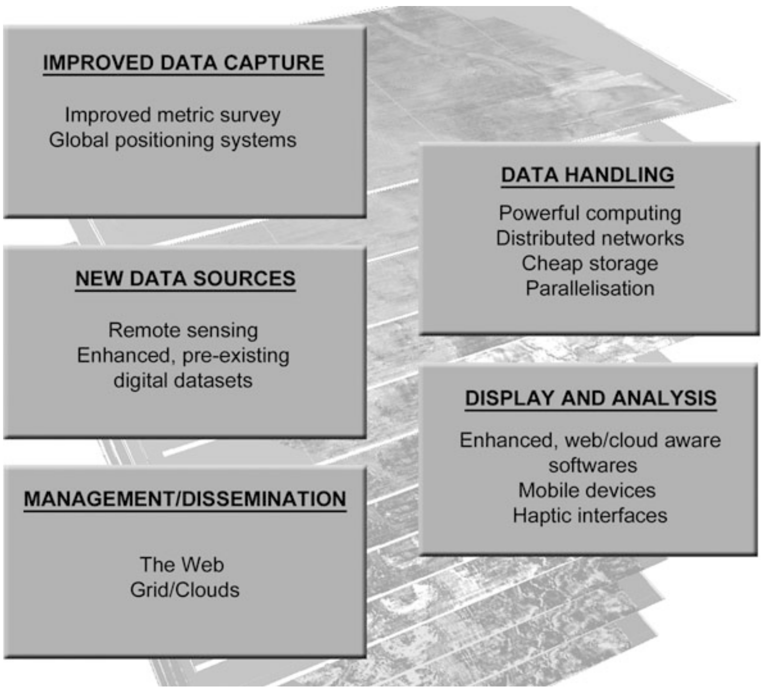

Fig. 1.1 The technology context of digital humanities

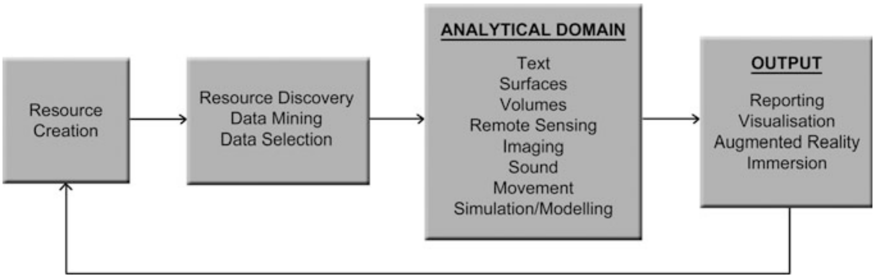

Fig. 1.2 Primary activities in E-science (reprinted from Ref. Gaffney 2008)

Consequently, the current volume presents interactive visualisation only as one part of an iterative process of investigation within the Humanities along with data capture, processing, analysis, interpretation and dissemination. This does not, however, suggest that any specific process is generic. The challenge of Arts and Humanities computing, following Alexander Pope, is that its subject is humankind. Whilst we can create entities that approximate reality, we cannot create reality itself—past or present. Specifically, the issues of scale dependant behaviour within the context of Arts and Humanities computing certainly come to the fore and the issues relating to the selection of representation remain an issue throughout the sections of this book (Lock and Molyneaux 2006). This should be evident in the organisation of papers in which is linked to both scale and process. The first Chapters are inspired by objects both in terms of data capture (Chapman et al. Chap. 2 and White Chap. 3), the organisation of data (Ch′ng et al. Chap. 4) and their representation and accessibility within increasingly complex sensory environments (Creed, Seville and Sears, Chap. 5). The study of monuments provides an equally complex arena for analysis or display that may cross temporal and physical scales. The capacity of monuments to communicate a variety of messages, perhaps at the same time, to change with time and to retain social values which may be highly contested, should be apparent to most observers (Bradley 1998). The complexities of adequate data capture for monuments (Santagati et al., Chap. 11) go hand-in-hand with studies that examine the evocative nature of monumental heritage. There should be ready parallels between the processes by which the mausoleum of Diocletian, a Roman emperor famous for his persecution of Christians, was transformed into a cathedral (Gaffney et al.) and the contemporary issues of representation of modern concentration camps (Sturdy-Colls and Colls, Chap. 7). At the landscape level, the issues of communication remain profound and transcend technology as a study in its own right.

Mapping is always contentious and multivariate in semiotic terms and these issues exponentially proliferate with technology itself (Edson 1997; Pickles 1994). The issues of mapping historic data and what these represent may become more problematic as the opportunity to integrate and analyse historic graphical, textual or numeric data increases (Ramsey, Chap. 8). This become explicitly contentious in heritage mapping at a supranational scale which brings with it issues relating to ownership and opportunity. In developing regions, how can our digital product support communities that may feel a deep connection with the heritage landscape and a wider society that may believe itself be philanthropic, but seeks to benefit from economic development of indigenous cultures (Kokalj et al., Chap. 9)—"Science without conscience is the soul's perdition" (Rabelais 1955). The future may be mobile but the use of mobile technologies both to collate information from respondents within the landscape (Shaw and Challis, Chap. 15) or to inspire an infinite number of interpretations of abstract rock art within the landscape (Areti, Chap. 10) or design space, is challenging for most heritage practitioners. What will happen as experts loosen their authoritative hold on data? Who owns the past has been debated before (Yoffee and Sherratt 1993), but the issues have never been so relevant as now. Today, data cascades through society, rather than learned societies, and how we construct our record, or record our understanding, is becoming a battlefield. Whilst in the past it may have been sufficient to understand the observed, the individual, or the society under study, today we are as likely to give as much weight, and occasionally more, to the observer when considering the results of humanities computing. If so, the increasing complexity, and adequacy, of our models will fast become an issue. Even the simplest societies challenge technology to provide an adequate representation of the past. Whilst the past as a foreign country is a cliché in heritage literature, the capacity of technology to reveal habitable landscapes that are physically beyond the reach of archaeologists and historians, rather than simply represented indirectly by the chances of survival, taphonomy and "time's arrow", present novel challenges in reconstruction (Fitch, Chap. 14). The potential for Complex Systems Science and the application of agent-based modelling within a multiagent systems framework is gradually coming to the fore in these and other, related contexts and there is a well established literature which remains to be tapped by Arts practitioners (Holland 1995; Kauffman 1996; Lewin 1993; Mainzer 1994; Miller and Page 2007; Mitchell 2009; Pagels 1988; Waldrop 1993). These are supported by emerging journals on complexity from large publishers (Complexity, Wiley, Journal of Complexity, Elsevier, Complexity, Springer) and numerous conference proceedings on the topic. There is increasingly an appreciation that Complex Systems Science is important if society and its understanding of its economic, scientific, cultural and political components are to advance. Heinz Pagel, in *Dreams of Reason* (Pagels 1988) provides a direct statement: "I am convinced that the nations and people who master the new sciences of complexity will become the economic, cultural, and political superpowers of the next century". Also, when asked what the next century will be, Stephen Hawking replied, "I think the next century will be the century of complexity" (Stephen Hawking, January 2000). How then we should anticipate this brave new world of Complex Systems Science and how is the study of complex systems relevant to the study of present and past heritage?

Complex Systems Science studies systems that have a population of interacting entities that are strongly coupled in analysis. These systems exist in every hierarchy of our universe, from the molecular level to populations of organisms within ecological boundaries and from society to the global environment and planetary systems. Complex Systems Science complements, but moves on from, reductionism; it explores and attempts to link macro-level properties of systems such as emergence and self-organisation (De Wolf and Holvoet 2005; Halley and Winkler 2008; Holland 1998) with interactions between individuals at a local level. The study of complex systems includes the by-products of society such as culture, economy and technological developments (e.g. the Internet, Social Networks and etc.). The principles of the study of complexity are similar across all complex systems and attributes at the micro level are similar to those that are in the meso and macro levels. This is the reason why complexity theory is appearing in many fields and where the maxim that "the whole is more than the sum of its parts" can be held (Aristotle, Metaphysica 10f–1045a). Complexity modelling and simulation via agent-based modelling can help us understand phenomena in ways that are impossible using traditional means—the distribution of wealth within a society, the emergence of social groups, population movements in climate change, the development of culture and the evolution of landscape use, among many examples. An appreciation of the "entanglement" or complexity of social and natural environments has recently come to the fore in a publication by Ian Hodder (2012). However, whilst such processes may be described in conventional terms it is unlikely that the complexity of the analyses that he proposes can be understood through traditional means (Hodder 2012). Complex Systems Science, ABM modelling and interactive visualisation is more likely to be essential in this field for hypothesis testing and for generating new knowledge within this emerging area of study rather than traditional methodologies.

In an increasingly mediated world there are real opportunities for transforming research in the Arts and Humanities, and for engaging the 'Net generation' (Tapscott 1998), 'Digital Natives' or 'Digital Immigrants' (Prensky 2001) through informative, media-rich and interactive learning and teaching styles (Prensky 2006). The penultimate group of papers in the volume builds upon and expands this area. Ch′ng and Gaffney (in Chap. 12), and Murgatroyd (Chap. 13) provide examples of ABM applications in prehistoric and historic contexts. These papers demonstrate that whilst many researchers may question the capacity of historic data sets to provide the answers we need about the past, it need not follow that data, even if it exists, is necessarily the answer. However, our emerging capacity to simulate human agents and their place in the world can provide different insights into very traditional questions. Finally, as consumers of digital data and interpretation, how will we relate to wider society in the future? What will our data collections look like in the near future and how will we access them (Richards, Chap. 16)? How will we react to the scale of data availability (Thwaites, Chap. 17) and will the mediated display continue to rule the passive visitor or will the visitor be in control?

Finally, the last paper draws together some of these themes and consider what may emerge in the future. In some senses the views here are generated by the experience of many of the authors who work or have worked within the Visual and Spatial Technology Centre (VISTA) at Birmingham. This is not coincidental, given the nature of technical development within academia and the relative size of the national communities engaged with heritage computing up till now. However, the success of VISTA at Birmingham was essentially a product of the people employed and the vision they displayed rather than simply the technology used. Technology was always adapted or developed on the terms of the Arts and Humanities. Pope's poem at the start of this introduction assertively states that the proper study of mankind is (wo)man. This was always the goal of the VISTA group and our appreciation that the Arts truly require resources capable of modelling exponentially expanding data sets and the complexities of human action. There was never a loss of nerve in respect of ambitious research development at VISTA in this respect and more recent developments, such as the Birmingham Digital Humanities Hub, largely represent an extension of these tenets. The torch may well have passed on from the archaeological technology team at Birmingham to a broader heritage grouping but we hope that the wider vision of VISTA has not been lost for the Arts—"the glory, jest and riddle of the world"! (Pope 1734).

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Part I
The Material World
Objects and Structures in Context

The fact that objects and monuments have their own lives and histories has been appreciated by cultural researchers for some considerable time. Malinowski's (1920) work on the objects involved in the Kula Ring is an early, seminal study on how objects acquire significance in an anthropological context and this applies equally to structures and monuments in archaeological and historic situations (Bradley 1998). These may acquire and change form over time and the original meaning of a monument may be lost or evolve over thousands of years. Such qualities, of course, do not change with the incorporation of objects and structures in the modern world, their display in museums or through the representation of objects in digital or other media. Indeed the situation has become even more complex. Whilst in the past museums may have battled with thorny issues of authenticity and the implications of reconstruction; today researchers explore novel forms of data capture and analysis, curators provide innovative means to

display cultural object and the public consumes this information in a novel and, increasingly personal manner. Who owns heritage and the terms on which we engage with that increasingly intangible concept is a contemporary problem. Here we explore some of the technologies that are contributing to this debate and the contexts within which they may operate.

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Chapter 2
More Than Just a Sum of the Points: Re-Thinking the Value of Laser Scanning Data

Henry Chapman, Eamonn Baldwin, Helen Moulden and Michael Lobb

Abstract High-definition laser scanning is becoming increasingly popular within the field of heritage, with applications ranging from the digital recording and analysis of landscapes to buildings and objects. In some ways the uptake of this technology reflects new ways of addressing old questions, but with the potential for greater accuracy and density of spatial information. Through the exploration of three case studies, this chapter highlights the additional value that laser scanning can bring to heritage applications, with each example showing how the re-tasking of the captured data can result in additional benefits that extend considerably beyond the initial intentions. It is argued that, unlike the results from more conventional survey methods, high-definition laser scan data can exist independently from the original intentions of the survey and that it holds considerable value for addressing previously unimagined possibilities.

Keywords High-definition survey · Laser scanning · Re-tasking data · Museums · Conservation · Presentation

H. Chapman (✉)
Digital Humanities Hub/IBM VISTA, Department of Classics, Ancient History and Archaeology, University of Birmingham, Birmingham B15 2TT, UK
e-mail: h.chapman@bham.ac.uk

E. Baldwin · H. Moulden
IBM Visual and Spatial Technology Centre, University of Birmingham, Birmingham B15 2TT, UK

M. Lobb
Geography and Environment, University of Southampton, University Road, Southampton SO17 1BJ, UK

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2.1 Introduction

The potential of high-definition laser scanning survey has been demonstrated within the field of heritage for its ability to capture highly detailed and accurate information regarding surfaces of objects, structures, buildings and landscapes. At its broadest level, airborne laser scanning (LIDAR—Light Detection and Ranging) has provided opportunities to generate highly accurate, high-resolution models of entire landscapes (e.g. Crutchley 2006), with the ability to map the topography of land surfaces even through dense tree cover (e.g. Doneus et al. 2008). At a terrestrial level, laser scanning has provided the opportunities to record built heritage at high accuracy and at dense resolution both on its own (e.g. Rüther et al. 2009) and in combination with other techniques (e.g. Al-kheder et al. 2009). At the object scale, laser scanning has been applied to the interpretation of artefacts and to the objective documentation of metric data, such as physical dimensions with the potential for using outputs to derive further information. For example, a study of Palaeolithic axes used the results of laser scanning to determine objective and systematic measurements that could be used in documentation and interpretation (Grosman et al. 2008). Similarly, a study focusing on the scanning of ceramics was aimed at extending metric analysis through measuring factors including the rotation axis of wheel thrown pottery (Karasik and Smilansky 2008). In some cases, similar approaches have been used to generate reference collections as aids to assessment and interpretation of material such as faunal remains (e.g. Niven et al. 2009).

It has been noted that “metric survey forms the base map upon which our conservation actions are planned and recorded: mapping the historic environment helps us to understand, manage and enjoy it” (Andrews et al. 2009, p. 1). However, despite the development of laser scanning as a method for capturing high-definition, high-accuracy datasets, the metrical description of an object, building or landscape is not in itself an act of interpretation (Gaffney 2008). Hence, the real potential of the data derived from laser scanning surveys lies in its facility for re-tasking that enables it to address multiple challenges at once. For all approaches of high-definition survey, including laser scanning, the output provides an archive of data that could be re-used in the future, both in terms of documented interpretations, but more importantly the scan data itself. The real value of the use of high-definition survey rests in the way in which data that was perhaps generated for a particular purpose can be re-tasked for additional purposes.

In this chapter, we present three case studies from the work of the VISTA Centre at the University of Birmingham. Each project focused on the collection of high-definition laser scan data in order to achieve a specific aim. However, in each case, the benefits of the resulting laser scan data have extended beyond the initial aim, including raising new questions and opportunities. Together the projects demonstrate the potential added value of high-definition data through its re-tasking for a range of additional purposes that extend from archiving, analysis, interpretation and accessibility and public presentation. The first example centres on the generation of high-resolution models of artefacts for the generation of a virtual museum with the aim of providing accessibility to wide demographics via the Internet. The second example focuses on issues of conservation regarding wet-preservation of organic artefacts and the implications for their future management and archiving. The final example concerns built heritage and the value of laser scanning as a tool for virtual preservation, but with added benefits of re-tasking the data for use by architects and for public communication. Together we argue that these examples demonstrate how the capture of high-definition data enables new ways of engaging with heritage at a range of levels.

2.2 Eton Myers Collection Virtual Museum

Museum collections provide excellent opportunities for both the study and public accessibility to the past. There remain certain challenges in that large proportions of collections are never on display, and that the public are separated from objects for the obvious reasons of fragility and economic value. However, perhaps one of the greatest challenges is the physicality of museum collections in that they need to be visited in person in order to experience the objects contained within them. However, there have been considerable attempts to embrace digital technologies and the Internet to, in part, address this challenge and so it has been noted that, “more and more the mnemonic function of the museum is given over to the electronic archive, which might be accessed almost anywhere” (Foster 2002, p. 95).

For the Eton Myers Collection, the challenge of accessibility was significant. This collection of ancient Egyptian art was bequeathed to Eton College, UK, at the end of the nineteenth century by Major William Joseph Myers (1858–1899) who had been a pupil at Eton during the 1870s. His military career as an Aide-de-Camp to the General commanding in Cairo led Myers to first visit Egypt in 1882 where he became interested in ancient Egyptian and Islamic art, and soon distinguished himself as one of the most important private collectors in Egypt. When he died in 1899, Myers bequeathed a collection of approximately 1,300 objects to Eton College, and these collections were subsequently supplemented by objects from el-Amrah, excavated by the Egypt Exploration Fund (1989–1899), prehistoric flint implements donated by the British explorer Seton-Karr and matching objects presented to the collection by Percy E. Newberry during the 1930s, including objects from Beni Hasan. Minor gifts followed (Reeves 1999), and in 2007 a major donation, the Peter Webb and Ron Davey Collection, was handed over to Eton College. It is estimated that there are currently at least 3,000 objects in the collection.

The demonstrable international significance of the collection for scholarly study has been tempered by lack of access, which is augmented by a lack of a complete catalogue or publication about the objects. Hence, in 2008, through collaboration between Eton College and the University of Birmingham, a programme of three-dimensional (3D) digitisation of the objects commenced, funded by the Joint Information Systems Committee (JISC). The primary aim of the project was to address issues of access by making parts of the collection accessible to the broadest possible demographic via the Internet as a virtual collection that could be useful to everyone, from the interested public, to schoolchildren and teachers, through to Egyptological specialists, thus providing a scalable range of need from basic imagery, to interactivity, to the potential for accurate metric analysis. The method chosen for this was laser scanning.

The scanning of the collection used a tripod mounted Konica Minolta Non-Contact 3D Digitiser VIVID-910 which provides relatively short range (most accurate between 0.6 and 1.2 m) but records positional information including colour rapidly and at a high accuracy (±0.22 mm (x), ±0.16 mm (y) and ±0.10 mm (z)). In addition, a selection of the objects was scanned using a NextEngine 3D HD Scanner (2020i) at an accuracy of ±0.13–±0.38 mm at a target surface resolution of 400DPI–150DPI. Both scanners use a triangulation method (using two fixed points on the scanner to determine the 3D position of the reflecting laser light on an object) to provide large quantities of highly accurate data. The 3D nature of the objects meant that it was necessary to scan each item from numerous angles to eliminate any chance of holes in the data and to minimise 'shadows' or 'striping' in the surface colour of the final model (caused due to inescapable variations in lighting). The scans for each object were registered together and archived as raw 'point clouds', before being meshed and cleaned using Geomagic software to provide continuous 3D models. These two outputs (point-cloud and mesh) form the objects that are curated as the high-resolution *Virtual Museum*, each with a file size of between 500 MB and 3 GB (Fig. 2.1).

For online delivery, the sheer file-sizes of the high-resolution models meant that they need to be decimated to a smaller size and converted to a format appropriate for web delivery. Each model was reduced within the Geomagic software and exported to Wavefront OBJ format. This is a simple ASCII-based format that is

Fig. 2.1 Photograph, colour 3D model and colour-stripped, artificially lit model of a shabti from the collection. This item has a hieroglyphic text encircling it and requires the object to be turned to be read

widely supported by most 3D modelling packages, and due to the ASCII representation, the model data lends itself to substantial file compression (approximately 60 %) reducing network transmission time if this is critical. Under this format Geomagic exports texture information in an accompanying material (MTL) file, which is an extension to the OBJ format. The texture images themselves are exported in the common Joint Photographic Experts Group (JPG) graphics format.

For hosting the online presence for the virtual museum established museum software was used. Willoughby MIMSY XG software that is used for online collections such as the British Museum was used to host the collection. However, whilst the software and supporting database is able to host a wide range of media, 3D models cannot be uploaded onto the system. For these models a download site was created to obtain models in a higher (typically between 10 MB and 25 MB) and lower resolution format which could be opened in a range of viewing software packages such as Meshlab.

For the virtual museum, the 3D objects were accompanied by an online catalogue including provenance (where known), interpretative and other information collated by a team of Egyptologists. The resulting online resource (http://www.vista.bham.ac.uk/3D%20LS/Eton_Myers.htm) provides access to the collection which includes photography, interpretation and the facility to download the OBJ files for the 3D models at two different sizes. Future resilience is provided by the archived high-resolution data from which new, higher resolution OBJ files can be processed, although these models remain accessible on request through the University of Birmingham. In addition to providing an online resource, the project also highlighted some of the advantages and disadvantages of laser scanning for the documentation of different materials, and in particular specific differences between the two different laser scanning approaches used.

The resulting dataset provides curation of a digital museum which is not now represented physically as a single collection (Chapman et al. 2010). The raw data in some way equates to the museum store, where the (virtual) artefacts are stored and looked after for the future. The various levels of decimation of these datasets for various levels of online delivery provide a more accessible series of objects, perhaps akin to museum displays, but with the added value of enabling interaction and metric analysis from anywhere in the world.

However, whilst the original purpose of the data capture was to do just this, providing unlimited access to an otherwise inaccessible heritage resource for a broad demographic, in practice, the resulting dataset has provided considerably more. The scan data provided a point-in-time record of the objects such that they are conserved for the future, albeit in a digital format. More specifically, the high-definition datasets provides a new way of seeing the objects—effectively enabling scholars to see the invisible. For some objects, cultural analysis was easier using the virtual object than the physical ones, due to the ability to zoom in, to remove colour information, to exaggerate surfaces and to alter lighting. This enabled text on some objects to be seen more clearly (Fig. 2.2) and, for one of the paintings, it revealed the initial sketching out of the image which was done by scratching into the wooden board (Fig. 2.3).

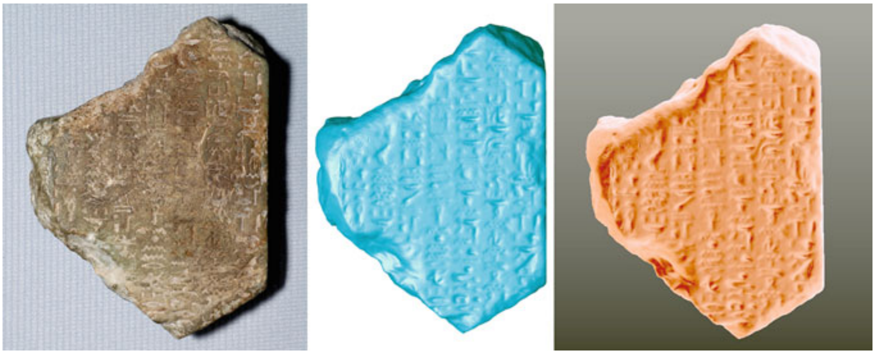


Fig. 2.2 Photograph of one of the objects (*left*) with various surface analyses of the laser scanned model to highlight inscriptions

The laser scan data also provided new possibilities for engagement with these museum objects themselves, both virtually, such as through haptic interfaces, and physically, through digital 3D rapid prototype printing. The potential of rapid prototypic might also offer economic value, such as through the facility of print on demand. These new ways of engaging with objects offer exciting opportunities for

Fig. 2.3 Photograph and colour-stripped, artificially lit 3D model derived from laser scanning data. The 3D data reveal both the depth of paint in the image and the indentations relating to the initial sketching of the image prior to painting

Fig. 2.4 3D scan and rapid prototype model of a mummy's hand wearing a faience ring. These technologies, along with approaches such as haptic interfaces, bring new opportunities for engaging with and handling fragile objects such as this

providing access to the collection, for example, for school groups and for users that are visually impaired which would not normally be feasible due to the fragility of some of the objects (Fig. 2.4).

2.3 Wet-Preserved Archaeological Wood

This second case study focused on issues of heritage conservation of fragile, unstable objects. In the case of organic materials, long-term preservation is a result of very specific conditions relating to their burial environment. Once these environmental conditions are altered, the processes of organic degradation are accelerated and so the object will deteriorate along with its potential to provide valuable information. One context where organic material can be exceptionally well preserved is within wetlands (*cf.* Coles and Coles 1986; Christensson 2004; Field and Parker Pearson 2003; Lillie and Ellis 2007; Van de Noort et al. 2007). In the UK and Europe, agencies concerned with heritage protection have a stated objective of preservation of archaeological remains in situ (Department of Environment 1990; Willems 1998). However, for wetlands, changing factors including groundwater levels, flowpaths and geochemistry mean that the long-term stabilisation of archaeological sites and artefacts in situ might not always be feasible (e.g. Brunning et al. 2000; Gearey and Chapman 2006; Gregory and Jensen 2006; Holden et al. 2006; Kenward and Hall 2000; Modugno et al. 2008; Van Heeringen and Theunissen 2002; Van de Noort et al. 2001) leading to the need for *preservation by record* through excavation. However, the removal or wet-preserved organic artefacts from their burial environment provides challenges for the storage, analysis, stabilisation and preservation of these objects which become threatened by both deformation through water loss and degradation through fungal and microbial activity (Grattan et al. 2006; Lillie and Smith 2007; Jiachang et al. 2009).

The most common material recovered from waterlogged contexts is anthropogenically modified wood, ranging from single artefacts (Morris 2000), to sewn plank boats (Wright 1990; Clark 2004), fishtraps (O'Sullivan 2005) and bridges (Salisbury 1995), with some sites yielding significant quantities of wet-preserved wood, such as from Fiskerton in Lincolnshire (Field and Parker Pearson 2003) and Flag Fen in Cambridgeshire (Pryor 2002), both in the UK. Organic, wet-preserved archaeological material presents considerable difficulties in terms of post-excavation recording, analyses and stabilisation. Upon exposure, water infilling the pore space capillaries within the wood will drain away or evaporate, unless the degree of saturation is maintained through total immersion in water (Brunning 1995; English Heritage 2002; Watkinson and Neal 1998). The time that elapses between excavation and analysis may be considerable and short-term storage solutions usually involve refrigeration or wet tank storage.

Archaeological recording of wet-preserved wood will typically include the measurement, description, photography and scale drawing of samples. At the most basic level, the analysis of tool marks from archaeological wood requires the measurement of the surviving tool signatures on the wood. However, due to the expense of long-term stabilisation of the material, it is often the case that only 'exceptional' wooden artefacts are retained for permanent preservation. Photography and 'signature matching' software has been used to record and compare tool signatures on waterlogged wood with some success (Sands 1997, p. 30), though the technique has not gained widespread use and would benefit from further research. The potential for deformation of wet-preserved archaeological wood within different storage conditions is unclear due to the difficulties in measuring change volumetrically, but an understanding of these processes is fundamentally important if we are to understand the validity of metrical analysis on these timbers following prolonged periods of storage.

Hence, a pilot project was established to examine the potential for deformation of wet-preserved archaeological wood within different storage conditions (including those most strongly recommended; *cf*. Brunning 1995; English Heritage 2002; Watkinson and Neal 1998). In addition to conventional recording (Van de Noort et al. 1995), the focus was on scanning the objects immediately after excavation and then again following storage under different conditions to enable comparison between the scans that might identify deformation in the wood. A total of seven pieces of wet-preserved archaeological wood were selected for analysis from the site of a Saxon fish weir within an infilled palaeochannel of the River Trent in Derbyshire, UK (Krawiec 2008). These seven stakes were digitised using a Konica Minolta Non-Contact 3D Digitiser VIVID-910 laser scanner, as used for the Eton Myers Collection outlined above, to establish a vertical resolution of about 0.4 mm with a lateral point accuracy of ±0.3 mm—a high level of point accuracy which was needed since change between different scans could only be detected outside of the range of twice the point accuracy of the equipment (Fig. 2.5).

Following their initial scanning, the seven pieces of wet-preserved archaeological wood were stored in a variety of different conditions; two were immersed in a tank of water, two were placed in refrigeration, two were stored in a freezer and one was wrapped in plastic and stored at room temperature to provide a ‘control’ sample. All of the pieces were then rescanned using the same settings after a period of 1 month, and then the two scans of each object were compared to assess changes in morphology. Variations within the range of ±0.4 mm were

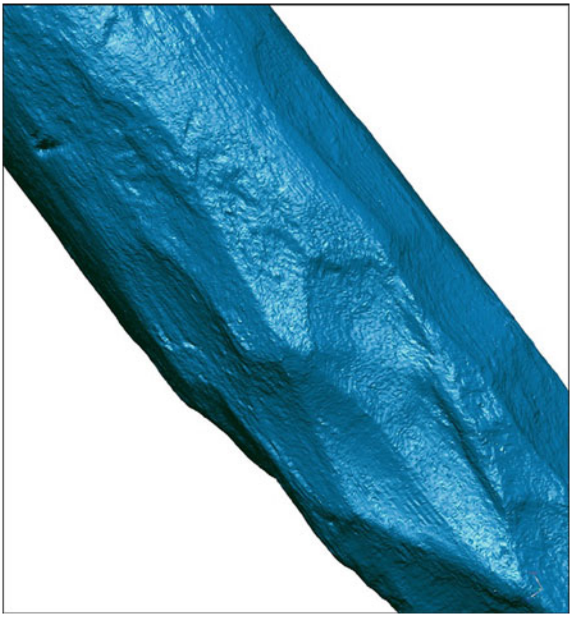


Fig. 2.5 Detail of a model derived from laser scan data of toolmarks on one of the stakes

discounted as they could not be validated due to the measuring tolerance of the instrument.

The detailed results of the comparative analysis have been published separately (Lobb et al. 2010), and show that all samples underwent some change within the first 4 weeks of storage, but that the degree of change did reflect the storage environment. The stake wrapped in plastic suffered significant distortion with a change in diameter at its widest point from 83.5 to 48.7 mm. Frozen samples swelled up by up to 2.7 mm across each face, which can probably be attributed to the expansion of water within the individual cells of the wood (Fig. 2.6). Refrigerated samples showed little change overall, although ridge detail and the tips of both samples suffered loss of definition, with shrinkage of up to 1.5 mm. The two samples stored in water revealed the least amount of change, although shrinkage was identifiable especially around ridges and ends by up to 1.5 mm per face.

Alterations in the morphology of objects appear to reflect distortion due to changes in saturation rather than degradation through fungal or bacterial action. The results confirm that, in the short-term at least, storage in wet-tanks is the most appropriate approach. However, the identification of morphological changes within a short time period, even within wet-tanks, indicates the potential for lost information that can be gained from subsequent post-excavation analyses such that

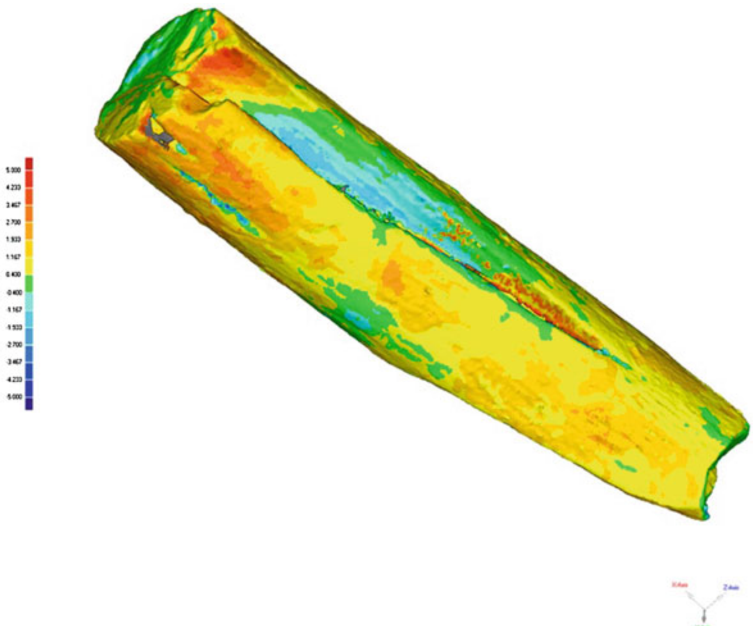


Fig. 2.6 Comparative analysis of one of the stakes stored in the freezer. The *red* and *blue* areas reflect expansion and shrinkage in the object, respectively, following one month of storage

metric recording and demonstrates that such recording should always take place as soon as possible following excavation, regardless of storage conditions. Furthermore, for the long-term archiving of material, this work demonstrated the limitations of physical storage, at least for metrical analysis. Whilst storage facilitates other forms of analysis, such as species identification and scientific dating, for the metrical analysis of tool marks, laser scanning provides perhaps the most effective solution since it preserves an accurate record of the object which can enable future measurements and analyses, in addition to adding to an archive that might be used for approaches such as ‘signature matching’.

However, whilst this project was aimed at exploring issues of conservation, it highlighted the potential for using scan data as an alternative method for generating an archive of wet-preserved archaeological wood which, for metrical analysis at least, provides a more sustainable and reliable dataset than the physical objects themselves. Furthermore, the more accurate capabilities of virtual objects for metric measurements, in addition to the ability to provide access to these datasets digitally to specialists anywhere in the world, highlights the value of this data for heritage needs more broadly. Once captured, such data also provides opportunities for public display, either digitally, or through 3D rapid prototype printing which preserves the volumetric accuracy of the objects which is unlikely to be the case for most methods of conservation for waterlogged organic remains (*cf*. Unger et al. 2001).

2.4 The National Public Housing Museum, Chicago

The first two examples explored the different uses of laser scanning data in terms of the heritage of objects. In this final case study, the application of laser scanning technologies to the recording of upstanding built heritage is presented. In 2013, the last remaining building of the Jane Addams Homes public housing development in Chicago will be converted into a museum dedicated to the interpretation of the experience of public and social housing in North America and globally, particularly focusing on the resilience of poor and working class families from across all races and ethnicities. This ambitious project, directed by Dr Keith Magee, will create the National Public Housing Museum (NPHM) which will be the first cultural institution in the United States dedicated to interpreting the American experience of public housing, in addition to providing a study centre focused on housing policy, an exhibition space, recreations of apartments from different decades from the twentieth century and an interactive area for learning about new visions for sustainable neighbourhoods (www.publichousingmuseum.org).

The building itself was constructed as one of a series of tenement blocks built under the Public Works Administration Act from the 1930s aimed at creating jobs and relieving the Depression era economy. The first large public housing project in the world (Hatch 2012, p. 11), it was designed by a team of architects led by John Holabird in 1932, and named after the 1931 Nobel Prize winning founder of

Chicago's Hull House, Jane Addams. The Jane Addams Homes provided housing, child care, employment counselling and a range of other social services including education (Deegan 1990). The building was occupied by successive generations until 2002, with a series of different communities occupying it at different times. In 2006, the building was saved from being knocked down, and remains as the last of the Jane Addams Homes.

There remained something of a paradox. Whilst the building was being saved from total destruction due to its future role as a public space, in order to create the museum, parts of the building would need to be renovated and altered. Therefore, it was considered fundamentally important to capture as much information about the building prior to any works that might alter it; to preserve the building virtually so that the important moment of transition from the end of its earlier existence as a tenement block and the start of its new life as a museum. It was decided that the best method for preserving the current fabric of the building was to record it digitally using laser scanning. Hence, through collaboration between the NPHM and the University of Birmingham, the VISTA Centre set to record the building in detail prior to its transformation.

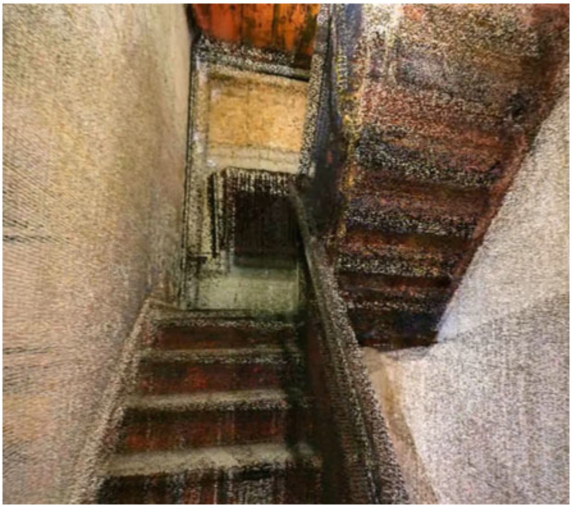
Laser scanning was considered the most appropriate method for the capture of data from the structure since it provides a high density of data at a high resolution and of considerable accuracy. For the project, a terrestrial scanner was used: the Leica ScanStation C10, providing an overall resolution of $\leq$0.4 mm and operates with a range of 0.2–c.300 m. The complexity of the tenement block structure, and the large number of apartments and small rooms contained within it, meant that numerous scans were needed, linked together by shared targets that could be seen from separate surveys. A total of 142 separate scans were collected with a total of around a billion data points represented in the final, merged point-cloud (Fig. 2.7).

The aim of the laser scanning project was to capture detailed information about the structure of the building as a point-in-time record of the final stage of its life as public housing, to provide a virtual version of the building preserving it digitally for the future. The scan data does this extremely effectively, and it is possible to see features such as the purposefully created holes in walls between apartments enabling movement between them, perhaps for nefarious purposes such as police evasion, and other features such as the stairwells (Fig. 2.8). It also captures the shape and detail about these spaces as homes.

At one level, therefore, laser scanning of the NPHM has provided a detailed record of the building; a virtual preservation prior to its transformation into a museum. However, since this work was completed in October 2012, the potential of this data has been realised far beyond initial expectations. A video showing a fly-through of the building has been placed on the NPHM website, providing a simulation of the building as an object that can now be accessed from across the world, significantly raising the profile of the project. Furthermore, the architects designing the transformation of the building into a museum have demonstrated a strong interest in using it in their work, due to the high metrical accuracy which by far exceeds the potential of existing plans and elevation drawings. For the future, the laser scanning data also provides a means of accessing the public housing at

Fig. 2.7 Point-cloud data of the exterior of the National Public Housing Museum

Fig. 2.8 Detail of part of the interior of the building



the end of its life using interactive technologies such as serious gaming. The potential of such an approach, in addition to the possibility of using the data as a foundation for reconstructing earlier homes within the building at different times, will most likely become a feature of the exhibition space within the museum when it opens, allowing visitors to explore the earlier phases of the structure. Hence in addition to the initial aim of virtual preservation of a specific point-in-time in the building's life, it has also become a tool for public dissemination, for architectural design and will form part of the future exhibitions within the museum when it opens.

2.5 Discussion: A Paradigm Shift in Survey?

This chapter has briefly presented three of the vast number of scanning projects undertaken by the VISTA Centre at the University of Birmingham. In each case, the aim of the project was specific, with the choice of laser scanning as a methodology being determined by this specificity. However, in each case, the resulting point-cloud data provided considerable, sometimes quite unexpected opportunities for its re-use, addressing other priorities. The Eton Myers Collection Virtual Museum project was aimed at providing accessibility to an otherwise inaccessible museum collection across a wide demographic, but resulted in a point-in-time record of the objects in addition to opening the exploration of novel ways of engaging with 3D digital data through haptic interfaces and 3D rapid prototype printing and the implications for accessibility to other groups, such as school groups of the visually impaired, through other senses such as touch. The models also provided useful tool for the analysis of the artefacts, such as through the ability to exaggerate surfaces, control lighting conditions and to remove colour textures to enable new discoveries to be made and, as such, are beginning to drive new approaches to the research of these objects. Ultimately, the project raised new questions about what a virtual museum could actually be.

In contrast, the laser scanning of wet-preserved archaeological wood was aimed at exploring methods of conservation through the comparison of highly accurate models of wooden objects directly after excavation and following different methods of storage. The project highlighted best practice, but also demonstrated the value of scan data for metrical analysis and its potential as an alternative approach to recording tool marks on these objects. Furthermore, the project highlighted implications for the conservation of wet-preserved wooden objects as an archive and for museum display, indicating that, in terms of the preservation of metrical accuracy, laser scanning offered a significantly improved solution compared with current approaches to the physical conservation of these objects.

The final example centred on the notion of *preservation by record*, through the high-definition recording of an historically significant building prior to its transformation into a museum. In addition to providing a high-resolution point-in-time record of the building, the scan data has also demonstrated considerable value when re-tasked as a tool for public engagement due to the ability to enable people across the world to experience the structure virtually. It is currently demonstrating the value of re-using data for the architectural process of renovation and transformation into the museum and, in the future, the data will be re-tasked again to provide a part of the exhibition on the past life of the building.

The value of high-definition data capture approaches such as laser scanning is in part due to its ability to rapidly collect high resolution, highly accurate data about the surface of an object, structure or landscape. However, the data itself provides additional values. More traditional approaches to survey were aimed at capturing data at a particular scale or resolution. For example, in archaeology, excavations are commonly recorded using plans and section drawings recorded at scales ranging between perhaps 1:10 and 1:50, whilst earthwork surveys might be surveyed at scales of between 1:250 and 1:25,000 (*cf.* Bowden 1999). These standard practices reflect the processes of recording, the perceived needs of the resulting archive and the potential scales of reproduction in reports and publications. With high-definition survey, the paradigm has arguably shifted. For the first time, the potential for capturing data at a higher resolution than that required for the vast majority of outputs means that survey resolution is no longer dictated by the scale of a drawing, but by the capabilities of the equipment (assuming that it is sufficient for purpose, as explored with the laser scanning of wet-preserved archaeological wood discussed in this chapter). For the first time, the capture of data is not determined solely by the intended outputs; the resulting datasets from high-definition survey normally require some level of decimation or generalisation, although this need is likely to reduce with increases in networking technologies. Hence, the captured data exists independently from the original intention of the survey, and this highlights its tremendous potential for re-tasking.

The three examples discussed in this chapter demonstrate this potential for re-tasking data, and the capability of high-definition survey data to address new ambitions following its capture. Whilst it is important to always critically assess the usefulness of data when applying it to a purpose for which it was not originally collected, high-definition survey represents a new way of thinking about recording heritage which is less reliant on the intentionality of the original survey. It provides a tool for capturing data that can be used and re-used for all stages of heritage processes, from archiving through to conservation, interpretation, public access and re-presentation.

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Chapter 3
Resolving the Carving: The Application of Laser Scanning in Reconstructing a Viking Cross from Neston, Cheshire

Roger H. White

Abstract The five Viking-Age carved stone cross fragments located at the Church of St Mary and St Helen at Neston, Chester and West Cheshire form a distinctive cluster of monuments attesting to Viking settlement in the tenth century. A project begun in 2008 proposed to use laser technology to reconstruct one cross completely and create a resin replica. The results would be used to critically examine the hypothesis, put forward by the author in an earlier paper, that two of the figural cross shafts belonged to the same monument. The resulting scans permitted the creation of a resin replica that formed the centrepiece of a community display on Viking heritage in the Wirral at the Grosvenor Museum Chester. The whole project thus became an exercise in community engagement, as well as generating real research outcomes that have fed into the definitive publication of the cross fragments.

Keywords Neston · Cheshire · St John's Chester · Viking age sculpture · Laser scanning · Reconstruction

3.1 Introduction and Background

The study of stone sculpture of any period is handicapped by the difficulty of manipulating the fragments in order to record them without damaging them. Traditional methods have relied on tracing fragments, always problematic on a carved and often unstable surface, or taking a 'squeeze', a papier maché mould of the surface, which also has the potential to damage the carving. Drawing from photographs bypasses these problems but introduces the issues of parallax error

R. H. White (✉)
Ironbridge International Institute for Cultural Heritage, The University of Birmingham, Edgbaston B15 2TT, UK
e-mail: r.h.white@bham.ac.uk

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and distortion, especially if the carved surface is curved. Laser technology is increasingly proving valuable in enabling millimetric accuracy in recording carved surfaces and permitting their three-dimensional (3D) reconstruction (Murphey 2011). This case study offers an example of how this technology was used to verify or refute an hypothesised reconstruction of a Viking-Age cross, and create a complete example of a decorated cross using the original fragments as the basis of the reconstruction.

The village of Neston lies at the base of the Wirral peninsula, close to the modern boundary of Merseyside, 16 km (10 miles) north-west of Chester. Dominating the centre of the village is the sandstone-built Church of St Mary and Helen whose fabric, apart from the tower, is Victorian. During the reconstruction of the church in 1875, necessitated by the deterioration of the masonry, a number of decorated stones were retrieved from unrecorded locations within the foundations (White 1988, p. 45). In 1985, the author was then invited by the County archaeologist, Ric Turner, to facilitate the proper display and academic study of the stones. When first seen, the group comprised four stones, three of which were figural. One was a trapezoidal-shaped fragment with figural decoration on the two broad faces and interlace of two different styles on the sides with a carved-rope (or cable) border to all sides (Fig. 3.1). The narrow top of the stone was finished with a decorated segment of a circle that plainly formed a fragment of a larger circle indicating that this was the top of a tapering cross-headed shaft. The figural decoration showed two men fighting on one side and a horizontally positioned angel on the other.

Before visiting the site, I had consulted the only readily available published source on the group, J.D. Bu'lock's study of Pre-Conquest Cheshire (1972) which had an illustration of another carved fragment incorporated within the window of the church tower. Fortunately, we were able to gain access to this window and this stone was immediately recognised of being similar character to the examples already displayed in the church. Visible on one broad face were two men on horseback, fighting with couched lances or spears. It was evident that the shaft was tapered and had cable moulding like the others and must, therefore, be another

Fig. 3.1 Neston 2 showing the broad faces and their figural carvings of a men fighting (*left*) and an angel (*right*) (photographs ©R.H. White)

cross shaft, indicating that the other three sides should also be carved. A little clearance of the plaster established another group of animals above the horsemen. A faculty was arranged and the stone was removed from the window, it was fortunately not being of structural significance to the window opening.

Once removed, the stone proved to be the most spectacular example of the group. In addition to the horsemen, there were two animals above, one chasing the other, while the other broad side carried an unusual scene showing a man standing above a stag which has been brought to bay by a dog at its throat (Fig. 3.2). The spear apparently passes right through the animal. Above, and to the right, are the lower halves of two figures. One wears a long plain tunic and the other, shorter, figure wears a pleated costume with broad sleeves: a conjoined carved disc and rectangle behind the second figure appeared to be a plait or ponytail. Although not complete, it was plain that the figures were of a man and woman, facing each other and clasped in an embrace. The narrow sides were decorated with patterns identical in style to the first fragment described. This, and the fact that the first stone was also carved with figures on the two broad sides, led to an investigation of the two stones to see if they did in fact belong together. Unfortunately, when placed in the position suggested by their tapering profiles, it was very clear that there was a gap between them where the shaft had been broken, the relatively soft sandstone presumably being shattered completely where the blow had been inflicted. Nonetheless, the ensemble looked promising. The sides were decorated in identical fashion and the figural scenes could be reassembled into an apparently coherent narrative. This showed on one side fighting and hunting scenes with a knife fight at the top, then the chase scene and last the horsemen jousting. On the other side there was a stag hunt, the couple embracing and (apparently) an angel flying above their heads. Absolute confidence in this reconstruction was not possible however

Fig. 3.2 *Left* to *right* Neston 3, *Face A*. The hunting scene and embracing couple; *Face B*. Ring-chain interlace. *Face C*. Chase scene and Fighting Horsemen. *Face D*. Step-key pattern 2 (photographs ©R.H. White)

as the stones were too heavy and fragile to lift and maintain in a position long enough to determine whether the critical side patterns were capable of being united in the available space. (Since both patterns repeated, it should be easy to work out the repeats and see if they matched.) The tentative reconstruction, illustrated as a pair of photographs, was published along with the other fragments (White 1988, plates 1 and 2).

From the artistic parallels for the group, and the form of the cross itself, it was plain that these carvings belonged to the late Anglo-Saxon period, the tenth or eleventh century, but were Viking in origin. This was established most clearly for the figure of the woman with a pigtail which finds close parallels on the Gosforth Cross, a clearly Viking monument that depicts Scandinavian mythology (Bailey 1980, p. 143 pl. 32). Other crosses from Kirk Michael, and Jurby on the Isle of Man show woman in similar attire (Kermode 1994, Appendices 18–19), as well as hunting scenes including a stag attacked by a dog (Joalf's Cross, Kermode 1994, 199–202, no. 105 [= Manx Museum 132]). Viking representations of women in identical dress in other media, such as metal pendants or brooches further demonstrate the conventional nature of the costume (Bailey 1980, pl. 33). The form of the cross had been demonstrated to have close parallels with other similar, more complete examples found in Cheshire and along the Cumbrian coast (Bu'lock 1959). The most important group were those located in the Church of St John the Baptist, adjacent to the city wall of Chester and very close to the Roman amphitheatre there (Mason 2007, p. 123). Taken together, the evidence points clearly to artistic parallels located largely in the Isle of Man and Cumbria, both areas that were settled by the Norse after their expulsion from Ireland in ca. A.D. 902 (Wilson 2008, p. 24; Griffiths 2010, pp. 143–150).

3.1.1 The Study Recommences

In 2002, the stones were once again redisplayed, the date being chosen to commemorate the traditional date of Viking settlement of the Wirral in A.D. 902. It had been hoped that a replica cross could be made as a celebration but no funds were available for such an expensive undertaking so the idea lay dormant. Fortunately, in 2007 Grosvenor Museum Chester were successful in obtaining a grant from the Heritage Lottery Fund for an exhibition based on Viking Heritage in the Wirral and Chester area. This enabled the commissioning of a laser scan with a view to recreating a cross that could then be placed outside the church for all to enjoy.

3.2 Methodology

The work was commissioned from the Conservation Technologies unit based at the National Conservation Centre, World Museum Liverpool who used the Modelmaker X laser scanning system to capture the data (Fig. 3.3). This system comprises a 3D Scanners UK Ltd. (now Metris Ltd.) 3D laser scanning sensor mounted on a seven axis Faro Technologies Ltd. 'Gold' measuring arm. The arm is mounted on a heavy duty tripod. The scanner uses the principle of triangulation to record the surface as a thin stripe of laser light is scanned across the object. The length (maximum) of the stripe emitted from the sensor during scanning is 70 mm. The distance between measured points along the stripe is 0.070 mm. The distance between stripes is dependent on the speed at which the operator moves the sensor over the surface, and on how many times the sensor is passed over a given area. The accuracy of the system is approximately ±0.1 mm. Actual accuracy will depend on the nature of the surface of the object and scanning conditions. Calibration checks were carried out to check the scanner was performing within specification (see above). The scanning system captures 27,000 points per second. The raw scan data was processed using specialist software (Innovmetric Inc. Polyworks v.10 and Rapidform 2006) to produce a watertight polygon mesh model of the fragment, suitable for visualisation and rapid prototyping.

The methodology adopted involved the scanning of three separate stones: the two carvings from Neston with figures on both faces that it had been hypothesised had come from the same cross and the complete ring-head of a cross shaft from St John's, Chester. The work was completed in 2 days, one at each site with post-fieldwork processing then occurring in Liverpool. The scanning of the objects proved relatively unproblematic with the relatively shallow nature of the carving ensuring that all facets could be captured without difficulty.

Once scanned, the author drew a suggested reconstruction of the full cross to scale using existing drawings and photographs of the stones which could act as a template for the digital technicians to work on in creating the digital 3D model of

Fig. 3.3 Scanning the cross head at St John the Baptist's, Chester and a screen shot of the scanning in progress (photographs ©R.H. White)

the complete cross. The two shaft fragments proved to match very well with each other in terms of taper and shaft thickness so that the initial impression that the stones fitted together was not unrealistic (Bailey 2010, p. 86). The scan of the cross head proved more problematic to incorporate. The actual diameter of the cross head proved to be identical to the cross arc preserved on the upper fragment of the Neston stones thus demonstrating the close relationship between the group despite the geographical separation. However, the Chester cross head proved to be thicker than the Neston fragments. This was remedied by digitally removing a segment of data within the thickness of the cross head so as to form a slimmer head that could marry with the shaft fragment. This was achieved without loss of design coherence on the carved outer edge of the cross ring and arms. The three sections were then digitally joined so as to form a complete cross without initially trying to link up the decorative elements.

3.2.1 Reconstruction

From this complete model, it was possible to trace out the geometric patterns on the narrow shaft sides on the two shaft fragments. One side comprised a step-key pattern type 2 and the other is a 'ring-encircled twist with wide glide between rings' (Bailey 2010, p. 86). Both patterns comprise repeated elements that can be predicted with some certainty and this permitted a plotting out of the designs on paper to measure the likely repeat. Doing so made it obvious that the two fragments could not be joined together, there being either too little or too much space for a repeat or continuation of the designs when considered in conjunction with the known distance between the stones, as projected by the tapering of the shaft. Furthermore, consideration of the angle of the cable carving on the borders of the shaft demonstrated a very different angle of cable repeat: the two could not be joined without arguing for a very sudden, and unlikely, change of style and spacing of the cable patterning.

With proof positive that the two fragments did not belong together, the question was posed as to how to finish off the cross. This was, however, relatively easy to achieve. The smaller of the two fragments was used as a template to supply the top of the cross shaft, the cable border and patterning found on the larger lower fragment merely being projected to fill the remaining section of the shaft. One of the broad faces of the design was left completely plain while the other was finished by providing heads for the embracing couple, the man being shown with a conical helmet as with the Brompton, Yorks and Sockburn, Co. Durham Crosses (Bailey 1980, Fig. 78) and the woman being restored with a round head and plait to connect with the existing element on the main fragment. The St John's cross head, suitably narrowed to match, was digitally overlaid on the arc at the top of the shaft to complete the cross. The restoration of one entire face demonstrated clearly that there could not have been spaced to have had the horizontally positioned angel on this cross. It was not felt wise to speculate on what had filled the space at the top of the shaft on the other side, given the unparalleled nature of the decoration, so this was left blank.

3.3 Discussion

The exercise in reconstructing the Neston Cross successfully achieved its outcome in conclusively demonstrating that the two Neston fragments did not belong together but must derive from two crosses, both carved with figures on the two broad faces. It also demonstrated a close relationship between the St John's crosses and those from Neston. The link had been made stylistically, and to a degree geologically, but the identical diameter of the cross head suggests the same workshop was involved in creating these monuments, presumably using the same methods. It is true that close conventional analysis of the fragments by Richard Bailey, and by Martin Cooper during the reconstruction process, had also determined that the two fragments did not belong together so the digital scanning was not, in that sense, necessary to prove or disprove the theory. Nonetheless, the exercise was of considerable academic value. It enabled the reconstruction to be attempted without risk of damaging the stones. The scans effectively rendered the fragments weightless, permitting the testing of different modes of reassembly with ease. The ability to cast light on the stones in differing angles, in a bland and neutral appearance so as to be able to discern the nuances of carving was also very helpful during the reconstruction process (Fig. 3.4).

The scans have also provided a permanent digital archive of the objects, which will be lodged with the Corpus of Anglo-Saxon Stone Sculpture at University of Durham so that if the originals ever get damaged, they can be recreated exactly.

Fig. 3.4 Image of the scan of Neston 3, *Face C* compared to the original demonstrating the definition of the scanned image and the effects of the neutral colouration (*Left* Image courtesy of Martin Cooper. *Right* photograph ©R.H. White)

Fig. 3.5 The reconstructed cross, based on fragments from Neston and Chester, displayed in the Grosvenor Museum, Chester 2009 (photographs ©R.H. White)

Last, in creating the cross, the project has allowed its exploration as a complete monument rather than as a collection of fragments. The completed cross was cut in resin at full size, painted imaginatively to represent an idea of what it might have looked like (Fig. 3.5), and is now on display in Neston, visible once again as a witness to the earliest Viking Christians on the Wirral peninsula.

3.4 Conclusion

The project to reconstruct the cross at Neston provided an excellent means to engage the community in their own heritage, whilst offering a research dividend in aiding a more complete understanding of the group of carvings at Neston. Research in the future will focus on recording the other stones in the group, and those at St John's, Chester, which remain vulnerable to damage, with a view to furthering our understanding of the nature of these carvings.

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Chapter 4
A Theoretical Framework for Stigmergetic Reconstruction of Ancient Text

Eugene Ch′ng, Andrew Lewis, Rolf Erlend Gehlken and Sandra I. Woolley

Abstract Cuneiform script, an intellectual breakthrough 5,000 years ago, made recording information possible. Cuneiform is mankind's first ever script, recorded and communicated using clay tablets for thousands of years across the entirety of the Ancient Near East. Remnants of the medium are now stored worldwide in many of collections and time required for the joining of the fragments using traditional methodologies means that the information recorded within these fragments will not be known in our lifetime. The research narrated in this chapter opens up a novel method for reconstructing the fragments, using nature-inspired approaches and new mobile digitising technology. It covers groundwork done to date for supporting a full-scale stigmergy reconstruction of cuneiform tablets and provides hypothetical scenarios within a theoretical framework for testing 'in the wild'.

E. Ch′ng (✉) · A. Lewis
IBM Visual and Spatial Technology Centre, University of Birmingham,
Edgbaston B15 2TT, UK
e-mail: e.chng@bham.ac.uk

A. Lewis
e-mail: AXL148@bham.ac.uk

S. I. Woolley
Electronic Electrical and Computer Engineering, University of Birmingham,
Edgbaston B15 2TT, UK
e-mail: s.i.woolley@bham.ac.uk

R. E. Gehlken
Institut für Archaeologische Wissenschaften, Goethe-Universität,
Gruneburgplatz 1 60629 Frankfurt, AM, Germany
e-mail: gehlken@mailer.uni-marburg.de

E. Ch′ng
Centre for Creative Content and Digital Innovation, Universiti Malaya,
50603 Kuala Lumpur, Malaysia

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4.1 Cuneiform Script: Medium of Communication in the Ancient Near East

Cuneiform script is, according to our knowledge, mankind's first ever script (3,300 BC). This intellectual breakthrough made the recording of textual information possible. The writer uses a reed stylus, the end of which is cut in the shape of a right-angled triangle for impressing the script into the surface of small pieces of clay (so called "cuneiform tablets"). Due to the shape of the stylus a single tablet imprint looks like a small wedge (Latin *cuneus*, therefore cuneiform).

Characters ("letters") are composed of a combination of wedges. Cuneiform was the medium of communication throughout the entirety of the Ancient Near East (an area that stretched from modern Egypt to Iran) and was even used at the beginning of the Christian era.

Current collections of thousands of inscribed fragments from complete tablets are distributed in museums worldwide. Pieces of any one tablet may be located in different museums due to illicit and unprofessional excavations. The largest collections are found in the British Museum, the Louvre (Paris), the Vorderasiatische Museum (Berlin) and the Iraq Museum in Baghdad. Smaller sets of collections in Britain are housed in The Ashmolean Museum in Oxford and also in The Birmingham Museum and Art Gallery. The University of Heidelberg houses a collection of about 2,000 unpublished fragments that belong to a single temple archive from the time of Nebuchadnezzar II (604–562 BC). In addition to those in collections, cuneiform tablets continue to be discovered. For example, in 2009, archaeologists found a cache of tablets dating back to the Iron Age (1200–600 BC) in a 2,700 year old Turkish temple in south eastern Turkey at Tell Tayinat (Bettam 2009).

The majority of the tablets in the collections are catalogued using photographs and hand-drawn copies. In some cases, large collections of tablets numbering thousands remain uncatalogued even after a century of storage. The ancient text on the fragments reflects a wide range of activities encompassing religious, literary, scientific, and administrative documentation including encyclopaedias, dictionaries, political texts, letters and school tablets. However, the fragmentary nature of so many of these tablets means that we can only obtain a very limited understanding of their potential. Hence, the urgent reconstruction of the tablets is a desideratum. Then researchers will be able to gain valuable insights into the social, political, scientific and historical aspects of the ancient cultures represented by the cuneiform tablets. There is also a time pressure on the need for bringing these fragmentary records together. As time progresses, fragments will inevitably gradually disintegrate and the text will be lost forever. Hence, at one level it is critical that these fragments are appropriately recorded to ensure the potential for future research. At another, the full interpretation of these objects will only be facilitated once the fragments are rejoined so that the full texts can be read.

This research proposes a nature-inspired framework for facilitating crowd-sourced, collaborative reconstruction of cuneiform tablets that will allow both the academic community and the public to participate in.

4.2 Traditional Methods for Reconstructing Cuneiform Tablets

The task of reconstructing cuneiform tablets presents a problem for scholars. It is projected that joining these fragments manually by individuals or even groups of researchers locally would take decades to complete. Under the present system of reconstruction, each academic accesses 2D photographic or lithographic representations of tablets from a series of printed catalogues. If a potential match between fragments is discovered, the curator of the museum housing the fragments would be notified and a manual reconstruction would follow. Such methods are often time consuming. Furthermore, 2D pictorial references present a real problem to scholars as 2D images do not fully present the surface information of physical pieces. Even if the reconstruction is conducted locally, the projected amount of time spent could be enormous. For example, the 2,000 unpublished fragments which belong to a single temple archive from the time of Nebuchadnezzar could take nearly two decades to reconstruct; a simple calculation projected that it will take one person 18.255 years working everyday on location, even discounting joining problems that may arise during the reconstruction. The number *c(n, k)* of all combinations of the *k*th class of n elements without repetition is

$$c(n,k) = \binom{n}{k} \tag{4.1}$$

Starting with 2000 pieces ($n = 2000$) of cuneiform fragments, and trying to join every piece to every other piece ($k = 2$) we therefore have the possibilities

$$c(2000,2) = \frac{2000!}{2!(2000-2)!} = 1999000 \tag{4.2}$$

The average speed for an expert is 30 possibilities per hour (at times faster, for example: one will not try to join a letter fragment and an economic text, or a thick and a thin piece. At times slower: there may be problems such as parts missing between the pieces, or tablets are encrusted by salt and not immediately readable). So 1999000/30 = 66633.33 hours are likely to be needed. A person may not be able to work more than 10 hours per day, thus about 6663 days that is 18 years, are needed (66633.33/(10×365) = 18.26).

A more rapid solution might be possible through the use of a digital approach and particularly through the use of digitised 3D representations of the objects rather than the physical ones. Previous works on digital cuneiform databases exist, such as the Cuneiform Digital Forensic Project (CDFP) (Arvanitis et al. 2002; Woolley et al. 2001), and The Cuneiform Digital Palaeography Project (CDP 2004) at The University of Birmingham. These earlier data acquisition experiments provide an insight into important technical issues such as graphical resolution and data volume. The resolution required for fine cuneiform details meant that the digitised data volumes could be extremely large. The experience also provided an insight into the need for clear and robust object tagging for any digital archive of this type (Woolley et al. 2002). In addition, the multidisciplinary aspect highlighted the importance of intuitive data representation to both expert and non-expert users across the disciplines. A third project involving the digitisation and visualisation of cuneiform tablets is The Stanford Cuneiform Tablet Visualisation Project (Anderson and Levoy 2002). Together, these related research projects have laid an early foundation which the present research project will build upon. For example, one problem is the stringent forensic resolution requirement of 0.025 mm resolution over the entire surface of a cuneiform tablet set by the CDFP. Such high resolution scan of a single tablet typically uses up a storage space of a single layer DVD (4.7 GB). The size of the digital data makes interactive visualisation impossible, not to say manipulate. Interactive 3D (i3D) reconstruction requires efficiency in processing speed and visualisation; this requires a much smaller storage capacity (or better digital representation). The requirement for efficient storage and processing becomes even higher when collaboration between multiple users is necessary. For collaboration, a synchronous client–server architecture-based tool is needed. Users wishing to collaborate may access an interface on the client-side via the network that displays 3D cuneiform fragments retrieved from the digital archive. The advent of research in Human–Computer Interaction, interactive 3D (i3D) computer graphics and high-speed networks should have brought advances to the community but a survey of literature did not find evidence for 3D collaboration platforms from progress in technology application, or any useful outcome in this area of research. Although concurrent versioning systems and computer supported cooperative work (Eseryel et al. 2002) and cloud-based groupware such as Google Docs are available, they are office tools rather than i3D platforms supporting cooperative reconstructions. However, lessons can be learned from issues related to psychological ownership and perceived quality of work (Blau and Caspi 2009; Dekeyser 2004).

A nature-inspired solution proposed in the present research for the reconstruction of cuneiform fragments using current technology can be structured into three main components. The first component prepares the medium digitally for facilitating the nature-inspired reconstruction, it addresses issues related to the digitisation and cataloguing of 3D cuneiform information in a structured database that allows fast and efficient transmissions over the network. The second seeks to construct an algorithm to filter fragments based on accessible information (size, form, ratio, and orientation) for fitting 3D fragments. The third component formulates a nature-inspired, crowd-sourced and agent-assisted reconstruction that advocates indirect cooperation via a virtual environment that supports i3D interface for the direct manipulation of real-time 3D data.

With regard to the first research component, a survey of the design of structured databases for storing cuneiform tablets that could facilitate the representation to be efficiently sent over the networks, and at the same time provide 3D manipulation, did not find any large-scale projects dealing with 3D data. The Cuneiform Digital Palaeography Project (CDP 2004) is perhaps the most structured that deals with 2D pictorial data. Some work has been done on scanning and coding (Hahn et al. 2006), and visualisation of a small collection of cuneiform tablets (Anderson and Levoy 2002; Woolley et al. 2002), but assisted reconstruction of cuneiform tablets from 3D data has not yet been attempted. A review of literature in other application areas yielded a number of projects that are of relevance to the problems that we may encounter in the reconstruction of cuneiform tablets (e.g. Kampel and Sablatnig 2004; Koller and Levoy 2004; Papaioannou et al. 2002; Zhu et al. 2008). Given the broad geographical grouping of cuneiform fragments, the traditional method of matching can be very slow and even a partial automation of the process would be beneficial. The CDP has been initiated to provide computerised catalogues of cuneiform signs, there has been no attempt to reconstruct fragmented cuneiform tablets using a computerised system.

When investigating the online, collaborative aspects of fragment reconstruction, there appears to be very little evidence of research that is directly applicable to the challenge presented by the fragments from cuneiform tablets. Some insights can be gained from related research (Farella et al. 2002; Bulmer 2002; Löffler 2002), however, the 2D jigsaw puzzling in Bulmer project is significantly different from the 3D mosaic problem associated with cuneiform fragments. The latter two papers also provide insights into considerations of bandwidth, concurrency and security when using distributed system for the visualisation of 3D resources.

4.3 Methodology: Nature-Inspired Approach for the Reconstruction of Cuneiform Tablets

Nature has a way of finding the best solution to difficult problems (Bonabeau and Théraulaz 2008), and those solutions are frequently the product of simple local interactions (i.e. cooperation) amongst entities. Cooperation is important in any large-scale mosaic-based reconstruction, particularly when the rare expertise of scholars plays an important role in the identification and joining of fragments belonging to the same text and period. There are approximately 600 cuneiform-related scholars in the world, including students. For a number of reasons, scholars scattered worldwide do not necessarily interact, communicate, or cooperate well with a common purpose. It seems that groups are frequently disjointed. How do we then facilitate common activities that will promote worldwide collaboration? What if scholars in the field do not want to communicate, can they collaborate without direct communication? Are there proxies that will allow the information worked on by an individual provide clues that will help other individuals reconstruct fragments without direct collaboration? It turns out that insects have been involved in such activities for thousands of years. The word stigmergy describes such activities.

4.3.1 Stigmergy: Coordination Without Direct Communication

Stigmergy was first coined in 1959 by Pierre Paul Grassé (Grassé 1959), who used the word to describe the effect of pre-existing environmental states on the actions of termites building a mound. Grassé noted (in French) that "The coordination of tasks and the regulation of constructions do not depend directly on workers, but the constructions themselves. The worker does not direct his work, he is guided by it. It is the stimulation of this particular type that we give the name of stigmergy," tanslated by Holland and Melhuish (1999, p.174). Studies in stigmergy are originally associated with social insects, which rely on the stimulus–response mechanism for coordinated behaviour. Stigmergetic interactions can occur in both social species (Bonabeau et al. 1997; Camazine 1991; Goss et al. 1990; Smith 1978) and those that are solitary (Peters 1970). It also occurs in highly intelligent species, such as human beings (Helbing et al. 1997a, b).

The observed collective behaviour of insects in the construction of mounds and nest structures (Bruinsma 1979; Grassé 1959, 1984; Smith 1978) is intriguing. At the individual level, it would appear that each insect works in solitude yet, at the collective level, an apparent work of coordination is observed. In the eye of an observer, it appears that an invisible hand is guiding such work. The mechanism coordinating the construction of structures depends on various concepts well covered in *A Brief History of stigmergy* (Theraulaz and Bonabeau 1999), and is reiterated here for the purposes of formulating a methodology for fragment reconstruction. One of the two concepts (Rabaud 1937) is *interaction*, in which an individual's behaviour acts as stimulus for modifying the behaviour of another. The other is *interattraction*, in which any animal within a social species is attracted by any other animal of the same species. Furthermore, the behaviour state of insects is influenced by a "critical number of specific stimuli from its nestmates" called a group effect. Each individual is a source of stimuli for other individuals, this stimuli-response "opens the way for an indirect coordination of individual activities" (Theraulaz and Bonabeau 1999). If the presence of an individual is a stimulus in itself, and so also the physical and chemical structures that these insects collate and leave behind, then there is not the need for direct coordination.

Two examples will make the concept clear (Fig. 4.1). The wasp *Paralastor* sp. (Smith 1978) constructs nest based on a stimulus–response mechanism where the completion of a stage of construction provides a stimulus for the construction of the next stage, until the nest is completed. In pheromone-based stigmergy, termites *Termitoidae* (Grassé 1959) use soil pellets covered with pheromone for building pillars, first depositing at an uncoordinated random location. Chance deposition of a critical pile of pellets provides a positive pheromone feedback for more activities at the location, therefore increasing the likelihood of coordinated construction of pillars. This process is termed quantitative stigmergy (Theraulaz and Bonabeau 1999).

The use of stigmergetic algorithms for problem solving is not new. Stigmergy has mainly been applied to optimisation problems, e.g. (Bonabeau and Théraulaz 2008; Holland and Melhuish 1999). However, there is no literature relating to the use of this approach within the context of large multi-threaded problem solving.

Stigmergy can possibly form the cornerstone of a nature-inspired and crowd-sourced reconstruction of cuneiform tablets, and it is easy to see the potential that stigmergy communication will have in a large, multi-threaded problem solving environment. A stigmergy reconstruction system does not need a single, central intelligence algorithm for the reconstruction of fragments. Individual reconstruction agents, an autonomous software unit that mimics insects in this context, can cooperate without direct communication, within a system at radically different speeds—so that humans and non-human agents can work together to solve a problem without direct communication. Later, we will formulate a methodology based on stigmergy for the reconstruction of cuneiform tablets.

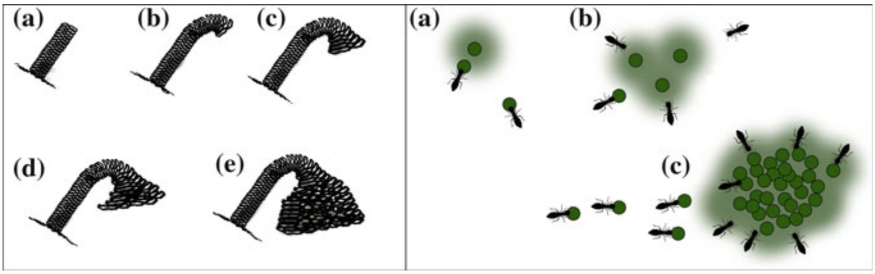

Fig. 4.1 Two examples of stigmergy in collective insect behaviour. The wasp *Paralastor* sp. (*left*) and pheromone-based stigmergy of termites *Termitoidae* (*right*). In the wasp nest construction mechanism, each stage of the construction process (**a**–**e**) provides a stimulus for another stage of construction. For the pillar building termites, a chance deposition of pheromone infused soil pellets **a** provides positive feedback for more activities in that location **b**, with subsequent positive feedback loops **c** until the pillar is completed

4.3.2 A Client–Server Framework Supporting Stigmergetic Interaction

A major requirement for nature-inspired reconstruction is a sufficiently powerful distributed multiprocessing agent framework. Given that a large number of agents may be operating at any given time, it would be a mistake to limit the processing engine to a single processor or workstation. Consequently, a framework has been developed to support multiple artificial agents, alongside a database of fragment geometry, and a socket.IO-based server that allows for real-time Web-based communication between different subsections of the reconstruction system (Fig. 4.2). The framework server receives and broadcasts messages from agents and users via JavaScript Object Notation (JSON), utilising the socket.IO specification to ensure that connected systems are kept in sync. The server holds a virtual representation of a 2D plane, which is used to sort and manipulate fragments. Agents may jump fragments from one position to another within this virtual space (or 'grid'), move a fragment on-screen, or rotate a tile in space. Any interaction or manipulation of fragments is ultimately processed and recorded by the server. In this way the messaging system and the server simulate what might be called the virtual law, an equivalent of the physical laws of the agent's universe. The server controls the passage of time and information between agents, and any rules implemented at the server level are immutable. Server rules affect every agent within the system in a way that cannot be avoided by any agent.

A simple example of a server-side or "universal" rule is the implementation of "caution" within the system. All agents within the system will avoid interacting with fragments that have recently been manipulated by a more dominant agent (e.g. a human). The sense of dominance and the reaction of an agent after it is

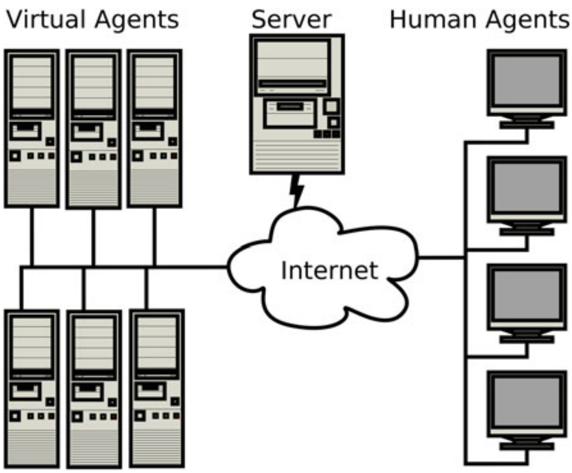

Fig. 4.2 A human agent cooperative client–server architecture

"frightened away" from a fragment can be controlled at the client level, but the overwhelming instinct to avoid the fragment is compulsory.

The socket server also acts as a rudimentary Web-server, transmitting the front end interface and any fragment model data to clients. Combining the file and socket servers onto a single system is both convenient and necessary for the proper operation of the system, as some Web browsers and brands of antivirus software wrongly classify the normal activities of the application framework as a potential cross-site scripting attack when resources were hosted on multiple servers.

All clients within the system are built using an agent framework. The framework is based in Python, and support for parallel processing as standard. Threading and FIFO queue systems have been implemented within the system to facilitate synchronous and asynchronous support for socket communications.

4.3.3 Agents as Stigmergetic Virtual Insects

A basic 'agent' class (a software template) is provided that supports a Life-Timer (a timer within agents that decides the longevity of its lifetime) and also a throttle to control execution speed. New agents can be automatically spawned on an appropriate local or distributed processing node, and can be given the power to spawn new agents if they require it. The life-timer of an agent can be adjusted at any point, extending the life of successful agents, and reducing the life expectancy of agents that make poor choices.

Agents can be created and added to the framework at any point, and may interact using one of two methods. The *Network Method* presents a location independent method of access, where the normal bounds of an environment are removed. An agent accessing the framework in *Network Mode* can access information about any fragment, rotate, or move any fragment to any position in a single tick. Agents within the *Network Space* have a complete overview of the fragments, abstracted from their physical location. They rely on metadata to make decisions about what to do with an individual fragment.

In contrast to this, the second method of access within the framework is the *Grid mode* (Fig. 4.3). Agents accessing fragments using the Grid mode are bound by the order and location of fragments within a 2D grid, and their knowledge of the fragment database is limited to fragments within adjacent grid positions. Movement of fragments is also limited to adjacent grid squares, effectively throttling the maximum speed at which fragments can be moved. Agents within the Grid make their decisions based on the best local solution to a problem, with the intention that multiple, simple agents can generate complex local structures and hierarchies that network-based agents (including human users) can exploit to improve the matching process.

Possibly the simplest example of a network layer agent is a *Lay-Flat Agent*. The Lay-Flat Agent visits all fragments in turn, and rotates them so that they lay flat on the surface, for example, with the text surface pointing face upwards. Once this

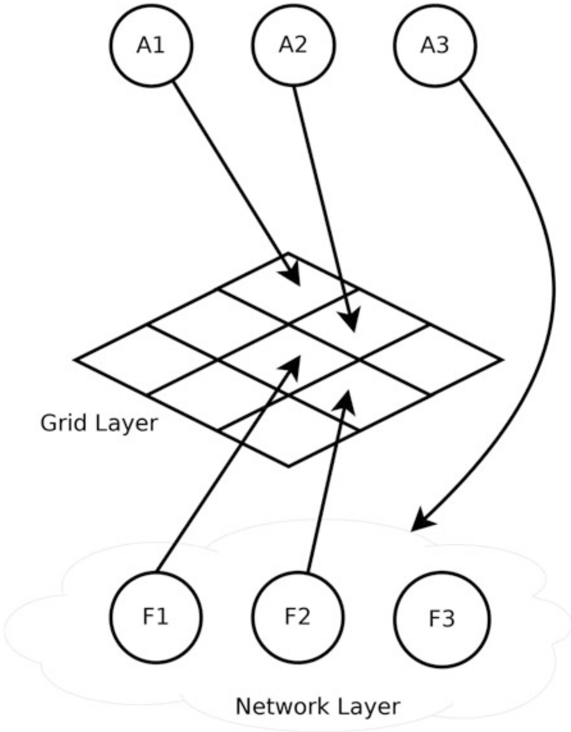

Fig. 4.3 Agents A1 and A2 are *Grid Agents*, and can only see fragments F1 and F2 on the grid. Agent A3 is a *Network Agent*, and can see all fragments including F3, which is not visible on the grid

agent has visited a fragment once, it leaves a non-degrading tag in the fragment's metadata and does not revisit the fragment unless the tag is removed.

A slightly more complex example of a network agent is a *Clustering Agent*, which takes fragments with similar metadata aspects (such as dig-site, text subject, or interaction history) and attempts to group them together in a particular area of the grid. The clustering agent will not interact with a fragment unless it has been left idle for some time, with no other human or agent interaction occurring. It is worth noting that this agent operates at the network level, but has a direct effect in the Grid space.

A Grid Agent operates in a manner akin to termites or ants. The actions of Grid Agents are defined by relatively simple rules that affect the environment of the grid, which in turn guide the actions of other grid agents.

A grid agent may be programmed with the simple rule set that swaps the position of fragments so that the total size of juxtaposing fragments is as close to the average size of a complete cuneiform tablet as is possible. If the size is close to the ideal, the agent's life-timer or 'energy level' will be extended. Once the agent has swapped the fragments and gained energy, it leaves a tag on the fragments and hops to an adjacent grid location in search of previously unmodified fragments. If there are no fragments to change, the agent will continue to hop from location to location, searching for fragments until its life-timer reaches zero. Conversely, if the agent is repeatedly successful, its life-timer reaches a pre-determined level, and the agent will duplicate itself, and divide its life-timer value between both agents.

The action of the swapping agent described above is very simple, in some ways akin to Cellular Automata (Wolfram 1986), but the alterations that the agent causes within the grid can lead to a very complex interaction with other agents. The simple act of grouping fragments by size can improve or worsen the ability of other agents to match fragments together, affecting their life-timer and therefore their prevalence within the system.

4.3.4 Special Agents

There are also a number of special cases where an agent may be created with unusual characteristics. In the case of a *Human Agent*, it is not beneficial to use the life-timer of the user in a normal manner. Users will typically work in environments with the potential of being affected by real world distractions, which could result in a premature end to an online session if the user is away for too long. So a human interacting with the system will remain visible as an agent until the user disconnects from the server by closing their session. Also, the association of a particular user with successful matches (assessed through matching of the user's tag in fragment metadata) could increase the reputation of the user within the system and could, for example, allow them to override the actions of less experienced users in the event of a real-time fragment locking issue.

Another instance where a special class of agent may be needed is the initial seeding and maintenance of the system. A *Super-Agent* can be used to act as a caretaker to the framework, setting up the initial conditions of the Grid and Network layers when the system is initialised or restarted. A similar agent may be used to track and record the growth and die-off of particular agent classes, and attempt to respawn or cull them if their numbers become radically unbalanced as the result of a short-term issue within the framework (such as deliberate human intervention). The *Caretaker Agent* could also contribute to the overall entropy of the system, shuffling idle fragments or affecting the behaviour of an agent contrary to its normal operation.

Finally, a *Glue Agent* could be used to hold the position of two fragments relative to each other, effectively bonding them into a single fragment. Similar to User and Caretaker Agents, the Glue Agent should have an infinite life-timer, hunt for fragments marked as matching, and bond them if their proximity tags have reached a particular level of potency. Upon bonding, the Glue Agent tags the fragments with a unique identifier, locks their relative positions, and co-locates them on the Grid layer. The Glue Agent then spawns a duplicate of itself to continue searching for more fragments. A Glue agent may bond more than two fragments together, and will release a fragment if the unique identifier which applies to the fragment is removed. If a Glue Agent has less than two connections, it sets its life-timer to 0 and then dies. This prevents superfluous agents from cluttering the system if incorrect bonds are formed.

4.3.5 An Example of Agent Creation

The following example creates a new agent that prints out its life expectancy, and then dies after three ticks. Note that in a multiprocessing environment, the text output would be suppressed, but in a single instance, the text will be output to the interpreter. The start() and stop() functions of the Agent class start and stop the execution of the agent. An agent that has been stopped will not age (its lifetime will not reduce) until it is started again.

```
from agent import Agent
class My_Agent(Agent):
    def main(self):
        print "I have ", self.LIFE, " life left"

a = My_Agent(life=3)
a.start()
```

4.3.6 An Example of Communication with the Server

All agents created with the agent class can communicate with the Node.js server from within the main() function by using self.ul.send() and self.ul.recv() functions. It is also possible to access the server without an Agent, using the Uplink class as shown below.

```
from uplink import Uplink
ul = Uplink(hn = "localhost", pn = 8000, pt = 10)
ul.connect()

for i in range(100):
    ul.send("rotate","fragment.js",1.2,1.2,1.2)
    incoming = ul.recv()
    if incoming:
        print incoming
```

The ul.send() and ul.recv() functions are tailored to the transmission of positional data, with the send() function accepting an action, fragment id, and x, y, z data. Differently formatted messages can also be transmitted and received using the ul.sendraw() and ul.recvraw() functions.

4.4 Methods Supporting the Nature-Inspired Framework

Designing a nature-inspired framework for research of this particular nature requires supporting methodology. These methods are photogrammetry, light weight 3D scanning of cuneiform fragments, a Web-based user interface for supporting an environment for hosting human agents, and 3D printing.

4.4.1 Photogrammetry

One of the most useful clues to the reconstruction of any object is a good understanding of its finished appearance. In order to understand the general shape of cuneiform tablets, a photogrammetric analysis of approximately 8,000 complete tablets from the Cuneiform Digital Library Initiative (CDLI) database has been made. This detailed analysis of images was a necessary step towards the reconstruction of cuneiform tablets, since many text records (both within the CDLI database and in the wider community) lack data on the physical size and shape of complete tablets and fragments.

By exploiting a priori knowledge of the CDLI image scanning system, it was possible to extract the scanning size in DPI (dots per inch) of images within the database by using the Exchangeable Image Format (EXIF) data within the stored images. A simple script was used to perform luminance threshold analysis of the image data, to extrapolate the dimensions of each tablet automatically. When checked against known good data from the CDLI database, the output of the photogrammetric analysis program was found to be accurate within approximately one millimetre of the recorded values. The study has revealed some interesting physical features and characteristics that could help increase the speed and efficacy of cuneiform fragment matching algorithms (Lewis and Ch'ng 2012).

4.5 3D Scanning

The impartial and accurate recording of physical features of cuneiform tablets is not a new problem. The issues associated with the recording and visualisation of tablets has been known since the 1800s. In 1864, the Quarterly Review (Murray 1864) in an article noted that:

> It is a boon of enormous value to be able in any instance to eliminate that fruitful source of error, the fallibility of the observer. Photography is never imaginative, and is never in any danger of arranging its records by the light of a preconceived theory.

To the modern recorder with a 3D scanner, the most 'fruitful source of error' (Murray 1864) is the subsampling and smoothing of data. From an archaeological standpoint, it makes sense to capture as much detail as possible when scanning a cuneiform fragment, for even though the process of 3D scanning is not normally destructive, it is possible that a fragment may not be available for examination in the future. In the absence of the actual fragment, unedited scan data could be of unexpected importance to future researchers. However, the accurate recording of small 3D features is still on the edge of our capability, and expensive equipment is frequently needed to scan objects at high detail. At the present time, the initial cost of scanning equipment, rather than the cost of reproduction, presents itself as a modern day analogue for the photographic dilemma faced by the nineteenth century curators of the British Museum. Some objects lend themselves to 3D scanning, while others can present a considerable problem to certain types of 3D scanner. Reflective, absorptive, and dispersive surfaces present a particular problem for 3D laser scanners. The shortcomings of laser scanning technology which are well reported by Hahn (Hahn et al. 2007) and Chen (Chen 2008) have also been anecdotally expressed by those familiar with 3D laser scanning in the field. There are many cases where coherent laser light is affected by an object in such a way that it cannot be detected by the optical sensors, and scans of dark or reflective objects are frequently corrupt and unusable.

Cuneiform fragments require multiple scans to reproduce them in their entirety. Each scan is taken from a different angle so that all surfaces of the tablet can be recovered in 3D. It is not unusual for the surface of a tablet to have a firing pattern that varies in tone from black to light grey or orange. This deviation in surface colour can leave significant holes in captured data, and make matching together individual scans very difficult. When unusable scan data is encountered, a human operator must decide whether to leave the hole in the data, attempt to rescan the area with different settings or let the computer fill in the hole using specialised algorithms. The traditional method used to overcome the problem of missing data in industrial models involves the application of a non-reactive powder or water soluble spray to mask difficult areas. Within the context of the heritage community, the application of such a chemical masking agent could irreparably harm a unique artefact. In order to scan difficult objects, an alternative to traditional laser scanning must be used.

A popular avenue for the capture of cuneiform fragments is Reflectance Transformation Imaging (RTI). RTI scanners usually employ an SLR camera in a hemispherical rig that is populated by fixed lights with a known position. Triggering the lights in sequence and photographing the effect on the fragment generates an interactive lighting model that can be adjusted to view the surface of a fragment. Although RTI was primarily envisioned as a 2D process, RTI images can be used to generate a 3D surface map. The principal issues associated with using RTI for 3D model generation are described by Macdonald (Macdonald 2011), and it is shown that while the dome scanner presents an excellent method for visualisation of fragments with variable lighting conditions, the quality of the 3D model generated from RTI images is less accurate than other methods.

Autodesk's 123D-Catch is also a popular contender for 3D scanning without lasers, but practical experimentation with small objects has shown that the time taken to capture a fragment and the low level of detail captured by the system prohibit the widespread use of this capture method for cuneiform fragments. Other examinations of the 123D-Catch system have shown that the resulting models are of lower accuracy than other methods, and are prone to distortion in some circumstances (Chandler and Fryer 2011).

4.5.1 Web-Based Collaborative Virtual Environment

To fulfil the needs of end users, a front end system has been developed that comprises a browser-based interface for the manipulation of multiple fragments (Fig. 4.4). The browser-based front end runs primarily in JavaScript, and interacts with a database and with a node.js server. Although the hardware requirements of the interface are higher than most websites, the interface, when tested, performs as expected on a computer or laptop of moderate power, with a normal connection to the Internet. Data transactions are minimised by local caching, and positional information is transferred by pulling information from the server when required.

A user may interact with the system by selecting fragments from the database using a catalogue. Since the database is hosted in SQL, it is possible to sort and filter the data in a variety of ways. Chosen fragments appear along the bottom of the in-browser 3D visualisation, so that they can be added to the work area one at a

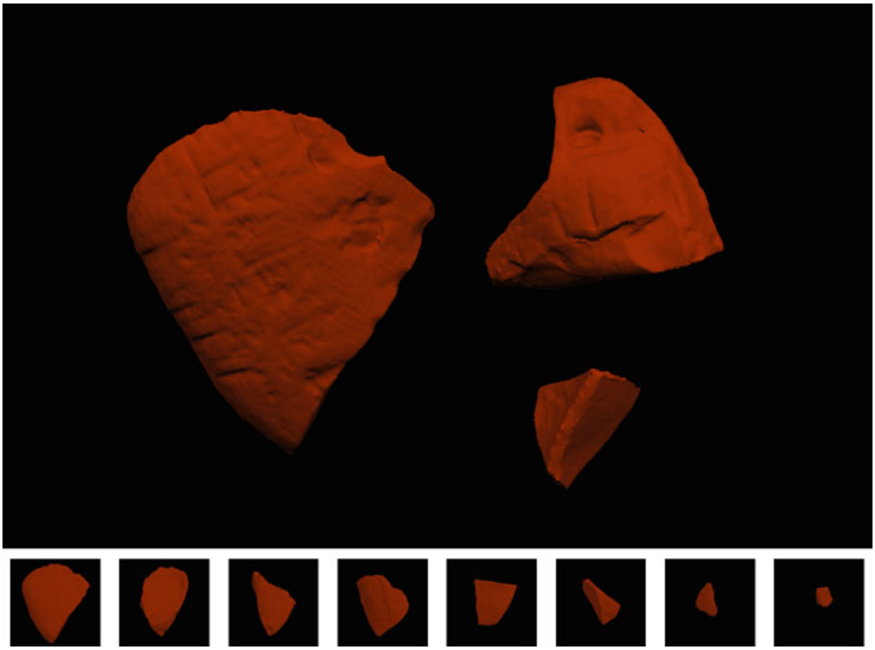

Fig. 4.4 The user interfaces supporting the Web-based collaborative virtual environment

time. As a user manipulates the fragments on-screen, the position and rotation of the pieces are transmitted to the server, and the position of on-screen fragments is checked against the server-side record every 100 ms. This means that multiple users can access the same fragment or collection of fragments, and the result of the manipulation can be viewed in real-time. In addition to standard information about position and rotation, each fragment within the framework supports the storage of metadata. The Web interface can read and manipulate the metadata as needed, supporting a diverse range of functionality including ‘scent’ or ‘pheromone’ trails that record user interactions, the last proximity of other fragments, potential matches and tags applied by different users.

As an example, an individual user may adjust the orientation and position of two fragments within the Web interface, concluding that the two fragments fit together. The user does not tag the fragments with any metadata, but keeps them close together on the screen. The proximity of the two fragments to each other creates a ‘scent tag’, a virtual insect pheromone trail that links the two fragments temporarily, but slowly degrades over time.

A second user may access one of the fragments at a later date and see from the ‘scent tag’ that it has been placed next to another fragment that seems to be part of the same tablet. The second user may then also choose to keep those two fragments close together on-screen, and possibly even tag them as a potential match. These actions will both increase the potency of the ‘scent tag’ linking these two fragments together. Once a critical level is reached, a specialist human or Artificial Intelligence (AI) agent will become aware of the potential match, and may bond the two fragments together permanently.

The metadata format used by the system is sufficiently flexible that new metadata fields can be added without affecting the operation of other agents, so that the evolution of the system agents and the web interface is possible without disruption to the system as a whole. No preference is given in the interface for cooperative or competitive work strategies, and a locking strategy is employed that takes the importance of an individual user and the time of the last interaction into account.

4.6 3D Printing

Manual reconstruction of cuneiform fragments allows for the direct manipulation of fragments in a 3D space, and it is reported by experts in cuneiform reconstruction that the tactility of a physical fit is an important feedback system in manual cuneiform reconstruction. The haptic feedback experienced when reassembling fragments of stone or clay often provides a strong indication of whether two fragments fit together.

In a virtual reconstruction system, however, the user is abstracted from the direct interactions of the physical world by a keyboard or touch screen, and manipulation of fragments by remote control is clumsy in comparison to direct manual reconstruction.

Modern domestic 3D printing technology makes it possible to reproduce cuneiform tablets using plastic or resin, and restore the haptic feedback of a real object to digitally stored fragments. The physicality of the printed object acts as a real world interface to the digital objects, communicating the effectiveness of a match between two fragments in a non-verbal way.

An additional benefit of 3D printing technology is the ability to place physical copies of fragments with scholars who may previously have had access to photographic resources. Also, fragments may be rescaled or manipulated before printing to allow for more accessible study or demonstration of a particular text.

Broadly speaking, modern 3D printers have the potential to provide each and every student of cuneiform studies (and every member of the general public) with complete, real world access to the entire body of virtual cuneiform source materials. 3D-printed parts are not precious or fragile, and so the process of sorting and matching fragments could be carried out by untrained hands prone to hazardous mistakes. Even museum visitors could be encouraged to try their hand at matching fragments together.

Until recently, powder deposition and UV resin printers provided the only practicable option for the reproduction of cuneiform tablets. However, the introduction of inexpensive plastic deposition printers such as the Makerbot Replicator or the UP! Personal Portable 3D Printer has provided a much more cost effective avenue for object printing. Despite the lower resolution of these systems, The VISTA-CR project and other projects like the Cornell Creative Machines Lab have both shown that the reproduction of 3D cuneiform fragments is possible in a variety of materials (principally PLA and ABS plastic) with sub-100 micron accuracy.

The quality of reproduction using deposition printing is generally good, but care must be taken when attempting to match fragments together printed using different types of plastic. The colour and type of plastic used can have a marked effect on the level of material shrinkage encountered as the fragment cools. For PLA plastic the effect is negligible, but for ABS, the final print may shrink by as much as 3 %.

4.7 Hypothetical Scenarios of Stigmergetic Interaction

This section attempts to formalise various hypothetical scenarios where users and agents may coordinate using the stigmergetic framework presented in this article.

4.7.1 Single User

A reconstruction system with only a single human user presents itself as an elaborate aide-memoire. The facility to tag and statically position fragments within the system endows the user with an augmented capacity for information organisation and recollection. Fragments are abstracted from the real world, and can be viewed and manipulated digitally without the special handling and security requirements associated with the original artefacts. The system becomes a workspace for linear examination and reconstruction that parallels traditional methods.

4.7.2 Two Users and Above

With the introduction of multiple human users to the system, additional variables could increase the complexity of the interactions dramatically. Even one additional human user adds permutations to the scenarios in the reconstruction process. For two users working with the same fragment, it is likely that the following aspects of the working relationship will affect the outcome of the reconstruction process.

Method of Encounter
An encounter within the system may be either accidental or deliberate. In the case of a deliberate encounter, the parties involved will likely have shared goals, such as the reconstruction of a particular fragment or collection. It is reasonable to assume that users working in the way will be more likely to work collaboratively, and may have developed a shared strategy to facilitate the achievement of their goals. In accidental encounters, users may potentially have antagonistic goals, and have dissimilar systems. In these cases, a series of activities is more likely to be the result of stigmergy, since no other form of communication will exist.

Strategy
A user may be either cooperative or antagonistic to the goals of another user. Antagonistic behaviour may not be deliberate, but may be the product of competing goals or strategies. As an example of this, consider the case of a tablet that is broken into three pieces. Two users already have a piece of the complete tablet, and both users attempt to manipulate the third piece (which fits between the other two pieces) so that it will match with the fragment that they already have. One or both of the users may behave antagonistically to reach their goal, constantly moving the piece back when the other user reorients it to suit their fragment's orientation. Alternatively, they may work cooperatively, by first allowing one user to move the disputed piece into alignment, and then moving their own piece to match the alignment of the other two pieces. If the users work cooperatively, both will achieve their goal, and their reputation will increase as a result of the successful match. Antagonism will result in either the match not being made, or a third party stepping in and taking credit for the match.

Timescale
Stigmergic communication does not require real-time interaction, but neither does it preclude it. Real-time non-verbal communications can operate independently of stigmergy, and subtle visual cues like shaking a fragment on the screen to draw

another user's attention to it, or moving a fragment away from a user can be used to enrich the matching process. Alternatively, users may rely solely on stigmergic communication to work with fragments when actions have a gap of hours, days or even months between them.

Geography

There are obvious real-time communication opportunities for physically and electronically co-located users, but there are also subtler reasons that geographical location is important to user–user interaction. The physical and social environment of the users has the potential to alter the interaction style of the user at a very basic level. Language and real time gestures common in one location may be completely different in another location, and at this level, it is easy to see how non-real-time stigmergic communication can be more useful than direct communication.

Dominance

As users interact with the system they gain reputation, which increases their effective dominance over other users. In situations where a deadlock may occur, the system will resolve in favour of the user with the highest reputation. The tag of a dominant user lasts for longer than that of a weaker user, and can have a greater effect on the actions of artificial agents. For these reasons, the outcome of an encounter between two users could be altered significantly if their dominance or equipotentiality were altered.

In the case of n users interacting with multiple fragments, the importance of dominance and cooperation increase. The interaction between multiple users could be considered similar to that of only two users, with the two most dominant individuals (or groups of individuals) being the main users in the system. The same variables discussed above would apply to the subgroupings of users, with the overall effectiveness of the group being decided by their individual effectiveness and ability to work cooperatively as a group.

Human Users and Artificial Agents

With the possible exception of some of the special agents described in the Sect. 4.3.4, a human agent will always exhibit dominance over an artificial agent within the system. Aside from this lack of dominance, it is hoped that the interaction between human and artificial agents should be very much like human–human interactions. Given that the primary method of communication within the system is stigmergetic, the normal issues of complex language parsing and real-time interaction faced by interactive artificial agents do not apply. Artificial agents within the system behave as simple creatures, they act as supporting actors in the environment, and a human would no more desire to communicate with them than he would with a termite or a wasp.

4.8 Conclusion

In this chapter, we formulated a novel theoretical framework for reconstructing ancient text. The long-term reconstruction of cuneiform tablets has been a difficult task for scholars due to various reasons—the distribution of uncategorised fragments in wide geographical locations as a result of the division of the finds after excavation between the country where the excavation was carried out and the countries the archaeologists came from (in Iraq until 1969), excavations carried out at the same ruin by different nations, illicit and unprofessional excavations, and other circumstances. Other difficulties are reflected in the way the fragments are traditionally catalogued as photographs and hand-drawn copies; others, however, have been left in an unstructured state in the archives even after a century of storage. A complete reconstruction of the tablets is important, as it will reveal centuries of social, political, literary, and scientific knowledge acquired since 3,300 BC.

A computational approach to reconstructing cuneiform tablets is greatly needed here. If n fragments are given, there are $0.5\ n(n-1)$ match possibilities (compare Gehlken 1990, pp. 7–8). A Brute force computation calculating 3D facts match for all possibilities is too expensive and might take far longer than manual human matching. A computational approach involving subdomains of Artificial Intelligence techniques is a better approach. However, popular search heuristics such as Genetic Algorithms and biologically inspired adaptive and learning algorithms such as Artificial Neural Networks are not going to be the most efficient as there are massive permutations in the fragmentation of the pieces. A methodology partly involving crowd sourcing from human and artificial agents is needed. The concept of stigmergy therefore, naturally falls into this category. The nature-inspired approach based on how social insects coordinate without direct communication is intriguing, and perhaps strikingly similar to a community of scholars that may not communicate very much yet have the same goal. These insects, apart from the fact that they only leave information in their local environment, either through pheromones or through their action on the physical materials and structures they built, do not have other means of direct communication.

Designing a framework for supporting stigmergetic interactions is not straightforward. For stigmergy to work as intended, all fragments need to be digitised as 3D textured models, this can be accomplished through our development of a pipeline of 3D scanning processes for this research. Our process pipeline for digitising fragments can be easily constructed with off-the-shelf software and inexpensive hardware. This will make it possible for scholars and curators to capture 3D models on and off locations for uploading to our Web-based virtual environment. Since networked virtual environment has no spatial or temporal limitations, and 3D models hosted within such an environment will make it possible for unlimited access to collections. This necessarily brings researchers from various geographical locations together into a single space. As stigmergy does not require synchronised time; stigmergetic actions can be sequential and still work, and therefore time is of no importance, although continual actions will greatly speed up the reconstruction. Our client–server framework supporting both human and artificial agents and Web-based user interface has made this a possibility. Furthermore, virtually reconstructed pieces can be confirmed via the 3D printing process we presented as a supporting method. Finally, a good practice in piecing together the fragments is to start with as much information as possible. Our work on photogrammetric analysis of approximately 8,000 complete tablets from the CDLI has given us an initial understanding of the general shapes and ratios and nature of cuneiform tablets. The supporting technical foundation for a truly nature-inspired reconstruction of cuneiform tablets has been prepared. We hypothesised that such a method will greatly speed up the reconstruction of the tablets, bringing the long-sought knowledge hidden in the scattered fragments to the public. Finally, we proposed various hypothetical scenarios on how human and artificial agents will likely coordinate within the stigmergetic framework we developed. These will allow us a structured approach for facilitating better coordination amongst the agents. We are but a short distance from obtaining ancient knowledge.

The success of the project has direct relevance to the digital preservation of cuneiform tablets for future access and cooperative reconstruction globally. The significant contribution that this project will bring to the academic community is the restoration of past knowledge and insights into the hidden past. Only 5–10 % of the ancient Greek literature has survived; saving and reading the burnt papyri from Herculaneum (Villa of the Papyri) by modern technology might increase this percentage considerably. Our task, comparable to the task of saving burnt papyri from Herculaneum is to recover cuneiform tablets by computationally joining the fragments from the ancient corpus of Sumerian, Babylonian, Assyrian and Hittite literature.

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Chapter 5
Multi-Touch Tables for Exploring Heritage Content in Public Spaces

Chris Creed, Joseph Sivell and John Sear

Abstract Multi-Touch tables are increasingly being used in public spaces such as museums, art galleries, and libraries to help to engage the public and provide access to collections. Designing applications for this type of environment where a wide variety of people can use the table raises unique interaction issues that need to be addressed. This chapter initially provides a detailed review of research studies that have investigated the impact of multi-touch tables in cultural heritage environments. A case study into the design of a touch table application for The Hive (the first integrated public/university library and history centre in Europe) is then presented where we highlight issues experienced and lessons learned during the development process. In particular, we cover requirements gathering, design approaches used, the selection of appropriate content (for a broad user base), installation and maintenance of a table and details of an initial informal evaluation.

Keywords Multi-touch tables · Public displays · Interactive tabletops · Gestures · Surface computing · Natural user interfaces · Digital heritage

5.1 Introduction

Cultural and heritage organisations are under constant pressure to create novel and innovative exhibits that meet the growing demands of tech-savvy visitors. People want social and collaborative experiences where they can have fun and learn at the

C. Creed (✉) · J. Sivell · J. Sear
The University of Birmingham, Edgbaston B15 2TT, UK
e-mail: creedcpl@bham.ac.uk

J. Sivell
e-mail: j.sivell@bham.ac.uk

J. Sear
e-mail: j.a.sear@bham.ac.uk

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same time (Black 2005). As such, museums and art galleries are increasingly making use of large multi-touch tables to help engage the general public (Geller 2006; Benko et al. 2009). Touch tables hold much potential for collaborative experiences as they provide the ability for multiple people to interact with content simultaneously (Isenberg et al. 2010). In a heritage domain, multi-touch tables can be utilised for a variety of purposes—for example, they are particularly useful for interacting with objects that are normally too precious or delicate to handle (e.g. mediaeval maps or ancient manuscripts). Tables can also be used as a hub for other activities where groups of people (e.g. school children) can work on tasks related to exhibitions during a day trip (Collins et al. 2012). Moreover, multi-touch tables can be used purely for entertaining and engaging games that help to make an exhibition more enjoyable and interesting (Arroyo et al. 2011). Heritage organisations also have a desire to provide easier access to a larger proportion of their collections. Only a small fraction of a collection is ever on public display often due to space and conservation issues. Touch tables can therefore be useful in providing a full digital representation of a collection thus making it more accessible to the general public.

The size of large touch tables and their use in public spaces raises new interaction and design issues that must be carefully considered when building multi-touch applications. The nature of the interaction means that a broad range of users can interact with the table simultaneously—that is, users of different ages, educational backgrounds, and varying levels of technical experience. This presents both opportunities and potential tensions that require further investigation. In this chapter, we explore these types of issues in more detail—we initially provide a review of the literature that focuses on the use of multi-touch tables in a heritage domain. In particular, we highlight the main findings from *in the wild* evaluations that have started to examine the impact of tables in public spaces. A case study into the design of a touch table application for the Hive is then presented where we highlight issues experienced and lessons learned during the development process.

5.2 Multi-Touch Tables

In this section, we define what is meant by the term "multi-touch tables" and highlight the different types of hardware used for detection of multiple touches. We also discuss the different methods available for developing applications for multi-touch tables and highlight the pros and cons of each approach.

5.2.1 What are Multi-Touch Tables?

We define a multi-touch table as an interactive horizontal display that enables multiple users to simultaneously interact with content presented on a table. This interaction is primarily through multi-finger gestures although other input devices can be used (e.g. a stylus, tangible objects, mouse, and keyboard). The design of a table lends itself well to having multiple people standing or sitting around it and collaborating on tasks. This is not easily possible with traditional graphical interfaces displayed on smaller monitors. The ability to use our hands to manipulate virtual objects is appealing as it can make interactions more intuitive and enjoyable. Touch tables also hold much potential for children working together on tasks through creating a more engaging experience (Dillenbourg and Evans 2011). Furthermore, the size of a table can make interacting with content easier for elderly users who may have trouble controlling standard computers or reading small text on screens (Loureiro 2011).

5.2.2 Multi-Touch Hardware

Multi-touch table technology has been discussed in several seminal papers (Lee et al. 1985; Wellner 1993) with more recent innovations including the development of the FTIR technology (Han 2005), the release of the Microsoft Surface in 2007, and more recently the Samsung SUR40 with Microsoft *PixelSense*.[1]

There are numerous other products available on the market that implement multi-touch using different approaches. These involve the use of infrared (IR) overlays, capacitive screens, and optical displays. IR overlays are appealing because they can easily be added to existing television screens to provide them with multi-touch capabilities. Capacitive screens are currently the most widely used touch technology and are typically used for multi-touch on smart phones and tablets. Capacitive technology used in phones tends to support up to 5 simultaneous touch points whereas tablets generally support 5–10 simultaneous touches.

Optical touchscreens use cameras to capture any objects that come into contact with the screen—image processing software is then used to check for multiple touch points. The PixelSense technology is an example of a camera-based system that essentially allows the table to capture an image directly upwards. This image is processed in order to generate any touch points and to capture other information—for example, tangible objects placed on the table can be identified by shape and size or by tagging the object underneath.

All of these approaches have pros and cons—IR overlays are relatively cost effective, but they might not be as responsive as capacitive or optical screens. However, whilst capacitive and optical screens are usually more responsive, they are also more expensive. Another issue with IR overlays is that touches can be detected even when a finger is not in contact with the screen—this can cause problems when ties or sleeves can be registered as touch points unintentionally.

[1] Microsoft PixelSense. http://www.microsoft.com/en-us/pixelsense/default.aspx.

5.2.3 Multi-Touch Software

There is a variety of tools and programming libraries available for creating multi-touch applications. Microsoft Windows Presentation Foundation[2] (WPF) has supported the development of multi-touch applications since Windows 7. Within WPF it is possible to capture either the raw input (touch) data or register for higher level manipulation events. WPF supports good separation of code and design which can allow programmers to easily collaborate with designers on touch table projects.

Another option is Microsoft's Surface SDK[3] which was originally intended for developing applications for use on the Microsoft Surface touch table. Two versions of this hardware exist although the newest version has been renamed the Samsung SUR40 with Microsoft *PixelSense*. The Surface SDK comes with ready-to-use components and user interface controls that are optimised for multi-touch tables. For example, developers can add images to an application that by default can be rotated, scaled, flicked, and dragged without having to write any additional code. This can help to facilitate the rapid creation of touch-enabled applications and can significantly reduce development time.

Open Exhibits[4] is a multi-user toolkit that assists the creation of interactive exhibits. It is free for non-commercial use including education and museum sectors although there also exists an equivalent commercial version called GestureWorks.[5] It includes over 50 different customisable user interface components making it easy to efficiently develop applications without much technical expertise. For instance, it is feasible for a technical museum curator to create their own exhibits by plugging together these components without any developer assistance. It is also possible to create your own custom components using the Open Exhibits SDK—this is written in ActionScript and supports both Adobe Flash and Adobe AIR. However, when building highly bespoke applications that deviate from the existing components available it can become a time consuming process.

Unity[6] is a game engine that is increasingly being used for developing multi-touch applications. Unity's main features include the ease at which developers can create professional quality video games and its multi-platform support (including the web, PC, Android, and iOS). The latest version of Unity supports Windows 7 touch events, however, this is limited and reports are that it only works for a single user as the events are mapped through mouse events. There are a number of options available to solve this issue with the simplest involving the use of W7Multitouch[7]—an extension developed for unity.

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[2] WPF. http://msdn.microsoft.com/en-us/library/ms754130.aspx.

[3] Surface 2.0 SDK. http://msdn.microsoft.com/en-us/library/ff727815.aspx.

[4] Open Exhibits. http://openexhibits.org/.

[5] GestureWorks. http://gestureworks.com/.

[6] Unity. http://unity3d.com/.

[7] W7Multitouch. http://bit.ly/Z0Nmyy.

NUITEQ developed a system known as the Snowflake Suite[8] that supports most interactive multi-touch display technologies. It is designed as an all-in-one solution for providing a table with a variety of applications and games designed around a multi-user touch interface. While it does support customisation and extension (using the C++ language) it is not intended as a platform for developing highly bespoke applications.

Until recently it is has not been possible to create multi-touch web-based applications although the rise of HTML5 (and its Touch Events API[9]) has started to make this more feasible. However, whilst some browsers have started to implement touch support for single users (in particular on mobile devices) few support full multi-user and multi-touch interactions necessary for the applications described in this chapter. With Microsoft's new focus on multi-touch interactions in Windows 8, Internet Explorer 10 now supports multi-touch applications with a number of sample HTML5 applications available online.[10]

5.3 Multi-Touch Table Research

Whilst multi-touch tables are increasingly being used in public spaces, there remain relatively few studies that have evaluated their usage within a heritage domain. In this section, we highlight the main research findings from studies in the literature—these consist of a variety of the wild and laboratory studies (Alt et al. 2012). We group the findings across several themes including how multiple users interact with tables, how people approach tables, interface design and content, and in terms of the gestures used when manipulating objects.

5.3.1 Multiple Users

Collaboration: One of the key benefits of multi-touch tables is the opportunity to collaborate and interact with others. However, research studies have found that this rarely happens in public spaces. For example, Hinrichs et al. (2011) found that people mostly browsed content individually without much interaction with other visitors. Arroyo et al. (2011) created an application that enabled people at two different museums to simultaneously interact with the same application remotely—however, feedback from visitors found that they would have liked the opportunity to use the table individually. These findings within a heritage domain are also consistent with evaluation results of multi-touch tables in other areas (Kirk et al. 2012). In contrast to these findings, Hinrichs et al. (2008a) found that people

8 Snowflake Suite. http://snowflakesuite.com/.

9 Touch Events API. http://www.w3.org/TR/touch-events/.

10 HTML5 Multi-Touch Applications. http://ie.microsoft.com/testdrive/.

often interacted around a table in groups of two with one person leading the interaction. It is important to note, however, that this application did not support multiple touches from different users.

Broad Range of Users: The use of touch tables in public spaces creates the potential for a wide range of people to interact with a table—people can vary in age, technical experience, and educational backgrounds. Research studies have highlighted some of the issues this can present—for instance, Hinrichs et al. (2011) found that on occasions children frustrated adults by throwing (virtual) objects around whilst adults wanted to concentrate and read the content presented on the table. Hornecker (2008) observed that different groups of users had varying attitudes towards a touch table—in particular, children tended to be more enthusiastic while adults perceived them as more of a "toy" for younger users.

Social Discomfort: Several studies have highlighted the social tensions that can be experienced during interactions on multi-touch tables. Marshall et al. (2011) evaluated a table installed in a tourist information centre over a 5-week period and found that interactions between strangers could lead to social awkwardness. This application was designed specifically for a group of people to form a plan of what to explore during a day out and when strangers joined the table it could cause tension. Hinrichs et al. (2011) evaluated the EmDialog application which included a horizontal touch table in addition to a large vertically mounted screen that mirrored their interaction with the table. In this study, it was found that people felt anxious and uncomfortable about others being able to watch their interaction with the table on the vertical screen.

Shared Control: Multi-touch applications typically give users shared control over objects displayed on a table. This can cause interaction issues—Hinrichs et al. (2011) found that people became frustrated when other visitors would enable or disable layers of information that would interfere with what they were viewing. Hinrichs et al. also highlight the issue of "stealing" objects from others—this can easily happen through accidently tapping an object that someone else is interacting with—the last touch will give control of that object to the "new" user.

Social Learning/Peripheral Interest: When multiple people are interacting at a table it presents an opportunity for users to observe what others are doing. For example, Hinrichs et al. (2011) found that individuals would often interact with an object individually, but would become interested in other content after watching others in their peripheral vision. In a separate evaluation, Hinrichs and Carpendale (2011) found that people regularly learned gestures from watching others using the table.

5.3.2 Approaching Tables

Honey Pot: Several in-the-wild studies have found that the *honey pot effect* also relates to interactions with multi-touch tables. This effect is typically used to describe how many people become interested in an interactive application when they can see other people using it (Brignull et al. 2003). Hinrichs et al. (2011) observed this effect while evaluating two different multi-touch table applications. This effect was also observed in the way people approached the EmDialog application (Hinrichs et al. 2008b).

Individuals and Groups: When designing applications for multi-touch tables it can be easy to assume that collaborations around a table will take place with coherent groups of users (e.g. a family of four). However, in a public setting, field studies have unsurprisingly found that this is not the case—instead, tables are approached by individuals, small and large groups of people (varying in age), families, and strangers. As Marshall et al. (2011) state, interactions around a table in a public space are: "*… more akin to a staggered 'buffet' table style of interaction than a 'dining' table sitting where all come together at the same time and use it …*".

Vertical + Horizontal: Some exhibitions have experimented by using horizontal touch tables along with large vertically mounted screens that are used to mirror what people are doing on the tables. This was the setup used for the EmDialog system and researchers found that the large vertically mounted screen was useful in attracting interest in the table (Hinrichs et al. 2008b). However, as noted previously, this also made people feel anxious and uncomfortable as others could publically observe what actions they were performing on the table.

Children versus Adults: Several studies have demonstrated that children are much more willing to "dive in" and start interacting with a table and experiment with a range of different gestures (Hornecker 2008; Hinrichs et al. 2011; Jokisch et al. 2011). Adults, on the other hand, tend to be more tentative and prefer to watch initially before they start an interaction with the table.

Motivating Usage: Hornecker (2008) found during a 70 min evaluation session that a large percentage of visitors walked straight past a table (installed in a museum) and did not stop to interact with it. This highlights the need to motivate visitors to start an interaction and to ensure the table does not look intimidating to use. It is important to note that this study is from several years ago when people were less familiar with multi-touch technology.

Robustness: Observations of people approaching and interacting with tables have shown that they often place objects on the table much like they would with a normal "non-interactive" table (Hara 2010; Hinrichs et al. 2011). Users will put heavy bags, food, drinks, books, and other items on the table and then try to interact with them. These items can result in touch points being recognised by the table which could cause interaction problems. It also highlights that tables must be robust, waterproof, and able to withstand rough usage.

5.3.3 Interface Design and Content

Input Device: Several different types of input devices can be used to interact with touch tables including hands, a stylus, mouse, and a keyboard. As Ha et al. (2006) found, direct input (e.g. finger and stylus) can help to support natural and fluid gestures and allow others to learn gestures through observation. On the other hand, indirect input devices allow out-of-reach items to be selected easier and are likely to be more familiar to users. However, a mouse can only provide a limited amount of actions, whereas a variety of multi-finger gestures can be used for different actions.

Captions/Text: Displaying large volumes of text is not necessarily best suited to large multi-touch tables—they are about "interactions"—not reading lots of content. Hinrichs et al. (2011), for example, found that people felt the captions used were dry and that having to read content was inconsistent with the dynamic and interactive nature of a touch table.

Text Input: Some museums may wish to collect feedback from visitors or text input may be required for other purposes. The issue here is that text input on large multi-touch tables can be problematic and a frustrating experience (Wigdor et al. 2007). A standard QWERTY keyboard is often the approach used, but researchers are investigating new methods (Hinrichs et al. 2007; Hinrichs et al. 2008a)

Visual Effects versus Content: Hinrichs et al. (2011) found that visual effects and interactive elements dominated over content. That is, people preferred to play with the table rather than engage with the content. A balance has to be struck between providing an engaging and enjoyable experience along with educating people effectively (although this will depend on the context of the application).

Complex Interfaces: Interfaces that are perceived to be complex and difficult to use will reduce engagement with the table and result in people leaving after short interactions. Hinrichs et al. (2011) noticed this with the Artic Exhibit for both children and adults. However, on occasions, the complexity of the interface actually resulted in more collaboration as people had to interact to understand how to use the interface.

Natural Affordances: Kirk et al. (2012) found that the use of "natural" affordances and metaphors in interface design for touch tables can cause confusion. This is because the action on a table cannot always exactly match the real world equivalent—it therefore does not feel like a "natural" interaction. As Norman states, "natural" is an overloaded term and touch interfaces are typically "unnatural" to use (Norman 2010).

Tangibles: Tangibles are regularly used in multi-touch table applications (Jordà et al. 2007), but relatively few applications have used them within a heritage domain (e.g. Hsieh et al. 2010; Nagel et al. 2009). This might be because tangibles can easily be stolen, misplaced, or damaged when used in a public space. One study that did examine the use of tangibles was conducted by Ciocca et al. (2012)—they found that elderly users struggled when using tangible objects to browse through large image databases (with a heritage focus) while other users had fewer issues.

5.3.4 Gestures

Multiple Gestures: Hinrichs and Carpendale (2011) conducted a detailed analysis of the gestures used on a multi-touch table and found that different people would try out a variety of gestures to perform the same actions. For example, for a drag and move gesture, different people used either a single finger (with their hand closed into a fist), all five fingers (with an open hand), or eight fingers (with an open hand). The same was also applied to actions such as rotating and resizing objects. Other studies have found that people experiment with a range of different gestures when approaching tables in a public space (Hornecker 2008).

Two Hands: Hinrichs and Carpendale (2011) found that users will often use two hands to interact with content on tables (a similar finding to Kirk et al. (2012)). In particular, they found that bimanual gestures tended to be symmetric with both hands having a similar posture and the same fingers being used for manipulations. Bimanual gestures were occasionally asymmetric—especially when children were using the table.

Gesture Sequences: Another interesting finding from Hinrichs and Carpendale (2011) is that people used "gesture sequences" when interacting with objects. For instance, they might select and drag a photo towards them and then (whilst still dragging) also resize and rotate it so that the object is facing them. These transitions were fluid and almost instantaneous.

Educating Users: Studies have provided mixed findings about users' ability to discover all gestures that can be used in a multi-touch table application. It is clear that it depends on many factors (e.g. technical experience)—even for more experienced users there might be multi-hand and finger gestures that need to be learned. Users therefore need to be educated—Vanacken et al. (2008) investigated this through the use of avatars in the interface although further work is still required.

Children/Adults: Hinrichs and Carpendale (2011) examined differences in gestures between children and adults and found that younger users attempt to take much more control of the screen than adults. Children had a tendency to use "larger" gestures that involved two flat hands, arms, and sleeves and would resize objects to take over a large majority of the screen. Adults, on the other hand, tended to use single handed gestures—especially when others were using the table at the same time.

5.3.5 Summary

Whilst relatively few evaluations have been conducted into the use of multi-touch tables, the research presented in this section highlights many of the key issues involved in building applications for this domain. In particular, these findings helped to inform the design of an application we developed for a new library and history centre which we describe in the following sections.

5.4 The Hive: A Case Study

In this section we describe our experiences in designing, developing, and evaluating a multi-touch table application for The Hive—the first integrated public and university library and history centre in Europe. The Hive is run in partnership between Worcestershire County Council (WCC) and the University of Worcestershire (Fig. 5.1). The building contains an integrated public and university library, the Worcestershire Archive and Archaeology service and the Worcestershire Hub (a place for all enquiries on county and district council services). The Hive attracts a broad range of user groups including children, university students, school trips, staff, and elderly users. The touch table was funded by the WCC heritage, arts and music service, and the WCC archive and archaeology service-both of which are based at the Hive. This had implications for the type content that needed to be made available on the table which we discuss in the following section. The table is located on the "Explore the Past" floor in a large open space next to a private study area.

5.4.1 Touch Table Requirements

The main goal for the touch table application was to create an engaging, fun, and educational experience that was accessible to all visitors. In initial discussions with members of the Archive and Archaeology team it became apparent that they had a

Fig. 5.1 The Hive building (Worcestershire, UK)

rich and varied collection which they wanted to represent on the table. However, due to the volume of content available, we had to make decisions as to which assets to use and how to structure the touch table application. We also had a very tight deadline and only a few weeks development time to create something for the Hive's opening day. We therefore needed to develop something relatively simple and robust, but still engaging and interesting for the general public to interact with.

We decided, therefore, to create an application that would enable people to interact with photos of interesting objects related to Worcestershire. This type of application makes use of the table's unique features (e.g. its larger size) through allowing users to zoom into high resolution images to examine areas of interest. This is not possible on other types of technology and we felt it would be sufficiently novel to engage and entertain the public. Due to the source of the funding for the table (the WCC) it was emphasised by the team working with us that additional content would be required for the table—in particular, details of other attractions in Worcestershire, information about Archive and Archaeology resources (signposted as "Explore the Past"), and a credits page describing the purpose of the table (including all logos of partners involved in the project).

We looked at several potential options for developing a photo viewer including Open Exhibits and several media player applications (e.g. Snowflake Suite), but none completely fulfilled our requirements. In particular, we wanted the ability to easily add captions, apply our own custom styling, and to lock down the system so users could not access the operating system (i.e. no "exit application" buttons). We therefore decided to custom build an application primarily using the Microsoft Surface SDK which provided all the functions we required.

5.4.2 Content Selection

The selection of content for the application was carried out in close collaboration with Archive and Archaeology staff at the Hive. The selection process involved a series of discussions and interviews over 5–6 days which largely involved the Archive and Archaeology staff educating us on the scope of the collections and then narrowing down possible options. One general criterion we had when working through the content was a strong preference for photos of people. It was felt that visitors tend to enjoy looking at faces from the past and can relate to the places people lived and worked. Also, we only wanted to include photos that were worth viewing at a large size—for example, an old milk bottle might make an interesting physical object, but there is no real value in making it larger on a table. In contrast, zooming into high-resolution maps can allow people to explore lots of details (e.g. tiny hand-drawn illustrations) that they would not otherwise be able to easily view on a website or smaller touch-based device. Another key focus was to look at material that is normally difficult for the general public and staff to access due to size or fragility.

The first theme that clearly came through was "agriculture"—this was a relatively straightforward choice as the collection contained an interesting range of photos from different periods and the subject matter was particularly relevant to the local audience. Worcestershire has always been a strong agricultural region and as such we decided to include photos related to hop picking (a region speciality) and the old cattle market. Another obvious category was regional maps which were well suited to the table due to their high level of detail. These objects tend to be very large and in some cases they are bigger than the actual table. They are therefore not easily accessible to the public as they can be awkward and delicate to handle—they are also light-sensitive so they have to be used with care.

"Ephemera" was another theme that came through as the archive contains many posters, pamphlets, leaflets, and advertisements that were relevant to Worcestershire. Such items present a rich historical record as they cover many aspects of daily life and depict changing styles and fashions over time. They also contain interesting details such as hand-written comments, amendments, and annotations. These types of items are usually difficult to display in large quantities because they can take up a lot of space in exhibition cases. "Shop fronts" is a category that was not immediately obvious, but something that was discovered through dialog with the Archive and Archaeology team. The photos chosen for this theme contain lots of interesting details (items in the windows, price tags, and old signs) that may help to create an emotional connection and a feeling of nostalgia.

The final category was "Landscapes and Artefacts" which was closely tied to the theme of archaeology. The Hive had previously commissioned an illustrator to create a series of scenes of daily life from the Palaeolithic to the late mediaeval period. These artist impressions included objects from archaeological discoveries in the local area—we were therefore able to create a category that contained the illustrations as well as photos of related objects.

5.4.3 Interface Design

In creating the design we needed to make it easy for people to select different categories and view objects that were of interest to them. We ideally wanted a 360° main-menu screen that would enable a user approaching from any angle to be able to select a category. However, due to time constraints, we had to produce a standard menu that had a fixed orientation. We also decided to use a fixed orientation for the resources and credits pages for the same reason. A 360° design was instead used for the category photos and we achieved this through scattering the photos all around the screen. For example, when the user tapped on the "agriculture" button, all the photos for that category were displayed around the screen which enabled a user to approach the table from any position and interact with the content.

After creating an initial version of the interface we found the number of assets in a category was an issue—if there were too many they could easily become hidden which made it difficult to sift through the different items. We termed this the "jumble sale"—examining the assets became a random sorting through piles of objects. Serendipity replaced active browsing whereas we wanted people to choose objects that were of interest to them and then explore further. We therefore had to be careful in how objects were displayed and had to ensure that photos did not initially completely overlap other content.

We varied the size, rotation, and position of objects within all the categories as we wanted to try and subtly suggest to users that the objects can be rotated, scaled, and dragged around the screen. We also thought about constraining the size of photos to avoid users making the images large enough to take over the whole screen. We experimented with several ideas to address this, but in the end we felt one of the key benefits of the table is the ability to scale images up to a large size. We did not want to restrict the ability to do this and as such users can currently resize photos to any size. We plan to explore how this impacts an interaction when multiple people are using the table in future evaluations.

Another issue we had to give consideration to was how people would navigate back to the main menu when inside a category. We wanted a button that did not take up too much screen real estate, but at the same time allowed anyone to easily select the button without having to walk around the table. We decided to place a rounded button on each corner of the interface—we felt this would allow people (no matter where they were standing) to easily navigate back up a level and select a different category.

A further issue relates to titles and captions that were attached to photos—we were initially unsure whether captions should always be on display or whether the user should have control over whether they wanted to read the content. We decided to hide the captions by default, but allow the user to easily toggle the display of a caption through tapping an icon. This was because we wanted (at least initially) the primary focus to be on the objects and photos—having the captions displayed as well would take up valuable space.

5.4.4 Touching History—A Multi-Touch Table Application

The Hive received an Ideum MT55 Pro multi-touch table that includes a 55-inch LCD screen that is capable of 32 simultaneous touches. The screen is 76 mm thick and includes 1920 × 1080 full HD resolution. The application initially starts with a main-menu screen that contains the six different categories discussed—agriculture, landscapes and artefacts (archaeology), Worcester maps, shop fronts, posters, and county maps (Fig. 5.2). There are also three buttons that allow people to get more details about things to do in Worcestershire, view resources available on the "Explore the Past" floor, and also get further details about the table (which includes credits and logos of all partners involved).

When the user taps one of the categories, objects related to that category are scattered onto the table using an animated effect (Fig. 5.3). People can then

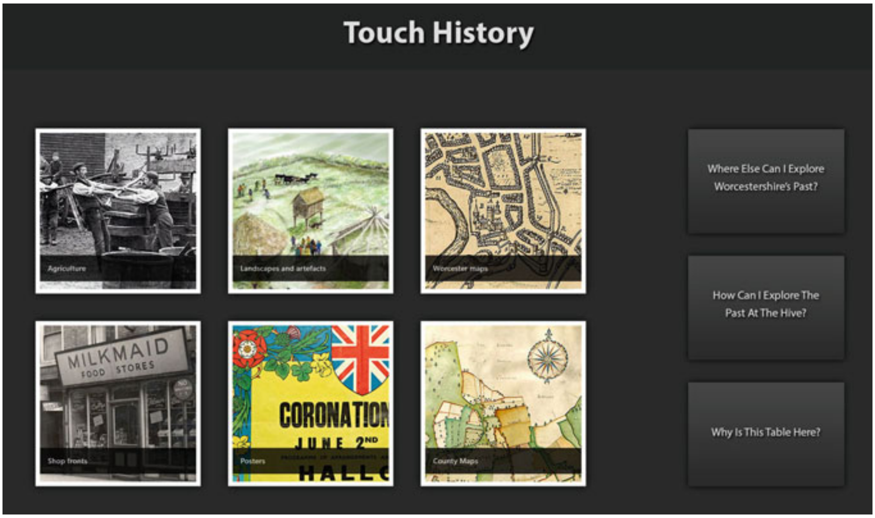

Fig. 5.2 Main-menu screen for the Hive

Fig. 5.3 The Worcestershire maps category

interact with these objects using a range of multi-finger gestures that enable them to drag, flick, resize, and rotate the photos. Each object also has a caption where further details can be obtained.

To allow users to explore other related locations around Worcestershire we used a map of the county along with location pins that users could tap (Fig. 5.4). When a user tapped one of these pins a photo would be displayed for that attraction along with a caption.

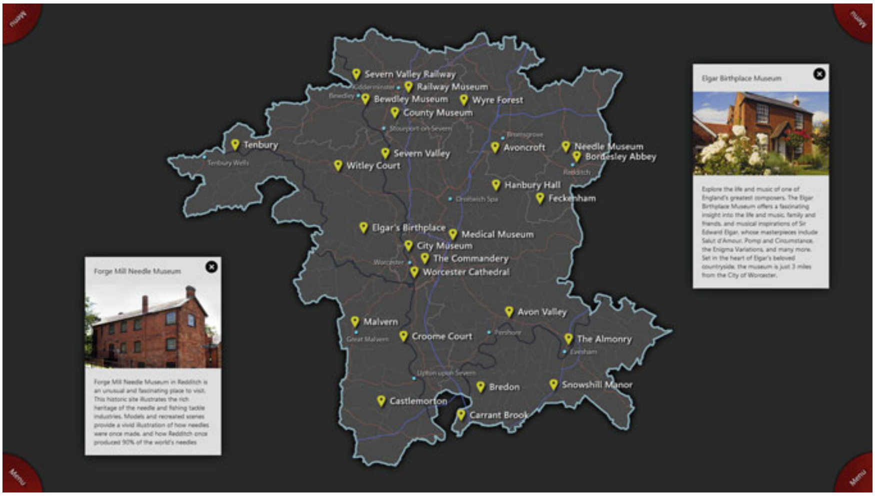

Fig. 5.4 Map of Worcestershire with points of interest

The resources section contained a list of resources that were available to the general public on the “Explore the Past” floor. There were five different categories of enquiries across the top of the screen all of which had subsections of relevant resources listed down the left-hand side. When a user tapped one of these buttons an image and some further details about that resource were displayed (Fig. 5.5).

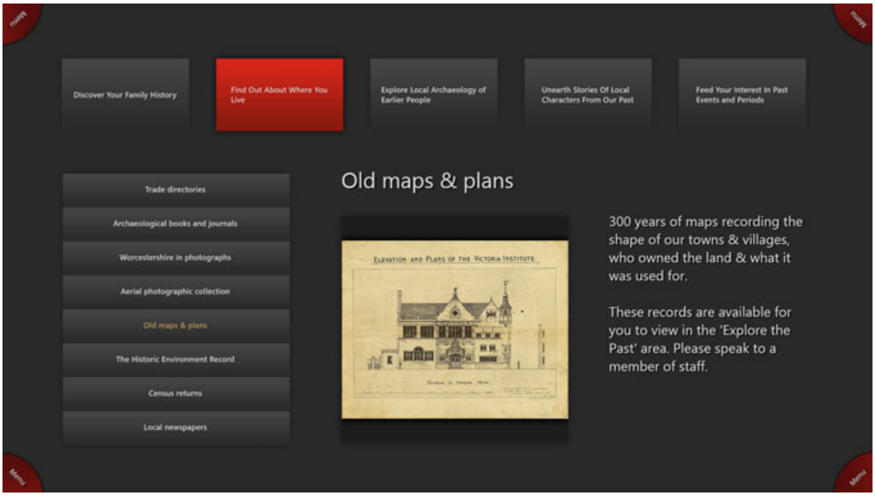

Fig. 5.5 The resources page

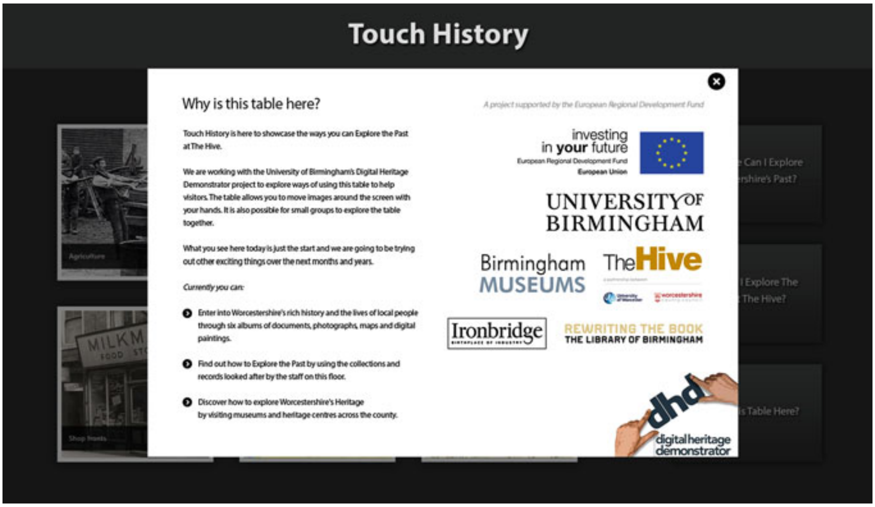

Fig. 5.6 The credits page

Finally, the credits page contained information explaining the purpose of the table as well as a collection of logos for every partner involved in the Digital Demonstrator Project (Fig. 5.6).

5.4.5 Operational Issues

There are several key operational issues to consider when building a multi-touch application for a heritage organisation. Below we detail the key experiences learned during development of the Hive application.

Location of the table: At the Hive there was no exhibition that the table needed to be incorporated into—it was a standalone item and its location was largely restricted to areas under the control of the Archive and Archaeology service. The table obviously needed to be in a location where the general public would walk past it—as such, the chosen site was situated on the first floor of the building in a large open area at the intersection of two routes, next to a private study area. Many visitors to this floor of the Hive are accessing various parts of the archive to research family or local history. Others are visiting the staff in their offices to discover what is known about archaeology of sites around the region.

Circulation Space: For the table to be used in a 360° manner there needs to be sufficient room around it both for table users to stand and for circulation past them (including wheelchairs). A reasonable free distance is often given as 2 metres (Majewski 2012)—we therefore ensured the table that had sufficient space around it to meet this guideline.

Power Sockets: Ideally the table should be installed directly on top of a floor socket to provide mains power. This removes any trailing wires which would be a trip hazard and blocks public access to the power socket. Wall sockets are not ideal as they require either that the cable is routed across the floor under a rubber cable ramp or that the table is positioned against the wall which removes the 360° nature of the experience. In both cases ensuring that users turn the power off is still an issue.

Network Access: It was useful that a network connection was available at the Hive via the floor box. Although the application did not require a network connection it was extremely useful to have three reasons: (1) installing the necessary libraries and tools onto the table (e.g. the Surface SDK) (2) getting the application files onto the table from the source code repository on the cloud (3) transferring back into the repository any code updates that are made directly on the table.

Signage: The Hive is a new building and the presence of the table was planned into the "wayfinding" scheme so there is signage from the entrance hall directing people to the "Touch History table". However, there is currently nothing above the table that informs visitors that it is the "Touch History table". This could potentially be an issue as the surface is horizontal and none of the screen content can be seen from a distance due to the low angle.

Lighting: Both windows and overhead lighting often cause problems as their reflection in the glass surface can make the screen content unusable at certain positions around the table. At the Hive there were fluorescent tubes above the table which could be independently disabled. When planning a location it is worthwhile conducting an early test using a mock up with sheet of Perspex held at the correct height (i.e. the height of the table).

Installation: Installation into a public space requires the coordination of many different teams. The hardware supplier, the interactive design team, the host organisation, IT services, and the security department (if the installation is to be completed out of public opening hours). Touch tables are large and very heavy especially when packed for transit and several people are required to move them (even if they are on a pallet trolley). An organisation will often have a dedicated loading bay for accepting deliveries although this might not always be suitable and may be outside (i.e. not secure).

Start Up and Shut Down: For reasons of energy efficiency the table needs to be switched on and off each day. Some installations control this remotely according to a timetable via a central show controller which is networked to all digital museum interactives. A more common method is for the start up to be part of the daily routine staff. However, at the Hive, the opening hours of the building are much longer than the office hours of the staff involved in the project. As a result, starting up and shutting down the table is handled by different teams. To provide full cover each team needed several people trained in managing the table.

Security: Once the application is running there is no way to gain access to the operating system without using the keyboard. This is important as users may potentially close down the application leaving the table displaying the operating system with no obvious way to restart the application. More importantly, if the table is networked this would represent a security risk for the organisation. As well as locking the keyboard away inside the table it is important to remember to disable the virtual touch keyboard that is available in Windows 7. For similar reasons no USB sockets should be accessible to the public.

Cleaning: Cleaning is a very important issue as the public will repeatedly touch and wipe their hands across the same piece of glass that hundreds of other people have used. The Hive cleans twice a day with an antibacterial spray and a microfiber cloth—the person that starts the table cleans the screen at the start of that day around 9 am. This individual also cleans it at the end of the day (around 5 pm) as the table will be used (out of hours) by the public (the Hive closes at 8 pm).

5.4.6 Evaluation and Lessons Learned

We installed the table on the opening day of the Hive (3rd July 2012)—we set everything up before opening time and then stayed the whole day to ensure no major errors occurred. We spent the day working at desks close to the main touch table which enabled us to get a sense of how the general public used the table. We noticed that a variety of people approached and used the table including children, adults, and elderly users. We did not keep records of how many people used the table, but we estimate it was at least 40–50 people over the course of the day. We found that the general response was very positive—staff started using the table with visitors (e.g. to highlight details on maps) within the first few hours of the table going live. This was surprising given that the majority of staff had not used touch tables before.

We also found that the general public were able to use the interface—as Marshall et al. (2011) found, people tended to approach the table either individually or in small groups. The honey pot effect also applied here as people appeared to show more interest in the table when others were using it. The ability to scale photos to a large size was something that continually received positive feedback from the public. However, we noticed that some elderly visitors did not even touch the table—or, at most, they only touched individual objects and dragged them around the table. Many of them never discovered the rotate, flick, and resize gestures—this highlights a need to be able to easily and quickly "educate" all users on the types of features available on the table.

We found one technical issue on the day in that the system became progressively slower the more that people interacted with it (typically over several hours). After further investigation, we found that this was an issue with the code and was something we were able to fix on the same day whilst we were there. This type of issue can be difficult to identify as it can only be detected when lots of people are using the table in unexpected ways. When developing an application it is common to only run it for short periods to test specific components of the application—as we found, it is imperative to stress test with lots of people using it for extended periods of time. This is not always easy to do before launching an application, but is a crucial test—there are utilities available that can help simulate lots of touches on an application (e.g. the surface stress tool[11]) but nothing can completely replace having large numbers of people use it in the wild.

Another issue we noticed is that the content on the screen could look a mess after it had been used repeatedly for several hours. It was clear that we needed to implement a reset feature or make the system jump back to the main menu after it had not been used for a set period of time (e.g. 60 seconds). The other key issue was related to the main menu—we noticed that people were accidently selecting the main-menu buttons through sleeves, ties hanging down, or elbows brushing against it when leaning across the table. This clearly frustrated people as they were not expecting the main-menu dialog box to be displayed. We are currently looking at adding a delay so that the button has to be pressed for around a second before the system considers the user to have selected it. This should help stop accidental selections from occurring in the future.

Table 1 provides a summary of the main lessons learned from the design, development, installation, and evaluation process.

5.5 Discussion

There are several additional areas related to multi-touch tables we intend to focus on that will help to inform the design and development of future applications. In terms of further development work, we are particularly keen on exploring the concept of the 360° menu. The menu we have at the moment on The Hive application is a little rigid—it may be better, for example, to create a more fluid, dynamic, and adaptive menu that allows people to select categories from any position on the table. One approach might be to let the categories float around on the screen and adapt their orientation to where users are positioned around the table.

In addition to developmental work, there are also research areas we are interested in exploring further. For instance, educating users on how to use all the features on a touch table application is a key interaction issue. As discussed previously, we noticed during informal observations that some users only looked at the content (without touching the table) or only discovered a couple of the most basic gestures for manipulating objects. This issue is not always as much of a problem when others are using the table as people can socially learn gestures. However, we have to deal appropriately with situations where this is not the case and people approach the table who are not aware of the gestures available. The question is how can we subtly and efficiently educate people without being too intrusive (in terms of screen real estate) and without frustrating users (i.e. attempting to teach gestures to users who are already aware of them). Some

[11] Surface stress tool. http://msdn.microsoft.com/en-us/library/ff727926.aspx.

Table 1 Summary of lessons learned

Design	
Object selection	Certain objects work better—in particular, photos of people, objects with lots of detail, and locations that visitors can relate to themselves
Unique table features	Touch table applications should make use of unique features such as potential for multiple simultaneous interactions (collaboration), fluid image zooming, flicking objects, and 360° designs
Object manipulation	Allowing users to scale up objects to take over the whole screen (as opposed to constraining object size) makes for an engaging interaction
Simple interactions	Simple interfaces that enable visitors to manipulate objects and content using basic gestures are sufficient for creating an engaging and entertaining interaction experience
Credits page	Tables used in a public space may require a "credits" page—check whether this is required early in the design process and how it needs to be incorporated into the application
Design of initial layout	Designing the arrangement of assets plays an important role in defining the interaction experience (e.g. piling photos up versus spreading them around the borders of the screen)
Multi-user	Avoid simple transferring of websites or mobile applications to this environment as they are inherently designed for a single user
Single task/flat structure	Applications with a hierarchical layout can be difficult to navigate in a multi-user environment. Keep structure shallow or confine the table to a single task
Social boundaries	People will naturally confine their actions to certain areas of the table—partitioning the interface space for multiple users is therefore not necessarily required
Top-down	Users are interacting with the table from above and hence content that is typically viewed from above in the "real world" (e.g. maps and photos) *feels* more comfortable when used on a table
Menu buttons	Placing menu buttons on each corner of the interface makes them easily accessible no matter where people are standing around table
Development	
Multi-touch software	There are several tools and programming libraries available for developing multi-touch table applications—the optimal approach will largely depend on requirements for the project
Locking down	The application on the table has to be locked down—it should not be possible for members of the general public to access the operating system
Layout tools	Creating tools that allowed us to arrange photos in an album using touch and drag gestures (i.e. a visual approach instead of writing code) helped to reduce development time and made the task accessible to designers and curators

(continued)

Table 1 (continued)

Stress test	Applications need to be stress tested before being made available to the public. Tools can be used to simulate large numbers of touches, but ideally tests should also require multiple people using the table for extended periods
Logging	Additional logging of user interactions and saving of crash logs is very useful in assisting with the debug process
Administrative controls	Hidden menus can be enabled through "unusual" touch combinations or key presses. This can provide additional administrative tools not usually available to users
Operational	
Circulation space	The location of the table needs to allow people to comfortably stand and move around without any obstructions that restrict movement
Power sockets	Power sockets for the table need to be available in an easily accessible location without any trialing wires that may present a health and safety hazard
Network access	Check whether the table will have network access—this should not be assumed as it may not be feasible in all heritage organisations
Lighting	Lighting above the table can cause issues with reflection—run tests early on to determine whether this is a problem
Start up/shut down	Create a start up and shut down routine with staff members that they can easily perform on a daily basis
Cleaning	Tables used in a public space can quickly become dirty—work with staff members to create a cleaning regime based around their daily activities
Evaluation	
Staff use	The table received an enthusiastic reaction from staff at the Hive, especially those not involved with the project. It provided a new tool for presenting to the public and answering questions
Accidental touches	Tables that use IR overlays can result in accidental touches via sleeves, ties, and elbows that can confuse and irritate users
Jump to main menu	Resetting to the main menu after no-one has interacted with the table for a set period of time is useful for allowing users to see all table features available
Gestures	Some people intuitively know which gestures they can use on the table while others will either not touch the table at all or will only discover a couple of basic gestures (especially elderly users)
Messy interfaces	The interface can start to look "messy" after the content has been manipulated by multiple users. A background "tidying" algorithm might be useful in helping to address this issue
Honey pot	More people approach the table when they can see others interacting with it. Conversely, people are more hesitant when no-one else is using the table
Age profile	Elderly users appeared to be far less daunted by the touch table than by traditional PCs. Younger children often play with the interface more and engage with the content less
Accuracy of task	Whilst control of a touch table interface is more direct, finer level manipulations are not easy (e.g. difficulty in trying to tap small buttons)

researchers have started to look at possible solutions to this problem (Vanacken et al. 2008), but this still remains a key issue for multi-touch tables used in public spaces.

In addition to educating users, we are also interested in the concept of "messy" interfaces. In our informal observations of the Hive application we found that the interface could start to look a little messy after continual use over several hours. We are therefore interested in approaches that could be used to autonomously tidy interfaces in a subtle way (almost as a background task) that does not irritate users. This raises the question of what is a "messy" interface? Also, is "messy" actually bad design in this context? It could be that it encourages exploration of material whereas people might not want to mess up a "tidy" interface where everything is laid out in a controlled and consistent fashion.

Related to the idea of messy interfaces is the study of how the layout of content influences movement around a table. For instance, if one layout has all items placed around the borders of the screen (e.g. Fig. 5.4) and another has all objects that are stacked in the middle of the screen, does this influence how people stand around the table? It could be, for example, that when items are scattered around the borders that people are more likely to stand around the table. In contrast, when items are stacked in the middle, it may be more likely for an individual to lead the interaction while others stand around watching. A deeper understanding of these issues will be valuable for other projects we work on in terms of structuring collaborative tasks and in helping to encourage people to work together.

5.6 Conclusion

In this chapter, we have highlighted the issues involved in building multi-touch applications within a heritage domain. We initially defined the term "multi-touch tables" and discussed the technology (hardware and software) involved in building multi-touch applications. We then provided an overview of research findings based on evaluations into the use of touch tables installed in heritage environments. In particular, we highlighted the issues around multiple users, people approaching tables, choosing appropriate content, and the range of gestures used during touch table interactions. A case study into the Hive was then presented—we described the process in creating the first version including design, development, and initial evaluations. We also discussed areas for future research such as how to subtly educate users and how screen layouts might influence collaboration around a table. It is clear from the work discussed in this chapter that multi-touch tables have the potential to engage, educate, and enhance interactive heritage experiences. Future work now needs to focus on how to make best use of this technology to create innovative and effective applications that help heritage organisations to fulfil this potential.

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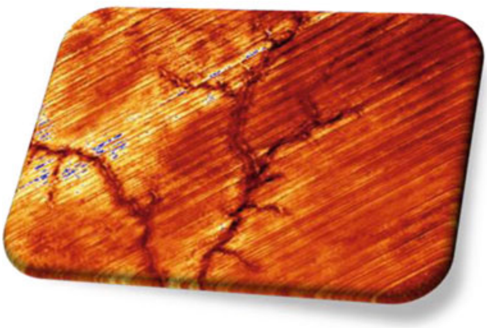
Part II
What Surrounds Us, Shapes Us
Digital Landscapes and Environment

The prosaic issues of the scale and historicity of landscape and environment almost inevitably demand the incorporation of technology and visual technologies and provide seamless access to areas or periods that researchers may not be able to study directly or provide experience of a landscape that cannot be visited by a tourist. In doing so the formative nature of the digital environment, built or natural, is often presumed in much the same way as occurs in other media. Indeed, the title of this section comes from the Berkeley Media Group's assessment of the impact of community environment on health (2009). Having said that we might well have quoted Churchill who, speaking on the rebuilding of the British House of Commons following the Second World War, stated that "we shape our buildings and thereafter they shape us". Churchill, of course, was concerned with how the actual physical structure of the political chamber formed debate within the United Kingdom but Digital Heritage researchers are clearly not exempt from such concerns. Indeed, these issues become substantive when seeking to represent environments that are redolent with cultural significance or, equally, when digital reconstruction of a disputed past requires that, as in Baudrillard's precession of simulacra (1983), the digital image "precedes the territory". The role of digital technologies in representing historic landscapes inevitably becomes a formative



act and the papers in this section explore some of these issues; touching on scale and the “spaces that difference makes” (Soja 1996, 83). They also considered how technology, imposed physically upon space, may itself generate novel relationships between environment and the observer in a manner never previously imagined or achievable.

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Chapter 6
Visualising Space and Movement: A Multidisciplinary Approach to the Palace of Diocletian, Split

Vincent L. Gaffney, Gareth Sears, Chris Gaffney, Armin Schmidt, H. Goodchild, M. Lobb, T. Sparrow, D. Tomcik, Branko Kirigin, Ante Milosević and Vedran Barabrić

Abstract The Palace of Diocletian, now the old town of Split, is one of the most important structures for the study of late Roman palaces, imperial ceremonial and urban change in late antiquity. At the heart of this palatial complex is the Mausoleum of Diocletian/Split Cathedral; a transformation which neatly encapsulates the transition from imperial residence to late antique and medieval town. Emerging from work undertaken by the Central Dalmatian Archaeological Project in 2009, this chapter will demonstrate how 3D spatial models can be integrated with subsurface exploration technologies in order to better understand the relationships between standing and subsurface remains at Split through the production of a 3D model. It will then use the integrated results from the 3D laser scanning of the Mausoleum and its surroundings and GPR in the Peristyle of the Palace to make suggestions about the nature of that space and how it might have changed over time.

Keywords: Croatia · Split · Diocletian · Late antiquity · Ground penetrating radar · 3D laser scanning

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V. L. Gaffney (✉)
IBM Visual and Spatial Technology Centre, Digital Humanities Hub,
The University of Birmingham, Edgbaston B15 2TT, UK

and

Centre for Creative Content and Digital Innovation, Universiti of Malaya, 50603,
Kuala Lumpur, Malaysia
e-mail: v.l.gaffney@bham.ac.uk

G. Sears
Department of Classics, Ancient History and Archaeology, IBM Visual and Spatial
Technology Centre, University of Birmingham, Birmingham, UK
e-mail: g.m.sears@bham.ac.uk

C. Gaffney · A. Schmidt · T. Sparrow
Archaeological Sciences University of Bradford, Bradford, UK
e-mail: c.gaffney@bradford.ac.uk

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6.1 Introduction

The Palace of Diocletian or old town of Split (ancient *Aspalathus*) is a key site for the investigation of a range of different processes that were occurring in the late antique and early medieval periods. These include: the spatial articulation of power; the development of imperial ritual and the creation and transformation of urban centres. For all of these processes the evolution and use of space is a key consideration and analysis using archaeological evidence, standing remains and literary material, where available, can help the archaeologist and historian to reconstruct the motivations and experiences of the builders and inhabitants of these structures. The current project was designed to examine some of these issues by creating an interrogable model utilising 3D visualisation technologies and ground penetrating radar. The Palace, through its considerable original standing remains embedded within medieval structures and the surviving subsurface archaeological deposits, is a perfect complex for the investigation of the potential of such a model to answer questions about the nature of the building as well as providing a resource for conservation.

This chapter will present the methodologies used in the creation of the model and suggest interpretations of the standing and subsurface remains. It will point to ways in which the creation of the model could aid our understanding of space and its use in late antique contexts. The chapter will: assess the place and nature of the

A. Schmidt
e-mail: A.Schmidt@Bradford.ac.uk

T. Sparrow
e-mail: T.Sparrow1@Bradford.ac.uk

H. Goodchild
Department of Archaeology, The University of York, York, UK
e-mail: helen.goodchild@york.ac.uk

M. Lobb
The Department of Geography, University of Southampton, Southampton, UK

D. Tomcik
The Institute of New Technologies and Applied Informatics in the Technical University of Liberec, Liberec, Slovakia
e-mail: david.tomcik@gmail.com

B. Kirigin
Centre Studia Mediterranea, Faculty of Philosophy, University of Split, Sinjska 2, Split 21000 Dalmatia, Croatia
e-mail: branko.kirigin@st.t-com.hr

A. Milosević
Museum of Croatian Archaeological Monuments, Stjepana Gunjače b.b, Split 21000 Dalmatia, Croatia
e-mail: ante.milosevic@st.t-com.hr

V. Barabrić
Faculty of Philosophy, Art History Department, University of Split, Split, Croatia
e-mail: vedbarba@ffst.hr

Mausoleum and its surroundings; address the 3D laser scanning of the Mausoleum and its surroundings and the ground penetrating radar (GPR) within the 'Peristyle'; present the model created from the data captured in the survey and finally present interpretations of the data from that survey. It will examine whether the GPR work and 3D laser scanning can be used to inform our understanding of the use of space in the Peristyle and in the complex more widely and whether it can add anything to our archaeological knowledge of that space. The results will be examined through the prism of the nature of the complex and its occupant; the space was orientated to the display of Diocletian as *Senior Augustus* and late Roman aristocrat.

The work in Split emerges from a long-standing research interest in this part of Dalmatia and the team's use of a combination of technologies to assess standing and subsurface remains in an integrated programme for the understanding of ancient urban areas (e.g. Gaffney 2004; Cuttler et al. 2007; Smith et al. 2006; Sears et al. 2012).

6.2 The Mausoleum and Peristyle

Built for the emperor Diocletian, the most important figure within the tetrarchy (emp. 284–305, 'retired' along with his colleague Maximian in 305 (probably died in 311/2, see Barnes 1973, pp. 32–5; 1982, pp. 30–2), the Palace of Diocletian at Split included apartments, audience halls, colonnaded spaces, baths, temples and the mausoleum of the emperor (see Fig. 6.2; Duval 1991; Mannell 1995). Following Diocletian's death the palace is infrequently mentioned but it was probably the residence of Julius Nepos, following his exile from Italy (Wilkes 1986, 85). It is traditionally thought to have been taken over by settlers following the abandonment of nearby Salona (Fig. 6.1) during the seventh century but the extent and nature of occupation is not entirely clear. US-Yugoslav excavations did however demonstrate the continued occupation of the palace in the fourth and fifth centuries and a cemetery to the north dates to the sixth century (Wilkes 1986, pp. 83–91; Dvoržak Schrunk 1989, p. 52; Wilkes 1991, pp. 450–2; McNally 1994).

The Mausoleum of Diocletian itself (Fig. 6.3) was built inside its own temenos on a high octagonal podium incorporating a crypt. To the west of the temenos was the 'Peristyle' and on the north the 'decumanus'; both were colonnaded. Entrance to the Mausoleum was via a stairway in the Peristyle. The structure's sheer bulk, enclosed as it was within its own temenos, would have loomed over the decumanus and Peristyle.

The identification of the monument is, of course, important for analyses of function and movement around the structure. Whilst there is no definitive proof that the structure was Diocletian's Mausoleum (by way of an inscription for instance) there is virtual unanimity in academic opinion that it was (but see Duval 1991). The opinion is based on Constantine Porphyrogenitus' assessment and portraits presumed to be of Diocletian and his wife Prisca on a frieze just underneath the dome (Constantine Porphyrogenitus, *De Administrando Imperii*, 29.137; Fig. 6.4).

Fig. 6.1 Split and Salona (courtesy of Henry Buglass)

The Mausoleum was one of a new line of imperial mausolea built during the fourth and early fifth centuries as monumental tombs for a ruler and his closest relatives rather than as an ongoing dynastic monument (Johnson 1991, 2009, p. 58; Deliyannis 2010; see Davies 2000 for earlier imperial tombs). It was converted into the town's cathedral, traditionally by Bishop John of Ravenna in the mid-seventh century, although there is no hard evidence for this (Wilkes 1986, 86; Chevalier 1995, pp. 237–238; Johnson 2009, p. 59).

A key element of the complex, and therefore the focus of both the laser scanning and GPR, is the so-called Peristyle. Its function, the use of that term to describe the space, and its relationship to other structures has been extensively debated over the last half century (Figs. 6.2, 6.6). Dyggve and others saw it as an 'open hall' where ceremonies in honour of the emperor could take place but its primary use well may have been to act as a unifying element for the complex as a whole, acting as a transitional space between areas constructed at different levels (Duval 1961–62a, 1965, p. 78; Duval 1961–62b, 1965, p. 156; Wilkes 1969, p. 390; Marasović 1982, p. 100; McNally 1989, pp. 17–19). Duval criticised Dyggve's conception of the Peristyle, 'Vestibule' and '*tablinium*' as a three part ceremonial space arguing that a retired emperor would not have partaken in ceremonies that needed more than an audience hall, they did not require the external space provided by circuses at imperial capitals (Swoboda 1961, p. 81; Duval 1961–62a, 1965, p. 78, 1961–62b, 1965, p. 156, 1971, 1991, p. 380; McNally 1989, 9, pp. 17–19, 34–5; Čanak-Medić 1995, p. 56). He also pointed to near contemporaries referring to Split as a villa, not a palace, and the differences

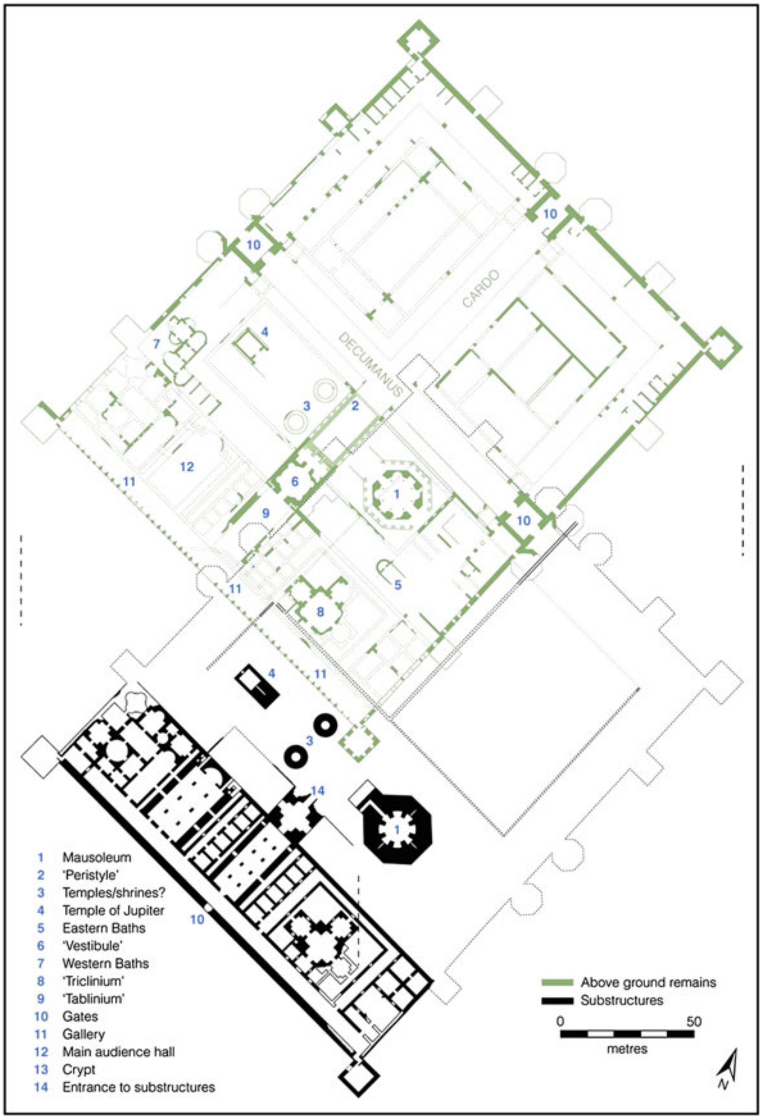


Fig. 6.2 The Palace of Diocletian (courtesy of Henry Buglass, adapted from Marasović and Marasović 1994)

between this complex and earlier Roman urban palaces such as Antioch, which for Duval further weakened the argument that this was an official residence or palace that would require exterior ceremonial space (Duval 1961a, 1961–62a, 1965, p. 70; Vickers 1973, p. 114; Eutropius 9.28; Hieron., *Chron*. a. 2332).

Duval's argument seems too rigid. It is right that we do not blindly apply the architectural vocabulary of imperial power to the space, and are not influenced by

Fig. 6.3 The Mausoleum of Diocletian from the *decumanus* (courtesy of Gareth Sears)

the fact that the space did become the principal Medieval square of the town, but, to some degree Duval's argument sidelines the most important element of the complex—Diocletian himself, both as an imperial personage but also as a late antique aristocrat who would have required a multiplicity of ceremonial spaces. Although our sources point to his retired status as a private individual (Zosimus, *HN*, 2.7 '*ιδιωτης*'; Eutropius 9.28 '*priuatus*') or as returning to a normal life (Aurelius Victor 39.48 '*communem uitam*'; *Epitome de Caesaribus*: *in propriis agris consenuit*—'he grew old on his own lands'), we should not think that this meant a reversion to an utterly non-imperial status. After AD 305 although he was not reigning emperor he was still imperial and appeared in art, inscriptions, papyri

Fig. 6.4 Diocletian (?) in the frieze of the Mausoleum (courtesy of Gareth Sears)

and on coins as either '*Senior Augustus*' or as the father of the *Augusti*. For instance on coins he was: 'Our Lord Diocletian, most blessed/most fortunate, Senior Augustus' (Fig. 6.5; Barnes 1982, p. 24, 1996, p. 552; Bizarri and Forni 1960; Bruun 1988–1989, p. 19–20; Corcoran 1996, 2006, p. 236; Stefan 2004, 2005; Srejović 1994) (Fig. 6.6).

Clearly this official material was propaganda on the part of the reigning emperors, designed to tie themselves to their illustrious predecessor in the eyes of the army and elites. It could be argued that these texts do not then reflect Diocletian's actual importance. On this model, inscriptions from small towns were copying official propaganda, however, idiosyncratically. However, even this use of the senior emperors demonstrates their ideological importance and suggests that they would have been treated as imperial personages.

In any case the retired emperors could wield power and influence. Although Maximian and Diocletian behaved differently the former's manoeuvrings after AD

Fig. 6.5 Obv. D N DIOCLETIANO FELICISSIMO SEN AVG; Rev. PROVIDENTIA DEORVM QVIES AVGG; Mint of Trier, AD 305–7. Barber Institute of Fine Arts R2534 (courtesy of Barber Institute of Fine Arts)

Fig. 6.6 The Peristyle viewed from the south (courtesy of Gareth Sears)

306 shows the potential (and limitations) of their power. Diocletian's political importance and influence is demonstrated by him being made consul, with the emperor Galerius as his colleague, for the tenth time in 308, with *Senior Augustus* again incorporated into his title and Diocletian's counsel being sought later the same year at the Council of Carnuntum (Lactant. *de mort. pers* 29.1; Zos. *HN*. 2.10).

Whilst a 'retired' Augustus would not have required an external space on the scale of the imperial circuses at Antioch or Thessalonica, it is not inconceivable that some exterior area such as the Peristyle would have been necessary on occasion, even if we cannot imagine anything approaching the ceremonial that accompanied a reigning Augustus. It is possible that the emperor might have expected some sort of ceremonial homecoming if he had been away from the palace, although whether such events ever took place in the open rather than in the confines of the audience halls at Split is unknowable. He may also have needed to receive local elites from Salona with the Peristyle being at least an awe-inspiring area through which they may have travelled. Finally, he would also have had a considerable staff, bodyguard and potentially workers in any *gynecaea* (workshops) in the northern half of the complex, who might have paid ceremonial homage to him at different times (Belamarić 2004; *Not. Dign.* [occ.] 11).

Duval perhaps also puts too much weight on brief statements in ancient authors that may not have been accurate in their use of technical language. The complex at Split was a monumental and richly decorated residence owned by a member of the imperial college and would have been to all intents and purposes a palace, even if it was not in a city and *palatium* was not used to describe it (hence the modern conception of it as a palace—e.g. Williams 2000, p. 193; Leadbetter 2009, p. 138 although these books essentially ignore the Dyggve/Duval debate). Perhaps more importantly Duval's argument also unnecessarily divides villas from palaces in their use of space and puts too much emphasis on the need to work out the exact prototypes utilised by the designers of the complex. There are obviously differences in terms of scale, ceremonial and use of space between the villas of aristocrats, governors' palaces, urban imperial palaces and rural imperial palaces such as Split, but the activities and ceremonial that went on in these places clearly bled from one to the other. Governors and local aristocrats were well aware of imperial ceremonial and space and made use of similar constructions and social constructs to emphasise their own power.

The closest parallel to Split is, despite occasional objections, the later complex of Galerius (293–311) at Gamzigrad (*Romuliana*) near the Danube. There palaces, temples and other buildings set within a fortification (Srejović et al. 1978; Srejović 1993, pp. 31–53, 118–63; Srejović and Vasić 1994). Unlike at Split, however, Galerius and his mother's probable mausolea and two ceremonial tumuli, were built a kilometre away from the complex on the Magura ridge that overlooked the palace and dominated the wider landscape (Srejović 1993, p. 51; Srejović and Vasić 1994, p. 127). As at Split, residential space, audience halls, temples obviously including external space for worship, all within a set of monumental walls and mausolea form the wider complex.

Other 'palatial' complexes related to all levels of the elite are known from throughout the empire. Large elite urban houses, some of which have been identified with greater or lesser plausibility as governor's palace, and rural villas demonstrate some of the same elements of an architectural vocabulary of power as Split and Gamzigrad (Lavan 1999, Balmelle 2001, pp. 155–77; Uytterhoeven 2007, pp. 33–9, 41–3). Some complexes were of a scale to compete with Diocletian's Palace. Complexes such as Piazza Armerina, in the centre of Sicily and Cercadilla on the outskirts of Cordoba were even more elaborate than some urban buildings. As is well known, both have been interpreted in the past as residences of Maximian, although they are now seen as belonging to powerful aristocrats or potentially, in the case of Cercadilla, a governor's palace (Arce 1997; Lavan 1999, p. 139–40). What late Roman aristocratic complexes have in common are large audience halls, often associated with open courtyards and what could be understood as monumental approaches. Split sits within an elite late Roman architectural vocabulary of power. Duval may well be correct that we should not see the Peristyle as an 'open hall', and that it was more a space for movement, but in making the argument he downplays the centrality of movement and awe in power relations in Late Antiquity.

In addition to late Roman elite residences, other architectural elements and conceptions of space were clearly important to the designers of the complex. Colonnaded streets from eastern cities, some of which were imperial capitals, early imperial mausolea and army camps may all have influenced the architects of Split. This does not mean that Split should be viewed solely through the prism of those types of architecture but that characteristics of those structures may have imbued it with some of their resonances. For instance, the similarity of the exterior of the palace to some tetrarchic forts would have given the structure the aura of military power, intensified by the presence of soldiers to guard the senior Augustus, despite its essential lack of defensibility (Wilkes 1986, pp. 69–71; Mackensen 2003, 2006, 2009; Constantine Porphyrogenitus, *De Administrando Imperii*, 29.138).

Whether the Peristyle was used as a ceremonial space or not during his life, in death Diocletian might have expected ceremonial to occur at the Mausoleum (McNally 1989, pp. 35–6; see Srejović 1993, pp. 51–3 for Gamzigrad). Any worship of the divine Diocletian would probably have been conceived of as requiring external space, space which is conspicuously lacking in the *temenos* of the Mausoleum, but which might have been provided by the Peristyle and especially given the space also provided connectivity with the temple(s) facing it (at Gamzigrad there was considerable space in front of the two temples and on the ridge of Magura as well). At the very least the Peristyle must have been a space through which worshippers were conceived of as passing/processing and its size meant that it could accommodate substantial numbers of people (see below for further discussion). In the event, unlike his colleagues Maximian, Constantius I and Galerius, Diocletian was not deified (Barnes 1982, p. 35). Constantine I, Maximin Daia and Licinius were either hostile to him or did not need his apotheosis.

How long the Mausoleum would have remained inviolate is unclear, although the implication of a story in Ammianus Marcellinus, about the non-theft of a purple covering from the tomb in 356-7, is that it was intact at that date (Amm. Marc. 16.8.4). At Gamzigrad, Mausoleum 1 was apparently still intact in the late fourth century but during the fifth century the mausolea were being used for building material (Srejović and Vasić 1994, p. 130). Neither Diocletian nor Galerius suffered official *damnatio memoriae*, which may have protected their mausolea, but given the pair's status as arch-persecutors Christian communities took matters into their own hands leading to many mutilated inscriptions. This suppression of their memories was entirely ad hoc however so whilst many inscriptions to the pair are destroyed in Africa (e.g. at Cuicul *ILAlg*. 2.3.7856 and 7867), near to Split at Salona the few inscriptions mentioning Diocletian do not show signs of erasure even though on one, *CIL* 3.8568, Licinius' name was erased (*ILJug* 3.2074, 2040b16, 2984, *CIL* 3.8568). Perhaps because they lay in an occasional imperial residence Diocletian's remains might have escaped interference for longer than Galerius' out near the Roman frontier.

The Peristyle would have formed a natural space to pause, however, briefly, as the individual moved around the complex. It can be linked to the colonnaded streets from eastern cities. These were frequently monumental passages through the city that formed major armatures, to use MacDonald's term (MacDonald 1986, p. 5–31). The Peristyle would also have been a nodal space where lines of communication came together and which was partially defined by monumental buildings on its perimeter (Lynch 1960, p. 72–8; Wilkes 1986, p. 72). Even if Duval is correct, and the focus of the palace was not on the Peristyle and Vestibule but on the suite of monumental rooms coming off the cryptoporticus, so that '*le*

'Péristyle' est rue plutôt que place ou cour', the Peristyle was still on the major axis and therefore central to space and movement within the complex (Duval 1961a, 1971; Čanak-Medić 1995, p. 57). It connected the imperial apartments and audience halls with the northern *cardo* and the principal northern gate and individuals coming from the east and west gates may also have passed through the Peristyle to reach the imperial chambers (Wilkes 1991, p. 450). Unless it was a restricted space, and the lack of barriers to movement through the Peristyle suggests that it was not, then it would have been an important for workers within the complex. Visitors from Salona, if they did not come by sea, they would also have come through the main north gate and then progressed through the Peristyle to reach the imperial apartments.

Although there was some debate about how the layout of the steps down into the Peristyle have been restored, they would certainly have forced the individual moving through the space to proceed carefully at the nexus between the temples of the gods, the (intended) resting place of the emperor and the entrances to the imperial residence. As McNally puts it they would have made 'the approach to the residence—and the *temenoi*—a little more difficult, that is, more impressive', this area was, after all, probably imbued with religious power because of the Temple of Jupiter and the Mausoleum (McNally 1989, p. 20; Frazer 1966, p. 387). The steps up into the Vestibule would have further emphasised the importance of the space and engendered an appropriate sense of trepidation. As with many processional routes, including Christian complexes, the complicated nature of the space and the location of controlled routes between monumental buildings was designed to create a great sense of spiritual awe (Brown 1981, p. 87). In a Christian context, this was to stimulate the emotional response of the devotee before they arrived at a *martyrium* or other spiritual space. In the context of the palace 'la rupture' produced by the differences in levels (Duval 1961a, p. 95) and the domination of the space by monumental structures housing the divine and/or a living Augustus would have had a similar effect. The fact that the structures of the palace were partially hidden away by columns, inter-columnar barriers (2.40 m in height) and the different levels is unimportant in this context. Half glimpses of spaces and structures such as the imperial residence, temples and Mausoleum should have created a sense of trepidation in the presence of emperor and gods. It is also worthwhile thinking of the individual moving from the substructures into the Peristyle, emerging into a bright space, very different from the subterranean space, that was framed by temples to their left and the Mausoleum to their right with the bulk of the Vestibule and the imperial apartments above and behind them. They were emerging into a space dominated by religious and imperial imagery.

A focus on the imperial apartments also plays down the importance of the Mausoleum to the palace. It would certainly be a mistake, despite its size, to think that the Mausoleum was the preeminent structure inside the palace complex in terms of the rhythms of daily life—audience rooms, dining rooms, the baths, temple(s) would all have seen greater traffic—but its bulk and height would have disproportionately dominated the perception of any individual moving around the complex or viewing it from a distance. This was clearly deliberate. The emperor was supposed to be a *divus* and remembered.

Any reading of the model and the results of the laser scanning in the Peristyle has to focus on Diocletian, his continuing status as an imperial personage and his personal power as an aristocrat and, in terms of physical space, the nexus of cultic, commemorative and kinetic elements that came together in the Peristyle and the Mausoleum.

6.3 Visualising Space

Given the centrality of the Peristyle to the complex and, the medieval and modern town it is unsurprising that it was a target of restoration from the Second World War onwards. Excavation work was carried out in 1959–1960 and a further sounding was undertaken in 1965 (Marasović 1961–62, 1965, p. 150; Marasović et al. 1972, p. 5; Marasović 1982, pp. 44–6; Wilkes, 1986, p. 43). The focus of the campaigns was on establishing the Diocletianic layout of the Peristyle and Vestibule and subsequently the restoration of its ‘original’ layout. This process resulted in the lowering of the level of the Peristyle. This work did reveal a central drain oriented north–south below the original pavement of the Peristyle with additional lateral branches (Wilkes 1986, p. 46). The GPR work that was undertaken by the Project was therefore focussed on establishing whether there was any undisturbed material left in the Peristyle area, whether an original land-surface could be reached in the Peristyle through GPR and to provide data that could be fed into an integrated model (for ground levels nearby in the complex see Marasović et al. 1972, p. 16). The laser scanning within the palace was directed at the Mausoleum and its immediate surroundings. The integration of the 3D model of the Mausoleum and the radar slices in the Peristyle will allow better comprehension of the volumetric relationships, interconnectivity and intervisibility of these structures.

6.3.1 Scanning the Mausoleum

The team used a Leica HDS6000 3D laser scanner to digitally scan as much of the Mausoleum and its immediate vicinity as possible including the Vestibule, Peristyle and *decumanus*; the bell tower, vestibule and a nearby hotel roof were used as vantage points to maximise coverage. The vast majority of the structures were scanned with only a small proportion of the interior and exterior of the roof being omitted due to health and safety issues.

Because the Mausoleum and its environment represent a complex set of spaces the monument and its surroundings were split up into several discrete areas for investigation. The resulting datasets were then combined to make the 3D digital

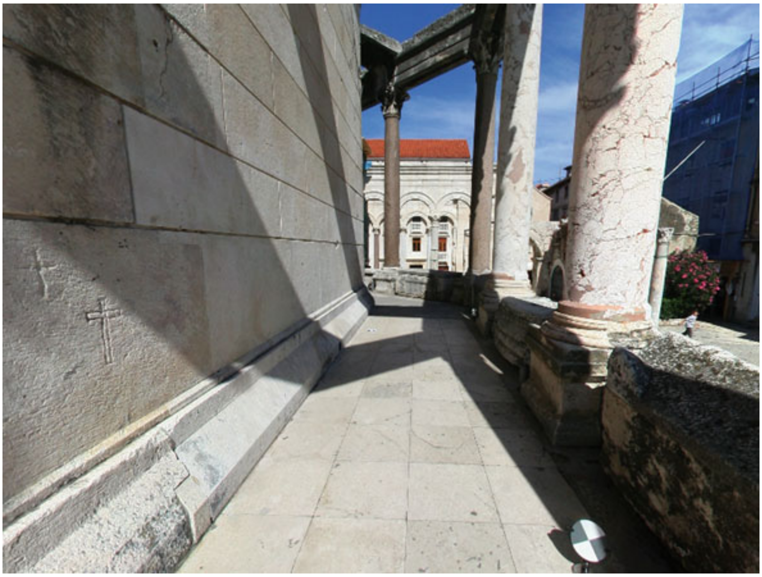


Fig. 6.7 The walkway around the Mausoleum. A control-point can be seen at *bottom right* and inscribed crosses on the wall at *left* (courtesy of Gareth Sears)

model. In order to do so each element was connected to the others by the provision of planned common control targets (Fig. 6.7), which are used to tie individual scans together (see below for modelling). At least three common control points between each scan location (a 'scan-station') and its predecessor were necessary in order to tie the scans together successfully. The laser scanner was used at the settings 'Highest' and 'High Power' producing a point cloud with accuracy to 0.8 mm. The model of the Mausoleum and its surroundings required 88 scans and encompasses a total survey data set of 95 GB of point data. A Leica SR530 Differential GPS base station and rover was used to plot three control points that appeared in more than one scan so that the model could be rectified to its real position within a GIS database (to a relative positional accuracy of ±0.02 m).

6.3.2 Modelling the Mausoleum

Two models were created using the laser scan data: one using the laser scan data; and one integrating laser scan and GPR data (see below). A model of the cloud point data was created in Leica Cyclone, a 3D point cloud dataset processing software based on object database architecture, into which the laser scans were individually downloaded and tied together. The tied scans could then be viewed and manipulated in one model space. Colour was then rendered onto the model by the tying of photographic cubes to the scanned points.

The model produced by the project has several research applications. The accuracy of the scanner goes significantly beyond what can be achieved by conventional archaeological planning and the model can be used to create 2D horizontal and vertical 'slices' through the structure at different levels using programmes such as CloudWorx, AutoCAD and Illustrator programmes. As the structure can be rotated through 360^{o} on all axes the researcher can examine details and relationships between parts of the structure that are not visible on the ground and cannot easily be examined because of the difficulty of examining elements of the frieze and the dome. For instance, the combination of laser scanning and the panoramic photography may result in the identification of features that cannot easily be seen with the naked eye. Additionally, the 3D model will form a digital resource preserving the structures as they stand at the beginning of the twenty-first century in case of damage caused by natural or man-made processes (Fig. 6.8).

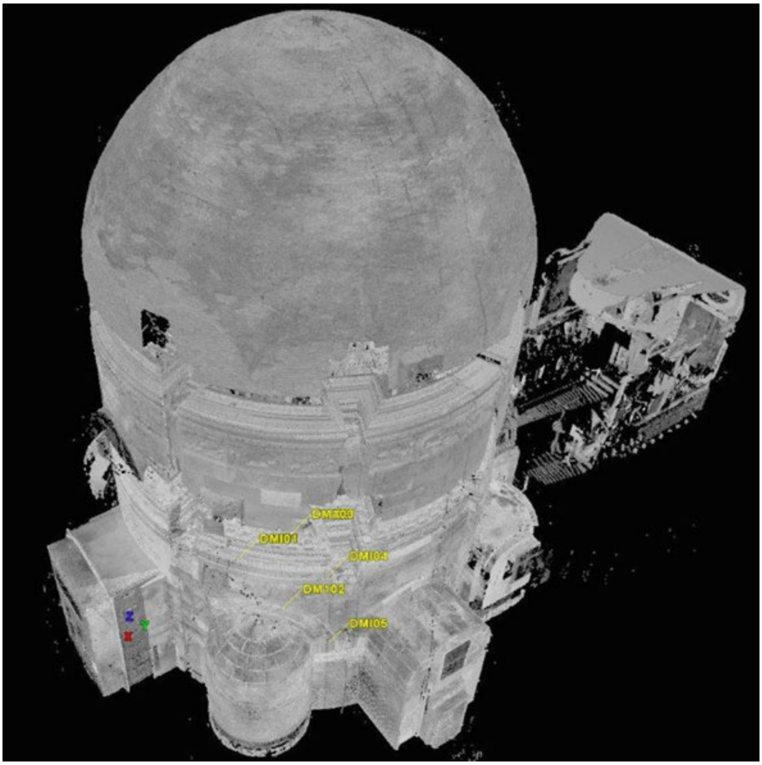


Fig. 6.8 Interior shell of the Mausoleum 'seen' from outside. Visible textures are those of the inside of the Mausoleum (courtesy of Central Dalmatian Archaeological Project)

6.3.3 GPR in the Peristyle

Alongside the laser scanning, geophysical survey was carried out in the Peristyle using a Pulse EKKO Pro Ground Penetrating Radar system. The work was designed to both complement the structural survey around the Mausoleum and to understand the geology and structures that underlie the current street surfaces.

In this project, the anticipated depth to the bottom of the structures was up to a couple of metres but the targets were deemed to be relatively small. As a result it was essential to combine high- and low-frequency GPR data to investigate features down to several metres in depth with a high spatial resolution, even if the latter is confined to shallower depths. The GPR was therefore used with three antennas of different frequencies. The frequencies were 100 (unshielded), 200 (unshielded) and 500 MHz (shielded). GPR data was collected in reflection mode along both single traverses or within a grid of parallel traverses. The 200 and 100 MHz antennas were used to cover a smaller area than the 500 MHz antenna. Data were collected along transects at 1.0 m intervals for the 200 and 100 MHz and 0.5 m for the 500 MHz antenna. The 500 MHz antenna produced finer detail than the other two, partly as a result of the centre frequency and also the increased data sampling. Data were collected to a depth of 3 m.

The GPR survey suggests the presence of several archaeological and/or geological features under the surface of the Peristyle. The GPR models seem to suggest the presence of a 'feature' at the southern end. This appears at around 0.4 m and looks like a mass of looser material held within a more reflective background. There is then further archaeological material for at least another metre below the top of this 'feature' into which the feature was dug or inserted (see below for discussion).

Just over halfway along the survey area (moving south to north) there is evidently a change in the nature of the material. The strong responses that can be seen in the sections (Figs. 6.9, 6.10) probably indicate a textural difference between what is probably a later infill towards the southern end of the Peristyle, which appears as the darker material in the scan, and a homogenous, possibly natural, fill towards the northern end of the Peristyle.

6.3.4 Creating the Integrated Model

Mausoleum and its surroundings were constructed by creating a cleaned surface mesh of each section of the point cloud data. Each individual surface or wall was processed separately with its relationship to other objects maintained. The separate wall sections were then placed into their correct position within the model (Fig. 6.11).

The processed GPR data, presented in a series of 'slices', was turned into a 3D model using 'GPR-SLICE' imaging software. Avizo was used to stack the slices in

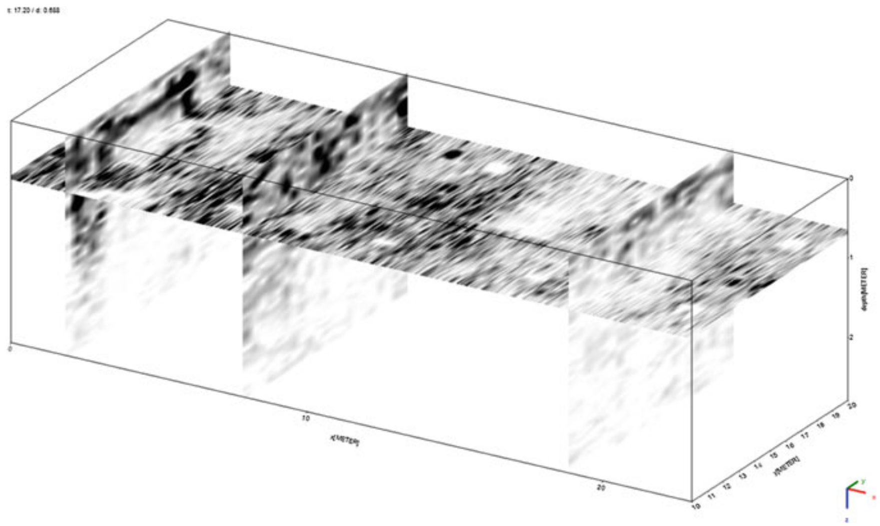
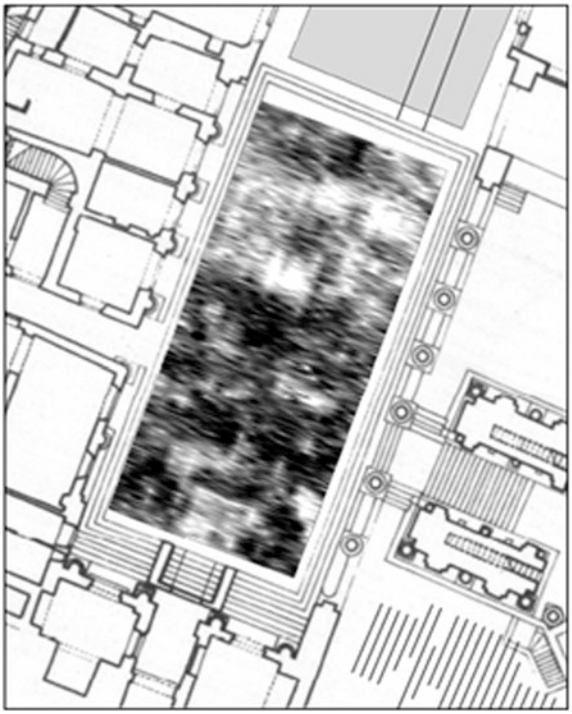


Fig. 6.9 Example of timeslice data (0.4 m depth, south at *left*) from the Peristyle using the 100 MHz antenna (courtesy of Central Dalmatian Archaeological Project)

Fig. 6.10 Example of timeslice data (0.4 m depth) from the Peristyle using the 100 MHz antenna (courtesy of Central Dalmatian Archaeological Project)



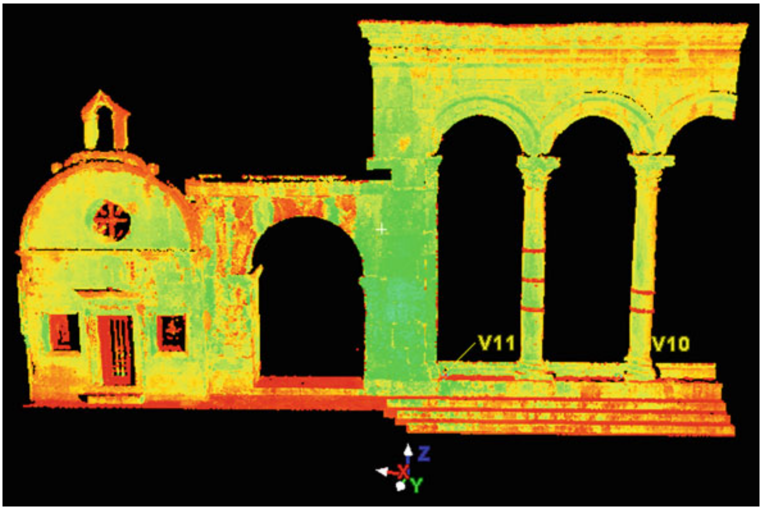


Fig. 6.11 Screenshot of cropped and cleaned section of the point cloud data (courtesy of Central Dalmatian Archaeological Project)

order to create a 3D model (Fig. 6.12) and the laser scan and GPR models were combined and rectified against a plan of the palace. The combination of the results from the different technologies allows the interpretation of the GPR data against an actual model of the built environment rather than against a plan (Fig. 6.13), which should help to clarify the relationship between the extant ancient structures and the subsurface material.

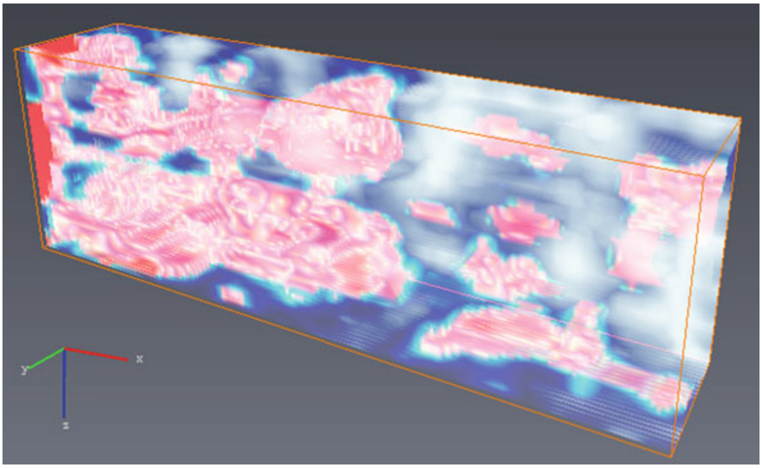


Fig. 6.12 Block of GPR data presented in 'Avizo' using the 'Voltex' tool (south at *left*) (courtesy of Central Dalmatian Archaeological Project)

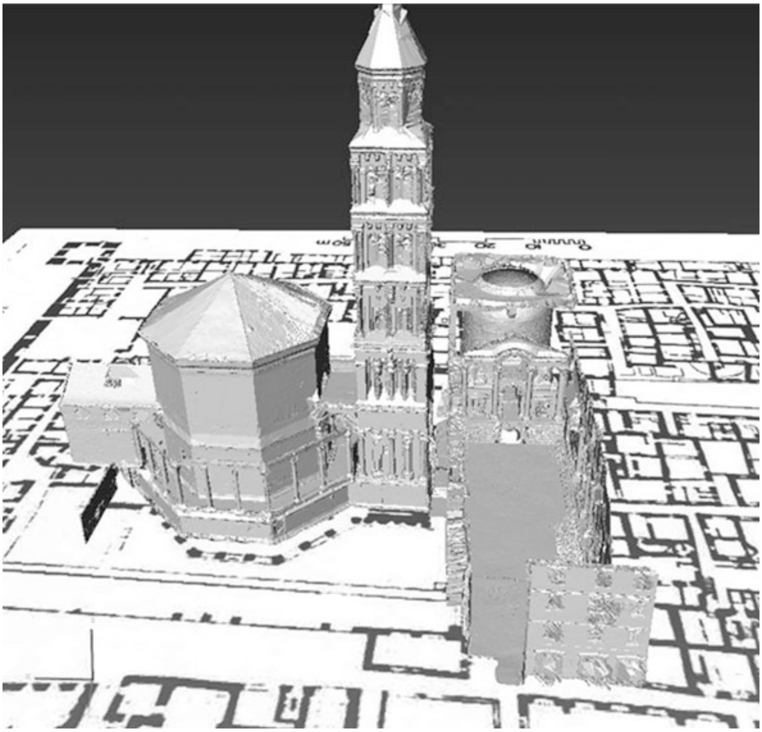


Fig. 6.13 Model of the Mausoleum, bell tower, Peristyle and Vestibule suspended over a plan of Split (courtesy of Central Dalmatian Archaeological Project)

6.4 Results and Discussion

The GPR results and the integrated model may offer tweaks to our understanding of the Peristyle and its role in the palace complex. The different responses in the GPR between the southern infill within the Peristyle and the homogenous, northern fill may reflect the southern, sea-end, of the survey area being built up to level the ground for the palace. Such a levelling process must be anticipated, it is after all one of the reasons for the presence of the substructures.

More interesting perhaps are the possible indications of some form of structure towards the southern end of the Peristyle. Given its position it would be tempting to see it as somehow connected to the stairs that lie immediately to the south, perhaps as evidence of a structure to support stairs heading further into the centre of the Peristyle then the existing ones (although it must be emphasised that the striations in this structure on the GPR image in Fig. 6.10 are not real). An alternative would be to see it as the foundation of a structure in the Peristyle—possibly for an extended podium projecting northwards from the entrance to the Vestibule, with the superstructure having been removed before the Peristyle became a central public square in the twelfth to thirteenth centuries and certainly before the publication of a plan of the city in 1666 (Marasović 1982, pp. 28–37).

Either possibility would have profound implications for space and movement within the Peristyle. Any extended podium would have required an entrance at either the front or the sides so that the steps down into the substructures would have been accessible. Such a structure would potentially have provided a more noticeable breakpoint for the pedestrian crossing the space. Such a projection by its very nature would have dominated the open plaza of the Peristyle in a way that the current reconstruction of a colonnade and two sets of stairs in front of the Vestibule do not (Fig. 6.14) and would imply a greater use of the space for assembly than Duval would suggest. A more substantial podium than currently exists would suggest that the space was felt appropriate for assembly of some variety even if this was not as an open 'hall'. The Peristyle could very easily have held more than three hundred and fifty people on a calculation of one person per metre squared (Peristyle = 27 × 13.50 m = 364.50 m^2). This is clearly a very rough and generous calculation and too much significance should not be attached to it (cf. MacMullen 2009, p. 14 for an attempt to calculate the Christian population of a town from the size of its basilicas; a not very convincing methodology given our incomplete knowledge of that town's Christian monuments) but it is a relatively appropriate measurement for comfortable standing room.

The alternative of a different stairway arrangement would also alter movement and space within the Peristyle. On this reading someone leaving the substructures would emerge 3–4 m further into the Peristyle and therefore closer to the

Fig. 6.14 The Prothyron, entrance to the basements and Peristyle (courtesy of Gareth Sears)

Mausoleum entrance (Fig. 6.14); providing an even more immediate physical and spatial connection between the different parts of the complex. It would, presumably, however, reduce the number of people who could actually gather in the Peristyle, if that was ever necessary.

Either thesis would help to explain why the entrance to the substructures as it stands is so unimpressive whilst being so obvious to the individual moving across the Peristyle. However, it must be noted that whilst the 'feature' must be pre-modern its exact date is impossible to establish from the GPR work—it could therefore post-date the Roman phases and be part of the transformation of the space as the palace became a town. (Fig. 6.15)

The integrated model is clearly a useful tool for visualising the relationship between the existing buildings and the buried archaeology (Barceló et al. 2000; Frischer and Dakouri-Hild 2008). For instance Fig. 6.16 clearly demonstrate the position of the 'feature' in the southern portion of the Peristyle in relation to the stairs, the Mausoleum and the Peristyle. The three-dimensional presentation of the fill in the northern half of the Peristyle also allows us to ascertain that the material fill may be fairly similar across the area which, in an urban context, is not so surprising.

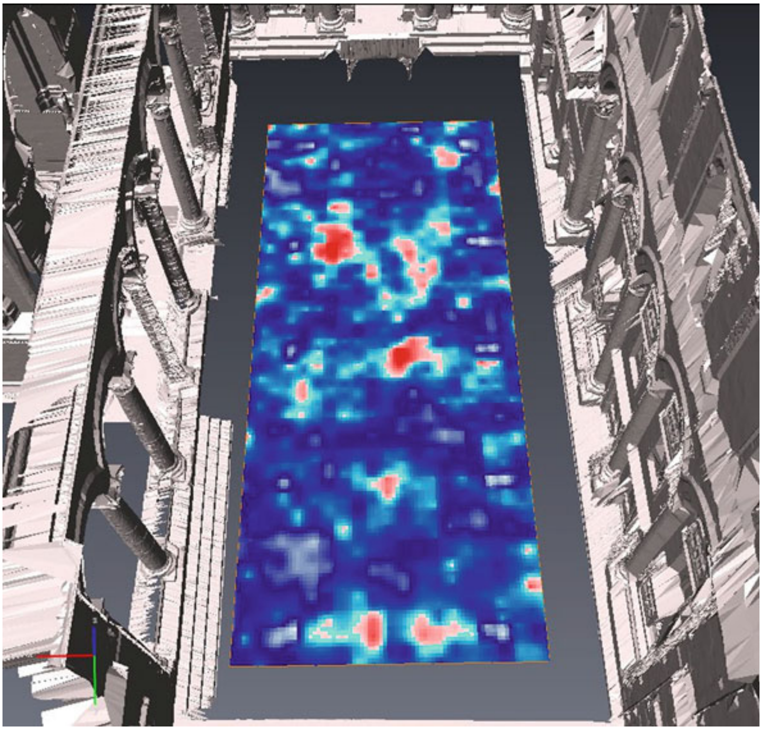


Fig. 6.15 A GPR slice within real 3D space below the Peristyle (courtesy of Central Dalmatian Archaeological Project)

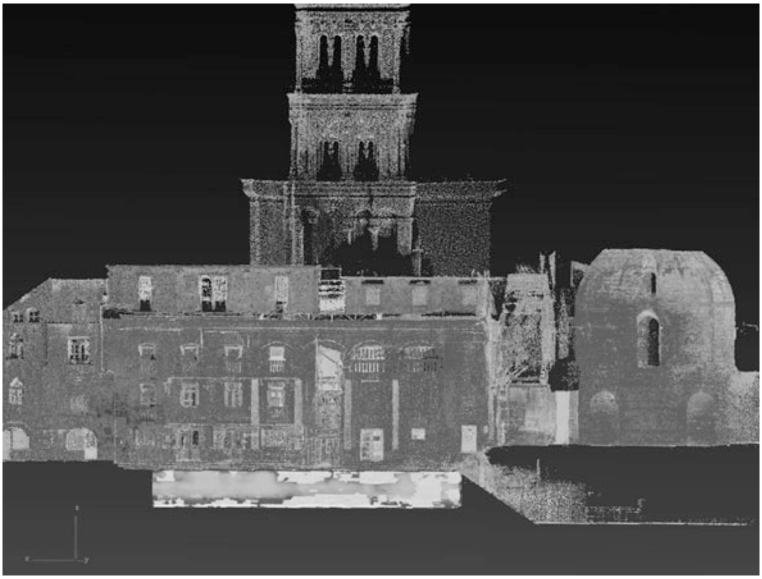


Fig. 6.16 Model combining GPR and laser scan point cloud data. The viewpoint is from west of the western façade of the Peristyle (courtesy of Central Dalmatian Archaeological Project)

6.5 Conclusion

One of the primary outputs of the project, both within research and heritage management contexts, has been the integration of two different datasets in one model. This chapter has demonstrated the potential for the integration of GPR and laser scanning data in order to effectively present the relationship between archaeological material and the built environment. The creation of models of this sort has considerable application to urban environments where archaeology and built structures are part of an ongoing topographical evolution. In environments where historic buildings have a relationship to both existing streets, but also to structures and street below modern ground levels and such volumetric models are invaluable in the understanding of change.

The 3D model and GPR data has some clear uses in adding to debates over the nature of the space and which could be productively be explored in future publications. We have not really dealt here with the use of the model to effectively demonstrate sight lines within the Peristyle and surrounding structures, which might also help to inform the use and experience of the space but they are clearly worth exploring.

Identification of potential structures within the GPR data and their relationship with the built environment can help us hypothesise about the use of space and its development over time, potentially adding to debates over the nature and use of the space and therefore the needs of the Senior Augustus and later communities within the structure. However, actual excavation would be needed to confirm the presence of the 'feature' in the southern Peristyle and to attempt to ascertain a date for it.

The structure of the old town at Split is a late antique environment that has been transformed into a Medieval, Renaissance and Modern town. Although post-World War II considerable focus has been put into the excavation and reconstruction of the original palace complex, the remaining buildings and archaeology shows a process of evolution. The integrated model helps to relate the standing and sub-surface remains that represent the hard evidence of this process to each other in a dynamic and interrogable way for the first time. Given the importance of the town/palace complex to our understanding of such transformative process, the work undertaken in 2009 cannot be over-valued. More specifically, the model allows observations to be made about the nature of the space and monuments that feed into key debates about the relationship of the retired emperor to the space and the use of such spaces in late antiquity.

Images

Figures 6.1, 6.2 drawn by Mr Henry Buglass. Figure 6.2 after: Marasović and Marasović 1994, Figs. 6.1, 6.2 . Figure 6.5 courtesy of the Barber Institute of Fine Arts. Figures 6.3, 6.4, 6.6, 6.7, 6.14 Gareth Sears. All other figures: Central Dalmatian Archaeological Project.

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Chapter 7
Reconstructing a Painful Past: A Non-Invasive Approach to Reconstructing Lager Norderney in Alderney, the Channel Islands

Caroline Sturdy Colls and Kevin Colls

Abstract Visual technology represents a powerful tool that can invoke a sense of place in a virtual world and bring the results of archaeological surveys into public consciousness. Such techniques are particularly useful when excavation is impractical or not permitted. This chapter outlines the results of the investigations on the site of the former labour camp of Lager Norderney in the Channel Islands. In the past, opinions concerning the site have revolved around the perception that it was destroyed. Archaeological survey has demonstrated that this is not the case and the presentation of these findings through digital means has offered new insights into their form, function and surviving extent without ground disturbance. By employing a methodology that addresses all of the physical and cultural layers associated with this painful period of history, it has been possible to generate resources that mitigate against some of the issues surrounding the investigation of the site.

Keywords Lager Norderney · Alderney · Archaeology · Non-invasive · Nazi occupation · Holocaust · Labour camps · Conflict archaeology

7.1 Introduction

The traditional view of archaeological investigation is one centred on the destructive elements associated with excavation. In the study of socio-historic conflicts this can raise concerns, which may inhibit research. This problem is

C. Sturdy Colls (✉)
Forensic and Crime Science, and Centre of Archaeology, Staffordshire University, Stoke-on-Trent, UK
e-mail: c.sturdy-colls@staffs.ac.uk

K. Colls
Centre of Archaeology, Staffordshire University, Stoke-on-Trent, UK
e-mail: Kevin.Colls@staffs.ac.uk

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particularly significant when investigating the archaeological sites of the Holocaust and Nazi Occupation of Europe given the variety of religious, political, social, and commemorative issues surrounding the thousands of sites that exist (Sturdy Colls 2012a and forthcoming). However, emerging digital humanities tools and visual technology offer the possibility for investigation, representation, and commemoration in a virtual world, thus facilitating preservation by record, providing new forms of commemoration, and invoking a sense of place. The benefits of such techniques were realised as part of an archaeological investigation on the island of Alderney, which was occupied by the Nazis during the Second World War.

Described as "the single most significant event in the history of Alderney", the Nazi Occupation of this small island in the British Channel Islands irreversibly altered the landscape and the lives of both the contemporary population and subsequent generations (Kay-Mouat 2009). The evacuation of the island's 1,500 inhabitants in June 1940 paved the way for a period of occupation by the Germans which would last until the 16th May 1945 (Sanders 2005). Due to its location, only 60 miles from the English coast and 8 miles from France, Alderney was of great tactical value to the Nazis and was deemed to be "the last stepping stone before the conquest of mainland Britain" (Bonnard 1991; Fig. 7.1). During the 4 years of the Occupation, thousands of slave workers were sent there from across Europe and were tasked with the construction of heavy coastal and anti-aircraft batteries, tunnels, bunkers and earthworks as part of the Atlantic Wall construction programme (Fig. 7.2). Standing at only 3.5 miles long and 1.5 miles wide, the ratio of Alderney's land mass to the number of fortifications per square metre makes it one of the most heavily fortified parts of Europe. The slave workers were housed in a network of labour camps (Lager Norderney, Helgoland, Borkum and Citadella) and the only SS camp on British soil (Lager Sylt) (Fig. 7.3). They were subjected to often fatal living conditions, whilst incidents of shooting, hanging and torture have been reported (Sanders 2005).

7.2 Statement of the Problem

Despite the significance of these events in terms of the history of World War II, the construction of the Atlantic Wall and the Nazi slave labour programme, public knowledge of them is limited. The Occupation of the Channel Islands is somewhat embedded within public consciousness but the sheer scale of what took place and the specific details of this part of Alderney's past have been neglected, misrepresented and misunderstood. This is compounded by the fact that there is no heritage management strategy in place to protect the sites connected to the Occupation or to disseminate knowledge about them. The majority are unmarked, dilapidated and unrecorded. Heritage provision in the Channel Islands does not fall under the remit of English Heritage, owing to their position outside of the United Kingdom. Therefore, none of the sites on Alderney are scheduled monuments and,

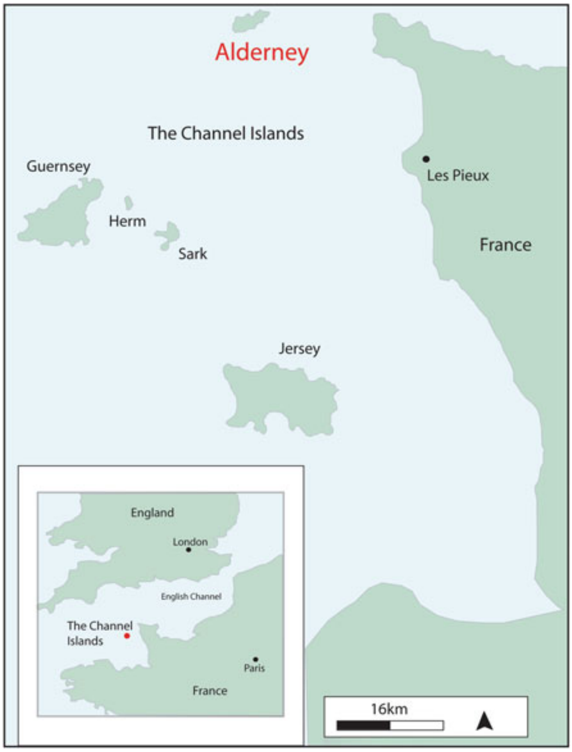

Fig. 7.1 Location plan of Alderney

consequently, they are not protected by law. This has allowed the sites of the camps to be redeveloped (Fig. 7.3); Sylt now lies in wasteland next to the airport; the gate posts of Helgoland have been incorporated into the gateway of a private property, the rest of the camp having been lost in the development; Borkum now stands in the island's refuse depot; Norderney is now a holiday campsite. The potential fifth camp at Citadella has never been definitively identified and, subsequently, is not marked. The sites of the Occupation survive as physical evidence of Nazis' plans to dominate Europe and as testaments to the suffering of the slave workers who built and were housed in them.

Therefore, there is an immediate need to research, record and commemorate them, and to disseminate knowledge to account for the vast number of people worldwide who are interested in learning about the events to which they relate. However, research into the political, social and ethical issues that have surrounded (and continue to surround) the Occupation itself revealed that this period remains a sensitive one in the island's history and, as such, traditional archaeological excavation and a large-scale heritage infrastructure revolving around museums, tours and in situ preservation of features is not welcomed by the current population (see below).

Fig. 7.2 Examples of the fortifications constructed by the prisoners and labourers sent to Alderney during the occupation. Camouflaged bunker (*top left*), machine gun position (*top right*), emplacement for a 20 mm Flak Gun (*bottom left*), defensive wall (*bottom right*) (authors' own photographs)

7.3 The Alderney Archaeology and Heritage Project

As a direct response to these issues, a research project was instigated by the authors to preserve the sites by way of digital record and to develop alternative forms of heritage presentation. This project has allowed the physical remnants connected to the Occupation to be recorded for the first time. Through an interdisciplinary methodology which combines historical research, cartographic and photographic data, and aerial reconnaissance material with non-invasive archaeological survey, new insights into the Nazi Occupation are being revealed. In turn, new opportunities for increasing academic and public knowledge of the sites are being realised through GIS analysis, 3D reconstructions and digital presentation of data. Although a number of sites have been, and will continue to be, examined as part of this research, the case study of Lager Norderney will be presented in this chapter as it demonstrates many of the trends observed by the authors at other Holocaust sites across Europe (Sturdy Colls 2012a, forthcoming). This chapter will demonstrate how non-invasive survey and digital heritage offer the opportunity to account for the various political, social and ethical issues surrounding some sites by removing the physical imposition of excavation and on-site museums in circumstances where these are deemed inappropriate, unnecessary or undesirable. Therefore, whilst this research will radically alter approaches to heritage presentation of the Occupation sites on Alderney, it has the potential to transform approaches to the investigation and presentation of other sites of socio-historic conflict and genocide across the world.

7.4 Background

Located in the north eastern corner of Alderney, the site of the former labour camp Lager Norderney is bounded by Saye Bay and Chateau L'Etoc to the north, Corbett's Bay to the east and Fort Albert to the west (Fig. 7.3). Although over 1,000 people of various nationalities were interred in the camp and subjected to forced labour, poor living conditions and harsh treatment, very little has been written about the history of the site and public knowledge concerning its role in the Holocaust and Nazi Occupation of Europe is limited (PRO WO311/12). Where it has been referred to, this has often been as part of a general description of all of the camps—"each consisted of wooden huts, erected by a volunteer force of French workmen"— or a few lines detailing the approximate number and nationalities of people sent there (Pantcheff 1981, p. 6). Initially, the camp housed French workers and was used as the living quarters for workers of Sager and Wörner of Munich

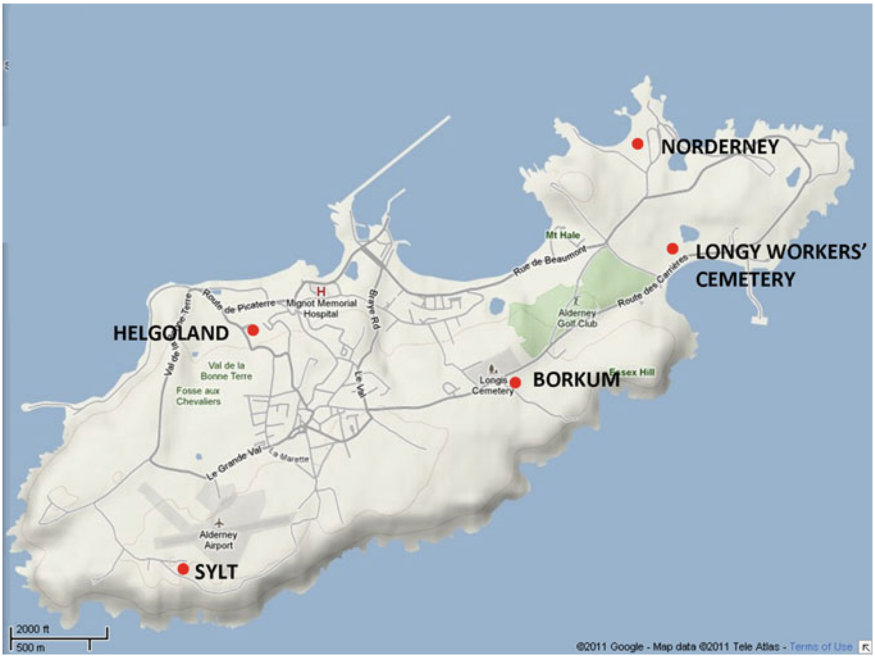

Fig. 7.3 Locations of the main camps constructed by the occupying forces on Alderney (adapted from Google 2011)

(Pantcheff 1981). Later, it was reported that mostly “Russians from the Ukraine” were housed in the camp (Pantcheff 1981). In reality, Poles, Russians and Dutch labourers, Moroccans, German volunteers, political prisoners and around 300 Jews were all housed there. Despite the fact that the Judge Advocate General assured the Foreign Office that the French Jews sent to Alderney were treated well compared to other labourers, many witnesses refer to brutal attacks against them (Bunting 1995, p. 296). The prisoner population in Norderney was far from static throughout the Occupation, as a result of deaths, re-assignments and the acquisition of prisoners when other camps were closed. A total of 900 prisoners were reported to have been housed there in January 1943 (Pantcheff 1981).

The fact that Norderney has been presented as a labour camp has often resulted in its role in the slave labour programme being played down. However, in its layout and scale, it was designed to house thousands of prisoners and Ginns (1994) has suggested that it may have been run by the SS. A review of historical material demonstrates that the “destruction through work” policy employed elsewhere in Europe was adopted with regard to those housed at this site, whilst brutal treatment was commonplace (Piper 2000, p. 65). One inmate from Norderney reported that “at the time of our arrival we had all been in normal health, but constant beatings and starvation diet had reduced us to an extremely feeble condition” (Jersey Heritage Trust 2009). Workers were issued with only 200–250 kg of bread, 15–20 kg of butter plus coffee for breakfast and a litre of thin soup for dinner yet they were made to work for up to 12 h a day, 7 days a week (PRO WO311/13). Szulc claimed that “anything up to 15 men a day were beaten in Norderney camp” (PRO WO311/12); beatings were carried out by the German staff and senior inmates (Ted Misiewicz in Bunting 1995). Many of the reports of ill-treatment came from members of the German garrison who were interviewed after the war, as well as from former prisoners. Conditions in the camp appear to have been at their worst up to early 1943, particularly when the camp was under the control of Dietz, with Norbert Beermart reporting that “every day you saw perhaps as many as five people die. At the beginning of 1943, ten people were dying in Nordeney daily” (Pantcheff 1981; Bunting 1995, p. 182). The camp was reportedly closed in July 1944; post-war investigators report that it had been dismantled by the Germans and the site levelled (Pantcheff 1981).

7.5 Current Approaches and Challenges: Current Site Conditions

The area in which Lager Norderney formerly lay is now a holiday campsite; colourful buildings have been erected, the grass is neatly mowed and tourists enjoy the nearby beach (Fig. 7.4). Davenport (2003, p. 107) is not alone in arguing that “apart from a few hut slabs and the half-buried bunker in the sand dunes, there is little evidence that this area was the site of a forced labour camp”. It is unlikely

Fig. 7.4 The current appearance of Lager Norderney, now the island's campsite (authors' own photo)

that the majority of people who pass through the site would even recognise these visible remnants as labour camp features, owing to the fact that in their current state they are barely distinguishable from other concrete remains of the Occupation. The site actually looks less affected by the Occupation than many other areas on the island. The perception that the site was destroyed by the Nazis and levelled has also contributed to the opinion that little remains as evidence of the camp's existence and has resulted in a lack of investigation into the surviving physical remnants.

7.6 Current Approaches to Memorialisation

The current use of the site means that there is little desire locally to draw attention to its former function and requests for permission to conduct excavations have been declined. There is a common feeling that promoting the darker aspects of the sites past, and that of the Occupation history in general, would discourage some visitors, encourage an unwanted focus on the atrocities and serve as a painful reminder of these events to members of the local population, particularly those who returned to the island after its liberation (States of Alderney pers. comm.). There is certainly no desire to erect memorials or other forms of in situ information at the site, and there is no possibility that the campsite would be moved to accommodate this. From an economic perspective, the site is a prime tourist spot, being one of the few areas on the island which is low-lying and has a sheltered bay with a large beach. Therefore, ethical questions arise over the imposition of in situ heritage strategies; whilst it is important to remember the victims of these atrocities, affecting peoples' livelihoods and opening old wounds in the name of commemoration of the past is unlikely to be looked upon favourably.

7.7 The Historical Narrative of the Occupation

In line with increased discussions concerning conflict archaeology, a handful of publications have addressed heritage management on Alderney in relation of the Occupation and have highlighted some of the trends concerning current and past approaches to the sites. Specifically, this literature has highlighting some of the competing historical narratives surrounding these events. Lennon and Foley (2000) were the first to highlight the dilapidated remains of the Occupation sites on Alderney in the context of dark tourism. Carr (2007, 2011) has also discussed what she has termed "the politics of forgetting" in the Channel Islands, including Alderney, in relation to aspects of the Atlantic Wall fortification programme, particularly with regard to how the public and enthusiasts view the bunkers. A comprehensive discussion of the political, social and religious issues impacting upon the approaches taken to the Occupation sites to date, in particular the camps, can be found in Sturdy Colls (2012a, b). In the context of assessing the issues that impact upon approaches to Occupation heritage at Lager Norderney and on Alderney in general, it is important to reconsider the current historical narratives of this period in brief here. In short, the current conditions of these sites and a lack of knowledge about the physical evidence of the Occupation appears to reflect the ongoing struggle between the various groups who have attempted to shape the history and memory of the site to date.

7.8 Archaeology and Heritage

Although a number of publications concerning the archaeology of Alderney exist (Monaghan 2011; Driscoll 2010; Gillings 2009; Migeod 1934; Kendrick 1928), these all focus on earlier periods in the island's history. The Occupation of Alderney has been considered by historians, as opposed to archaeologists, and they have for the most part focused on the fortification of the island, including architectural analysis the bunkers, the evacuation and the liberation. A focus on these aspects, coupled with the lack of investigation of the physical evidence relating to the sites connected to the slave labourers, has diluted knowledge concerning certain aspects of the Occupation and has contributed to the process of forgetting.

7.9 The "Official History" of the Occupation

An "official history" of the Occupation has emerged, cemented by the publication of a State-sponsored book claiming to be such by Charles Cruickshank (1975). Numerous articles written by the Alderney Society and in the Channel Island's Occupation Review, as well as Davenport's (2003) Festung Alderney, aim to provide a comprehensive overview of the military landscape. Whilst such texts are clearly important additions to knowledge about the Occupation, the absence of discussion regarding the slave labourers is notable. Despite claims in a letter to survivor Francisco Font that "if the official history of the Channel Islands during the occupation is to be properly balanced it must pay due attention to the plight of the slave workers" (JAS L/F/64/A/9), Cruickshank (1975) dedicated only four pages to the camps on Alderney and only refers to the OT workers, as opposed to slave workers and prisoners. This official history was further cemented by the publication of an account by Major Pantcheff, who led one of the investigations concerning the occupation of the island immediately after the war (Pantcheff 1981). This account did include a discussion of the camps but only a plan of Lager Sylt, which was purportedly derived from these investigations. Once again, a number of so-called "facts" about the Occupation were presented, all of which archival research has confirmed to be the official stance taken by the British government: all of the slave workers were reported to have been Russian (despite the fact that 27 nationalities were represented amongst the slave workers), it was stated that they were all labourers not prisoners and the brutality of events was diminished. Analysis of recently declassified material has demonstrated that these "facts" differ from the findings of an earlier investigation team, sent to the island immediately upon its liberation, and from many of the witness testimonies given by survivors of the camps (Sturdy Colls 2012b). In fact, they also differ from many of Pantcheff's findings, reported in several unpublished contemporary periodical reports located in the archives (PRO WO311/13). This information has continued to influence subsequent presentations of the history of this period and the texts by Cruickshank (1975) and Pantcheff (1981) have continued to be viewed as the main sources of information about the Occupation. This "official history" also appears to have had a direct impact upon perceptions of the physical evidence that survives from this period; just as there has been little discussion concerning the slave workers in historical narratives, there has been little attention paid to the sites at which they lived, worked and died.

7.10 Responses to the "Official History"

As a direct response to what has been termed an "unspoken conspiracy of silence" surrounding the more contentious aspects of the Occupation, since the 1980s there has emerged a handful of publications which discussed contentious issues such as burials, slave labour, the nature of the camps and the presence of Jewish prisoners in the Channel Islands (Bunting 1995; Cohen 2000; Fraser 2000; Sanders 2005; Freeman-Keel 1995). Whilst none centred on the physical remains specifically, many such texts sought to demonstrate the complexity of the forced labour programme and its built infrastructure (Steckoll 1982). Alongside these texts, claims about “a little Auschwitz on British soil” and mass executions emerged, as a direct response to a lack of knowledge about these events by the general public and limited investigations by the authorities (Steckoll 1982, p. 16). This, coupled with an abundance of newspaper reports centred upon such notions, has resulted in a situation whereby the term sensationalist has come to be applied to all subsequent researchers who challenge the official history (Knowles Smith 2007); for example, one book located in the Alderney archive possessed a cover note stating that it was not of interest as it contains information about “the bad and brutal way that the German army did things”. In turn, this retaliation by the local community has often been seen by many as a further sign of conspiracy to underplay the events, thus resulting in a constant cycle of defence and attack, suppression and exposure. Breaking this cycle and overcoming the perception of non-islanders “passing judgment”, appears to pose the greatest challenge to future researchers (Bunting 2004). The two differing stances taken by those who maintain the official history and those deemed sensationalist has resulted in considerable myth and conjecture surrounding the Occupation. Thus, there is a need to re-evaluate the primary evidence pertaining to this period.

7.11 Methodology

Due to the lack of an adequate solution to the problem of how to record and present the sites of the Occupation in a way that compensates for the issues involved in discussions of this period, there has been a lack of understanding of the spatial and chronological development of the camps. The perceptions that all evidence of them has been destroyed has been maintained; either due to a genuine believe that the remnants were entirely removed by the Nazis—as indicated in the historical literature—or due to lack of a desire to confront the physical evidence of this period. Consequently, in order to rectify the lack of investigation, whilst respecting concerns surrounding the sensitivities of this period, a non-invasive methodology was employed. Documentary, cartographic, photographic and aerial reconnaissance data from various worldwide archives was located and examined. In the first instance, published material was re-evaluated on the basis that archaeologists will ask different questions than historians of archival sources. Consideration was given to the potential for physical evidence to survive in the light of construction and demolition practices, the potential archaeological signatures of the camp structures, and the intrinsic and extrinsic factors impacting upon the evolution of the burial environment; thus old data can provide new information. In recent years, a considerable amount of archival material relating to the Occupation has been also declassified and catalogued, including maps, plans, official reports, intelligence data and ground-level photographs.

The digitisation of archives, a form of digital heritage in itself, has provided access to previously unseen material, in particular recently catalogued, previously unseen aerial images from over 100 sorties that flew over Alderney during the Second World War. Whilst modern aerial images have long been used in archaeological contexts, until recently the use of military aerial imagery has been predominantly restricted to use by military historians attempting to identify fortifications or bomb damage, or by post-war investigators locating unexploded ordinance (Ferguson 2008). Yet, aerial images of this type offer the opportunity, through shadow, vegetation and lighting conditions at the time the photographs were taken, to identify landscape features largely invisible from the ground (Hunter and Cox 2005). These features might include building foundations, tracks and roads, pits and disturbances such as mass graves. Additionally, the recent availability of satellite and shuttle data has the potential to provide information about the nature of archaeological remains in a given area (Parcak 2009). Preliminary site investigation data is easily accessible given the introduction of Google Earth and other internet-based mapping programmes (Myers 2010). This freely available data, along with other national datasets, provide opportunities for landscape analysis in advance of fieldwork; surviving archaeological remains visible from the air can be assessed, historical imagery can be examined in order to monitor man-made and natural landscape change, and images can be used as base maps for GIS packages (Myers 2010). The use of such data for assessing conflict and internment sites has been demonstrated in recent years (Stone 2008a, b; Thomas et al. 2008) and this data was used as part of this methodology. Additionally, higher resolution aerial imagery, taken by various private organisations was utilised, when available.

This desk-based analysis of the sites of the Occupation was complemented by a non-invasive archaeological field survey. The implementation of these methods served three purposes: to ground truth the information derived from the desk-based assessment, to facilitate the collection of information relating to the surviving remnants of the sites examined, much of which could not be derived without in-field investigation, and to collect data in a way that prevented disturbance of the remains. In order to assess the extent and nature of sites for survey, and to conduct archaeological reconnaissance in line with the standards defined by the IfA (2010) and English Heritage (2007), walkover surveys were carried out in advance of all other in-field survey methods. This allowed databases of GPS locations, dimensions, descriptions of above-ground features, taphonomic indicators, e.g., vegetation change, depressions, soil disturbance, and present land-use details to be recorded within the defined search areas. This information not only provides a detailed overview of the features relating to the Occupation, but it can also be easily integrated into the local Sites and Monuments Record (SMR). 360° photographs of selected sites were also taken and these will form the backdrop for a Graphical User Interface (see Sect. 7.16).

A range of complementary field survey and geophysical techniques were used in order to allow various aspects of the landscape to be recorded spatially and subsurface features to be mapped without excavation. In order to record features visible on the surface, Differential Kinematic GPS (DGPS) was primarily utilised during this project, on the basis that it provides the greatest level of accuracy. DGPS can have multiple uses and benefits as part of an archaeological survey. It can be used to record isolated points and the outlines of notable features, create site plans, plot in and establish survey grids, collect broad topographic data and record microtopographic data, which may reveal subsurface change consistent with buried remains and which can facilitate the production of three-dimensional Digital Terrain Models (DTMs). It is also capable of locating features which are not visible within the present landscape, but which have been identified using historic documents or geophysical survey (Ainsworth and Thomason 2003). Resistance survey and Ground Penetrating Radar (GPR) survey were used in conjunction given that, as Kvamme (2003, p. 439) argues, "surveys with multiple methods offer greater insight because buried cultural features not revealed by one may be made visible by another".

Following processing in the appropriate equipment-specific software, all of the data collected was assimilated into a Geographical Information System (GIS). Georectification of aerial images, cartographic data and site plans was also completed to identify correlations between the datasets. The use of this system essentially provided a digital database of the data collected, thus facilitating an analysis of spatial and temporal relationships, and the creation of digital representations appropriate for dissemination (Chapman 2003; Neubauer 2004). A variety of complementary software, such as AutoCAD, Adobe Illustrator and Surfer were also used to aid data presentation. Three-dimensional visualizations of selected areas were also produced using ArcGIS and Google SketchUp, and the Graphical User Interface mentioned above is being created to demonstrate some possible methods of dissemination. These resources will be utilised in developing education, heritage and commemoration strategies appropriate for the sites being considered in the future. The methodology employed demonstrates that archaeological and historical data should not be seen as independent but instead as complementary sources that can provide a richer narrative of events.

7.12 Results: Archives, Images and Cartography—Assessing the Origins of Norderney

After thorough archival research, the key to analysing the origins and the overall layout of Norderney at different periods of operation lies in the conversion of maps, photographs and aerial images into digital format to allow accurate comparison in GIS. Many of the maps and photographs were previously either classified or unidentified. Two maps, one produced in 1943 (JAS L/D/25/G/1A) and one in 1944 created by M.I.19 with a series of accompanying reports (PRO WO106/5248B), reveal that reconnaissance was undertaken by the British government during the war. Whilst this information was most likely derived to assess the fortification programme, it demonstrates that the government did possess knowledge concerning the camps on the island, despite claims to the contrary in the following years (JAS L/D/25/A/4). These maps provide the most comprehensive assessment of the physical remains of this period to date. Given that the M.I.19 map remained classified until recent years, this resource in particular offers considerable potential to re-evaluate the Occupation landscape. Prior to the war, the area was open grassland and only Saye farmhouse, two stone outbuildings and a glasshouse existed on the site (AMA 00/122/10).

These buildings were incorporated into the camp, with the farmhouse being used as the camp commandant's headquarters and the outbuildings being used as accommodation by the German staff and the camp kitchen (Davenport 2003). Many discussions of Norderney, and the other camps on the island, have relied heavily on aerial photographs taken after demolition or on the observations made by post-war investigators (Davenport 2003; Pantcheff 1981). Whilst the former presents only a snapshot of the camp's history and reveals the extent of the site following attempts to mask its former function by the Nazis, the latter failed to focus on determining the specific details concerning the camp layout and often focused on standing structures alone. A considerable number of aerial images of Norderney are included in the recently re-catalogued National Collection of Aerial Photography and, coupled with these wartime maps and archaeological survey, they have allowed the layout of the camp to be reinterpreted. Annotations of some of these images are shown in Fig. 7.5 and form the basis of this reinterpretation, presented below. Although Bonnard (2009) states that the camp was constructed in 1941, wartime aerial photographs show no extant remains on the site until 1942, aside from those pre-war buildings alluded to above (ACIU MF C0809). By March 1942, a considerable number of structures had been erected and several more were in the process of being built. The camp boundaries made use of the natural topography: fence lines were added alongside existing roads to the south and east, and sand dunes and a raised plateau to the north (AMA 00/122/10; ACIU MF C0792). The construction of a road to the west of the camp, which would come to form part of the boundary, occurred to facilitate access to Bibette Head where the construction of considerable fortifications began in June 1942 (ACIU MF C0766; ACIU MF C0809; ACIU MF C0913). An internal road bisected the camp, likely dividing the administrative buildings from the prisoner's barracks. The existence of these separate zones is further supported by tracks shown in contemporary aerial imagery. Excepting a few minor additions and changes to the appearance of internal trackways between structures, the site retained this layout throughout its period of operation.

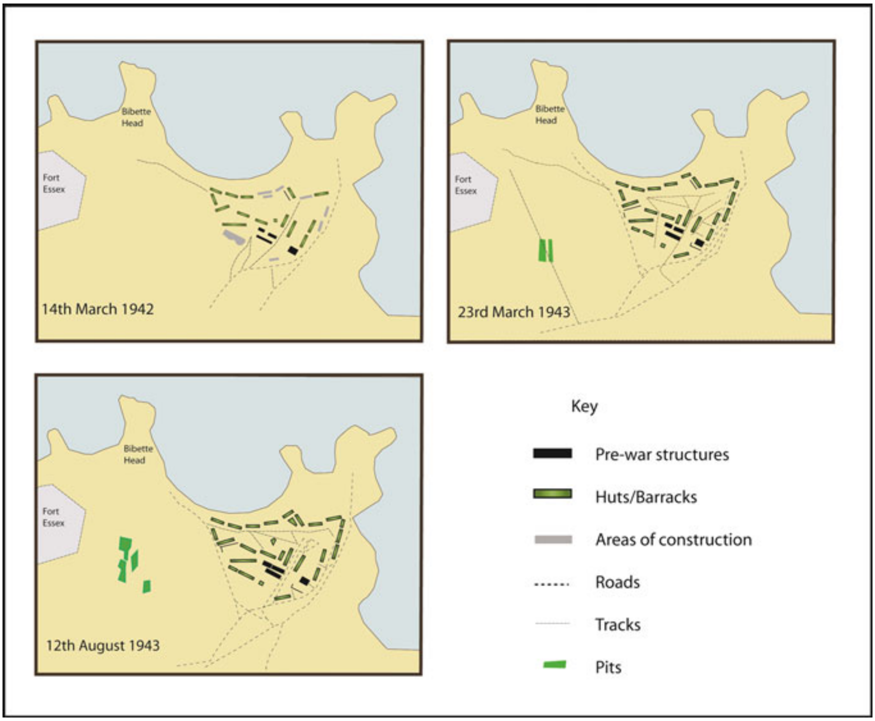

Fig. 7.5 Annotations of aerial images showing the development of Lager Norderney

Pantcheff (1981) cites the Normandy landings of June 1944 as the catalyst for the withdrawal of the Jewish, French and Moroccan inmates and the destruction of Norderney in July 1944. However, contemporary aerial images demonstrate that the camp buildings to the north of the farmhouse had been removed in March 1944, whilst some of the huts in the main camp compound had also been destroyed in May 1944 (ACIU MF C1978; ACIU MF C2208). By the time the liberating forces arrived in May 1945, they commented that Norderney was "dissolved…some time ago", but aerial images demonstrate that some structures remained intact and the outlines of other buildings were still visible (PRO WO311/11). Post-war witness accounts and further aerial images suggest that the eastern portion of site was levelled by the liberating forces, with some alluding to the presence of a bull-dozer (Packe and Dreyfus 1990; pers. comm. Barney Winder). Aerial images taken in May 1966 and post-war photographs demonstrate that this area had certainly been levelled by this time (Fig. 7.6).

Fig. 7.6 Post-war photograph of Lager Norderney showing the surviving structures and levelling that had taken place (reprinted from Ramsey 1981, p. 100)

7.13 Archaeological Data Collection

Contrary to the belief that little survives of the camp, analysis of aerial images taken throughout the war and archaeological site investigation as part of this study demonstrated that numerous additional features pertaining to the camp do exist, both buried below the ground and disguised by obstructive vegetation. A total of 38 features were recorded with GPS during the walkover survey at the site with the locations of each overlaid onto contemporary aerial images (Fig. 7.7). To further characterise the south-western area of the camp, a geophysical survey was also completed to investigate the subsurface characteristics of a number of areas of vegetation change (Figs. 7.8, 7.9).

An analysis of this data demonstrates several important points relevant to an understanding the layout of the site, what remains of it and, consequently, the post-war processes that have shaped its current state. Only the location of four barracks along the northern camp boundary could not be identified on the ground due to the sand dunes which have inundated that boundary of the site (Fig. 7.7). A number of barrack foundations (5, 6, 8, 10, 14, 15, 16, 20, 25, 27, 29, 32, 37, 39 on Fig. 7.7) were identified within the camp boundaries, several of which were visible as concrete remains on the surface or areas of vegetation change.

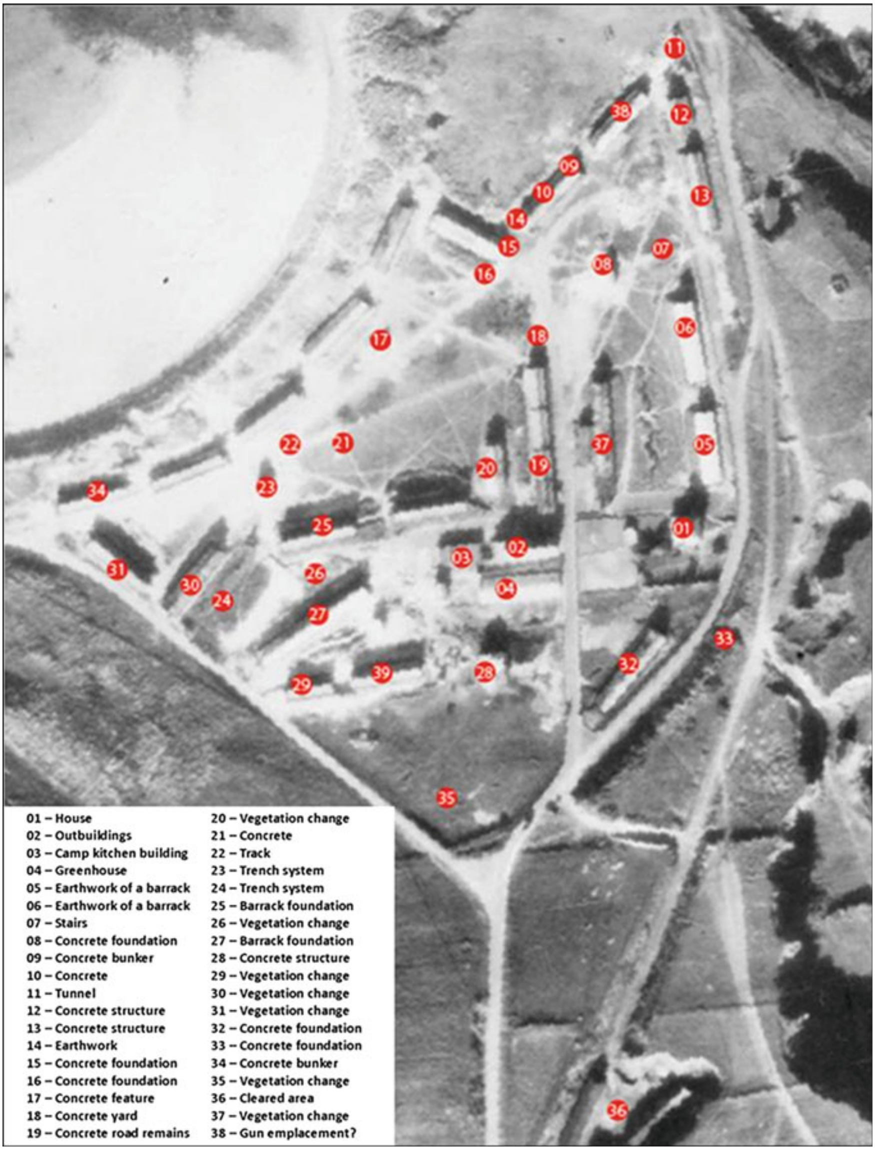

Fig. 7.7 Plan of features identified during the survey of Lager Norderney, overlaid onto a contemporary aerial photograph (reprinted from RCAHMS: National Collection of Aerial Photography aerial.rcahms.gov.uk)

One such feature (31; Fig. 7.7) was further characterised as a high resistance anomaly after the geophysical survey (G1 and G2; Figs. 7.8 and 7.9) and this location is reported in the literature to have been the hospital barrack (Freidman 1963). The use of the resistance meter at the site proved extremely difficult, owing

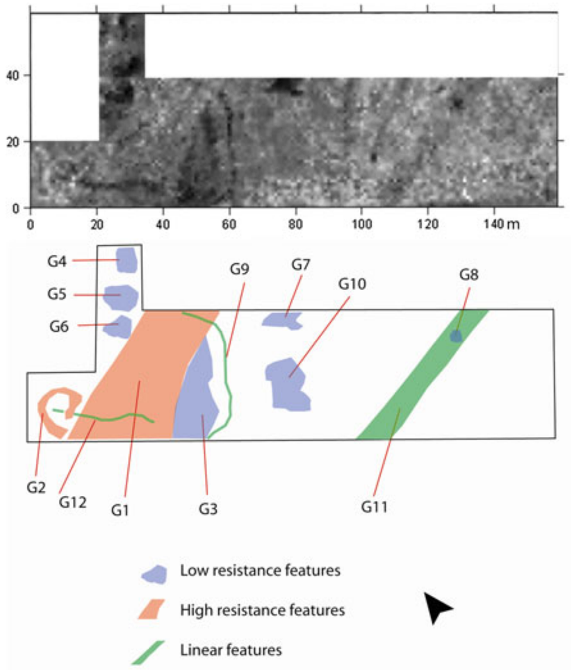

Fig. 7.8 Resistance survey data for Lager Norderney

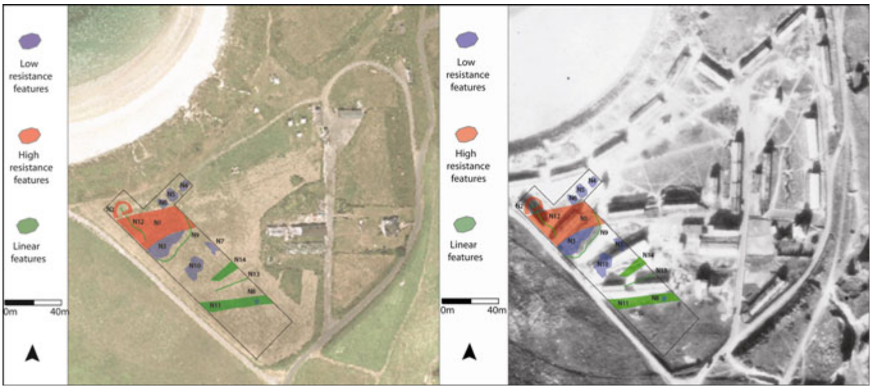

Fig. 7.9 Interpretation plans of the resistance survey at Lager Norderney over modern aerial image (*left* adapted from Google 2013) and over 1943 aerial photograph (*top right* reprinted from RCAHMS: National Collection of Aerial Photography aerial.rcahms.gov.uk)

to the presence of an apparently solid surface only a few centimetres below the ground and the extremely dry conditions during the survey. Therefore, a number of null readings had to be entered; however, these difficulties actually provided evidence of the existence of features. The presence of such a surface and the aforementioned foundations indicate that both the demolition of the camp by the Nazis and post-war activities resulted in the removal of the wooden barracks alone (Packe and Dreyfus 1990, p. 122). The foundations and concrete structures remained intact, with the sand, overburden and vegetation that they would become disguised in actually serving to protect them from further demolition. The presence of subterranean features close to the surface was further confirmed by service excavations (water) undertaken at the site during the survey, which revealed that the road that ran across the northern edge of the camp still exists and comprises of cobbles. Perhaps most significant is the fact that, although the pre-war buildings that still exist on the site are often described as the only standing remains, the discovery of several partially buried bunkers and concrete structures reveals this to be false. Similarly, this demonstrates that the notion often expressed in historical literature, that excepting the post-war buildings the entire camp comprised of Belgian sectional huts, does not accurately convey the complexity of the site (Bonnard 2009, p. 64). Indeed, it appears that a number of defensive structures were present within the camp (09, 34 and 38, Fig. 7.7). It is possible that feature 09 is the machine gun post referred to by witnesses as being located near to the tunnel (feature 11; Fig. 7.7) that lead to Corblett's Bay (Knowles Smith 2007, Steckoll 1982; Bloch in Jersey Heritage 2009). This tunnel was often referred to as a "death tunnel" where inmates were to be sent should the British invade the island (Knowles Smith 2007; Steckoll 1982). Dr Bloch stated:

> They put us into the tunnel and hermetically sealed the doors and air vents. This tunnel was about 20 m long and 5 m wide. Eight hundred of us were forced into it. In front of the entrance to the tunnel, a German sat manning a machine gun. It is certain that had we been kept inside for a few hours, most of us would have died. We were kept there for 15 or 20 minutes and many became ill (Jersey Heritage 2009).

The location of this gun emplacement (feature 38) and a concrete bunker (feature 34) within the camp, also raises questions over the purpose of such features (Fig. 7.7); their locations, being bounded by the sand dunes on one side and the camp barracks on the other, indicates they would have been of little use in defending against aerial or sea-borne attacks and, thus they are more likely to have been guard positions for monitoring those interred in the camp. A number of other concrete structures were also recorded that have not previously been alluded to in the literature as having survived after the war (features 12, 17 and 28; Fig. 7.7). Probable doorways and dividing walls of subterranean features were observed for features 12 and 28 when obstructive vegetation was removed, as shown in Figs. 7.10 and 7.11. This not only demonstrates the presence of buried structures within the camp, but it reveals that features which historians believed to be the foundations of structures that were demolished, actually represent the roofs or upper floors of previously unidentified features. This clearly shows the lack of investigation of the physical remains that has been carried out in the past and demonstrates how non-invasive methods and the simple act of clearing obstructive vegetation can provide new insights into neglected areas. The nature of these features has also not been noted in the past where wartime aerial imagery has been

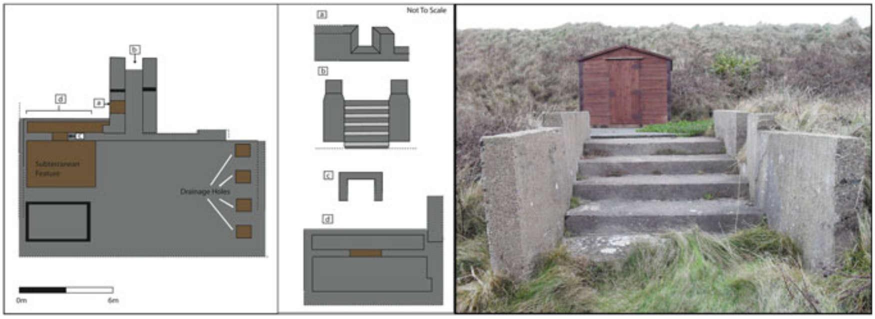

Fig. 7.10 Plan and photograph of feature 12, located within Lager Norderney (author's own photograph)

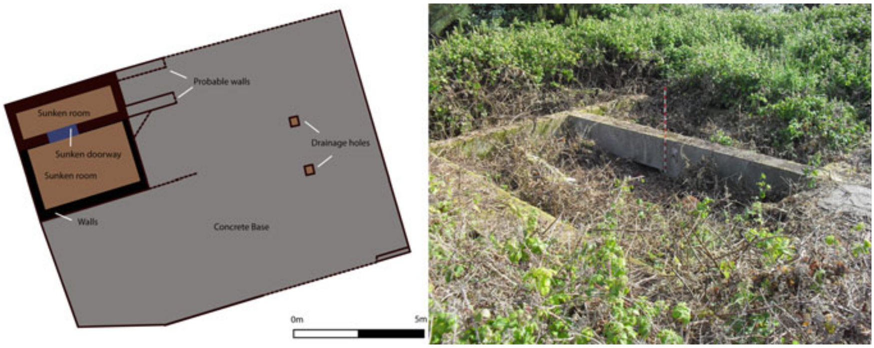

Fig. 7.11 Plan and photograph of buried structure (28) located at Lager Norderney (author's own photograph)

the sole source. Although clearly extremely useful for locating features, the characterisation of structures using this data alone is often difficult for those that are discrete or camouflaged when viewed from the air. Therefore, such analysis should be coupled with on-site investigation which, in this case, has allowed surviving features to be located and defined in terms of their extent and nature. The identification of these features raises important questions over their function within the camp. Georgi Kondakov, a former inmate on Alderney, suggested that feature 12 was the toilet block of the camp, which may be supported by the existence of apparent drainage holes (Bonnard 1991). Yet the subterranean features on the south side of this feature indicate an additional function. Informants interviewed by M.I.19 suggested that an underground Benzine dump, and shower and bathing facilities existed in this area and it is possible that feature 12 could be the latter (Fig. 7.10).

The existence of the buried structure 28 in the area that housed the majority of prisoners and labourers is particularly difficult to explain without further intrusive activity. Aerial photographs demonstrate that this structure was not fenced off with the pre-war buildings inhabited by the camp administration and was in fact located inside the main camp area (Fig. 7.7). This structure comprises of partially buried doorways and internal walls at its northern end, where the height of the ceiling appears to have been level with the current ground surface, whilst the southern end comprises of solid concrete with possible holes for plumbing (Fig. 7.11). On the one hand, the appearance of this structure once again suggests an underground storage facility or personnel shelter. As with feature 13, would the camp administration have risked housing materials, particularly fuel or ammunition, so close to the living quarters of the prisoners and labourers? The other possibility is that feature 28 was used for defence purposes and the existence of other bunkers around the camp perimeter suggests that there was a desire to patrol the area. Once again, questions remain about whether such a feature was in place to defend against enemy attacks or maintain control over the camp's population. Whatever the function of these structures, their existence in the bracken and the fact that they have not been noted in any of the literature concerning the camp, once again reveals important information concerning attitudes to this site.

7.14 Assessing the Wider Landscape

The survey also permitted the identification of further features in the immediate vicinity of the camp, which can be seen to have formed part of its wider landscape; indeed an examination of camps pertaining to this period should not be restricted to the physical boundaries denoted by fences. Some significant examples are discussed here to demonstrate the potential of wider landscape analysis. Barrack foundations were identified both to the east (feature 33), in the form of concrete visible on the surface, and the south (feature 36), in the form of vegetation change (Fig. 7.7). These barracks were likely to have functioned as temporary accommodation or storage for labourers working in the nearby quarry. Finally, a track leading to what appears to be a series of linear pits on the hillside on the west side of the camp can first be seen in aerial images dating to March 1942. Further tracks appear to have led from Fort Albert to the west. By July 1942, it appears that these pits had been backfilled and they continue to be visible as vegetation change until June 1944, when they seem to have been partially reopened. It is interesting that the use of these pits appears to coincide with the construction and demolition phases of the camp's operation. However, their location, upon a difficult to access part of the hillside, raises questions over their function and prevented access with geophysical survey equipment. Although Lager Sylt is often referred to as the main camp on Alderney, the survey has revealed that Norderney was actually the largest labour camp on the island, both in terms of the number of buildings on the site and the number of prisoners and labourers sent there (Pantcheff 1981). The combined use of survey and research methods has allowed a comprehensive overview of the surviving extent of the camp to be provided and has demonstrated attitudes towards the site that have emerged since the war.

7.15 Digital Heritage Resources: Research and Preservation

Information communication technology (ICT) can facilitate the production of resources of use to researchers and heritage professionals in the protection and dissemination of heritage (Ledig 2009b, p. 169). The outputs of the research on Alderney have been geared towards ensuring that new knowledge can be generated, the sites in question can be preserved by way of record, resources can be produced which can inform planning decisions in the future and dissemination told can be created for use in heritage and education. The combined analysis of historical and archaeological data has facilitated the development of three dimensional models which integrate multiple data types (Figs. 7.12, 7.13). These models will act as tools to enhance understanding of the site. Topographic data capture also preserves landscapes by way of record and thus provides a heritage resource which can be of use in future landscape or planning management, something which is particularly important on Alderney with its lack of archaeological planning control (Ledig 2009a; States of Alderney 2006). Three dimensional plans go beyond what an aerial image alone can provide and can set the site in its landscape context; thus enhancing the interpretation capacity of the data. From the model of Lager Norderney, it is easier to appreciate the topography of the camp, in particular the dune systems to the northwest which act as a natural camp boundary. This is also important as a high proportion of the slaves at Norderney would have worked on the major fortification at Bibette Head (600 m to the south) which would have been obscured from the camp by the aforementioned dunes. The

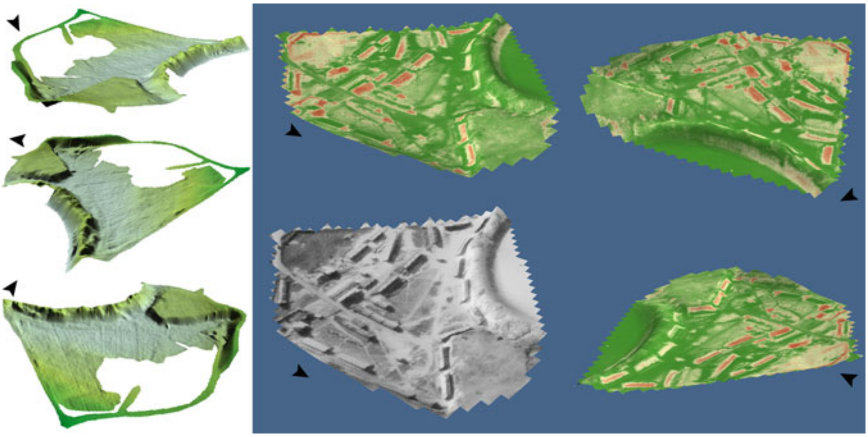

Fig. 7.12 Digital terrain models of Lager Norderney based on DGPS elevation data (*left*) and an aerial image of the site, taken on the 21st January 1943, overlaid onto the digital terrain model (*middle bottom* reprinted from RCAHMS: National Collection of Aerial Photography aerial.rcahms.gov.uk)

Fig. 7.13 3D visualisation of Lager Norderney based on historical and archaeological data (*bottom left* and *top right* adapted from Google 2013; *top left* and *bottom right* reprinted from RCAHMS: National Collection of Aerial Photography aerial.rcahms.gov.uk)

models also highlight the road network around the site and facilitate analysis into how these routes would have been utilised and modified by the camp administration. At a micro-topographic level, several barrack platforms were visible in the topographic data, as well as regular linear features which suggest that the interior of the camp has at some point been ploughed.

Multiple models can be produced, thus demonstrating the landscape change that has occurred over time, both during the camp's period of operation and after, through the analysis of aerial photographs and map regressions. In the past, there has been a focus solely on individual aerial images of a site; usually those taken after or close to the end of its abandonment. Therefore, single plans of how camps appeared have been produced. However, this is to ignore the fact that these camps did not remain static; they evolved according to the number and groups of prisoners interred within them, the development of Nazi policies and the situation in Europe. The large number of sorties that flew over Alderney can be attributed to the flight paths taken by the reconnaissance forces and, in fact, the large number of images available exist almost accidently, in that they were taken at the start and end of rolls of film on the way to mainland Europe (The National Collection of Aerial Photography pers. comm.). Thus, the almost daily record of the development of the camps provided at times by these images represent a previously untapped digital heritage resource that has been utilised as part of this project to demonstrate further layers in the camp's history. This of course represents a different mechanism to establish site phasing than traditional stratigraphic methods but it is perhaps of greater value than such techniques when examined the broader landscape context. The use of GIS packages and other digital platforms through which historical and archaeological data can be compared has allowed documentary sources to be revisited, examined based on alternative questions (compared to those asked by historians) and has allowed revised interpretations of the sites. Traditional historical records, e.g. witness testimonies, photographs, plans and reports, etc. can be visualised through such comparisons and mechanisms such as geotagging. In circumstances where excavation is not permitted, desirable or possible, the use of digital recording technologies now facilitates access to the sites and compensates for sensitivities surrounding investigation of this period.

7.16 Dissemination

These observations play an important role in improving our understanding of Lager Norderney. It is also important to highlight the role that these three-dimensional landscape models can have in placing the results in the public consciousness, both locally on the island and across Europe. Transforming scientific and technical archaeological data into formats which are easily interpretable by non-specialists and the general public has been given considerable attention due to the technological advancements over the last decade (e.g. Styliaris et al. 2010; Stanco et al. 2010). This issue is particularly pertinent within the field of Holocaust Archaeology given the social, political, geographical and religious factors associated with studying this period of history. Given the number of individuals, groups and communities which need to be consulted before research into this period of history commences, it is vitally important to produce data and images that are universally clear, and available for use as distance learning and educational tools. Models and topographic data of this type are also particularly useful on web-based platforms as the full potential of three-dimensional rotational images can be fully realised. "Visitors" will experience a variety of documentary, cartographic, oral and archaeological source material relating to the site, to a greater extent than would be possible during a visit to a traditional museum (Figs. 7.14, 7.15; Deegan and McCarty 2012).

As Ledig (2009a, p. 162) has highlighted, these forms of digital heritage also allow "access to heritage without factual, time or location constraints", something which was acknowledged as a priority in the Faro Convention (Council of Europe 2005). This is important given the aforementioned issues with memorialisation of the slave labour camps on Alderney, particularly Norderney given its function as the holiday camp. A web-based platform combining all of the data and results of this survey will open up access to a wider audience, including those who cannot visit Alderney, whilst not physically forcing members of the local community to confront a painful heritage (for example, through on-site memorials or museums of Occupation).

It also allows those unable to travel to the site, for whatever reason, to gain information about its history. Multiple representations and interpretations can also

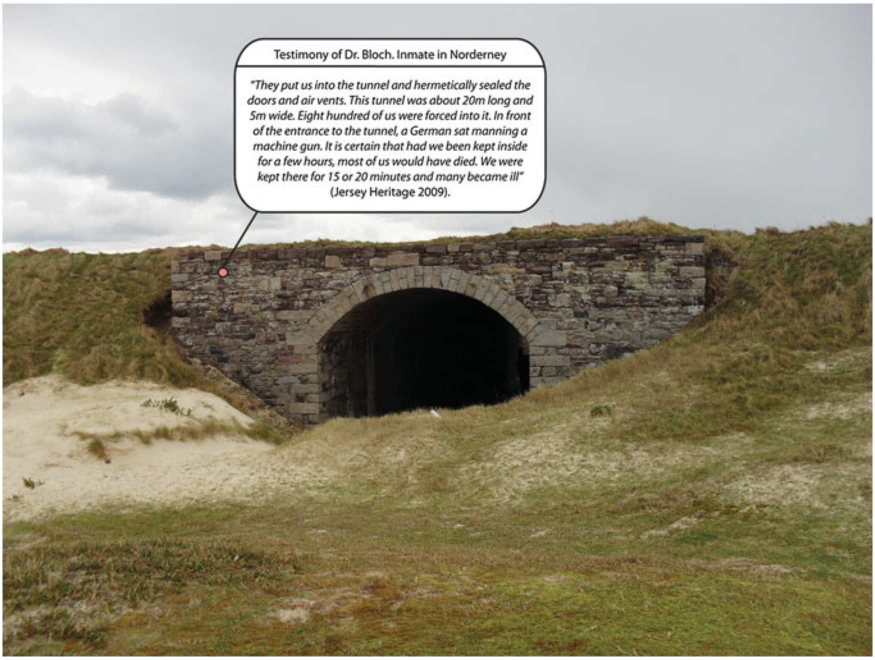

Fig. 7.14 An example from the 3D graphical user interface being developed for the Alderney archaeology and heritage project. Scrolling over the *red dot* allows the user to view a witness testimony relating to the tunnel in Lager Norderney through geo-tagging

Fig. 7.15 A further example from the 3D graphical user interface being developed for the Alderney archaeology and heritage project. Scrolling over the *green dot* allows the user to view historical and archaeological information about one of the buried structure identified during field survey

be more readily presented alongside each other, whilst the ability to present multiple data types, e.g. witness testimonies alongside physical evidence, overcomes some of the issues connected to ownership of the site and does not prioritise the opinions of one group over another (Kalay et al. 2007). Crucially, however, as stated by Kalay et al. (2007, xv),

> Digital media could be utilised for much more than re-creation and re-presentation of physical entities. It has the capacity to become a tool to capture the tangible and intangible essence of both the cultural heritage and the society that created or used the sites.

The survey strategy employed during this research ensured that the more subtle indicators pertaining to the sites were recorded and that the post-abandonment history of the sites was also thoroughly examined. Thus, recording practices involved the survey of all physical remnants present at the sites, not just those relating to the Occupation, in order to access the physical layers present. These remains, and associated research into the issues that have influenced the cultural memory associated with them, have highlighted the intangible heritage of these conflict sites. Through the publication of these findings in association with the results of the surveys and the integration of these findings into digital heritage resources, it is possible to provide a fuller narrative of events. That is not to say that representations through such means are without problems. Issues with the complexity of such resources, when too many representations of the same site are presented, and the ability of technology to quickly become obsolete has been observed (Kvan 2007), alongside concerns over the loss of authenticity when digital media replaces on-site experience (Kalay et al. 2007). The desire by visitors to dark tourism sites to "feel something", thus treating visits as performances, has been observed by scholars (Smith and Waterton 2009; Baxter 2009). Such a desire cannot be met through digital heritage. Perhaps most crucially, these resources are unlikely to provide a substitute for the ability to visit the site by survivors, family members or those wishing to commemorate the dead; indeed it is not the suggestion of the authors that this should be the case. However, these resources do offer a complementary, and in some cases a necessary alternative, form of commemoration when on-site memorialisation is not permitted or possible.

7.17 Conclusion

The survey of Lager Norderney has been presented as a case study in order to demonstrate the benefits, in terms of research, preservation and dissemination, of employing a non-invasive methodology that incorporates multiple survey methods and data types, alongside the use of digital heritage tools. By employing a methodology that addresses all of the physical and cultural layers associated with this painful period of history, resources have been generated that mitigate against some of the issues surrounding its investigation. In the past, opinions concerning the site have revolved around the perception that the site was destroyed;

archaeological survey has demonstrated definitively that this is not the case and the presentation of these findings through digital means has offered new insights into their form, function and surviving extent without ground disturbance. This approach has allowed the remains of the Occupation to be recorded for the first time. As the survey work at this site, and at others on Alderney continues, a web-based package will continue to be developed that allows the integration of multiple data types, thus realising a more tangible, user-friendly, widely available and sustainable heritage and education tool. The application of digital technologies and the production of digital heritage tools should not be restricted to the Occupation sites alone; there remains an abundance of sites from other periods of history, including the Napoleonic and Victorian forts, that have also not been satisfactorily recorded owing to the planning and preservation policies on the island. Thus, this work has the potential to revolutionise the preservation and presentation of the island's heritage. In a broader sense, these investigations demonstrate the future potential of such methodologies to be applied at other sites of socio-historic conflict. The realisation of a methodology that seeks to compensate for the issues involved in the examination of what can be termed painful heritage is intended to provide a platform for investigation of sites where archaeological work has been seen as undesirable or unnecessary in the past. In fact, the success of this non-invasive methodology opens up the possibility of access to sites to which have previously been "off limits" so to speak. One of the biggest challenges for us as practitioners is to recognise the difference between what it theoretically and practically possible in terms of field recording and preservation at such sites, something which can only be achieved by gaining a broad understanding of the context in which the work is being undertaken. Although it is not being suggested that digital heritage should replace traditional forms of commemoration, whilst the events of the Holocaust and Nazi Occupation remain in the grey area between history and memory, such methods offer one mechanism through which these events can be remembered.

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Chapter 8
Urban Scrawl: Reconstructing Urban Landscapes Using Documentary Sources

Eleanor Ramsey

Abstract Whilst many heritage projects utilise new technologies for the creation and analysis of novel digital datasets, these projects require the object or landscape under study to currently exist. For urban landscapes that are no longer extant, however, there is a large amount of data in a non-digital format that can potentially be mined to reconstruct in detail those areas which are now physically beyond the reach of archaeologists. This chapter aims to show that by including documentary sources such as census returns and trade directories in a suitable digital format, technologies such as GIS can be used to facilitate access to this data, and also provide a way of analysing, understanding and visualising the information held within them in many novel ways. The period studied here, nineteenth century Britain, was a time of intense change, especially in terms of the booming population and industrial output and, as a consequence of the continued development of urban areas, the archaeology and built environment of this period is under considerable threat. Trade directories, census returns and GIS have all been used in historic and archaeological research period before, however, previous research tends to focus on specific industries or aggregate the data at a large scale. This chapter demonstrates that aggregation of data at street or suburb level provides a much finer level of detail and enables novel insights regarding the spatial distribution of buildings, population and trades, and furthermore enables new maps to be created that allow changes to these attributes to be mapped and analysed.

Keywords GIS · Urban landscapes · Nineteenth century · Trade directories · Census

E. Ramsey (✉)
IBM Visual and Spatial Technologies Centre, The University of Birmingham, Edgbaston B15 2TT, UK
e-mail: ellie.ramsey@gmail.com

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8.1 Introduction

The application of new spatial and visualisation technologies is now standard within many heritage projects and their use has resulted in the creation and analysis of novel digital datasets. It is true, however, that many of these projects actually represent extant physical structures, landscapes or directly linked proxy data such as that provided through remote sensing. This situation is not always true within urban landscapes. Urban landscapes may often be modified beyond recognition as the historic cores of towns are transformed into modern city centres. In some cases, the transition may be so dramatic as to break the link with past urban structures completely. Given that the development of urban structures is amongst the most important research themes within geographic or historic studies (Reader 2004), there is a clear requirement that we seek alternative routes to understanding the development of these complex entities. We are fortunate, therefore, that there is a large amount of data in a non-digital format that can potentially be mined to reconstruct, in detail, those areas which are now physically beyond the reach of archaeologists, geographers and historians. This research demonstrates that converting the information contained within documentary sources such as census returns and trade directories into a suitable digital format, allows technologies such as GIS to access the data, and provide a way of analysing, understanding and visualising the information held within them in many novel ways.

A suitable example of such a process can be provided through the study of Britain in the nineteenth century. This was a time of enormous national change, both physically and socially, and especially within industrial and urban areas. It has long been understood that the archaeological and built remains of this period are vulnerable, especially in urban areas marked for redevelopment. They are a fragile and finite archaeological resource, and while the relative importance of individual sites is perhaps only of local or national importance, aggregate data for these larger urban landscapes can be of international importance in understanding the nature and impact of urban change over time. Indeed, English Heritage state *In a globalised world it is all to easy to forget that England was the cradle of modern industry. The monuments to our extraordinary industrial past are all around us—but they are fragile and we neglect them at our peril* (English Heritage 2011).

The significance of the remains of this defining period is increasingly being acknowledged (ibid.). Individual monuments and industrial landscapes such as Ironbridge Gorge, Saltaire and Blaenavon are now UNESCO World Heritage Sites. However, much of the urban industrial landscape of the nineteenth century was not as impressive as these designated areas and has not attracted similar appreciation or protection. Indeed the Victorian terraces, courts and back-to-backs that had been constructed as housing for the new urban population, and the small-scale industrial buildings in which they worked, had deteriorated by the early twentieth century to the point they were considered slums, and the Housing Act of 1930 encouraged their clearance. However, these landscapes of the working class are also an important part of our industrial past. The West Midlands Regional

Research Framework identified several themes pertinent to this research (WMRRF 2003). These included the importance of studying both change and continuity during this period, as well as consideration of how to best use the abundance of documentary evidence to enhance the archaeological record.

While documentation of this period is quite extensive, both through records and maps, the majority of previous research using these resources is directed at individual people or specific industries (for example Knowles and Healey 2006). Likewise, although the use of GIS in historical and archaeological research is now well established, most recent or current studies involve the study of areas and aggregate data at a scale too great to be of use for detailed analysis of smaller areas (for example Raven and Hooley 2005).

This research focuses on the use of GIS and documentary sources to map, analyse and understand urban and industrial change in nineteenth century Dudley (Fig. 8.1), an area that saw considerable transformation throughout this important and dynamic period in history (DMBC 2004).

The study was carried out in order to create a holistic dataset that could map all of the data recorded in these sources, both spatially and temporally, at street and suburb level. By converting the information held in documentary sources into a digital resource, it would be possible to map the nature and evolution of the urban environment in detail, and in ways that had not previously been possible. In particular, using GIS-allowed elements of the urban landscape, such as the density of population, changes in number of buildings, range of trades and industries

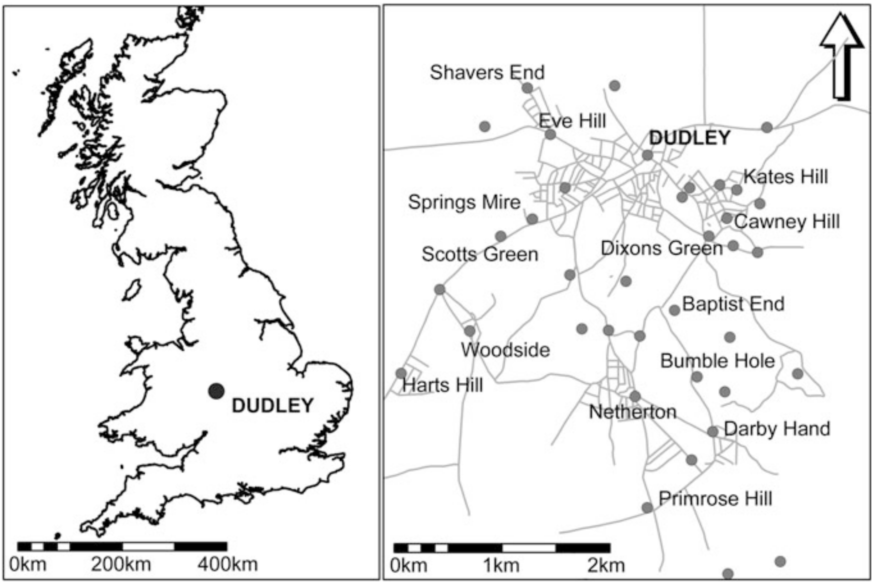


Fig. 8.1 Location of Dudley; streets and suburbs used in the research

present in any particular street or suburb and distribution of all specific industries to be mapped. Furthermore, this data could be used as a dataset that contextualises current repositories such as the Historic Environment Record (HER) and Black Country Historic Landscape Characterisation (BCHLC—Quigley 2009, 2010).

8.2 Methodology

In order to digitise as many streets and suburbs as possible, the Ordnance Survey 1st edition was used to rectify the earlier historic mapping, and these, along with the documentary sources were used to identify as many streets as possible. During this process, a central line was created for each street identified, and a point shapefile was created for the suburbs, denoting the approximate centre point of each individually named 'place'. Where these names changed overtime, the latest name was used.

The Trade Directories chosen for the analysis were those that were available online at www.historicaldirectories.org, and which were determined to be the most appropriate in terms of their accuracy and compatibility. Additionally, the Pigot Smith directory of 1860 was input, although this was not available online. This provided a relatively even temporal distribution of the datasets (1828, 1835, 1842, 1851, 1860, 1876). The initial trade directory database had the fields: Directory date, directory name, title, first name, surname, trade or occupation, address (number or name), address (street) and address (suburb). Where multiple names were recorded in the directory as one entry, such as Addenbrook and Cook, or Bloomer, Benjamin and Son, these were treated as one entry. The reasoning behind this decision was that the 'industry present in street' was the key data, not the person or persons involved. Where the same person or business was listed at two separate addresses, the entry was duplicated for each address for similar reasons.

The data was then manually cleaned and standardised. The trades and occupations were classified using the Booth-Armstrong industrial classification system, developed by Charles Booth at the end of the nineteenth century and published by W. A. Armstrong in 1972 (Armstrong 1972). This classification system for occupations comprises a hierarchical approach, by which 10 broader categories are further subdivided. The final database contained the additional fields Revised Street, Revised Suburb, New Trade Name, Simple Category (such as Dealing (D), Manufacturing (MF) etc.) and New Category (MF4 (Iron and Steel), MF6 (Gold and Silver) etc.). Information from the censuses from 1841, 1851, 1861 and 1871 were also inputted into a database. The initial census database contained the fields Census Date, Census Number, Sheet Number, Address (street/suburb) name, Houses inhabited, Houses uninhabited, Males and Females. This data was manually cleaned and standardised, with the final database containing additional fields Revised Street Name and Suburb.

The data in the two databases was then cross-tabulated at the Revised Street and Revised Suburb level to give a numeric value (count) of various attributes. Further attributes were calculated from these including ratios between the counts, and changes between the values for each consecutive year of the sources. In order to map the data, the new attribute databases were then joined to shapefiles using standardised fields.

It should be stressed that not all streets on the maps were able to be named, and not all addresses in the documentary sources were able to be mapped. Where there was correlation, however, the shapefiles and tables could be joined in ArcGIS using the unique streets and suburb names, giving each street and suburb a series of attributes regarding number of houses, individuals and trades present in each recorded year.

A series of maps was then produced that symbolised these attributes, and which were analysed, specifically to look for spatial components of character and changes in that character through time.

These results were then used to demonstrate how the results can enhance and contextualise previous research and sources of data. A particular street (Wolverhampton Street) was used, in order to demonstrate how the results can be used to enhance currently available datasets.

8.3 Background

Dudley is an English town situated in the heart of what is known as the Black Country, an area comprising a network of industrial towns to the north and west of Birmingham, centred on the South Staffordshire Coalfield. The term was coined in the nineteenth century and is presumed to be a reference to the industrial grime of the area, and today includes four Local Authorities; Wolverhampton, Walsall, Sandwell and Dudley (Quigley 2009, 2010). For the purposes of the research, the boundaries of Dudley and its suburbs were defined by addresses in the census returns and trade directories that had been recorded as Dudley etc., rather than any official boundary (Fig. 8.1). Historic mapping can be used to illustrate the origin and growth of the town; however, as the landscape continued to evolve after this period, much of the original landscape is lost to us now (Fig. 8.2).

Dudley was chosen as a study area for a number of reasons. While the town has a unique and important history of its own dating back to the medieval period, it is also representative of many of the industrial towns in the nineteenth century Black Country as a whole. This suggests that any successful methodologies developed could theoretically be applied to towns elsewhere in the region, and indeed other industrial areas within Britain as a whole. The size of Dudley was also an important factor. Due to the nature of the research, a town or area was needed that was substantial enough for the trade directories and census to list people by street (as opposed to smaller towns and areas which only listed by area), and not so large

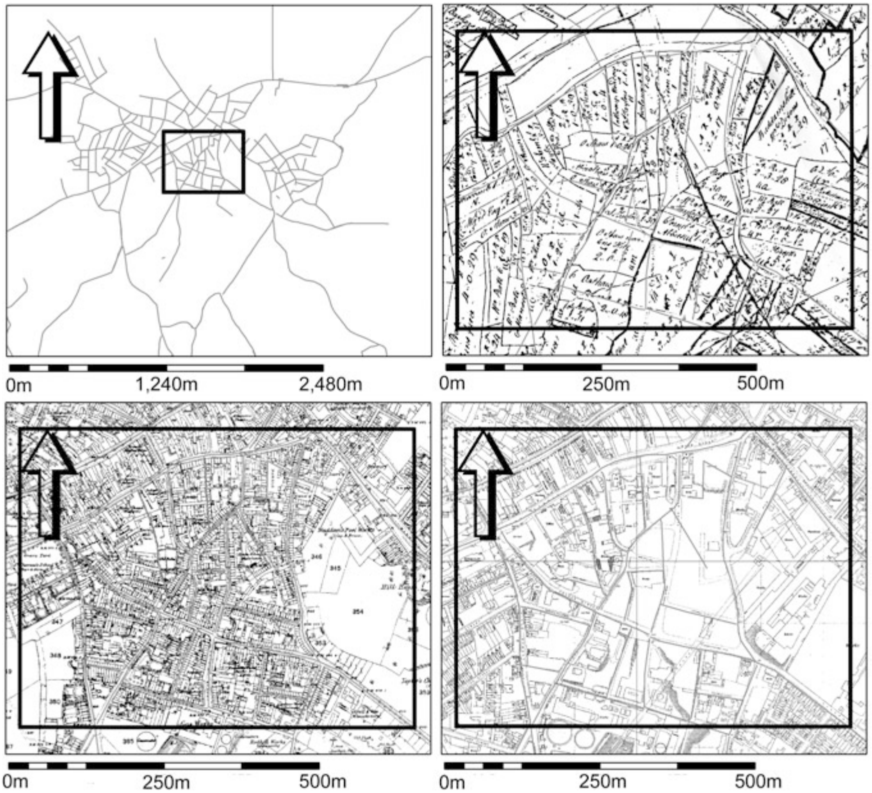


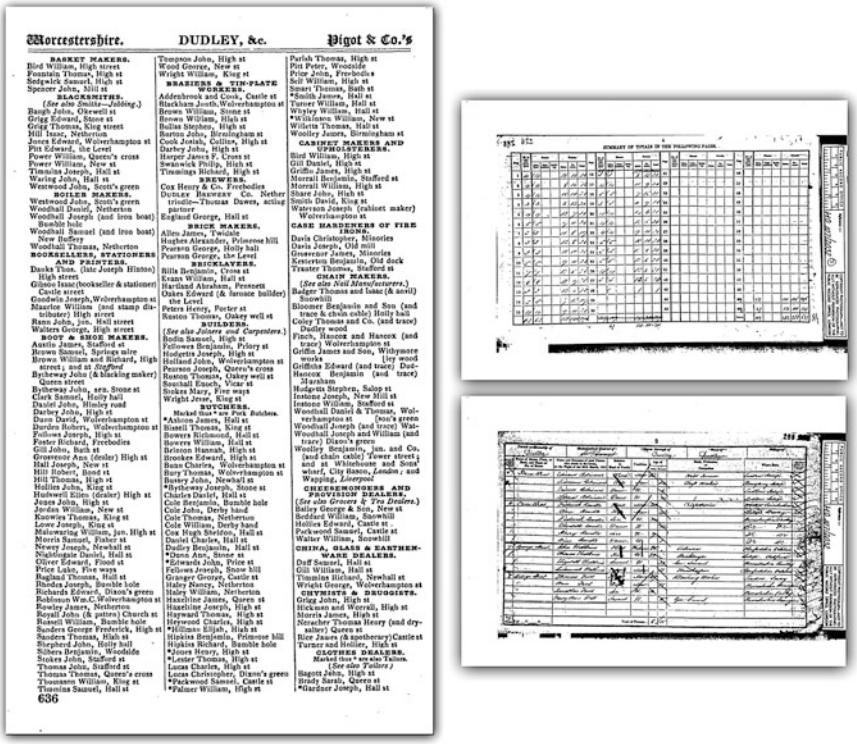
Fig. 8.2 Outline of streets; detailed maps of 1776; Ordnance Survey 1:2500 1890s; Ordnance Survey 1:2500 1960s

(such as Wolverhampton or Birmingham) as to make it impossible to input all relevant data.

Dudley has a relatively comprehensive map sequence that covers the period under investigation. The earliest map used was from 1776, and while this map only shows Dudley itself as a solid block, it depicts the field systems surrounding the populated area, the pattern of which had a significant influence on the development of the later town. The next available maps are Treasure's map of 1835 and an anonymous map of 1836. The former is quite stylised, but does name many of the streets within the town centre, and the latter annotates many of the suburbs and areas that ringed the town. Richard's map of 1865 was also used, as were British Ordnance Survey 1st Editions from the end of the nineteenth century.

While many documentary sources from this period are available, the research focused on the census and trade directories. These two disparate datasets were used to gather data about population, buildings, and industry.

The earliest British trade directories (Fig. 8.3) were published at the end of the seventeenth century, although they became more widespread in the eighteenth



Worcestershire. DUDLEY, &c. Pigot & Co.'s

BASKET MAKERS.
Bird William, High street
Fountain Thomas, High st
Sedgwick Samuel, High st
Spencer John, Mill st
BLACKSMITHS.
(*See also Smiths—Jobbing.*)
Baugh John, Okewell st
Grigg Edward, Stone st
Grigg Thomas, King street
Hill Isaac, Netherton
Jones Edward, Wolverhampton st
Pitt Edward, the Level
Power William, Queen's cross
Power William, New st
Timmins Joseph, Hall st
Waring John, Hall st
Westwood John, Scott's green
BOILER MAKERS.
Westwood John, Scott's green
Woodhall Daniel, Netherton
Woodhall Joseph (and iron boat) Bumble hole
Woodhall Samuel (and iron boat) New Buffery
Woodhall Thomas, Netherton
BOOKSELLERS, STATIONERS AND PRINTERS.
Danks Thos. (late Joseph Hinton) High street
Gibson Isaac (bookseller & stationer) Castle street
Goodwin Joseph, Wolverhampton st
Maurice William (and stamp distributer) High street
Rann John, jun. Hall street
Walters George, High street
BOOT & SHOE MAKERS.
Austin James, Stafford st
Brown Samuel, Springs mire
Brown William and Richard, High street; and at *Stafford*
Bytheway John (& blacking maker) Queen street
Bytheway John, sen. Stone st
Clark Samuel, Holly hall
Daniel John, Himley road
Darbey John, High st
Dunn David, Wolverhampton st
Durden Robert, Wolverhampton st
Follows Joseph, High st
Foster Richard, Freebodies
Gill John, Bath st
Grosvenor Ann (dealer) High st
Hall Joseph, New st
Hill Robert, Bond st
Hill Thomas, High st
Hollies John, King st
Hudswell Ellen (dealer) High st
Jones John, High st
Jordan William, New st
Knowles Thomas, King st
Lowe Joseph, King st
Mainwaring William, jun. High st
Morris Samuel, Fisher st
Newey Joseph, Newhall st
Nightingale Daniel, Hall st
Oliver Edward, Flood st
Price Luke, Five ways
Ragland Thomas, Hall st
Rhodes Joseph, Bumble hole
Richards Edward, Dixon's green
Robinson Wm.C.Wolverhampton st
Rowley James, Netherton
Royall John (& patten) Church st
Russell William, Bumble hole
Sanders George Frederick, High st
Sanders Thomas, High st
Shepherd John, Holly hall
Silvers Benjamin, Woodside
Stokes John, Stafford st
Thomas John, Stafford st
Thomas Thomas, Queen's cross
Thomasson William, King st
Timmins Samuel, Hall st
636

Tempson John, High st
Wood George, New st
Wright William, King st
BRAZIERS & TIN-PLATE WORKERS.
Addenbrook and Cook, Castle st
Blackham Jos̃th.Wolverhampton st
Brown William, Stone st
Brown William, High st
Bullas Stephen, High st
Burton John, Birmingham st
Cook Josiah, Collins, High st
Darbey John, High st
Harper James F. Cross st
Swanwick Philip, High st
Timmings Richard, High st
BREWERS.
Cox Henry & Co. Freebodies
Dudley Brewery Co. Nether triadle—Thomas Dawes, acting partner
England George, Hall st
BRICK MAKERS.
Allen James, Twidale
Hughes Alexander, Primrose hill
Pearson George, Holly hall
Pearson George, the Level
BRICKLAYERS.
Bills Benjamin, Cross st
Evans William, Hall st
Hartland Abraham, Pensnett
Oakes Edward (& furnace builder) the Level
Peters Henry, Porter st
Ruston Thomas, Oakey well st
BUILDERS.
(*See also Joiners and Carpenters.*)
Bodin Samuel, High st
Fellowes Benjamin, Priory st
Hodgetts Joseph, High st
Holland John, Wolverhampton st
Pearson Joseph, Queen's cross
Ruston Thomas, Oakey well st
Southall Enoch, Vicar st
Stokes Mary, Five ways
Wright Jesse, King st
BUTCHERS.
Marked thus * are Pork Butchers.
*Ashton James, Hall st
Bissell Thomas, King st
Bowers Richmond, Hall st
Bowers William, Hall st
Brinton Hannah, High st
Brookes Edward, High st
Bunn Charles, Wolverhampton st
Bury Thomas, Wolverhampton st
Bussey John, Newhall st
*Bytheway Joseph, Stone st
Charles Daniel, Hall st
Cole Benjamin, Bumble hole
Cole John, Derby hand
Cole Thomas, Netherton
Cole William, Derby hand
Cox Hugh Sheldon, Hall st
Daniel Charles, Hall st
Dudley Benjamin, Hall st
*Dunn Ann, Stone st
*Edwards John, Price st
Fellows Joseph, Snow hill
Granger George, Castle st
Haley Nancy, Netherton
Haley William, Netherton
Hazeltine James, Queen st
Hazeltine Joseph, High st
Hayward Thomas, High st
Heywood Charles, High st
*Hillman Elijah, High st
Hipkiss Benjamin, Primrose hill
Hipkiss Richard, Bumble hole
*Jones Henry, High st
*Lester Thomas, High st
Lucas Charles, High st
Lucas Christopher, Dixon's green
*Packwood Samuel, Castle st
*Palmer William, High st

Parish Thomas, High st
Pitt Peter, Woodside
Price John, Freebodies
Self William, High st
Smart Thomas, Bath st
*Smith James, Hall st
Turner William, Hall st
Whyley William, Hall st
*Wilkinson William, New st
Willetts Thomas, Hall st
Woolley James, Birmingham st
CABINET MAKERS AND UPHOLSTERERS.
Bird William, High st
Gill Daniel, High st
Griffin James, High st
Morrall Benjamin, Stafford st
Morrall William, High st
Share John, High st
Smith David, King st
Waterson Joseph (cabinet maker) Wolverhampton st
CASE HARDENERS OF FIRE IRONS.
Davis Christopher, Minories
Davis Joseph, Old mill
Grosvenor James, Minories
Kesterton Benjamin, Old dock
Traster Thomas, Stafford st
CHAIN MAKERS.
(*See also Nail Manufacturers.*)
Badger Thomas and Isaac (& anvil) Snowhill
Bloomer Benjamin and Son (and trace & chain cable) Holly hall
Coley Thomas and Co. (and trace) Dudley wood
Finch, Hancox and Hancox (and trace) Wolverhampton st
Griffin James and Son, Withymore works
Griffiths Edward (and trace) Dud- [ley wood
Hancox Benjamin (and trace) Marsham
Hodgetts Stephen, Salop st
Instone Joseph, New Mill st
Instone William, Stafford st
Woodhall Daniel & Thomas, Wolverhampton st
Woodhall Joseph (and trace) Wal- [son's green
Woodhall Joseph and William (and trace) Dixon's green
Woolley Benjamin, jun. and Co. (and chain cable) Tower street; and at Whitehouse and Sons' wharf, City Bason, *London*; and Wapping, *Liverpool*
CHEESEMONGERS AND PROVISION DEALERS.
(*See also Grocers & Tea Dealers.*)
Bailey George & Son, New st
Beddard William, Snowhill
Hollies Edward, Castle st
Packwood Samuel, Castle st
Walter William, Snowhill
CHINA, GLASS & EARTHENWARE DEALERS.
Duff Samuel, Hall st
Gill William, Hall st
Timmins Richard, Newhall st
Wright George, Wolverhampton st
CHYMISTS & DRUGGISTS.
Grigg John, High st
Hickman and Worrall, High st
Morris James, High st
Neracher Thomas Henry (and drysalter) Queen st
Rice James (& apothecary) Castle st
Turner and Hollier, High st
CLOTHES DEALERS.
Marked thus * are also Tailors.
(*See also Tailors.*)
Bagott John, High st
Brady Sarah, Queen st
*Gardner Joseph, Hall st

Fig. 8.3 Sample page from a trade directory; sample pages from the census

century, and grew in number substantially in the nineteenth century. They evolved in tandem with the growth of trade and commerce, with the earliest directories merely listing traders and their addresses, with later directories including additional information such as postal systems, private residents and municipal buildings (Shaw 1982).

Publishing trade directories was a commercial concern, which in some ways strengthens their viability as a resource, but in some ways introduces bias in what was recorded. They do not record the employment or profession of every individual, instead focusing on those who had a certain level of 'importance'. Previous assessments that compared the number of entries between the trade directories and census data have concluded there are significant omissions, both in the types of trades listed, and the location of where those trades were taking place, with central streets recorded more comprehensively than side streets and suburbs (Page 1974). However, individuals with similar trades were grouped together under specific headings, which adds a level of categorisation to the data. The trade directories vary by publisher, and some publishers were more comprehensive than others. While this limited the number of trade directories that could be used in analysis, consecutive directories by the same publisher were acknowledged to be useful for comparing changes over time.

It should be noted that alternative datasets concerning the trades and industries of towns and regions are essentially unavailable. Despite requirements for national census enumerators to note whether an individual employed others, and the numbers, this requirement was only fulfilled on a piecemeal basis (Crompton 1998). Similarly, the recording of an individual's profession was also less than accurate in the census. The rate books only focus on particular types of data, and for properties over a certain value, leaving working class areas systematically under-represented in these records (Raven 1997).

As such, the information in trade directories, despite inherent bias and inaccuracies, has relative strength and value when researching subjects including the development of industry, trade and retail, but it should be accepted that it does not have the same value when socio-demographic subjects are the subject of study.

In contrast, the objectives of the national census (Fig. 8.3) were to accurately and comprehensively record data on all persons, houses and occupations. The methodology devised for the 1841 census was used throughout the century. In order to ensure accuracy of the data collected, avoiding omissions or double counting, it was decided that the census should be conducted at the same time, everywhere and preferably within a timescale of 1 day. The registration districts identified for the earlier censuses were subdivided into Enumeration Districts, and were limited in size by the number of houses they contained, or the distance between them in sparsely populated areas. 35,000 enumerators were required to cover the whole of England and Wales. The schedules were delivered to every householder a few days before the appointed day, ordering them to complete the forms with financial penalties for non-compliance. The complete form recorded who was sleeping in the house on the night of the census, and these were collected the day after, following which the enumerator transferred the answers to their own schedule University of Portsmouth and others (2009).

The data was then collected centrally, and published in three volumes. However, despite the intention to ensure uniformity and conformity in the data, it was still not always achieved. In particular, issues regarding the number of households in each building and who exactly was the head of house, were not well resolved. This was mainly because of the inherently complex nature of living arrangements. Very few instances actually record situations as simple as one family, one head of household, one building etc. (ibid.).

The recording of occupations, too, was less than standard. First, as there was no requirement to categorise the occupations, anything could be written down. The same occupation could be recorded in a number of ways and individuals with multiple occupations or skills were invariably a problem. Second, the occupations of individuals were recorded as they themselves understood their occupation. Consequently, there was a record of a specific occupation even if the respondees were actually unemployed, engaged in another occupation or simply retired. Consequently, the census record is not necessarily a record of the employment of the person at the time of record (Raven 1997).

The bias in sources therefore needs to be taken into account. Trade directories alone do not provide a comprehensive list of trades and industries, whilst the census, by definition, only really records population and therefore cannot be used to reconstruct much of the extractive and agricultural landscape.

Despite this, the study of Dudley research clearly demonstrates that this data, when mapped in GIS can show in much more detail, and for certain areas, the evolution of the industrial and urban landscape of Dudley in the nineteenth century.

8.4 Results and Analysis

A total of 735 attributes were generated from the data and joined to the GIS shapefiles (Ramsey 2012). Not all these attributes were analysed, or visualised in the final GIS project. They are, however, all present within the attribute tables of the street and suburb shapefile, which can be disseminated to support future research.

An attribute of First Date was generated for the street shapefile that filled in the gap in the historic map sequence by identifying when each street was first mentioned in the documentary sources. This attribute shows discrepancies between the two datasets, as several streets were depicted on the 1835 and 1836 maps that were not mentioned in the 1836 Trade Directory or 1841 census. The cumulative length of the streets within each suburb was calculated (Fig. 8.4), and, overall a pattern

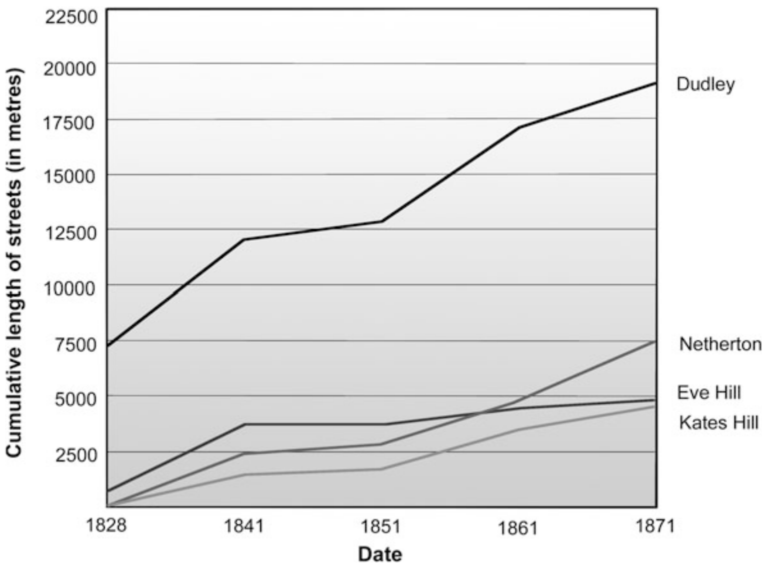


Fig. 8.4 Growth of Dudley and selected suburbs by cumulative street length

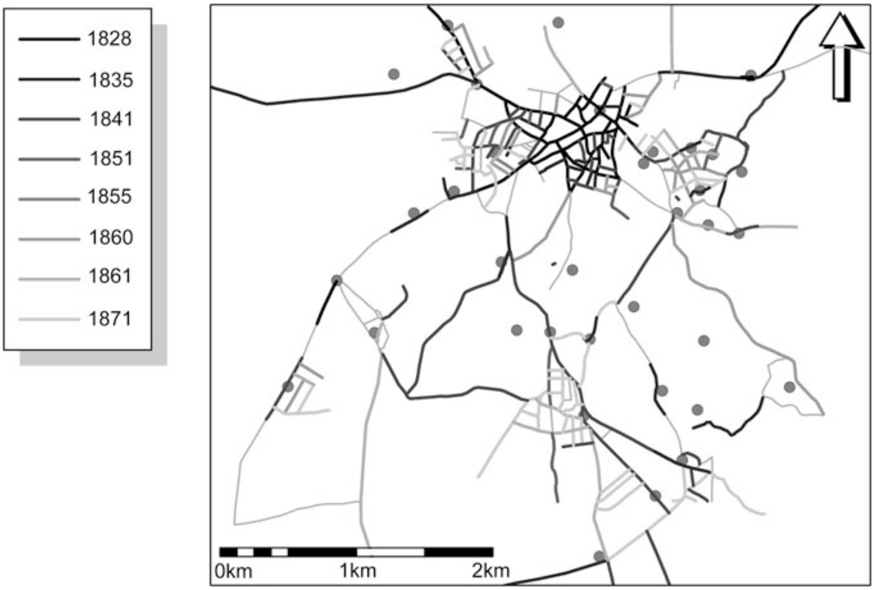


Fig. 8.5 Streets by first date mentioned in the documentary sources

emerges not only of outward growth, but of development within previously urbanised areas (Fig. 8.5).

Attributes were generated for both suburb and street level, with the hope of identifying broader patterns within the landscape at suburb level, and then being able to analyse these in more detail in a street level. The numeric data itself showed various patterns of growth, change and decline, and these trends were visualised spatially through mapping.

The attributes can be divided into four different categories; counts for street and suburb in individual years, ratios for street and suburb in individual years, change between the counts for street and suburb in consecutive years and change in the ratios for street and suburb in consecutive years.

In general terms, it was hoped that counts of buildings and population would help map the relative size of each urbanised area in terms of the built environment and the inhabitants. Likewise, mapping counts of trades, albeit very biased in terms of the original recording, was hoped to provide an indication of the size, nature and distribution of particular industries and occupations throughout the area. The range of category count was provided in order to map diversity of trades within the landscape at both suburb and street level.

The counts included range of trade categories (Fig. 8.6), number of trade entries, count of population (Fig. 8.7a) and number of buildings. Counts of individual occupations and industries at Simple Category level and New Category level (Fig. 8.7b) were also calculated, as were counts of specific selected occupations within the MF4 (Iron and Steel) category itself (Fig. 8.8a–d).

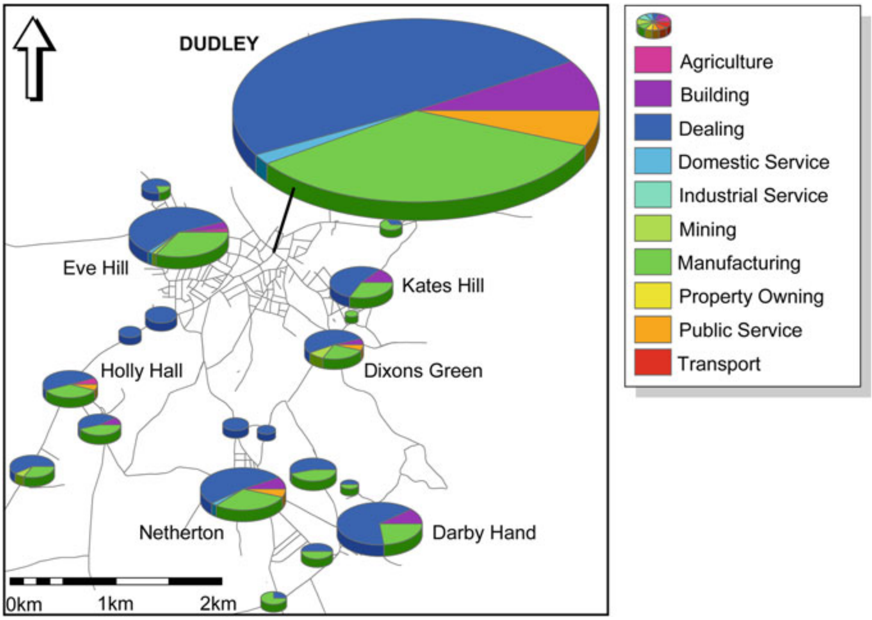


Fig. 8.6 Range of trades listed by simple category in 1842

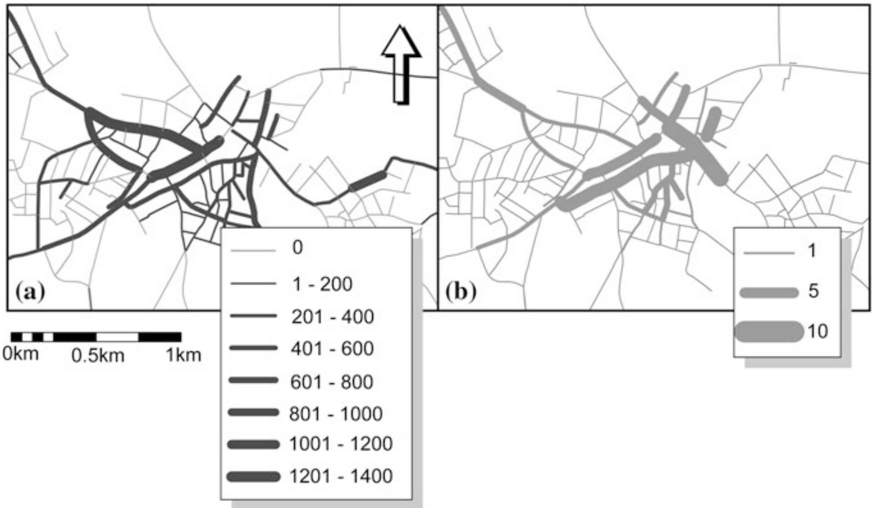


Fig. 8.7 **a** Count of population in 1841; **b** Count of trades allocated to the ironworking category in 1842

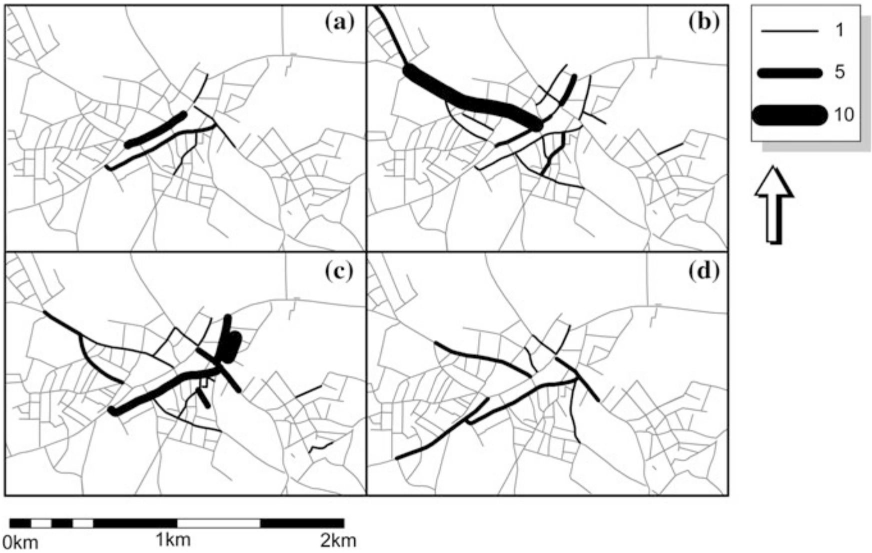


Fig. 8.8 **a** Count of iron founders in 1835; **b** Count of chain, anchor, trace and nail manufacturers in 1835; **c** Count of fenders and fire irons makers in 1835; **d** Count of blacksmiths and wheel wrights in 1835

It was determined that while the tables of simple counts could be used to symbolise the streets, the count itself was not always appropriate. The number of buildings, people or trades recorded is linked to the length of a street, and anomalies can occur when the count for an individual street or suburb is very low. Ratios of selected datasets were, therefore, also calculated to attempt to analyse and visualise the data in a more coherent way.

In mapping these ratios, it was hoped to highlight areas of overcrowding of population and buildings (potentially as an indicator of wealth), and of the character of an area in terms of the occupations of its inhabitants. For instance, from the census data, an index of population density was created by comparing the number of buildings to the number of people. Throughout the period under investigation, this showed a general trend downwards (Fig. 8.9). This suggests crowding (Fig. 8.10a), as although the number of buildings themselves would give an idea of density, the number of inhabitants per building may be used as an index of relative wealth, status or condition. Another index was created to compare the number of buildings to street length (Street Length/Buildings Fig. 8.10b). This particular index is likely to be erroneous for the longer, linking streets where buildings would cluster at particular places, but is considered relevant in built up, established areas. Mapping attributes such as the percentage of manufacturing activities was carried out to identify industrial areas within Dudley and the suburbs, in contrast to more residential areas (Fig. 8.10c).

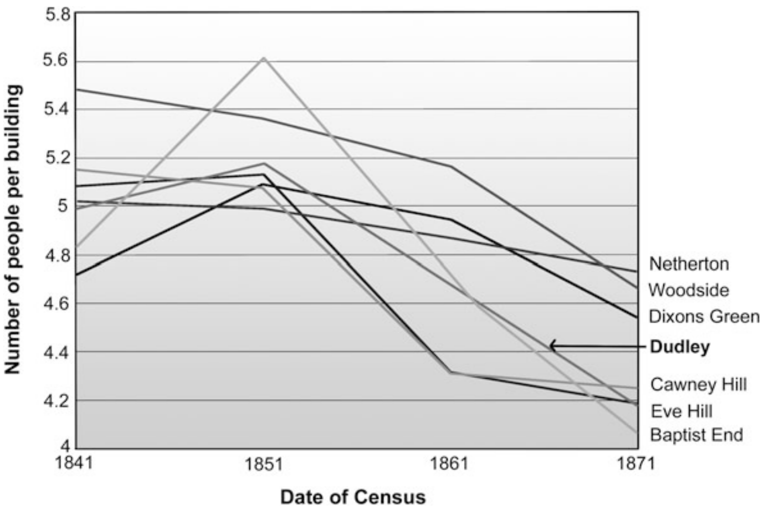


Fig. 8.9 Ratio of population per building calculated from the censuses for Dudley and selected suburbs

An idea of the bias in the trade directories, in terms of spatial distribution of entries, can be gained by calculating the ratio of trade directory entries to the results of the census data (Fig. 8.10d). Only the 1851 directory and census were of a comparable date, although further studies may allow researchers to extrapolate the counts between years. The trade directory data (count per street) was compared with count of population, but may also be compared with buildings, rather than individuals for the year 1851. This ratio would reflect the fact that the census data as was inputted did not record the ages of the population (although that data is in the original dataset). The population count, therefore, does not take into consideration how many people were of employable age. However, it is likely (though not necessarily the case) that each building would contain one or more households with someone who was an employer or employed.

Mapping changes to these values using both count and ratio helped identify growth, decline and character, in terms of buildings, population and industry, within the landscape at both suburb and street level (Fig. 8.11a–c). Overall trends in the data can be seen to be unevenly spatially distributed, and these not only indicate change, but may go some way to identify the type of change occurring, be it a change in building stock, individual wealth or a change in industrial character of a particular street or area.

The change values can be calculated as a count, or as a percentage rise or gain of population or buildings. Changes in density by buildings/street length can be calculated giving an indication of physical change in any particular street, but also trends in the density of population within each building, which can perhaps be used as an indication of change in social status.

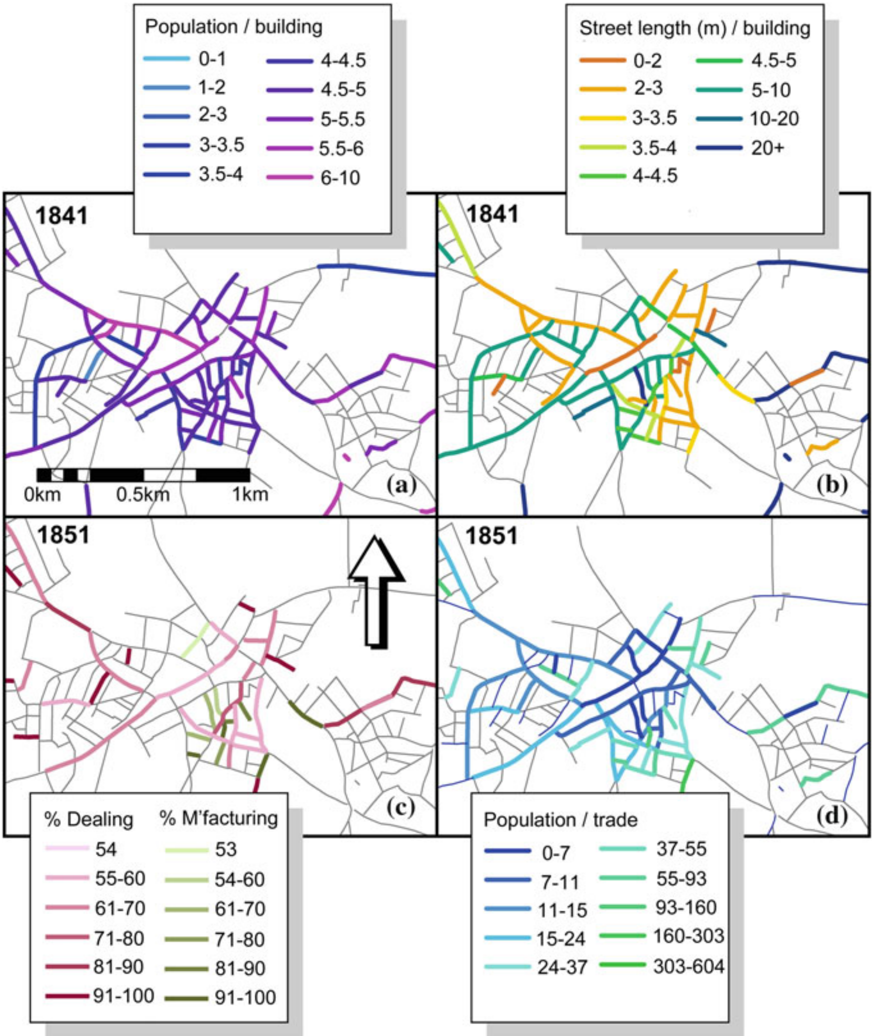


Fig. 8.10 **a** Ratio of population count per building in 1841 census; **b** Ratio of street length (in metres) per building listed in 1841 census; **c** Percentage of manufacturing and dealing categories relative to total counts (where the percentage was greater than 50 %): **d** Count of buildings listed in the 1851 census per entry in the 1851 trade directory

8.5 Integration with Existing Datasets

As well as illustrating overall patterns within the urban landscape, the mapped data can also be used to enhance our understanding of pre-existing GIS datasets, such as the Black Country Historic Landscape Characterisation and Historic Environment Record (BHLC).

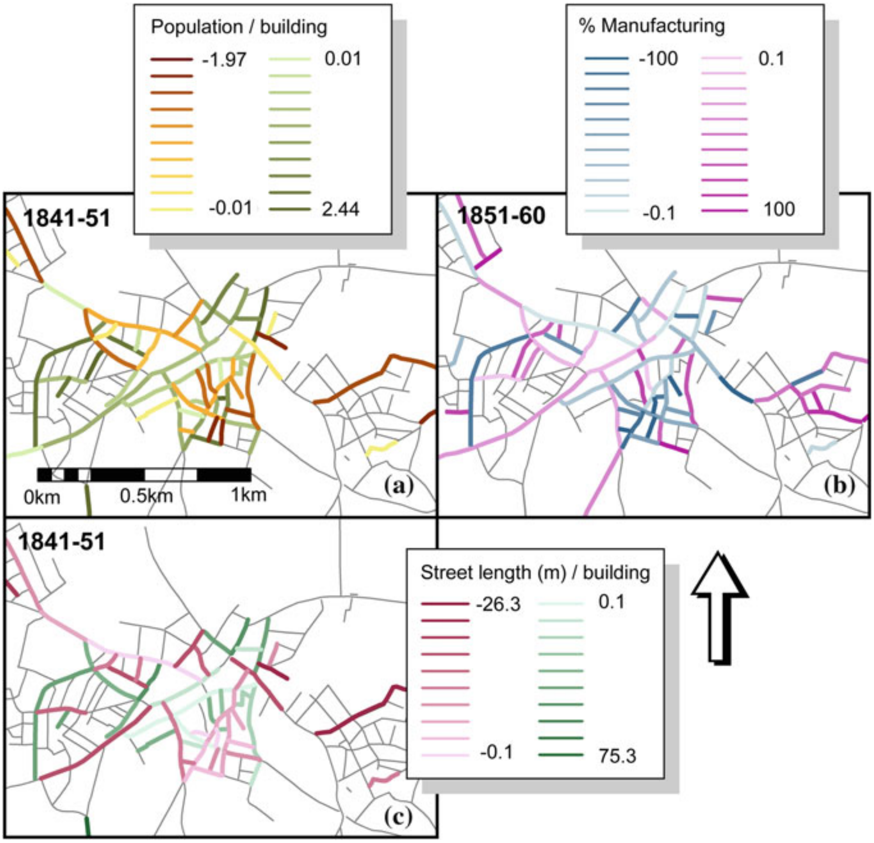


Fig. 8.11 **a** Changes to the ratio of population per building between 1841 and 1851; **b** Changes to the percentage of manufacturing trades compared to overall entries listed in the directories of 1851 and 1860; **c** Changes to the length of street per building between 1841 and 1851

An illustration of how the new data can be used to enhance our understanding of the character and evolution of the urban landscape and the integration with other datasets can be provided with reference to a BCHLC unit along Wolverhampton Street (Fig. 8.12a, b).

This unit (HBL6911) is described as small domestic terrace dating from the late eighteenth or nineteenth century. 176 Wolverhampton Street is listed on the HER (4977), and also within this polygon are two historic buildings associated with a school. The historic map sequence depicts the frontages, as developed by 1835, in stylised detail (Fig. 8.12b), with the school shown to the rear of the properties in the OS 1st Edition in the 1880s.

It can be seen from the new data that in the early part of the nineteenth century, the houses along Wolverhampton Street were some of the most crowded in terms of people per building in the region (Fig. 8.10a), with 6–10 people recorded per building in 1841. In addition to this, Wolverhampton Street had the most

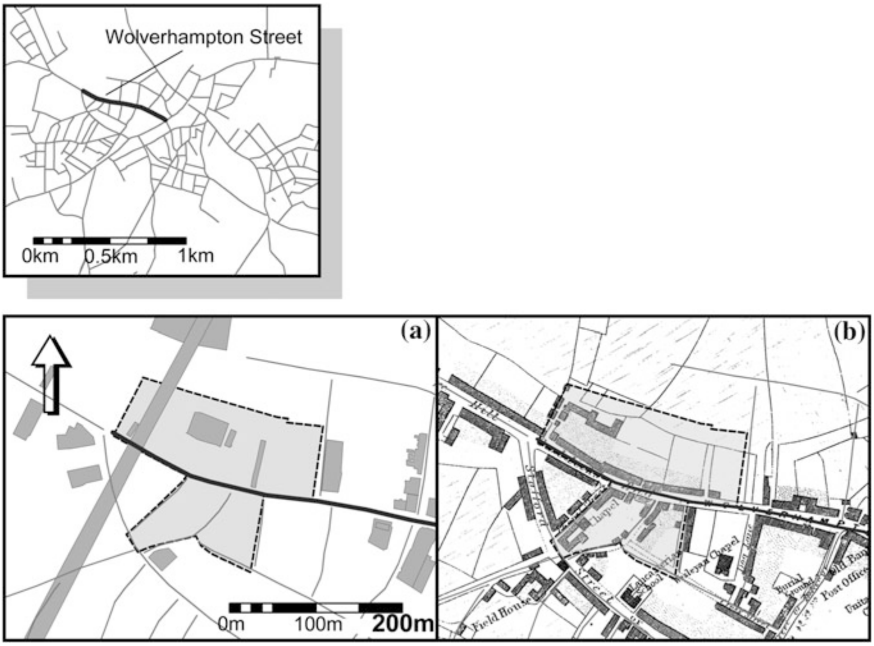


Fig. 8.12 **a** BCHLC region HBL6911 shown in *light grey*, HER entries shown in *dark grey*; **b** Wolverhampton Street on Treasure's map of 1835

nail-makers of any street in Dudley (Fig. 8.8b). This small-scale industry was likely to have been conducted out of these properties. As the century progressed, after 1835 nail-making in Wolverhampton Street (as regards its inclusion in the Trade Directories at least) declines. At the same time it can be seen that the ratio of people per building decreases (Fig. 8.11a), and the number of people listed as residents increases.

It might be suggested therefore that the character of Wolverhampton Street changes throughout the century from small-scale industrial to less-crowded residential, and that the construction of the school was a response to, and part of this change in character. Furthermore, as the ratio of buildings per street length appears to remain relatively stable, it can also be suggested that this change in character was one of population and occupation, rather than one of the built environment, something that is not possible to ascertain from the historic map sequence.

8.6 Discussion

Overall, the study achieved its aims in filling in gaps in our understanding of the urban and industrial landscape within the Dudley area, and illustrating changes within that landscape during the mid-nineteenth century. The town of Dudley and its environs can be seen to have undergone dynamic changes, not only in the physical growth of the urban area, but also in respect of the population, the built environment in developed areas, and urban character in terms of trade and industry itself. These are characteristics that cannot be represented on the historic map sequence. The research also achieved the aim of creating an accessible resource that can be integrated with other spatial datasets and used as a basis for further research.

The map sequence illustrating streets by date first mentioned, as has been noted, is not quite in concordance with the historic mapping. However, whether a street was mentioned in the sources or not may be significant, as it potentially shows the 'importance' of a street. It can also omit speculative building projects from the study whereby a street might look occupied but not actually have anyone living in it. It also shows clearly whether a particular street at a particular time has associated data. The growth sequence itself shows that the urban development was not a smooth progression away from the centre, and that individual areas were developed at specific times and that the area was impacted by infilling of land blocks within the town centre as well as growth on the outskirts.

Mapping the distribution of buildings, and changes in the number of buildings at a suburb level between censuses, potentially shows in a finer temporal detail changes to the built environment at the time (although it should be noted that only residential buildings are recorded on the census, and not factories, works and municipal buildings).

It is also true that mapping the value of street length per building does not necessarily give an accurate indication of the actual size of the buildings (determined by frontage), but does give an indication of the density of buildings within a particular street or area. The mapping from 1835, 1836 and 1865 depicts stylised buildings along the frontages of the roads, and little can be drawn from these other than a building's presence. Comparison between the patterns identified within the street length/building maps and Ropers map of 1850 (not used in the analysis) does suggest that this is relevant, and therefore the methodology has the potential to identify areas of particularly dense buildings including those behind the frontage and in areas where no detailed mapping was available. Also, changes between years can highlight areas where there were physical modifications within the built environment, and identify these changes down to the nearest decade. Moreover, the analysis suggests that there were significant trends in the population per building value, and was able to map these to determine spatial patterns.

Occupations that were conducted within a residence such as shopkeeping and small-scale manufacturing are unlikely to show on the historic map sequence, but by mapping the trade directory data at both street and suburb level, this detail can be added to the landscape. Although it is difficult to make concrete statements about urban character without looking at the actual composition of the trades identified and listed for each street, overall changes to areas and streets can be identified. This may objectively highlight areas of continuity or change that might be worth investigating further. Also, by mapping the data at a variety of scales, and with a range of details (from general category down to specific trade/industry groups) the trade and industrial character of the landscape and changes in this character can be put into context against other values and datasets. For instance, changes in the number of trades within a street can be analysed against changes in particular trade categories, and can be verified against overall changes in the number of buildings and the actual population. While this still represents only a part of the activities within the study area, such data certainly enhances our current knowledge of these areas.

Underlying problems with the datasets themselves, along with the processing methodology, need to be acknowledged. Individual maps generated by the project are not necessarily illuminating on their own, and at times may be downright misleading. While many biases and inaccuracies are noted within the sources, it was assumed that these biases were consistent through time for comparable editions. While only those trade directories that were initially identified as reliable and comparable were used in the research, further analysis did identify changes in recording methodology for these publications. Consequently, any changes identified between certain years may reflect this, rather than representing real change within the landscape. It should be noted, however, that it is only by looking at the datasets as a whole and by assessing the comparative evidence for overall change that such biases can be identified and taken into consideration.

In this way, although perhaps the count and distribution of trades reflects only a small part of the overall industry of an area, identifying change between years is still a valid exercise. It may be that the precise nature of the change is not fully understood by analysis of this data alone, but it is possible to objectively highlight areas where change was occurring and at the same time, drill down into the data to potentially identify what was driving that change.

However, irrespective of any bias within the datasets, caution is needed when interpreting the results. The values themselves can be quite misleading if taken out of context, and it is important to assess the data further for significance in the results. For instance, a 100 % increase in the number of manufacturing entries listed for a particular street, may only represent a change from 1 to 2 entries. Also values such as the street length per building are likely to be erroneous for ribbon development along arterial routes where only some of the road digitised was colonised at any particular time. However, an attempt was made to counter these potential problems by creating a variety of values that calculated both count and ratio, so that the most appropriate value for any particular question could be mapped.

Analysis of the census data indicates further problems. In some areas there were omissions of data, and not all streets were identified. For the most part, the street layout itself did not change dramatically throughout this period, and the Ordnance Survey 1st edition is representative of early street networks. Where there had been changes within the urbanised area, these tended to be infilling of street blocks, rather than wholesale demolition and reconstruction as has happened in the twentieth century. However, it was not possible to find some streets listed in the documentary sources.

The underlying database itself undeniably has research value in its own right, and it might be suggested that the true value of such a study comes from its comparative value with other spatially recorded data.

8.7 Conclusion

Previous research using Trade Directories and GIS has proven its value in analysing spatial and temporal changes within industries. Raven and Hooley (2005) for instance conducted extensive research looking at urban and industrial change for towns in the Midlands, which included the relative distributions of industries, growth of industries over time and increase of specialisations within the towns (Raven and Hooley 2005). Knowles and Healey (2006) used industry specific trade directories along with approximately 50 other sources to create a comprehensive GIS project involving mapping sites associated with the iron industry. In the case of the research by Raven and Hooley (and with much other research that uses trade directories), the data was aggregated at a 'town' level, and it is hoped that the current research can complement this by developing a methodology that utilises the spatial component of the trade directory data as well as census data at a finer 'street' level. Likewise, while trade directories and GIS in mapping the distribution and change of specific industries has been successfully used (Knowles and Healey), it was hoped that by creating a comprehensive, rather than selective, database for all industries, individual industries can be analysed in context.

At a local level, it can now be demonstrated that where there is confidence in the data, a far more detailed picture of the people and occupations of Dudley in the mid-nineteenth century can be provided. This mapping can be used in its own right to highlight patterns of population movement and industry, at a broad scale and detailed level. By splitting the data to a street level gives an element of detail and description not easily accessible or visible previously.

Combining the information in the databases with a GIS project allowed the visualisation of the data, which helped identify and highlight spatial patterns held within the documentary sources, as well as providing detailed information regarding particular streets and particular industries. In addition, by combining numeric attributes such as the number of buildings with spatial attributes such as street length, new information can be generated.

The data might be used in several ways. The first is to gain an overall insight into the nature, distribution and changes of occupations and population in the landscape, by using the whole dataset to create broadscale mapping. While the attributes themselves need further research to identify whether there is genuine meaning to the values, they can be used to identify character and changes to that character within the landscape over time. In this way, the temporal resolution of the changes evident in the historic mapping can be improved, as changes present within the documentary sources can be identified at closer units of time than the historic mapping itself.

Another way is to use the particular details at a street level, to give added information to previously identified spatial units. These could be those identified on the BCHLC or listed buildings on the Historic Environment Record, or to areas of proposed development, to enhance and facilitate desk-based assessments and Environmental Impact Assessments.

While only a small amount of detailed mapping was generated, specifically for the MF4 Ironworking category, there is the potential for further maps similar to this to be created for other manufacturing or activity categories. There is much previous work conducted using trade directories to map the locations of specific occupations and industries, however, by having the data on a database and linking the data into a GIS facilitates this type of research and also allows the data to be analysed and cross-referenced with other forms of geographic information.

The use of spatial technologies as analytical tools, both for visualisation and dissemination, suggests further uses of urban datasets both in the British Midlands and in other urbanised areas with similar data. If this is the case, then the results of analysis provided here indicate how such studies may develop. For instance, it is generally presumed that urban expansion and development is best understood as a horizontal process, with new build inevitably, and primarily, encroaching on the fields surrounding the towns and cities. The data for Dudley demonstrates that urban development was actually far more sophisticated and that there were substantial changes within the already urbanised areas themselves. These areas show fluctuations and patterns of population movement, and potential rebuilding that would not be evident from the results of a standard map analysis. Consequently, this evidence is rarely considered in the literature. However, this information is critical if we are to understand the nature rather than the extent of urban development. Such changes must have been evident to the population of Dudley and without that information, we cannot really provide an adequate assessment of the overall nature of historic urban change, or indeed the quality of life, within any historic town.

In many senses, cities remain "the defining artefacts of civilisation" (Reader 2004, p. 1) and it also remains true that as urban populations inevitably, and exponentially, expand, that we must seek to understand the processes that lie behind their development and provide the unique living environments for their inhabitants. This chapter presents a first step in the process of understanding historic urban development in a holistic manner, but it is clear that we still need to take these issues further and develop methodologies or technologies that explore these factors extensively, with greater resolution and more efficiently if we are to proceed further.

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Chapter 9
Crossing Borders: A Multi-Layer GIS Mapping Framework for the Cultural Management of the Mundo Maya Region

Žiga Kokalj, Peter Pehani, Helen Goodchild, Vincent Gaffney and Krištof Oštir

Abstract This chapter describes a Geographic Information System (GIS) mapping framework, guidelines and implementation of the internet mapping site for the cultural management of the Mundo Maya region. The challenges of bringing together an extremely large dataset derived from a variety of sources and across five Central American countries were significant. Data of various quality and integrity were integrated and prepared for internet use. The final mapping site contained an interactive map with the appropriate visual and contextual tools that allow dedicated management of the region's cultural sites and routes. Aside from topographic data, the site also provided general information on the Mundo Maya project area including, for instance, demography, details of communication routes and land use, potential areas of tourist interest, information on relative wealth and political and administrative boundaries. Together, these data are able to assist in

Ž. Kokalj (✉) · P. Pehani · K. Oštir
Scientific Research Centre of the Slovenian Academy of Sciences and Arts,
Novi trg 2 SI-1000, Ljubljana, Slovenia
e-mail: ziga.kokalj@zrc-sazu.si

P. Pehani
e-mail: peter.pehani@zrc-sazu.si

K. Oštir
e-mail: kristof@zrc-sazu.si

P. Pehani · K. Oštir
Centre of Excellence for Space Sciences and Technologies, Aškerčeva 12 SI-1000,
Ljubljana, Slovenia

H. Goodchild
Department of Archaeology, University of York, The King's Manor,
YO1 7EP, York, UK
e-mail: helen.goodchild@york.ac.uk

V. Gaffney
IBM Visual and Spatial Technologies Centre, The University of Birmingham,
Edgbaston B15 2TT, UK
e-mail: v.l.gaffney@bham.ac.uk

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managers in making decisions related to tourism development. The chapter also discusses the ethical and social issues of providing such information and the importance of local ownership of spatial data.

Keywords Internet mapping · Heritage management · Maya · Central America

9.1 Introduction

The ancient Maya settled a region of almost 500,000 sq. km across four Central American countries (Belize, El Salvador, Guatemala and Honduras) and five Mexican states (Chiapas, Tabasco, Campeche, Yucatan and Quintana Roo). Their legacy is fundamental to the region's unique archaeological and cultural identity. This rich heritage, the contemporary culture of the Maya, and the unequalled natural beauty of the region form the basis of a developing tourist industry. The number of visitors is growing (Table 9.1), and the risk of unsustainable use of resources and exploitation of the culture is significant.

It is also true that this unique environment has a wider, global significance. It spans an incredible variety of ecological zones and includes a 1,000 km shoreline that is part of the Mesoamerican Reef system, the largest barrier reef in the western hemisphere. It also incorporates a number of volcanic mountain ranges and a tropical rainforest, safeguarded in more than 300 protected areas. The area offers numerous natural attractions that support the development of cultural, eco- and adventure tourism. As a large number of potential archaeological attractions are located within these areas or close to them, this emphasises the potential of these sites as a destination for existing and future tourist groups.

Sustainable use of the region will require optimization and rationalisation of forestry and land use as well as appropriate management of the archaeological and scenic resources. However, the engagement and support of local communities will also be critical to the success and sustainability of a regional tourism programme.

The National Geographic Magazine coined the Ruta Maya concept in its October 1989 edition (Garrett 1989). Following the designation, Mesoamerican tourism authorities created the Mundo Maya Organization (MMO) in 1992, (part

Table 9.1 Number of international inbound tourists for the countries of the Mundo Maya region (in thousands) and their increase during a 2000–2010 period (WDI 2012)

	2000	2010	2000–2010 (%)
Belize	196	239	21.9
El Salvador	795	1,150	44.7
Guatemala	826	1,876	127.1
Honduras	471	896	90.2
Mexico	20,641	22,260	7.8

of the World Tourism Organization) with the mission of promoting the sustainable development of tourism in the Maya region and the preservation of the Mayan environment and cultural heritage for future generations. In January 2003, the MMO entered into a strategic alliance (the Mundo Maya alliance) with Conservation International, Counterpart International and the National Geographic Society with the objective of collaborating in support of the Mundo Maya Sustainable Tourism Programme (MMSTP). The MMSTP seeks to contribute to the sustainable social and economic growth of the region through cultural, environmental and adventure tourism via cultural heritage conservation and environmental preservation, ensuring the participation of the Maya and other local communities. The preparation phase of the strategic plan included publication of guidelines for the development of an internet mapping site to assist relevant decision makers throughout the process (MMSTP 2002).

The complexity of such a goal which demands the complex spatial assessment of a wide range data to assess the feasibility and sustainability of tourist destinations was clear from an early stage in the process. In 2003, the University of Birmingham Visual and Spatial Technology Centre and the Scientific Research Centre of the Slovenian Academy of Sciences and Arts were commissioned to trial a web-based mapping site that might support the development goals of the MMO. The following sections of this chapter presents some of the decisions that have drove the preparation of these guidelines, and the implementation of a mapping site, including data organisation and integration and some recommendations for future development.

9.2 Background

The impact of tourism on archaeological sites is significant. Some sites can be over-visited to the extent that their very existence is threatened whilst others are rarely seen or remain essentially unknown to tourists. Sites which are poorly known may also suffer from neglect as a consequence, and this may occur despite the value of specific locales to indigenous groups (Magnoni et al. 2007, p. 361). In cases where areas attract too many tourists, managers often seek to guide tourists to other sites and relieve those which are common tourist destinations. Consequently, the decision to develop sites for tourism cannot be based solely on their cultural and natural attractions; there must be some consideration of the physical nature of the site and their ability to support tourism at a specific scale. Not surprisingly, there are a number of published examples of the use of Geographic Information System (GIS) to calculate tourism carrying capacity (e.g. Lo Tauro 2005, p. 311; Avdimiotis et al. 2006). However, such systems can play a wider role in protecting the natural and cultural heritage or even attracting tourists who may simply not have been aware of the opportunities to visit. The accessibility of a wide range of relevant data linked to the potential development of tourism a web-based GIS can support a broader audience with specialist interests in development or conservation including scientists, regional planners and indigenous communities. It is therefore not surprising that there are numerous cases web GISs used for environmental management (e.g. Zhu 2001; Kelly and Tuxen 2003; Tsou 2004; Gouveia 2004; Rao et al. 2007; Simão et al. 2009).

Whilst the specific example of a web-based GIS presented here is, in some senses, historic, the delivery technology itself is not so significant as the issues associated with the creation of the datasets and their use, and this may have significance to projects that may be undertaken today. In deciding on the functional and structural framework of the Mundo Maya mapping site, the team sought to ensure that a finished and fully implemented site would:

- combine and integrate geographic data and provide secure access to map services,
- give support to a wide range of users and have an appropriate range of GIS capabilities,
- have a highly scalable architecture and a standards-based communication and
- provide useful metadata services and have a management component.

The following basic concepts were considered important to achieve these goals:

- The site had to integrate efficiently all available information and serve various potential users, including: environmental managers and governmental institutions who may plan, monitor and inform their wider public of development issues, academics to model, analyse and simulate events, the private sector to enhance productivity and prepare added value products and the general public who may need access to spatial information in order to engage, productively, with any proposed development;
- The site had to be simple, easy to understand and manage;
- The site had to provide tools for basic spatial analysis.

Any mapping site that supports strategic management and planning should obviously allow strategic managers to provide appropriate information to local and indigenous representatives (e.g. mapping and reporting, quantified results of modelling, on-line delivery and provision of data), as well as tools to engage with the needs and concerns of local representatives and communities (e.g. established mechanisms of feedback and reporting, equitable access to data for localities, integration of locally gathered data).

The MM site was designed with the ultimate aim of having multiple user levels and providing information in English and Spanish. Provision of English and Spanish language support at least ensured the widest potential market penetration in global tourist terms but the possibility of adding other languages from those countries that might provide a tourist income in the future was also appreciated (Fig. 9.1).

It was also appreciated from the outset that there is a variation in user knowledge of the use of spatial mapping systems or even an interest in using the tools that might be provided. There was also a disparity in required security policies for different datasets. Consideration of the range of potential users suggested that three

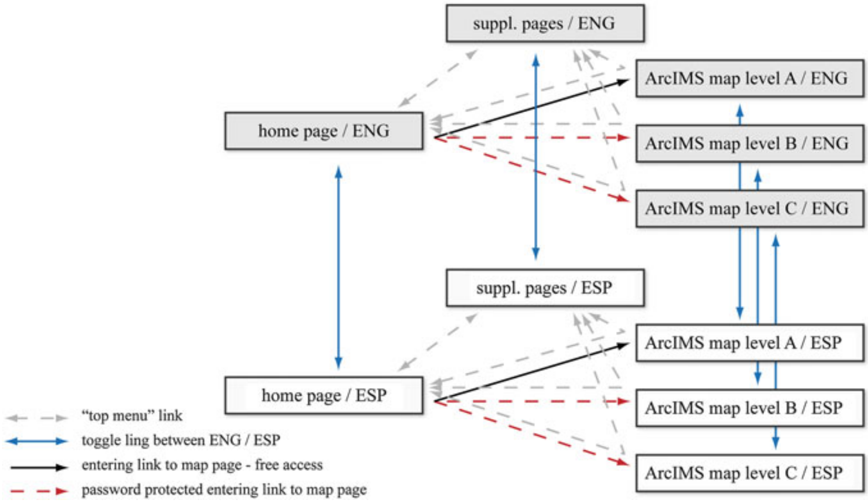

Fig. 9.1 A conceptual diagram of the Mundo Maya web site interconnecting web pages

access levels appeared to be an optimum in design terms. These included general users, needing generic information about the area and Mundo Maya project activities, expert users whose daily work is connected with the Mundo Maya Project. These might be divided further into users with an average knowledge of GIS technologies and advanced GIS users. A distinct web-based GIS page should be accessible from the main (intro) page for each of the user levels. It was envisaged that web pages for different user levels should differ in the:

- set of available tools,
- degree of availability of data (scale, set of layers),
- degree of data generalisation,
- degree of data correction (manipulation),
- number of data categories available, and
- different security measures (public access versus login, min–max scale available, set of displayable attributes).

In this way, three distinctive web pages, one for each level, could be constructed from the same data (Fig. 9.2).

9.3 Data Integration

It was intended from the outset to establish options for further desk-based assessments and on-site data collection over the course of the MMST Programme, in collaboration with Alliance members and other appropriate parties, such as the

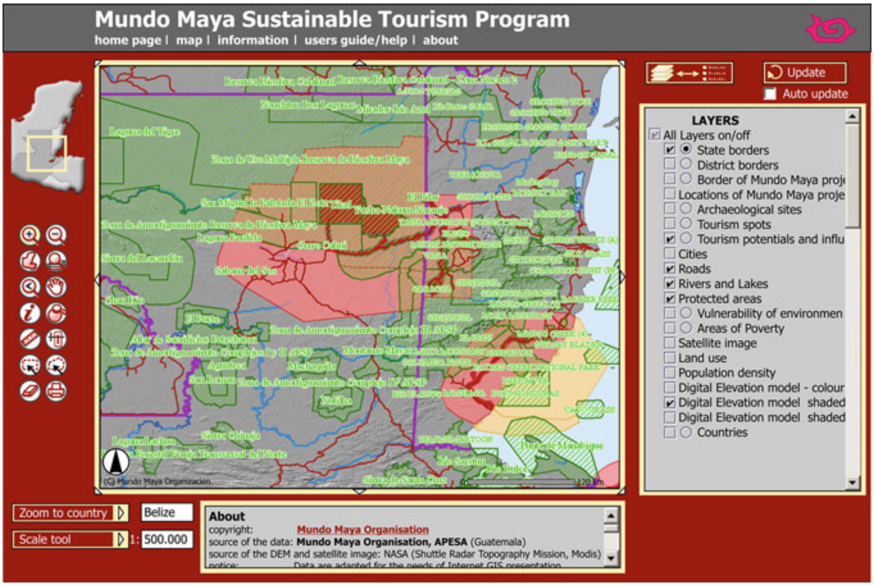

Fig. 9.2 The Mundo Maya Organization internet mapping site

Centre for Native Lands and national mapping agencies. The final set of overlays needed to integrate archaeology, biodiversity, ethnography, geo-economics, the built environment, land use, infrastructure, and other components. Much of this data can also be used to create regional consumer tourism maps in a marketing phase.

Because all the Central American countries use differing data management software and consequently variable data formats, it was important to establish a common database and data management system that was easily accessible over the internet. The MMO internet GIS site was established with ESRI ArcIMS and ArcGIS software, a de facto industry standard at the time the project was undertaken. ESRI shapefile vector data format and Erdas Imagine image file raster data format were used as "transfer formats" as they are easily recognisable by most of the spatial data management software. The decision not to utilise ESRI coverage or database data formats was made as a consequence of the poor data topology and because line and polygon vector files contained overlaying and sliver polygons, intersecting lines and a range of other errors.

Vector data layers included in the project comprised basic cartographic layers such as administrative division, country borders, roads, rivers, streams, lakes and other larger inland water masses, urban centres and toponyms. In addition to these layers, there were vector data for archaeological sites, protected areas, environmental vulnerability, tourism elements and potential, sociodemographic descriptions and the locations of proposed Mundo Maya projects. The datasets were very heterogeneous as the source map scales varied from 1:50,000 to 1:1,000,000, and there was no common map projection. Hence, it was not surprising that significant location distortions between layers were present within the datasets (Fig. 9.3). Due to discrepancies in the data these had to be unified to the same projection (WGS 84), then combined, homogenized and simplified, i.e. generalised and categorised (Fig. 9.4). Unification to the same projection was done to comply with international standards and make the data more easily available to the international community. However, it is also significant that Central American countries are switching to this datum as part of a planned geodesic network modernization, as shown in the case of Guatemala (PROCIG 2004).

A key data layer for use in the GIS was the digital terrain model (DTM). Many user functions of the system are dependent upon the quality of the DTM, and it has a major role in visual display. DTM provision involved the use of several raster layers derived from two basic sources. The first was a digital elevation model (DEM), derived from the Shuttle Radar Topography Mission data (SRTM). SRTM DEM was produced using radar interferometry and, at the time, the best DEM available for almost the entire globe. Due to the nature of radar acquisition, the original dataset contained voids (no-data areas) in hilly regions, and spurious points such as anomalously high ("spike") or low ("well") values. Coastlines and

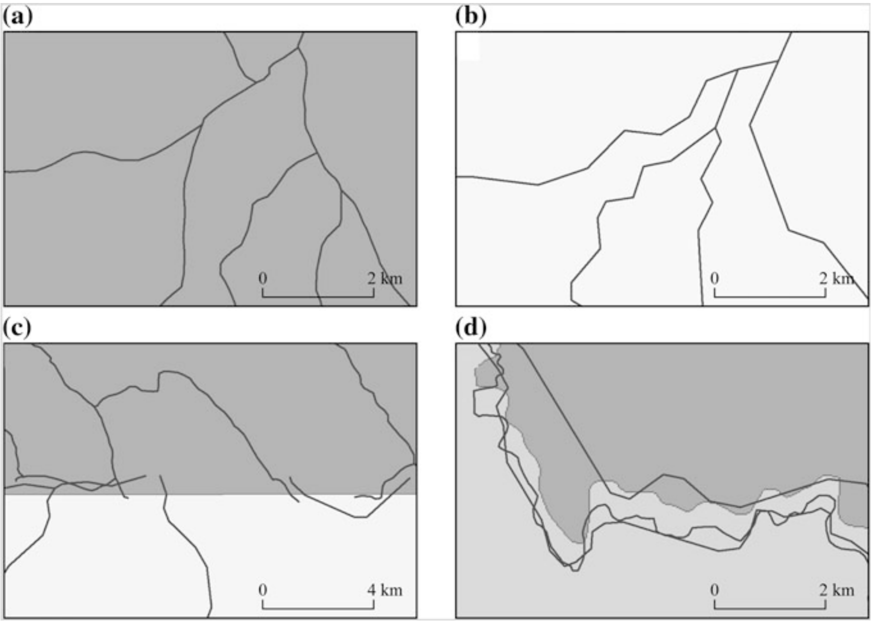

Fig. 9.3 Data was provided from a range of sources and presented a significant challenge to prepare for use in a common map system. For example, data for rivers was clearly derived at a larger scale for (**a**) Mexico than (**b**) Honduras, which consequently has a more angular appearance when displayed at the same scale. **c** Rivers originally did not connect on the Mexico (*dark*)–Guatemala (*light*) border. **d** River courses on the border between Mexico (*dark*) and Belize (*light*) were triplicated in some places, while none of the lines coincides with the national border

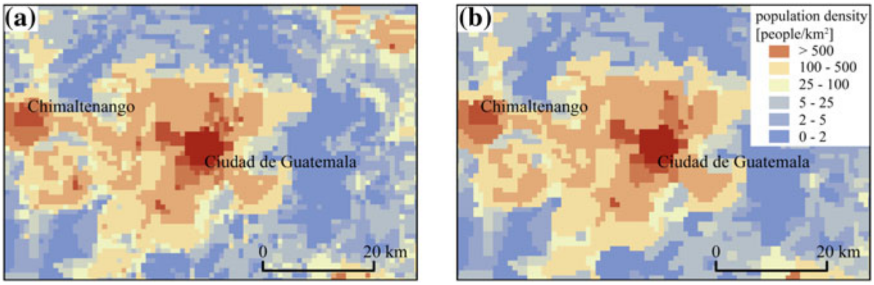

Fig. 9.4 The population density map was first simplified to a lower number of categories and later converted into its original raster format. Generalisation was performed with filtering out regions smaller than two pixels. The figure shows an area around Guatemala City (**a**) before and (**b**) after filtering

shorelines of water bodies are typically not well delineated and may not appear flat. These anomalies have been removed from upper level products (SRTM versions 2, 3 and 4), but they were not available while building the original database. Therefore, the team had to process the original SRTM data in-house.

Voids were removed using spline interpolation. This process performs a two-dimensional minimum curvature spline interpolation on a point dataset resulting in a smooth surface that passes exactly through the input points. The interpolation procedure is most effective where voids are small, as was the case in most of the Yucatan peninsula. Interpolating voids of greater dimensions can result in geomorphological errors in the form of plateaus and steep slopes, which did not actually exist. Coastlines were defined using processed vector data. The Atlantic and Pacific Oceans were masked and given the height value zero (even though in reality they have different elevations). Mainland water bodies were not levelled (flattened) because the procedure required reliable elevation data of average lake water level, and this was not available. Finally, the DEM was resampled to the spatial resolution of the 250 m MODIS satellite image. A 250 m spatial resolution was also used for visual representation of the Yucatan peninsula. MODIS surface reflectance data is freely available on the internet via the EOS data gateway (http://redhook.gsfc.nasa.gov/~imswww/pub/imswelcome/). However, the standard MODIS surface reflectance product (MOD09) was developed with scientific integrity as the primary objective, as opposed to the MODIS L1B data (the calibrated, geolocated radiances), which is based on custom surface reflectance code that has been developed with the specific aim of maintaining image integrity. The MODIS rapid response system team uses this "raw" data and special algorithms, as well as additional "hand-tweaking" to enhance the appearance of the images; for example, a different colour stretch may be applied to the terrestrial and oceanic parts of an image. It would require considerable time and resource for an individual to generate imagery that can match those from the rapid response team in either quality or accuracy, as their algorithms are not fully published. As a result, it was decided to use one of the images from their gallery and process it further for use in the Mundo Maya web gateway.

A full data layer list is provided as an appendix to this chapter. These are not discussed in detail and were never considered to be an authoritative or exhaustive group but data sourcing was prioritised to provide datasets, which could be sued for management and included archaeological site boundaries or locations, transportation infrastructure and factors, which might impact on existing sites, such as deforestation and unplanned settlement. The site was designed in a manner that facilitated the simple addition of further data as it became available.

The description of the site's design and functionality allows any system administrator with at least basic GIS and good internet server knowledge to change the functionality, update the site and include new or revised data. At the conclusion of the project, the project team advised that a single administrator was appointed for the MMO internet GIS site management and data uploading.

9.4 Discussion

Several issues and opportunities were generated by the Mundo Maya mapping project. One practical issue relates to language. Although the site was envisaged to be fully operational in at least two languages (English, Spanish) it was only fully implemented in English. Therefore, it remains necessary to translate the user interface, documentation (manuals, help), messages and responses from software, metadata and data attributes (Fig. 9.5).

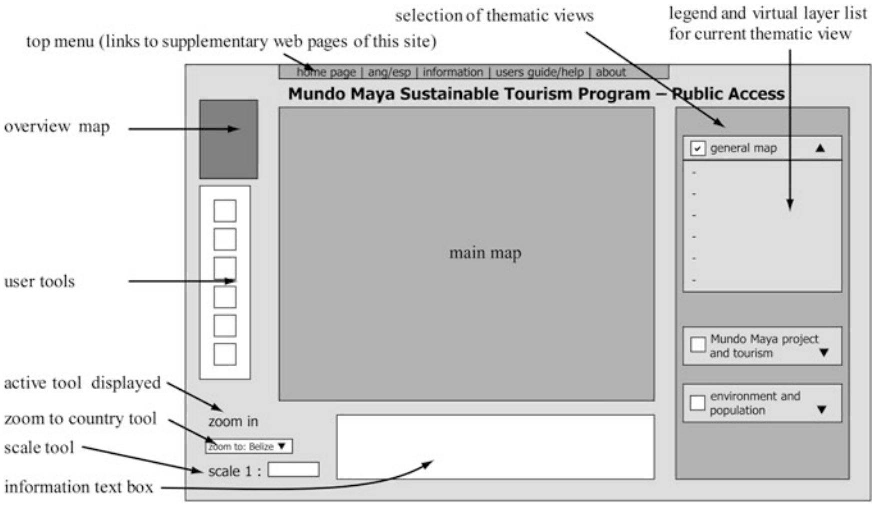

Fig. 9.5 Viewer page has an intermediate user interface with predefined virtual and thematic layers

Traditionally, the process of field data collection and editing is time-consuming and error-prone, as geographic data was in the form of paper maps. Developments in mobile technologies have enabled GIS projects to be taken into the field as digital maps on laptops, tablets, and mobile phones, providing field access to enterprise geographic information. This enables organisations to add (near) real-time information to their enterprise database and applications, thus speeding up analysis, display and decision making by using up-to-date and more accurate spatial data. Whilst ArcIMS has been replaced by ESRIs later server-side and mobile systems (http://www.esri.com/products), the product is still capable of providing mapping tools and data access to a variety of clients, ranging from wireless devices, lightweight browser-based clients, to a full-featured GIS desktop client. It was always clear that potential users may not have the most effective connection options but the site was designed to be accessible to clients using less than optimum network links including portable computers and internet connection, via a mobile phone (or a suitable GSM card), satellite telephone or in the worst case, a modem over a stationary line.

Obviously if the project were to be started today, the product would have been oriented towards handheld devices including mobile phones, tablet computers, etc. It is also true that the current user interface is too complex for the small displays offered by those devices and should be simplified. Data should be further generalised and stripped to allow both simple display and fast transfer speeds. This is also important for the integration with GPS receivers that could provide an effective tool for using the facilities in the field as well as a source for updating or adding new spatial data.

To date only overview datasets have been incorporated into the existing MMO internet mapping site. However, to fulfil the requirements for regional and local planning, more detailed spatial information is needed. Local level data, in particular, should be accessed to provide accurate and up-to-date information of site physiognomy and topography, and this must be of highest quality. Data collection should focus on specific archaeological or environmental areas of interest, but also include neighbouring regions where development may have a detrimental impact. There are many suitable satellite systems that now provide high and very high resolution data, e.g. World-View, GeoEye, Spot and RapidEye. Detailed DEMs can be produced using either stereopair optical satellite images, radar interferometry from recent high resolution radar satellites (e.g. TerraSAR-X, TanDEM-X, COSMO-SkyMed) or aerial laser scanning (lidar). In recent years, Lidar has become more and more important as it offers very detailed elevation data (up to a 100 points per square metre). Detailed data, both vector and raster, at a local (site) scale could also be obtained from appropriate maps, plans and sketches collected by on-the-field researchers. The National Geographic Society, as one of the most important promoters of sustainable tourism in the area, might well facilitate such a process through its access to existing projects that might provide such data. Additional (non-mapping or qualitative information) can be also be added as text, multimedia documents or hyperlinks.

9.5 Conclusion

Although the construction of an internet map service is no longer a novel event, it should be clear that creating the Mundo Maya site was a substantial undertaking involving harmonisation of diverse datasets of differing quality and integrating these in a manner that had the potential to be accessible and informative to the widest range of users. It is also true that the mapping site was a product of its time and that the advent of tablet computing and 4/5G services will provide significant opportunities for the development of distributed mapping services. However, the Mundo Maya mapping project had to take into account a wide disparity of access to technology when it was created and widely varying competence amongst user groups. Many of these issues remain current within the region.

The latter points are particularly important because the use of mapping data is never simply a technical issue. No internet mapping site can succeed if those who use it are convinced of its legitimacy, are trained to use the data appropriately and have adequate support. It is therefore necessary to increase the awareness of mapping agencies and other (governmental and non-governmental) organisations of their responsibility to provide suitable data and support. Only basic training was provided to the Mundo Maya Organization staff during this project and it remains necessary to train and support managers, potential users but also local contributors so that they can benefit from access to the mapping data and fully exploit the opportunities provided by such systems.

It is also important to stress that the value of such developments will also depend on the ethical use of the available information and equal access to the data and sites developed for the purpose of sustainable tourism. Mapping is a highly politicised activity, and there are negative social issues relating to improving accessibility to isolated regions. For instance, drug production in some areas develops in tandem with accessibility and may threaten social cohesion or future economic development (Camacho et al. NDA). It is also critical to understand who is likely to benefit from the availability of mapping. Ultimately, however, mapping sites including the Mundo Maya site (and any other similar internet GISs) will only be deemed successful if regional collaborators perceive a value in the resource, use it, and maintain and enhance the service to meet future requirements and provide clear regional benefits.

Acknowledgments The team would like to thank and acknowledge the support of the following individuals: Dr. Margaret Watters, Dr. Jonathan Tourtelot, Thierry De Pierrefeu.

Appendix 1 Data Layers

Layer Number	Actual layer (file)	Layer properties	Labels
1.	D_Borders.shp		1
2.	D_Central_america_d.shp	Render (scale depend)	YES (scale depend)
3.	D_Project_border.shp		
4.	D_P_locations.shp		YES (scale depend)
5.	D_Access_rd.shp		
6.	B_Arch_sites.shp		
7.	D_Tour_elements.shp		YES (scale depend)
8.	D_Tour_potential.shp		
9.	D_Toponimy	Scale dependent	YES
10.	B_Toponimy.shp	Scale dependent	YES
11.	D_Urban_centres.shp	Scale dependent	
12.	D_roads.shp	Scale dependent + render	
13.	B_Roads.shp	Scale dependent + render	
14.	B_Water_bodies.shp	Scale dependent	
15.	D_rivers.shp	Scale dependent	
16.	B_Rivers.shp	Scale dependent + render	
17.	D_Pa_Belize.shp		YES (scale depend)
18.	D_Pa_El_Salvador.shp		YES (scale depend)
19.	D_Pa_Guatemala.shp		YES (scale depend)
20.	D_Pa_Honduras.shp		YES (scale depend)
21.	D_Pa_Mexico.shp		YES (scale depend)
22.	D_Vulnerability.shp		
23.	D_Poverty.shp		
24.	MM_Modis.img	Semi-transparent	
25.	D_Oceans.shp		
26.	B_Land_use.img	Semi-transparent	
27.	B_Pop_Denst.img	Semi-transparent	
28.	D_DEM_c8	Semi-transparent	
29.	D_DEM_s	Semi-transparent	
30.	D_DEM_s_c	Semi-transparent	
31.	D_Central_america_c.shp		YES (scale depend)

Layer	Virtual layer	Thematic views for public access		
Number	Virtual layer name (for the end user)	General map	Mundo Maya project and tourism	Environment and demography
1.	State borders	Always ON	Always ON	Always ON
2.	District borders			
3.	Border of Mundo Maya project	ON	ON	ON
4.	Locations of Mundo Maya project		ON	
5.				
6.	Archaeological sites			

(continued)

(continued)

Layer	Virtual layer	Thematic views for public access		
Number	Virtual layer name (for the end user)	General map	Mundo Maya project and tourism	Environment and demography
7.	Tourism spots		ON	
8.	Tourism potential and influences (M.M. project only)		ON	
9.				
10.	Cities	ON		
11.				
12.	Roads			
13.				
14.				
15.				
16.				
17.				
18.				
19.	Protected areas			ON
20.				
21.				
22.	Vulnerability of environment (M.M. project only)			
23.	Relative prosperity (M.M. project only)			
24.	Satellite image			
25.	No name/not in legend	Always ON	Always ON	Always ON
26.	Land use			
27.	Population density			
28.	Digital elevation model–colour			
29.	Digital elevation model–shaded greyscale	ON	ON	ON
30.	Digital elevation model–shaded colour			
31.	Countries	ON		

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Chapter 10
Situating Cultural Technologies Outdoors: Empathy in the Design of Mobile Interpretation of Rock Art in Rural Britain

Areti Galani, Aron Mazel, Deborah Maxwell and Kate Sharpe

Abstract Mobile applications are presently at the forefront of interpreting outdoor historical and archaeological sites. This chapter discusses the methodological approach adopted in the Rock art mobile project (RAMP) which addresses the challenge of designing and delivering mobile interpretation at three Neolithic and Early Bronze Age rock art areas in Northumberland, UK. RAMP proposes a departure from the more traditional design approaches of delivering scientific content in the form of an archaeological mobile guide. It acknowledges that rock art interpretation requires a 'design space', which facilitates empathy between users and designers, and allows the existing archaeological content, the public's fascination with the 'cryptic' meaning of the rock art sites and the technological, environmental and personal situation of the user to be explored and to inspire technological development.

NoteA previous version of this article was published in: Galani A et al. (2011) Situating cultural technologies outdoors: Designing for mobile interpretation of Rock Art in rural Britain. In Trant J and Bearman D (eds). *Museums and the Web 2011: Proceedings*. Toronto: Archives & Museum Informatics. Published March 31, 2011. Available at: http://www.museumsandtheweb.com/mw2011/papers/situating_cultural_technologies_outdoors_desig The content of the RAMP web application and additional information about this research is available on: http://rockartmob.ncl.ac.uk/

A. Galani (✉) · A. Mazel
International Centre for Cultural and Heritage Studies, Newcastle University, Newcastle upon Tyne NE1 7RU, UK
e-mail: areti.galani@ncl.ac.uk

A. Mazel
e-mail: aron.mazel@ncl.ac.uk

D. Maxwell
Edinburgh College of Art, University of Edinburgh, Edinburgh, UK
e-mail: d.maxwell@ed.ac.uk

K. Sharpe
Department of Archaeology, Durham University, Durham, UK
e-mail: kate.sharpe@durham.ac.uk

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10.1 Introduction

Rock art—ancient carvings 'pecked' onto natural stone surfaces—forms a hugely significant part of the heritage of the North East of England. The abstract motifs, often referred to as 'cup and ring marks', provide a tangible and iconic link to our prehistoric ancestors which extends beyond the basic activities of everyday survival, to hint at a much richer, creative, and potentially spiritual dimension to their lives. Mostly found in situ, on outcrops and large, earth-fast boulders, rock art also reflects the intimate relationship that Neolithic and Early Bronze Age people had with the natural landscapes they inhabited between 6,000 and 3,500 years ago. Rock art in the North East of England presents a concentration of approximately 1600 panels of various sizes and details (see Figs. 10.1 and 10.2), representing a significant proportion of the known rock art panels recorded in the whole of England. The purpose or meaning of the cups and rings remains shrouded in mystery and continues to challenge archaeologists. The open, dynamic, debate around British rock art (see, for example, Barnett and Sharpe 2010; Beckensall 2010; Mazel et al. 2007) together with its physical availability, primarily above ground, makes rock art an accessible and 'democratic' part of the historic environment.

None of the rock art sites in North East England are proactively managed; no purpose-built visitor facilities are available, and few have any signposting or interpretation boards. Most are situated on private land with open access to the public, under the countryside and Rights of Way Act 2000 (CROW). Under these

Fig. 10.1 Typical motif at Weetwood Moor, Northumberland

Fig. 10.2 View over carved panel at Lordenshaw, Northumberland

circumstances it is difficult to make confident assumptions about visitor numbers; a recent study of heritage visitation patterns in Northumberland indicated that 78 % of surveyed day visitors came from within the region, and 'the Countryside' was found to be the second most visited destination (Smith-Milne 2008). This is supported by a one-day survey undertaken on a Bank Holiday (May 2010) by the author, which found that the majority of the 63 survey participants at Lordenshaw in North Northumberland lived locally (less that 40 miles away) and were regular visitors to the countryside. Public interest in rock art was confirmed in the overwhelming response to the website *Northumberland Rock Art: Web Access to the Beckensall Archive* (http://rockart.ncl.ac.uk) launched by Newcastle University in 2005; during the first 5 days of its launch more than 15,000 unique visitors accessed over 350,000 web pages (Mazel and Ayesteran 2010). An additional indication of enthusiasm for rock art was reflected by the high number of volunteers, more than 150 over four years, in the subsequent *Northumberland and Durham Rock Art Pilot Project*, which updated and extended the Beckensall Archive to include the rock art of county Durham, consolidating all records in the *England's Rock Art* (ERA) website (http://archaeologydataservice.ac.uk/era/) in 2008 (Sharpe et al. 2008).

Significant digitisation work took place in both projects: the ERA website hosts considerable digital assets, which include detailed descriptive records together with 14,600 images and drawings, and 420 3D models for 1,574 carved panels in the North East of England: a rich resource which has yet to be fully exploited for either academic research or heritage interpretation and management purposes.

The Rock art mobile project (RAMP) aimed to bridge these desktop-based digital resources and the physical carvings by bringing the database into negotiation with the Northumberland landscape, and into the visitors' reach, through the application of mobile platforms (see also Mazel et al. 2012). By putting user experience at the heart of the design process, this project not only takes advantage of the 'variability' of digital media (Manovich 2001), which enables the flexible re-use of cultural digital assets on mobile platforms, but also seeks to address the reported tension between handheld guides and narrative (Parry 2008). Therefore, RAMP explored design methodologies that would have the capacity to situate mobile content in the personal narratives of rock art visitors—the exploration of these narratives forms the main body of this chapter.

Rather than focusing on the whole of Northumberland, RAMP concentrates on three rock art areas which were considered suitable for mobile media interpretation (namely: Lordenshaw, Weetwood Moor[1] and Dod Law) based on the interest value, quality and range of the carvings, general site accessibility and, perhaps most importantly, the ability to withstand any potential increased visitor numbers This was determined using conservation and management data in the ERA database, and through discussions with local heritage managers and stakeholders.

This chapter initially locates RAMP within the technological and natural context of rock art visits. It then presents the rationale for adopting experience-centred design methodologies in the delivery of the project. Although, recent years have seen a significant increase in the use of mobile applications for heritage interpretation, design methodologies for these heritage products continue to rely largely on traditional production workflows that prioritise heritage managers' and interpreters' views of what needs to be communicated and how. Drawing on ideas of empathic and experience-centred design, the chapter discusses a series of participatory workshops which were deployed by the RAMP team to facilitate the formation of a 'design space', which would allow digital heritage designers and participants to co-explore content and media suitable for the mobile interpretation of rock art. Subsequently, the chapter discusses three emerging 'user needs' in this context; namely, the need to locate the rock art in the landscape, the desire for archaeological speculation, and the inclination to reflect on one's sense of place. The chapter concludes with a discussion of the design sensitivities which have emerged from this process and our reflection on the role of empathy in digital heritage design approaches.

10.2 Context: Technological and Natural Landscapes

Archaeological findings, both urban and rural, often inhabit outdoor environments which may not be adequately served by traditional interpretation media for a host of aesthetic, conservation or statutory reasons. It is easy to envisage how such sites and digital mobile media could work together, and indeed early research projects such as ARCHAEOGUIDE (Vlahakis et al. 2002) focused on the delivery of archaeological content in situ via location aware hand-held devices. In these cases, as well as in more recent commercial reiterations of the concept (e.g. the GPS-based multimedia guide in Culloden battlefield (Pfeifer et al. 2009)), the motivation was firmly grounded in both the flexible delivery of sound archaeological information on site and the perceived user need for content personalisation. In the

[1] Since January 2013 access to Weetwood Moor requires the landowners' permission.

majority of these initiatives, digital mobile guides are introduced in managed archaeological or heritage sites, and are delivered through institutionally-owned devices on loan to visitors for the duration of their visit.

The location of rock art panels in open access outdoor sites, due to their occasional and impromptu visitation patterns, require a different approach to the design of mobile digital interpretation; this should take into consideration (i) the current technological landscape, and (ii) the physical environment of rock art, both of which we consider in the following section.

10.2.1 Technological Landscape

Mobile development is a growing trend: the 2009 Oxford Internet Survey (Dutton et al. 2009) indicated that 89 % of British people owned a mobile phone and in May 2010 AdMob (2010) reported that Western Europe experienced a more than six times increase in mobile traffic over the previous two years. This trend of increasing mobile traffic is not only due to mobile or cellular phones but also includes the increasing array of tablet and ebook devices (e.g. Apple's iPad and Samsung's Galaxy Tab). This rapidly moving field brings complexity as well as exciting new possibilities, as mobile platforms encompass a plethora of screen sizes (including variable orientation from portrait to landscape), hardware capabilities (e.g. gyroscope, GPS and accelerometers), input methods, and proprietary operating systems.

In the cultural heritage context cultural institutions are increasingly contemplating the possibility of developing digital mobile interpretation, as indicated by a recent Museums and Mobile Survey (Tallon 2011), with an emphasis on utilising users' own devices, multimedia guides and smart phone applications (see also Doyle and Doyle 2010). However, the most recent Mobile Survey by Tallon (2013) specifically suggests that heritage sites and heritage museums are slower in developing mobile provision. In the meantime, feedback from the current cultural providers of mobile content suggests that on one side, apps is the most promising way for iPhone and Android users to find and use content (Bernstein 2010), versus the potential for wider visitor access through mobile websites (Forbes 2010). However, in general, development trends in the museum and heritage sector are skewed towards iOS-based applications, with the mobile web and Google Android development far less supported, despite Android's rapidly growing install base. Apps range from being simply a pre-packaged, mobile-friendly version of an existing website, to interactive games (e.g. *Tate Trumps* iPhone app), augmented reality (e.g. Museum of London's *Streetmuseum* iPhone app) and guided interactive video tours (e.g. Untravel Media's *Walking Cinema: Murder on Beacon Hill*). Location-aware applications support navigation around outdoors physical locations through a range of solutions such as GPS (Tarasoff et al. 2009), Quick Response (QR) and similar 2D codes (e.g. Manchester Art Gallery's *Decoding Art* project). Geo-tagged photographs (e.g. Beeharee and Steed 2006) are an exploratory alternative to the above, seeking to tackle GPS limitations, for example under tree cover and 'urban canyons' (i.e. signal obstruction by buildings) as well as increased battery depletion for GPS-enabled mobile phone handsets.

10.2.2 Natural Landscape

By comparison with these examples of indoor and urban mobile applications, rock art in Northumberland is situated in the rural landscape, amidst windswept hills and moorland where electricity supply is not readily available. Frequently located at sites affording extensive vistas (see Fig. 10.2), the carvings generally occur on flattish, exposed sections of bedrock. They are often found closely grouped, perhaps separated by bracken or heather; they are exposed to the elements, partially covered by lichen, moss and general detritus. When looking at rock art, the visitor is also exposed to the elements of nature, such as wind, rain or bright sunlight which reflects on mobile device screens reducing visibility.

Yet in heritage management terms and, as we will argue, in user-experience terms these hostile conditions lend themselves to mobile devices better than static alternatives (e.g. wind up mp3 players). Mobile interpretation can be delivered via both visual and personal audio formats without physically augmenting or intruding upon the landscape as many rock art sites are subject to statutory protection. Additionally, any installation may potentially be subject to livestock and human vandalism due to their use as grazing grounds and their open access location. The above conditions also restrict the installation of alternative energy solutions, such as solar powered kiosks.

The environment offers two further challenges: a seasonally changing, relatively featureless landscape which can make finding the carvings difficult, which we discuss later in the chapter, and variable network signal, which has often been reported by local residents as nonexistent. However, a systematic feasibility study of five major UK mobile service providers, carried out at the three RAMP rock art sites, revealed some encouraging results: although network signals vary considerably between the three sites, all have strong availability of network signal in several of the rock art panel areas, especially in higher altitude spots. One site enjoys stable and strong signal with all major network providers, whilst the other two are more variable. Frustratingly, weak signal has been found in the public parking areas of the three sites, admittedly the natural starting point of any activity, which may account for the visitors' perception of 'no signal' mentioned above.

10.3 Methodological Approach

With a significant amount of digitised media in place and a good understanding of the feasibility of mobile applications in the natural context of the rock art panels, this research acknowledged from very early on that significant exploration should focus on the narratives, interactions and conversations which take place in people's everyday encounters with this environment. The design process, therefore, actively sought to engage with the 'situated' nature (Suchman 1987) of these encounters and to allow for 'empathy' to be developed between designers and users. Wright and McCarthy (2008) explain:

> In an empathic relationship the 'designer' does not relinquish his/her position to 'become the user', a position from which nothing new can be created, rather the designer responds to what they see as the user's world from their own perspective as designer. By holding onto their own perspective each person is able to creatively respond to the other from their own perspective.

This design position, the authors continue, allows the designer to understand and anticipate users' response to novel technological encounters, which they have not previously experienced. Although empathic design has been discussed both in marketing (e.g. Leonard and Rayport 1997) and in product design contexts (e.g. Koskinen et al. 2003) since the late nineties, it has not been used in the design of cultural heritage applications, often due to its resource intensive nature and its speculative outcomes. Its emphasis, however, on opening up design possibilities beyond a specific group of participants was particularly attractive for RAMP researchers, due to the serendipitous nature of the rock art visit.

Drawing on these principles, the project developed three one-day co-experience workshops held in late 2010 with predominantly local participants. The workshops aimed to create a 'design space', which would bring to the fore visitors' experiences and relationships with the rock art environment, and their rapport with interpretive and communication media; they also allowed designers to share expertise and knowledge and float preliminary ideas. This flexible approach enabled the team to expand the traditional boundaries of the system requirements capture process to include not only technical functionalities and content needs, but also to investigate and incorporate more open-ended concepts, such as the role of ambiguity in archaeological information, the pace and tone of delivery in a self directed activity, and the relative importance of the visitor's sense of place in the experience of rock art.

The workshops took place in Wooler (Wlr1) and Rothbury (Rth2, Rth3), the closest villages to the chosen rock art areas. Membership of the workshops was initially informed by a preliminary in situ visitor survey, as mentioned above. This day-long survey had suggested that people who visit rock art sites are likely to come from within the local area and visit in a group (i.e. two or more people) which includes repeat visitors. Several workshop participants were recruited from this initial survey. In addition, participants were found from local contacts in villages close to the project rock art sites, responses to posters in community centres, and from direct correspondence with relevant groups (e.g. a local ramblers group, amateur rock art and archaeology groups, heritage organisations and the local geocaching community). Twenty seven people participated, which included some groups of friends and same family members; ages ranged from a teenager to retirees, with a trend towards older (retirement age) participants.

The workshops deliberately adopted a low-tech, informal approach. Drawing on the design approach of 'cultural probes' (Gaver et al. 1999; Mattelmäki and Battarbee 2002), which helped the research team to focus on the "cultural implications of our designs", they combined conversations, some of which were around maps of the area which explored participants' favourite spots (Fig. 10.3), a site visit, a storytelling session about participants' own mobile phones, a set of prompts written on lollipop sticks, and flash cards. These activities were designed to support first-hand engagement, multisensory (and multimodal) experience and self-reflection—in a bid to shift away from perceived 'truths' or generalisations about visitor needs and behaviours at heritage sites.

The aim of the site visits was not to provide a guided tour experience, which would favour the archaeological narrative of the encounter. Rather, the research team aimed to lead participants to rock art panels and allow them to engage with the landscape and group as they saw fit. The dialogue which emerged between specialists and participants evolved naturally, indicative of the information needs of participants. Knowledge sharing with the specialists was partly in the form of answering questions, enabling group members to probe the extent of known facts and archaeological interpretation, and also served as a moderating sounding board when participants put forward suggestions about the rock art. Participants could also use booklets with sample visual content from the existing database (Fig. 10.4), listen to spoken words (e.g. a poem recital) and music on mp3 players, and make notes on wooden lollipop sticks, which carried prompts such as: "This reminds me of…", "This landscape makes me feel…" and so forth. Brushes and a profiler gauge were also provided to allow participants to physically interact with the rock (Fig. 10.5).

The workshops generated a rich and diverse pool of documentation in the form of notes, photographs, video recordings, participant photographs, and notes on lollipop sticks. This material was then used to generate a set of conceptual thematic maps, similar to affinity diagrams (Beyer and Holtzblatt 1997), using sticky notes (Fig. 10.6) which afforded not only a plasticity in data coding, but also encouraged a collaborative and visual method of working between the project team. This

Fig. 10.3 Group discussion around favourite places (Rothbury, Workshop 3)

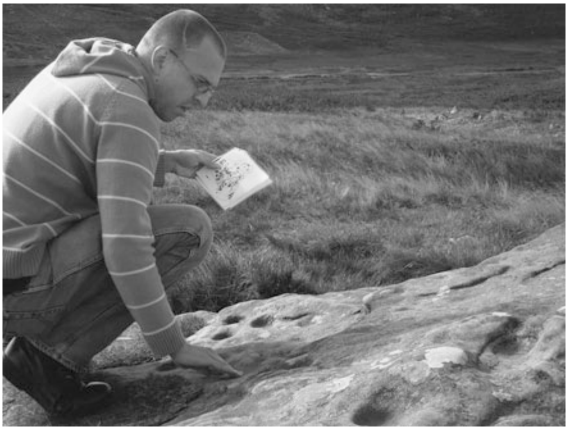

Fig. 10.4 Participant exploring the carving through touch and visual material, Lordenshaw site visit (Rothbury, Workshop 3)

Fig. 10.5 Participants engaging with rock art, Lordenshaw site visit (Rothbury, Workshop 3)

treatment of the collected materials highlighted significant personal and shared realisations of the rock art experience, three of which we discuss in the next section.

10.4 The Rock Art Experience

The documentation of the workshops provided insights in the ways that participants experience rock art visits. The remaining of this chapter focuses on participants' nuanced reflections on landscape use and personal interactions with the landscape and their peers, which have affected our design inspiration. More specifically we discuss:

- Practices around finding rock art ('findability');
- The place of archaeological speculation in engaging with rock art; and
- The participants' connection with the landscape ('sense of place and self').

Fig. 10.6 Conceptual thematic map on sticky notes

We conclude this section by reporting on the participants' types of mobile handsets and usage levels in their rock art visits, countryside activities and everyday life. Although these insights derive from research in rock art sites, they also have broader relevance to how visitors experience a wider variety of cultural and natural environments, such as archaeological sites, industrial landscapes and natural conservation areas.

NB. All participant names have been changed.

10.4.1 'Findability'

As described in the *Natural Landscape* section, the physical locations of rock art mean that they are not necessarily visible from a distance; easy viewing can be very much dependent on oblique sunlight and low vegetation growth. Anita (participant in workshop Wlr1) told us about visiting Weetwood (one of the RAMP sites):

> I'd been up there before and I'd seen some of them, but I saw some today that I hadn't seen before. The one that was in the wood, I'd never seen that one before, I didn't even know it was there—because all it says on the map is 'cup and ring marks'. And the last time I was up there I couldn't find that-the main one, I couldn't find it at all. And we walked backwards and forwards, and backwards and forward until everyone said, 'Come on! We want to get to Wooler before the tea shops shut'. And in the end I gave up. So I

was particularly interested to go up there today and I've taken it all down on the GPS and got the, er, map references so I can find them again.

Anita (retired) is a keen walker and countryside visitor; she is a volunteer ranger for the Northumberland National Park, so is comfortable in the countryside. Yet her recollection of difficulty in finding rock art rang true for several participants over the three workshops. Her story illustrates several key points, (i) she was unaware of all but the main rock art panel (which is situated on a pathway) despite the existence of several other carved panels in a 250 m radius, (ii) there is a lack of interpretation in situ and in mainstream information channels (i.e. tourist information brochures and on Ordinance urvey (OS) maps), and (iii) she developed a method for dealing with the 'findability' issue by recording panel co-ordinates with her GPS.

Anita's story is typical of other participants, many of whom did not know about less obvious rock art panels in the general area, despite having visited the site and the most well-known carvings previously. On the workshop site visits, several less obvious panels were visited, selected to show a range of rock art motifs and contexts. This range perhaps prompted these responses, and served to enthuse some participants who did not realise that there was so much archaeology on their doorstep. For these participants, the lack or vagueness of the available visitor information both on site and through traditional tourist information channels limited their experience of rock art, especially within the context of a leisurely group visit. Participants' accounts of their troubles in finding the rock art panels gave us insights in the situation of these visits: purposeful, regular, social, and often relying on intuition around the landscape. For instance, only two of our 27 participants spoke of actively using the ERA and Beckensall websites to find and check rock art locations pre-visit.

Anita's method of storing rock art locations for future reference was a relatively new experience for her, having only recently acquired a GPS. Other participants adopted different mechanisms for finding rock art, with one member claiming to enjoy "getting lost", only navigating with OS maps. It took Robyn (retired, Wlr1) three occasions to locate a specific carving, only succeeding after serendipitously meeting Stan Beckensall (doyen of rock art studies in Northumberland and the UK) in a local café and asked for help. It may be initially hard to comprehend the motivation in seeking a simple carving on a rock in the middle of the countryside, especially when it drives someone to search for it on three separate occasions, but it is important to ground this in the setting of the landscape and the user group.

The landscape was cited as its own reward, where regardless of the success of the rock art search, "…one has a nice day out in lovely countryside looking for them and I think that sort of adds to it—they're usually somewhere where there's a lovely viewpoint" (Robyn, Wlr1). The importance of environmental context was reinforced by Dennis (Rth2) who noted that, "If you had the same stones in a museum in Newcastle, well, I would not be bothered at all. It's the landscape, the environment that makes it". Despite the lack of information and interpretation, rock art panels held a fascination for our participants, which was evident throughout our conversations in the three workshops. This was often expressed through ongoing speculations about the rock art panels themselves, which we discuss in the next section.

10.4.2 Desire for Speculation

The inconclusive explanations about rock art provoked discussion, reflection and speculation. "What does it mean?" was the underlying question at the root of all our workshop discussions and site visits, and was articulated by participants time and time again. A typical conversation among the participants is exemplified by the following dialogue excerpt (Wlr1):

John	We haven't really got a clue. I mean there's loads of ideas but…we do not know. Because it's a mystery it's much more alluring, yeah? [General murmurs of agreement]
Stephen	It makes it more interactive in some way does not it?
John	Well it allows your motivation [Unheard all talking together]
Anita	Every time you go you think—well I said today, 'It's a game. It's a game like that one in Africa where you put stones'
Stephen	Which makes it more engaging doesn't it?

Anita's comment in the above excerpt highlights the role of speculation in the overall rock art visiting experience, suggesting that on each subsequent visit her view of rock art alters. All of the workshop groups enjoyed speculating on the purpose and possible meaning of the abstract marks. The wooden lollipop or 'memory' sticks (see Fig. 10.7) recorded a host of imagery (e.g. bicycle wheels, labyrinths, maps, a board game, graffiti or doodles, ridge and furrow plough marks, millstones, ripples from throwing a stone in water, and 'planets around the sun') (see also (Morris 1979) for 104 possible rock art meanings).

For the participants, the perceived mystery and enigma of rock art, in combination with the lack of any signs of authoritative interpretation in situ, enabled a degree of intellectual accessibility, where non-specialists can experience a sense of conversing on a comparatively level footing with specialists, qualifying with "we [i.e. *everyone*] do not know [what it means]". During the workshops and reportedly in previous visits, making sense of the rock art panels was practiced through dialogue both on site and in discussions post-visit, opening up a space for speculation and providing an opportunity not only to hear the available archaeological answers but also to discover and hear more questions in a group context. Rock art therefore was at the centre of an evolving set of personal narratives, shaped by ongoing experience and social interactions with peers and specialists—a similar understanding to how people make sense of natural quietness in rural environments was reported in Giaccardi et al. (2006). On a more personal level, a smaller group of participants made sense of rock art through their creative practice. Stephen (Wlr1) writes poetry, and rock art has in the past inspired some of his work,

Fig. 10.7 Discussion around comments on lollipop sticks (Wooler, Workshop 1)

which he brought to the workshop. Similarly, his wife Jean (Wlr1), recounted visiting rock art with her sister-in-law who used the carvings to prompt an artistic reflection post visit; John (Wlr1) and Matthew (Wlr1) take photographs of rock art, which have now been uploaded onto the Flickr account of the project, and both Dennis (Rth2) and James (Rth2) have installed geocaches close to rock art sites.

10.4.3 Sense of Place and Self

An overwhelming aspect of rock art experience, in the context of the workshops and beyond, was the participants' connection with temporal, social and physical aspects of the landscape through the rock art itself. In our team's discussions of the workshops we loosely referred to this aspect of the visit as 'sense of place and self' following Jorgensen and Stedman's (2001) approach where 'sense of place' is considered to be "an attitude towards a spatial setting" comprising of identity (beliefs about the relationship between self and place), attachment (emotional connection to place) and dependence (conative, i.e. directed towards, action).

Participants who attended the RAMP workshops were comfortable in the rural environment, being largely regular visitors to the countryside, in line with Tuan's (1974) claim that "familiarity breeds affection when it does not breed contempt". They talked about the countryside in terms of being able to connect with and be part of nature, giving them a sense of 'being alive and carefree'. Several individually written responses to the lollipop stick prompt, "This landscape makes me feel…" said simply, "Exhilarated".

A sense of tranquillity came out from the responses too, with participants citing a multisensory experience: panoramic views from hills or coast, the sounds of birds and the wind rushing, lying in heather watching sky larks dart across the sky, and drinking coffee from a flask or eating a picnic lunch. This was reflected both in the measured way participants moved through the rock art sites, sometimes sitting down to absorbing the atmosphere, and in discussions afterwards. For instance, Louise (Rth2) wanted to simply "sit there for 20 min" and Karin to "experience what there was to feel" (Rth3). This correlates with survey findings (Smith-Milne 2008), which suggested that heritage tourists are "motivated by a wider range of factors than the heritage itself", including a "desire to be entertained, an emotional and/or social connection with a particular place, subject, culture, history and so on. Other types of experience include a desire for peace and tranquillity, an interest in learning".

Participants explored the environment through sensory engagement with the landscape and the rock art, touching carvings with their hands (Figs. 10.4 and 10.5), and in a couple of instances, their bare feet. Several participants claimed that by touching the hollows and tracing the grooves they were able to feel more of a connection with the ancient carver. As Michael (Rth3) explained:

> I think often perhaps we are told that things are fragile and 'Don't Touch it' and, you know, '[Don't] look at it', and, 'Not too near it' and, 'Don't walk on it', and by not touching it, we make it lost. Whereas I felt an interesting thing where I was running my hand through some of the cup marks and I thought, hmm, perhaps if this has been done so many times and I remove another thirty little grains from the outside of weathering then I'm also taking part in that process.

Michael's account of his experience suggests a felt connection between the past and present, bringing a direct sense of individual participatory engagement with the carving and the landscape. His contemporary take on the carving and erosion process provided an opportunity to reflect on his personal contribution to the longevity and continuity of rock art which was shared by other participants in the group. It appears then that in this case, Graham et al.'s (2009) suggestion that "the historic environment contributes towards a distinctive sense of place and a sense of continuity which can support a greater sense of people's self-esteem and place attachment", is particularly materialised through the visitors' situated and multisensory experience of rock art.

Before we discuss the design sensitivities associated with the above issues, it is worth pondering on another aspect of the RAMP workshops, the participants' relationship with their mobile technologies.

10.4.4 Participant's Use of Mobile Technologies

The co-experience workshops discussed above were designed to open up dialogue among participants, and between participants and designers. Given the premises of the project, the team sought to understand the relationships participants have with their mobile phones, especially in the context of their visits to rural landscapes. This would allow the research team to develop designs not necessarily for the current technical skills and hardware capabilities of the specific participants and their phones, but in a way that would enable these participants (as well as other future rock art visitors) to feel comfortable in engaging with a technological intervention in the context of a rock art visit. The conversation around personal mobile technologies brought up a series of details regarding uses and handset capabilities, ranging from those participants who extolled the virtues of Bluetooth to those who had never sent a text message (though both extremes were in the minority). The majority of the participants had older mobile phones, some as 'hand-me-downs', and others as deliberate selections made at purchase. The majority of the participants reported low usage of these devices which correlates with the lower-end capabilities of the handsets, and the corresponding fact that most of the phones were Pay-as-you-go as opposed to contract-based (which generally have a higher specification and bundled internet access). Unsurprisingly, participants were concerned that any kind of mobile tour might deplete their pre-paid phone credit.

More importantly, however, participants were asked to tell the group a story about their mobile phones; in these stories mobiles were cited largely as producing feelings of 'safety' and security when in remote rural settings or when out driving. As a result, participants would always carry their mobile phones in their rock art visits. This admission, however, came hand-in-hand with the perception that mobile signal at rock art sites was non-existent, perhaps borne out by the fact that signal strength is weak at all the 'site entrances', as discussed above.

Participants were also divided between those who actively engaged in imagining the positive transformative effects of a mobile application for the rock art experience, and those who warned the RAMP team about the disruptive effect of technology in the tranquillity of the landscape. Furthermore, participants with smart phones were observed taking photographs throughout the visits and in two instances to combine low capability mobile phones with high-end iPad devices (Fig. 10.8)—the majority of the group used their electronic cameras to capture the visit. They also accepted and made calls throughout the day. The overall experience, hence, was regularly recorded, mediated and in some instances disrupted by the use of an array of technologies.

Fig. 10.8 Participant using own iPad during Lordenshaw site visit (Rothbury, Workshop 2)

10.5 Design Considerations

The co-experience workshops indentified new perspectives for the mobile interpretation of rock art that are not often included in heritage interpretation manuals, namely the visitors' need to speculate around the making and the meaning of these sites and their desire to connect with the landscape during their visits. The workshops also provided the research team with more defined questions to ask around already known interpretation needs, such as the visitors' need to be able to locate the site/artifact in the landscape before they engage meaningfully with its message. These findings have inspired digital mobile interpretation sensitivities which are further discussed in Mazel et al. (2012) and are summarized below:

10.5.1 Hybrid Media Ecologies

When it comes to technological decisions, the co-experience workshops suggested that rock art visitors make use of a variety of media in their personal sense making of rock art, including iPads, cameras, maps, books, websites and the physical infrastructure. Understanding how these "hybrid [media] ecologies" work in the context of the heritage visit in rural environments will help us to support the nature of cooperation and interaction in these environments, which merge physical and digital encounters (Crabtree and Rodden 2008). For example, RAMP was faced with a fundamental dilemma of whether to work to the lower-end phone specification, perhaps by the use of SMS (e.g. Botturi et al. 2009) or recorded voice messages, or to push the user boundaries and adopt a higher level specification, perhaps through the use of an app, despite the fact that most of our participants would be unable to access it in the first instance. Furthermore, there is always the temptation to simply translate the existing database directly into a mobile format, which, however, would contradict our participants' need for situated interpretation, appropriate to repeat, purposeful and intuition-based encounters with rock art in a social group or alone.

The final implementation of the mobile interpretation explored a multi-pronged approach to digital cultural communication by (i) developing a mobile web application, reusing key resources from the existing database (e.g. optimised imagery) and creating additional material as required, to allow Internet enabled mobile devices to access content in situ, (ii) by adopting the emergent Bring your own device (BYOD) paradigm through the development of multiple versions of the web application for low-, mid- and high-end devices, (iii) by making components of the interpretation available for visitors to download on alternative personal devices (e.g. mp3 players) or print pre-visit, and (iv) by incorporating QR codes in the landscape for quick and efficient access by smart phone and tablet users. This approach aimed to provide maximum access to the mobile interpretation content at various stages of the visitors engagement before, during or after the visit.

10.5.2 Granular Navigation

Arguably, one of the fundamental rules of any heritage interpretation, analogue and digital, is for people to be able to physically find it and access it. As discussed previously, the perceived intellectual accessibility of rock art and the relationship with its natural context is one of its appeals. The somewhat hidden nature of its location could well have been another manifestation of this, a puzzle or riddle to solve, another facet of its enigmatic nature. However, the discussions in the workshops clearly demonstrated that this was not the case, as people expressed frustration in not being able to locate the panels in past visits. They further revealed the participants' enjoyment in using their intuition and resourcefulness in navigating the landscape.

The co-experience workshops highlighted three aspects of the participants' way finding practices when visiting landscapes with rock art sites. These broadly include navigating around the landscape, locating potential rock art panels and confirming that the panels they are looking at contain rock art carvings rather than other naturally occurring shapes. The workshops also revealed preferred navigation techniques: (i) the use of static GPS coordinates, the method of choice for rock art enthusiasts and geocachers, (ii) the use of mainly Ordinance survey (OS) paper maps preferred by regular walkers in the countryside, and (iii) intuitive navigation around the landscape using natural features and own recollections of previous visits.

The final implementation of the mobile interpretation combines these elements by providing a schematic map of the site with annotated photographs of views and actual panels (a solution also discussed by Wenig and Malaka 2010). The navigation functions in both environments, the users' mobiles through the application, and the physical site through considerate and managed physical interventions in the landscape in the existing public path signage. Durable inconspicuous plaques with the map of the site and QR codes have been installed on existing way findings markers to provide anchors for landmark-based navigational descriptions. Static GPS coordinates are also provided in the web application but no content is triggered by the users' GPS location given the challenges of this technology for heritage applications (e.g. Pfeifer et al. 2009), the mobile technologies used by the visitors to these sites and the serendipitous nature of the rock art visit.

10.5.3 Interpretive Openness Through Dialogue

In their exploration of ambiguity as a design opportunity, Gaver et al. (2003) commenced their discussion by accepting that, "ambiguity can be frustrating, to be sure. But it can also be intriguing, mysterious and delightful". This certainly rings true in the case of rock art experience as already discussed. On the other hand, it was obvious to the RAMP team that the specialists' point of view is that although there are a lot of things we do not know about rock art, and therefore speculation around these issues is welcome, there are certain things that we *do* know, which should form the basis of any meaning making exploration.

The co-experience workshops particularly highlighted that participants seamlessly interwove and evolved their own archaeological narratives about rock art through (i) their engagement with the natural landscape, (ii) their sensory explorations, and (iii) the more evidence-based conversations with rock art specialists in the group and more 'knowledgeable' peers.

Therefore, the final implementation of the mobile interpretation sought to explore designs that would combine Gaver et al.'s (ibid) suggestions for "enhancing ambiguity of information" with techniques used in archaeological research. It realises this by (i) providing an evidence-based set of material and insights which leave space for the visitor to make their own informed judgements on aspects of rock art, (ii) mirroring conversational dialogue in both audio and text interpretation to introduce informality and openness and to avoid one authoritative voice, and (iii) inviting users to respond to speculative questions about the meaning of rock art to be shared with other users on-site and online via the applications' desktop version. The dialogic approach to interpretation is expected to overcome limitations of meaning derived from the inherently positivist medium of terse mobile interpretation by opening up the space for conversations, whilst putting forward a sound archaeological discourse.

10.5.4 'Felt' Experience of Place

One of the challenges for RAMP was to contradict Malpas's (2008) proposition that digital media, by removing "spatial and temporal distance *and* difference", and by "the way they release things, including ourselves, from place may also bring with it a loss of any proper 'sense' of place, and so of any proper sense of identity." Connecting with the natural, historic, and social aspects of the landscape through one's senses and previous understandings appears to be an essential part of the rock art experience.

The co-experience workshops highlighted the nuanced character of rock art visiting experience which often interlaces rock art engagement with moments of relaxation, attention to the natural and built elements of the landscape and personal reflection; due to the tactile nature of the rock art panels and their embeddedness in a living and changing landscape the rock art visit is also inadvertently multisensory and tempts people to physically interact with the panels.

The final implementation of the mobile application prioritised (i) the creation of flexible, modular content, which favours the user's personal pace by avoiding interdependencies between content associated with traditional linear guided tours of heritage sites, and (ii) the inclusion of content for other aspects of the landscape, such as views, plantations and remains from other archaeological periods (e.g. hillforts). This latter approach also signifies a move towards a more holistic style of interpretation of rock art, and of archaeology more generally, informed by an empathic understanding of the visitors' viewpoint. Although the mobile interpretation provides considered encouragement for users to use all senses during the visit, it also advises against touching or walking on the rock art panels. Arguably, this latter point highlights a real-life tension between the tactile aspects of the rock art experience and the concerns of heritage conservation, which are particularly prevalent in rural open access sites.

10.6 Conclusion

This chapter has outlined the contextual background to the RAMP. It has particularly highlighted the technical and environmental context of the project and the rationale behind the chosen empathic and experience-centred design methodologies. One might then question how the empathic design approach compares to more traditional system design processes used in digital heritage. RAMP aimed to situate digital mobile interpretation within the personal, technological and natural context of rock art visits; it also sought to introduce an interpretation delivery mechanism which is 'novel' for both the sites and the traditional user base. Through the adopted experience-centred methodology, the design team achieved an 'empathetic' relationship with both the landscape and its users. The workshops generated rich visual and textual accounts of participants' specific content and modal preferences, as well as the range of participant mobile usage patterns and experience. They also, crucially, exposed a series of observations and comments revealing how visitors experience and engage with rock art and the wider countryside. As the premise of this chapter is that experience-centred design methodologies can lead to nuanced, thoughtful reflections for conceptual design, it is important to consider what these reflections can tell us in terms of design sensitivities. Whilst conscious of Dourish's (2006) concern for notional, wide-sweeping design implications based on fleeting observations, several clear points emerged which RAMP used as inspiration springboards in the design and implementation of the mobile interpretation.

Wright and McCarthy (2008) warn us that experience-centred approaches might run the danger that "empathy will be regarded as something vague, mysterious, unwarrantable, undocumentable and unusable". RAMP aimed to address this issue by putting in place an iterative design process, establishing a longer term relationship with participants, and evaluating design prototypes through further participatory design exercises (Mazel et al. 2012). In all these steps, a keen awareness of the design sensitivities has driven each decision. While the evaluation of the mobile interpretation with visitors is currently underway, and will be reported in a forthcoming publication, the empathic design approach explored in this project has already achieved to challenge designers, heritage professionals and participants involved in the co-exerience workshops to consider mobile interpretation not only as a vehicle for heritage information in situ, but also as an opportunity for active engagement with one's companions, the archaeology and its surroundings.

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Chapter 11
Digital Reconstruction of Archaeological Sites and Monuments: Some Experiences in South-Eastern Sicily

Cettina Santagati, Mariateresa Galizia and Graziana D'Agostino

Abstract Over the past few years, technological innovation has contributed to the development of the methodology to acquire, analyse, use and convey information about cultural heritage. Among all the possible methods for acquiring data, those related to 3D laser scanners (Time of flight or structured light) stand out. By using these technologies it is possible to sample, in a short time and with great accuracy, millions of points from real world objects obtaining a detailed 3D representation. This study presents the results of research carried out on archaeological sites and monuments of South-Eastern Sicily. The case studies presented belong to different type sites and they have been dealt with using methodological approaches chosen for the specific purposes of the study (restoration and conservation project, 3D reconstruction and visualisation, 3D documentation). The comparison between the different case studies might be the starting point for a new standardisation of digital representation of archaeological heritage objects and new methodological procedures.

Keywords Laser scanning · 3D modelling · Virtual archaeology · 3D reconstruction · Conservation · Digital heritage

C. Santagati (✉) · M. Galizia · G. D'Agostino
Laboratory of Architectural Photogrammetry and Survey "Luigi Andreozzi", Department of Architecture, The University of Catania, Viale Andrea Doria No. 6 95125 Catania, Italy
e-mail: cettina.santagati@dau.unict.it

M. Galizia
e-mail: mgalizia@dau.unict.it

G. D'Agostino
e-mail: graziana.dagostino@gmail.com

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11.1 Introduction

Over the past few years, the growing interest of the scientific community, professionals and public corporations in the digital three-dimensional (3D) documentation of cultural heritage has led to several projects for the 3D acquisition, documentation, visualisation, conservation and restoration of large sites and monuments.

Today, capturing accurate and detailed geometric models of real world objects by using range-based (3D laser and structured light scanning) and image-based modelling technologies has become a common process (Andreozzi 2003; Andreozzi 2007; Docci et al. 2001; Gaiani et al. 2000; Guidi et al. 2010; Migliari 2001; Russo et al. 2011; Stanco et al. 2011; Valentini et al. 2004).

The use of these technologies allows for the creation of 3D models which are digital copies of real world objects on which each scholar could conduct various types of cognitive research. Moreover, 3D models are a precious, realistic and accurate documentation through which the object might be passed down to future generations.

The intensive use of these technologies requires the identification of best practise for the definition of standards in 3D digital documentation.

This study presents the results of research conducted on archaeological sites and monuments in South-Eastern Sicily by a team of experts from the Laboratory of Architectural Photogrammetry and Survey "Luigi Andreozzi" of University of Catania. The case studies presented belong to different typologies of monument, and they have been dealt with according to methodological approaches aiming at the specific purposes of the study (including restoration and conservation, 3D reconstruction, visualisation and 3D documentation). They are also in keeping with the Seville Charter principles on Virtual Archaeology (the implementation of the London Charter in the field of archaeology officially approved during the III International Congress Arqueologica 2.0, held in Seville). Those principles are: (1) Interdisciplinarity; (2) Purpose; (3) Complementarity; (4) Authenticity; (5) Historical rigour; (6) Efficiency; (7) Scientific transparency; (8) Training and evaluation.

The 3D laser scanning technology (Time of Flight) and the related software for data management and processing were tested. Both the strong points and the weak points encountered during the different phases of the 3D documentation pipeline were highlighted: from data acquisition to the 3D reconstruction of surfaces, from texturing to the visualisation of the model, from data interpretation to geometric analysis.

Moreover, the opportunity to have a digital copy of the objects studied opened new interpretative scenarios and made possible a dynamic approach to the problems related to restoration and conservation projects (allowing real-time verification and simulation) and highlighted the innovative potential of 3D documentation compared to the traditional 2D approach still used by many scholars.

However, there are still some unresolved issues such as: the problem of how to manage the huge amount of data obtained from 3D surveys; the possibility of creating multi-resolution models with different Levels of Detail (LOD); the need to automate the procedure to move from the point-cloud to a semantic geometric model sorted into component parts (Gaiani and Micoli 2005; Manferdini and Remondino 2012).

This chapter will be structured as follows: Sect. 11.2 will give an overview of current surveying and 3D modelling methodologies for an accurate and detailed reconstruction of archaeological sites and monuments; Sect. 11.3 will provide an in-depth look at three case studies in South-Eastern Sicily (the Roman funerary monument named "Torre Rossa" in Fiumefreddo di Sicilia; the "Terme dell' Indirizzo" in Catania; the catacombs of San Giovanni in Syracuse); discussion and future work will be described in Sect. 11.4; finally, in Sect. 11.5, the acknowledgments and bibliography will conclude the chapter.

11.2 Overview of the Actual Surveying and 3D Modelling Technologies

The documentation of cultural heritage artefacts cannot be based only on 2D graphic representations, due to the intrinsic characteristics of the objects being analysed (irregularities and fragmentary quality of the surfaces, roughness of the materials, missing parts, structural instability, deterioration) (Barbarini 2006; Cherubini 2008; Di Grazia 1991; Giuliani 1976).

Since the first decades of the previous century, stereophotogrammetry has been among the techniques used for the acquisition of 3D information. Over the past 20 years the use of digital technology has renewed the way in which researchers work in this field of study thus making possible the improvement of results and 3D visualisation (Remondino and El-Hakim 2006; Remondino 2005; D'Andrea 2006; Gabucci 2005; Mascione 2006).

However, the photogrammetric procedure, though having the advantage of acquiring immediate information on-site, requires that specific results of the surveyed object must be confirmed. This is particularly evident when the dimensions of the objects or of the site are large.

With the introduction of Laser Scanners—active sensors able to survey real world objects in a relatively short time and with great accuracy—it is possible to reproduce a 3D image consisting of millions of points of *xyz* coordinates in a point-cloud. In this way, the 3D model can be visualised during the phase of the on-site survey, thus improving the accuracy of the spatial characteristics of the object and/or the site. Laser scanners are divided into Terrestrial Laser Scanners (TLS), able to carry out land (close-range) data acquisitions, and LIDAR or airborne able to carry out acquisitions from an airplane (Campana and Francovich 2006; Crosilla and Galetto 2003; Remondino et al. 2009; Remondino 2011; Sansoni et al. 2000; Santana Quintero et al. 2008; Vassena and Sgrenzaroli 2007; Crosilla and Desqual 2006).

There are three categories of terrestrial laser scanners based on three different measurement principles: optical triangulation, Time of Flight (TOF), and phase-based measurement.

Optical triangulation laser scanners are used for objects of small dimension and are based on the principle of trigonometric triangulation. A sensor "captures" the laser light which is reflected by the object, and the system measures the distance between the object and the scanner. These systems, whose scan range goes from 0.1 to 2 m, and whose accuracy is of a few tens of microns, reproduce the scanned object in the form of a polygonal model.

The TOF laser scanner measures the time elapsed between the emission and the reception of the laser beam, the angle of inclination of the emitted beam to the vertical axis of the instrument and the azimuth angle to a reference horizontal axis. The system creates a cloud of 3D points which must be converted into a mesh afterwards. The scan range goes from 2 up to 1,400 m according to the characteristics of the instrument; the dimensional accuracy is between 4 and 25 mm.

The phase-based scanner works in a way similar to the TOF systems but it uses a light beam thus quickening the process of acquisition. The dimensional accuracy is about 1 mm, and the scan range is between 0.6 and 120 m, which is considerably smaller than that of a TOF scanner.

Spatial information (x, y, z) relating to a single point is generally enhanced through the RGB component which is acquired through a sensor inside the instrument or an external camera which may be axial to the instrumentation (for high-resolution acquisitions).

The high quality of 3D models, which today are obtained within archaeological research through the use of laser scanning technology, is documented by experience gained over the years.

The numerous and diverse applications of laser scanning technology have involved several research teams which have contributed to the progress and improvement of the potential offered by the use of this technology within the context of cultural heritage. Among them the following applications stand out:

- The joint project carried out by the CNR-ITABC researchers in collaboration with the Archaeological Superintendency of Rome concerning the Archaeological Park of Via Appia for the reconstruction of the archaeological landscape. The 3D images acquired through the integration of various technologies (laser scanner, remote sensing, photogrammetry) were aimed at the real-time design, reconstruction and exploration of the archaeological landscape (Forte et al. 2005a, b; Gaiani et al. 2007).
- The START project concerning the Roman catacomb of Saint Domitilla, conducted by the Institute for the History of Ancient Civilizations of the Austrian Academy of Sciences in collaboration with the University of Vienna. The use of laser scanner technology aimed at the 3D documentation of the architecture of the catacomb along with its early-Christian funerary painting through the interactive visualisation of the site. Furthermore, the huge point-cloud obtained, both for the wide extent of the site and for the high quality of the data, required a

system of data management able to manipulate and visualise the acquired information. For this purpose an out-of-core octree structure was created, and a number of interactive editing tools were used in order to perform various archaeological tasks on the whole point-cloud (Scheiblauer et al. 2009; Zimmermann and Esser 2008; Zimmerman 2009a, b, 2010).

- The project conducted by the Scuola Normale in Pisa in partnership with the Superintendency of the Archaeological Heritage of Naples and Pompeii and ARCUS SpA (Association for the development of art, culture and entertainment) aimed at the documentation, archival management and communication of the archaeological site of Pompeii. The integrated methodological approach entailed the use of photogrammetry for the extraction of 3D information from the digital photographic images as well as triangulation and TOF laser scanning. The 3D model of the survey was indexed within a Unified Information System for the Superintendency. An experimental multi-resolution semantic approach was tried on elevated structures (building units, decorations, elements of classical order) as well as on single finds classified according to their geometry and typology by creating abaci of architectonic elements which could be analysed individually and/or in context (Apollonio et al. 2012; Benedetti et al. 2009; Gaiani et al. 2009, 2011; Gaiani and Benedetti 2010).
- The research concerning the Archaeological Park of Kaukana in Ragusa (Sicily) is a joint project between the Department of Architecture of the University of Catania and the Superintendency of Environmental Cultural Heritage of Ragusa. The aim of the research is the documentation of various aspects of the site which range from the flora and natural context to the archaeological and architectural data. The heterogeneous nature of the objects to be studied as well as the extent of the area led the research team to use 3D laser scanning technology in order to survey the whole system in a more rapid and accurate manner. The 3D acquisitions were carried out with a TOF laser scanner. During this phase some low-cost spherical targets were tested for the following phase of alignment (Galizia and Santagati 2009; Restuccia et al. 2012).

11.3 Three Case Studies in South-Eastern Sicily

The following case studies, each with their own characteristics, contribute to the current debate on the search for methodological standards and operating protocols within the 3D digital documentation of archaeological heritage by means of laser scanning. Moreover, in the approach to the study of these monuments/archaeological sites a reference was made to the principles stated in the Seville Charter.

The research experiences reported here represent the exemplary phases which have contributed towards structuring and improving the methodological path followed. Overall, the operating protocols are closely linked to technical (objective-instrumental) and operational (individual-interpretative) criteria. The first criterion concerns the contribution of technological innovation within the research to both the instruments and dedicated software. Aspects which affect the research work in terms of time, costs, methods of acquisition and quality and quantity of data. The second criterion takes into account the cultural background of the researchers and their experience in the area of study, besides the characteristics of the object to be documented.

In this context, the methodology is structured according to a procedure which concerns:

1. the acquisition of data on-site, curently still in a standardisation phase, characterised by the identification and/or combination of the most appropriate technologies (Benedetti et al. 2002, 2009; Bohler and Marbs 2003; El-Hakim et al. 2004; Guidi et al. 2002, 2009; Lerma 2010).
2. the processing and extraction of data through the use of various dedicated software according to both the typology of data and the aims set in advance.

There are currently no standardised protocols for these two phases which cover the whole process. In fact, it is possible to define broadly a few key phases necessary for the subsequent processing which is conducted empirically by the researcher:

- *Data filtering*. Elimination of isolated points and noise, calculation of the normals, calculation of the depth and orientation discontinuities.
- *Recording of data in a single system of reference*. Manual collimation of the homologous points on pairs of scans and/or semi-automatic alignment through the use of 2D or 3D targets.
- *Passage from the numerical model to the polygonal model*. Creation of a triangular mesh which follows the topology of the point-cloud and/or a simplified multi-resolution mesh with fewer triangles by modifying some parameters (maximum dimension of triangles, accuracy, proportions of triangles, orientation discontinuity).
- Correction and calibration of photographic images on the model.
- Texture mapping of the model.

Nevertheless, it is still not possible to identify unequivocal procedures due to the diverse variables which come into play and which are closely linked to the characteristics of the object as well as being influenced by the interoperability of the software.

Another fundamental passage is that from the 3D model to 2D information often necessary in the study and documentation of the archaeological artefact. Thus, adequate reference systems are chosen in order to extract 2D orthophotos and outputs such as profiles, plans, views and sections.

Moreover, further processing can be conducted on the high-resolution textured models aiming at, for example, visualisation on the Web (by dealing with the problems of the definition of the various levels of details) as well as the structuring of data in a semantic information system (through segmentation and parametrisation). These latter issues are still under study by the various teams working on the identification of methods and procedures (Guidi et al. 2009; Pecchioli and Mazzei 2011; Fantini 2012; De Luca 2011; Manferdini et al. 2008).

11.4 Digital Survey and Conservation: The Sepulchral Monument Named "Torre Rossa"

The first case study aims to provide information about the Roman funerary monument named "Torre Rossa", located in Fiumefreddo di Sicilia (Catania), for its conservation (Buda et al. 2012; Cluverio 1619; Wilson 2003). The state of conservation of the monument and the difficulty in identifying some of its typological features required a critical interpretation and the integration of the data acquired through various cognitive analyses for a suitable conservation intervention. Probably dating back to the end of the first century and the mid-second century AD, the monument is shaped like a high parallelepiped (about 8 m tall) placed on a three-step podium and with a semi-underground funerary chamber. The chamber has a barrel vaulted ceiling and there are two pairs of niches on three walls, which originally contained cinerary urns.

There was a stairway to enter the sepulchral chamber, of which some traces still exist, along the south-western wall, near the western corner. This led us to think that the entrance door was in this place, where before the restoration there was the largest missing part in the brickwork (Fig. 11.1a, b).

The stairway continued by up inside the southern and eastern walls, until it opened onto the summit. The opening on the eastern side of the structure is modern.

The whole of the lower part had been chiselled and stripped of its brick covering, undoubtedly used by the local peasants for their houses, compromising the stability of the monument.

The severe state of deterioration of the building was already visible in the eighteenth century as depicted in iconographical representations made by Jean Houel (1782–1787). In 1782, the French traveller portrayed the stripping of the brick wall surface of the lower part which gave the monument a mushroom-shaped outline (Fig. 11.2).

Solid retaining brickworks were added later to prop up the east and south corners, thus further changing its formal aspect.

The state of conservation of the monument required an interdisciplinary approach in order to investigate the following features:

- Historic and iconographic.
- Archaeological.
- Geometric-dimensional.
- Chemico-material.
- Geo-structural.

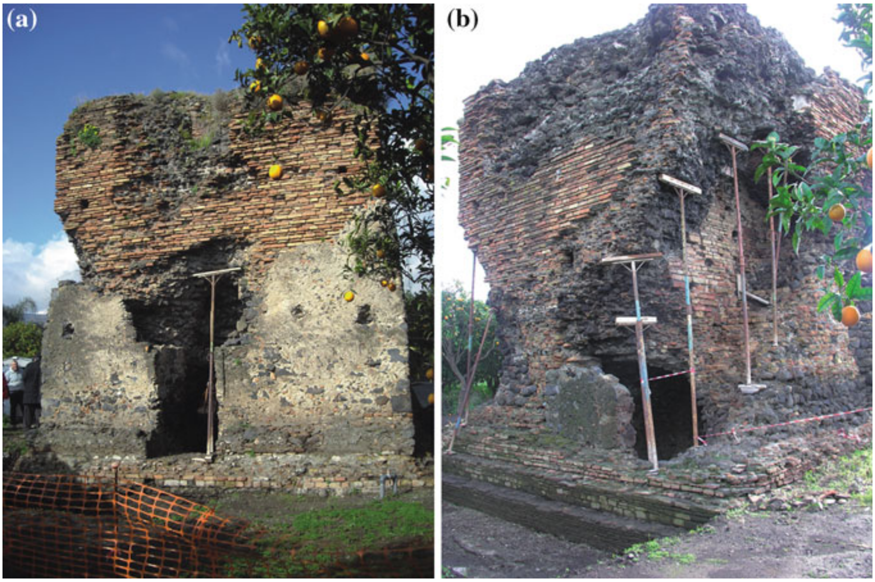

Fig. 11.1 View of the (**a**) South-Eastern Façade and of the (**b**) West corner of the “Torre Rossa”

Fig. 11.2 Guaches by Jean Houel, 1782 (La Sicilia di Jean Houel all’Hermitage 1989) (reprinted with permission)

In particular, the scope was to verify: the typology of the planimetric shape (original entrance, position of the stairway); whether or not the top of the wall complex contained the chamber which Jean Houel had assumed in the description of the monument appearing in his late eighteenth century publication; the building phases (whether the hypogeum and the part above ground, including the stairway, had been built during the same phase); whether any detachments had been the result of movements of the structure as a whole, that is, if it had undergone collapses, fractures or rotations.

The 3D laser scanner model was able to provide accurate documentation on the metric and material characteristics as well as the state of decay of the structure and of its materials. It was also the tool with which to perform and relate the various analyses.

The Leica Geosystem HDS 3000 Time of Flight (TOF) 3D laser scanner was used. The technical specifications are described in Table 11.1.

The scan protocol and the data processing took into account the following steps:

1. Data acquisition;
2. Data processing:

- Registration of data in a single reference system;
- Data filtering;
- Passage from the numeric model to the polygonal model;
- Correction and calibration of photographic images on the model;
- Texture mapping of the model.

1. Data acquisition

The phase of the on-site data acquisition took into account:

- The geometric-spatial and material features of the monument;
- The condition of the structure and the accessibility to the monument;
- The required LOD so as to document the wall surface, the missing parts, the consistency of the cement nucleus and possible fractures in a comprehensive manner. This latter parameter determined the resolution of the cloud of points.

Twenty-one scans were carried out. They were divided into: four station points for the semi-underground chamber; eight station points by the axes and the diagonals of the quadrangle at the base providing a closed polygon for the outside

Table 11.1 Laser scanner HDS 3000 specifications

Accuracy	Position 6 mm; distance 4 mm
Scan rate	4,000 point/s
Field of view	360° × 270°
Range	300 m @ 90 %; 134 m @ 18 % albedo
Spot size	From 0 to 50 m: 4 mm (FWHH-based); 6 mm (Gaussian-based)
Laser class	3R (IEC 60825-1)

lower part; also, four additional station points were planned for completion of the stairway. The survey of the roof entailed five station points: four by the corners and one by the stairway landing. The scans were carried out at a height of 9 m by using a basket lift firmly fixed to the ground.

2. Data processing

Cyclone software, provided by Leica Geosystems (data registration), and Reconstructor by Gexel (following phases) were used for:

- *Registration*. The 21 scans were assembled in one reference system, for a total of 61 million points, through the identification of homologous points between contiguous scans. The average initial maximum error of alignment equal to about 13 mm was reduced to 4 mm by optimising the parameters of calculation (sub-sampling percentage; maximum number of interactions).
- *Data filtering*. Pre-processing of the clouds (noise filtering, calculation of depth and orientation discontinuities, calculation of the confidence interval and of the surface inclination).
- *Passage from the numeric model to the polygonal model*. In order to comprehensively document the roughness and the material characteristics of the artefact high-resolution meshes were created (Fig. 11.3a). This resulted in a high number of triangles which made the visualisation and management of the file difficult.
- *Correction and calibration of photographic images on the model*. High-resolution images using a Nikon E8800 camera with 8 MP resolution were acquired. The calibration of the images on the point-cloud was, then, performed through the collimation of homologous points. A mean deviation of 1 pixel (about 0. 02 % of the image size) error was obtained.

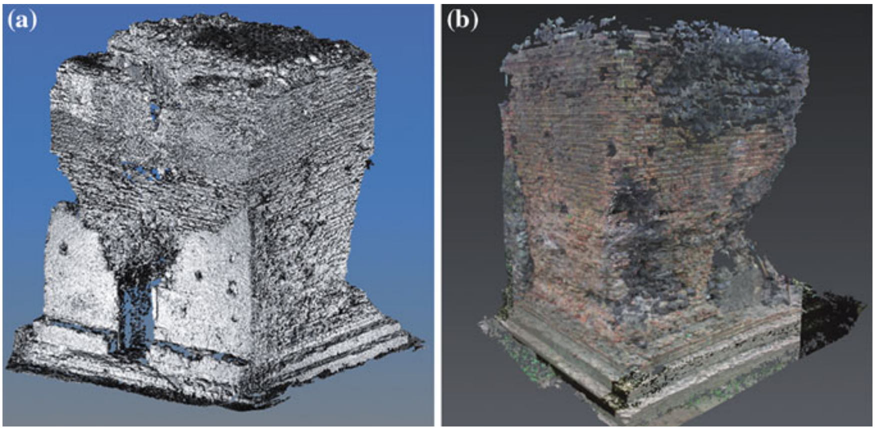

Fig. 11.3 View of the (**a**) mesh and of the (**b**) textured model of "Torre Rossa"

- *Texture mapping of the model*. The images were projected on the mesh model, and a radiometric correction was carried out since they were acquired in various light conditions (Fig. 11.3b). This final phase entailed some issues due to software bugs and the computational capabilities of the computer. Then the clustering of the meshes in one textured model was carried out.

The 3D textured model provided a very faithful record of the monument and was able to detect, to recognise and to map the areas of decay on the wall surface.

Furthermore, the 2D technical drawings (plans, elevations, sections), useful for the geometrical, spatial and material-stylistic knowledge of the construction as well as essential for the drafting of the restoration project, were obtained from the 3D model.

Being able to use a digital copy of the monument on the computer contributed to a more dynamic approach to the interpretative process since it was possible to generate, at any time, new information to compare with hypotheses as they were being formulated (including static characteristics and comparison with Houel's drawings).

We chose to perform the graphic analysis on the monument using Cloudworks, a plug-in of Leica Geosystem for AutoCAD able to extract horizontal and vertical profiles from the numerical model. This protocol was essential for the study of the static behaviour of the construction: for each side of the tower five section-profiles were drawn in order to identify "out of plumb" walls, the alignments and all other information useful to the designers responsible for structural consolidation.

Also, the choice of the heights at which the plans were to be made was defined according to our knowledge of "Torre Rossa" (Fig. 11.4a). Seven plans were made: at 0.70 m from the floor of the chamber (documentation of the underground chamber); at the heights at which two core drillings were made; at the impost of the vault of the chamber, at the height of the roof and at another two intermediate heights.

The 2D and 3D documentation of the funerary monument made the typological features of the construction, now in a severe state of deterioration, clearer and more comprehensible.

Specifically, in order to plan a suitable conservative intervention was necessary to compare the survey and the drawings of the "Torre Rossa" passed down by Jean Houel (the only documentation of the structure).

In the section drawn by Houel the funerary chamber is almost completely above the ground, unlike the current structure in which is semi-hypogeal. Furthermore, the height of the funerary chamber is about 35 cm less than that surveyed and the entrance of the chamber lies along an axis in line with the North-Western Façade, a hypothesis not completely supported by the surveyed data (Fig. 11.4b). This led us to suppose that the entrance should lie on the western corner.

Further diagnostic tests (endoscopy) verified the absence of an additional inaccessible funerary chamber inside the huge wall block (Buda et al. 2012). Moreover, the homogeneity of the composition of the lime mortar samples taken from both the inside and the outside of the brickworks dispelled possible doubts

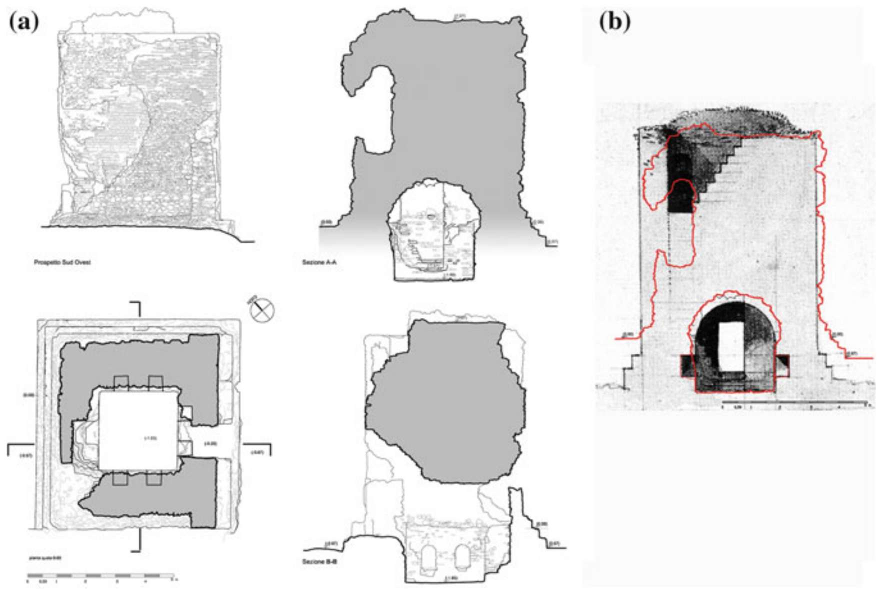

Fig. 11.4 (**a**) 2D graphical representations and (**b**) superimposition of the survey drawings on Jean Houel's drawing

and confirmed that the tomb was built in one phase, even though it must be assumed that because of the presence of the stairway it once had at least one additional floor.

Finally, it was verified that the deterioration progressed only because the wall surface became heavier as a result of vegetation growing on the structure. This was corroborated by the high quality of the mortar and of the bricks and by the absence of relevant structural movements.

The resulting digital model allowed us to simulate the possible phases of the project for the stabilisation and the integration of the original walls and of the small vaults which covered the stairway, whilst also retrieving the original structural scheme.

11.5 Digital Survey and Geometric Study: The "Terme dell'Indirizzo" in Catania

The second case study addressed our knowledge and interpretation of the geometry, building and material complexity of the archaeological site "Terme dell'Indirizzo" in Catania. The characteristics of the archaeological complex required a close examination through the use of digital technologies. Consequently we are able to reproduce a complete 3D documentation of the site.

Fig. 11.5 View of the thermal complex of S. Maria dell'Indirizzo

The thermal complex (Fig. 11.5) lying in the historic centre of Catania is partially incorporated in the structures of the eighteenth century Carmelite Convent of Santa Maria dell'Indirizzo, now home to the Amerigo Vespucci primary school.

The construction has been dated back to the late Imperial Age (II c. A.D.) by some scholars, although, to this day, the various chronological phases have not been clearly defined. Its proximity to the port has led the scholars to suggest a public use for the thermal complex (Branciforti 2005).

Of the imposing ruins ten rooms, covered with the original vaulted structures, still remain. The wall structure consists of a cement mortar core covered with square blocks of lava rock. The floor is now at a height beneath the street level. The inner rooms can be accessed through a small stairway lying on the north-eastern corner.

Inside the building, the *frigidarium* and the *tepidarium*, along with annexed rooms of smaller dimension, the *apodyterium* and the *laconicum,* can be identified. From the *tepidarium* it is possible to access an octagonal room topped by a hemispherical dome with large openings—the *calidarium*. On the walls of the *caldarium* are three quadrangular niches, *clipei*, covered with barrel vaults. Probably, the *clipei* were originally furnaces for heating the halls, the air in the ducts and the water in the pipes.

To survey the site the Cyrax 2500 Laser Scanner, whose technical specifications are indicated in Table 11.2, was used.

The scan protocol and the data processing took into account the following steps:

1. Data acquisition;
2. Data processing:

- Registration of data in a single reference system;
- Data filtering;
- Passage from the numeric model to the polygonal model;

Table 11.2 Laser scanner Cyrax 2500 specifications

Accuracy	Position 6 mm, distance 4 mm
Scan rate	1,000 point/s
Field of view	40°×40°
Range	100 m
Spot size	From 0 to 50 m: 6 mm
Laser class	2 CFR 1040

- Correction and calibration of photographic images on the model;
- Texture mapping of the model.

1. Data acquisition

The data acquisition project took into account:

- The characteristics of the site;
- The geometric-formal aspects of the thermal complex;
- The characteristics of the instrument being used.

The narrow angular field of view of the instrument, along with the planimetric complexity as well as the small dimension of the rooms, affected data acquisition of the interior (Giuffrida et al. 2005).

The impossibility of applying reflective targets onto the artefact made it necessary to plan a dense mesh of station points so as to carry out both general and high-precision acquisitions in order to identify well-recognisable references for the following phase of alignment of the scans.

Thirty-four scans were planned: 7 external stations and 8 scans (5 land scans and 3 from above); 14 internal stations and 26 scans. In particular, for the survey of the *calidarium*, the acquisitions were carried out according to a radial pattern and by making 2 scans for each station point, thus setting up 8 station points and making 16 scans. A further hyposcopic and barycentric scan completed the survey of the dome ceiling.

2. Data processing

The Cyclone software by Leica Geosystem (data registration) and Reconstructor by Gexel (following phases) were used for:

- *Registration*. The 34 scans were assembled into a single reference system generating 24,000,000 points. The alignment was carried out through the identification of homologous points. The difficulty in finding notable points of reference on lava rock masonry was overcome thanks to the high density of points acquired. From the operational point of view, in order to obtain better error compensation, polygonation was achieved, where possible, by hooking each scan to the scans preceding and tracking in both a vertical and horizontal direction so that the last scan reconnected to the first scan. The optimisation of some parameters (subsample percentage, number of interactions, max search distance), which were conveniently balanced in order not to make the calculation too heavy without losing robustness, allowed us to minimise the alignment error between the scans. This latter remained, in fact, at about 7/8 mm on average, and, in some instances, it decreased to 4 mm.

- *Data filtering*. Pre-processing of the clouds (noise filtering, calculation of depth and orientation discontinuities, calculation of the confidence interval and surface inclination).
- *Passage from the numerical model to the polygonal model*. In this phase both high-definition meshes (useful in 2D representations) and meshes simplified through the definition of multi-resolution parameters were created. The set parameters made the file smaller without losing the geometric precision of some fundamental elements.
- *Calibration of photographic images*. For the image data acquisition a NIKON E4100 digital camera was used. The small dimension of the inner rooms required the use of a wide-angle lens, in order to reduce the number of photographs. The calibration was obtained through the collimation of the homologous points which were well distributed and visible within the margin of a 1.2 pixel error.
- *Texture mapping*. The images were re-projected on the mesh model. The strong contrast between bright and dark areas inside the thermal complex affected the quality of the acquired photographic images thus making their radiometric correction necessary, in order to improve the photographic quality of the overall textured model. Finally, clustering of the mapped meshes into a single textured model was undertaken.

The complete 3D model thus obtained (Fig. 11.6a, b) is a copy of the real object which allowed analysis and control, as well as the measurement and evaluation, of the dimensional characteristics of the thermal complex.

The resulting point-cloud provided the basis for the production of both traditional (plans, views, sections) and 3D (mesh, orthophoto, photographic model) outputs, with the additional advantage of immediate communication for non-experts.

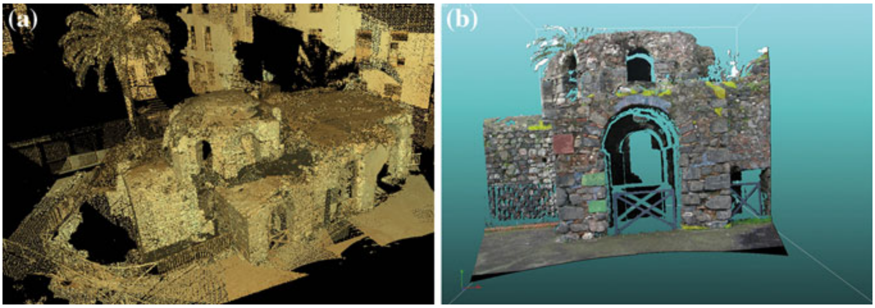

Fig. 11.6 View of the mesh (**a**) and textured (**b**) model

Moreover, the reflectance datum associated with each surveyed point, besides being an essential element for the operations of both the collimation of the points and the texture mapping, allows us to formulate hypotheses on the nature and deterioration of the materials which form the studied surface, thus making possible a further close examination of their state of conservation.

Once the overall model was fine-tuned, its 2D analysis was started in order to describe the geometrical conformation of the thermal complex in a comprehensive manner according to traditional documents. Then, a geometric analysis was carried out of the octagonal room of the *calidarium* and its hemispheric dome.

The identification of planimetric conformation at various levels (under and above ground) was obtained through the use of CAD. The textured model was then re-projected in compliance with selected planes thus obtaining metrically exact orthophotos which enriched the 2D plans as well as documenting the nature of materials, the use of colour and the state of conservation of the artefact. In addition, three vertical cross-sections, traced along the planes regarded as the most significant for the subsequent processing on the room of the *calidarium* (Fig. 11.7), were extracted from the model.

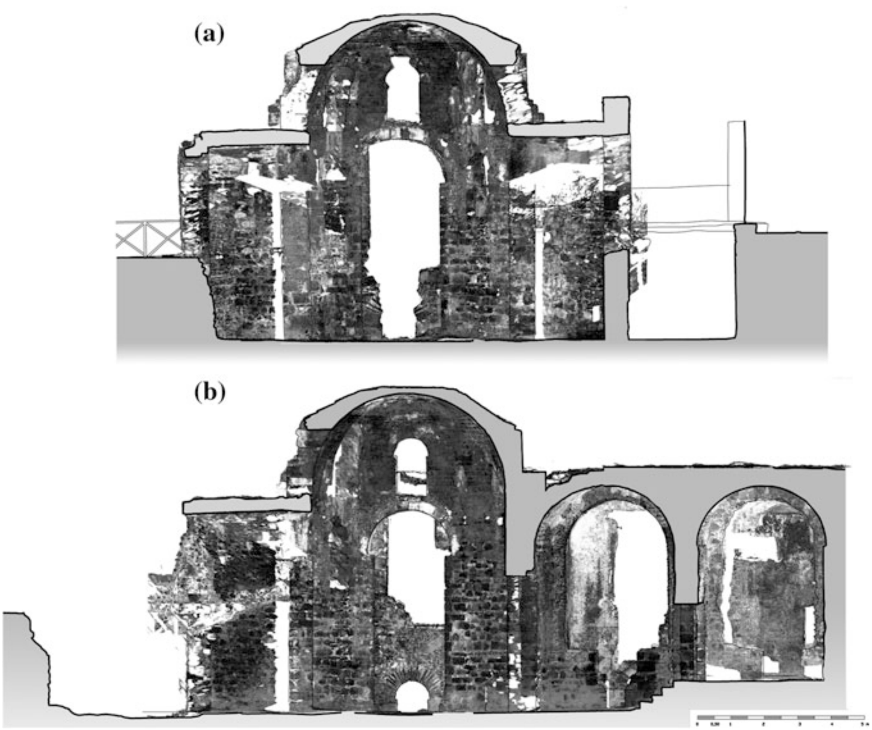

Fig. 11.7 Transversal (**a**) and longitudinal (**b**) cross sections

This latter process proved to be fundamental to the study of the geometric matrix of the dome, making possible the identification of the curvature of the surface as well as its variation between the lower octagonal structure and the upper circular structure.

The hyposcopic plan with orthophotos played a special role in the study of the geometric matrix of the dome (Giuffrida et al. 2007). As a matter of fact it facilitated the interpretation of the octagonal ichnographic structure of the room and highlighted the characteristics of the dome which consists of concentric rings of square stone ashlars linked to staggered joints.

Fourteen horizontal sections with a 20 cm step-scan were then extracted from the 3D model of the dome, thus obtaining the first contour representation of the analysed vaulted surface (Fig. 11.8a, b).

These sections were integrated with five vertical radial sections (along the apothems and diagonals of the octagon) to support geometric descriptions of the profiles representing the hemispheric vault. These sections also allowed us to identify various potential problems.

It was found that the centre of the hemispheric structure lies on a lower level (about 0.39 m) than the plane of the impost block of the dome (height 7.00 m); and that the radius of the impost block is 2.89 m, whereas that corresponding to the vertical radial sections ranges from 2.925 to 2.955 m.

In order to analyse the geometry of the surveyed surface in an accurate manner, and to compare it with the hypothetical, theoretical surface of the structure, the most significant points of the (horizontal and vertical) generating profiles were selected from the points lying on the intrados.

The average of the centres, radiuses and of the height of the impost block of the selected profiles, identified the possible centre of the theoretical sphere and the relevant theoretical radius (2.933 m) and the height of the impost block (6.63 m).

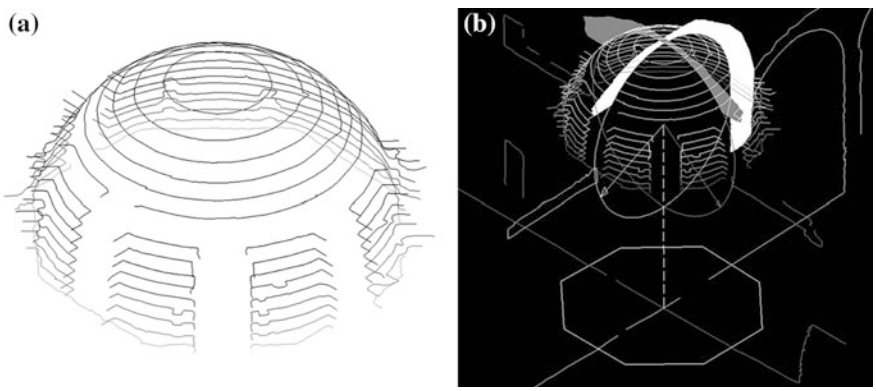

Fig. 11.8 Representation of the *calidarium*'s dome through contour lines (**a**) and geometric study (**b**)

By superimposing the horizontal sections of the intrados of the dome with the corresponding sections of the theoretical half sphere, it was possible to highlight better shifts from the theoretical curve. It can be inferred that the major deformations is north-south along which the shift between the two curves reaches a maximum value of 6 cm.

The analysis of the intrados of the dome which was carried out on the point-cloud, thus highlighting the interruptions, the irregularities, the variations of curvature, the depressions, as well as quantifying, localised partitioning, deformations, or events which have affected the structure over time.

11.6 Digital Reconstruction and Enhancement: The Catacombs of San Giovanni in Syracuse

Whilst the study on "Torre Rossa" aimed to explore its conservation issues and that on the "Terme dell'Indirizzo" addressed our knowledge and interpretation of the archaeological site, the aim of the study on the catacombs of San Giovanni in Syracuse was the understanding and documentation of the building for its enhancement and dissemination across both the cultural tourist network in Sicily and on the web, through the creation of interactive models, virtual reconstructions, etc. (Bonacini 2011; Bonacini et al. 2012). Hence, this study involved different disciplinary areas.

The archaeological complex comprises the catacombs, the ruins of the Basilica of San Giovanni Evangelista and the crypt of San Marciano. These spanned the centuries between that of Classical Greece and Late Antiquity. The archaeological site is a monumental cemetery with various burial types: niches, tombs, *sub divo*, all commissioned by pagans (Fig. 11.9). It was designed with an almost regular urban plan which re-uses pre-existing hydraulic structures (aqueducts, private drains, circular or conical section wells and bell-shaped cisterns) of the ancient city of Syracuse (Collin-Bouffier 1987; Griesheimer 1989; Tolle-Kastenbein 1990; Tolotti 1980; Sgarlata 1996), thus facilitating the construction of tunnels, *lucernaria* (skylights) and private chambers (the rotundas of Marina, Adelfia and *Sarcophagi*).

The considerable historical stratification of the catacomb complex as well as its plano-altimetric and geometric-spatial complexity, required a 3D methodological approach to survey, planning and 3D visualisation. In fact in this example the use of digital technologies (Zimmermann and Esser 2007), including a 3D laser scanner was essential, and was a powerful research tool to support archaeological studies for the enhancement of the site.

The laser scanning survey allowed us to obtain a 3D model that documents and makes the underground space visible through virtual reality models which are metrically accurate and rich in material and dimensional information. During the

Fig. 11.9 View of the rotunda of Adelfia

first part of the project, four adjacent private rooms were surveyed: the Adelfia and Sarcofagi rotundas, which are probably built on pre-existing hydraulic structures, the Eusebio and Paolo quadrangular cubicula and their connecting tunnels (Fig. 11.10).

A Leica Geosystems HDS 3000 TOF Laser Scanner was used, whose technical specifications are indicated in Table 11.1.

The scan protocol and the data processing took into account the following steps:

1. Data acquisition;
2. Data processing:

- Registration of data in a single reference system;
- Data filtering;
- Passage from the numeric model to the polygonal model;
- Correction and calibration of photographic images on the model;
- Texture mapping of the model.

1. Data acquisition

The data acquisition project took into account:

- The complex grid system that is composed of a variety of galleries and large rooms connected together;
- The characteristics of the spaces that contain multiple niches and *arcosolia* cut perpendicularly into the rock walls and laid out side by side.

The surveying protocol involved six scans: one for each area to be surveyed (in a barycentric position) and two transition scans. These latter two were captured

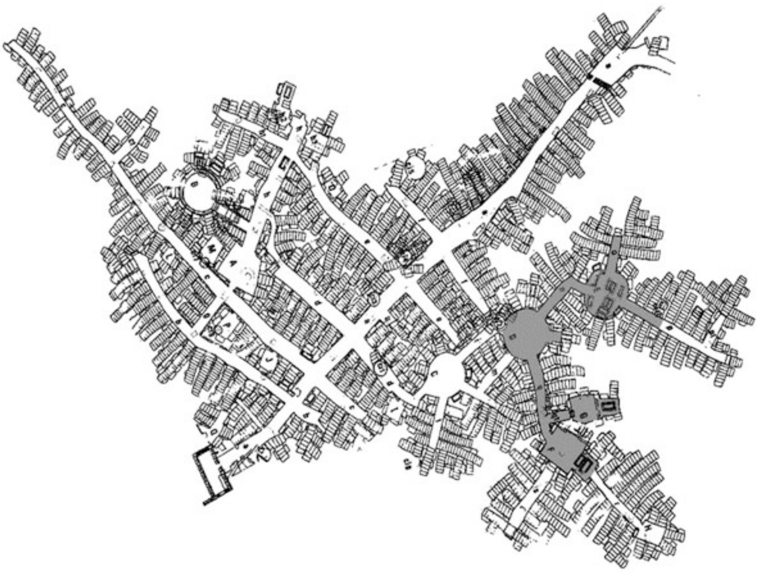

Fig. 11.10 The ground plane of the catacombs where the areas of interest are highlighted in *grey*

from the galleries so as to survey the numerous *arcosolia* in as detailed a manner as possible, while also reducing black areas necessary for scan realignment within a single system of reference.

In the *Sarcophagi* rotunda, the station point was chosen in order to mediate between the option of a barycentric position and the necessity of documenting the seven maidens *sarcophagi* that occupy most of the space. Particular attention was given to the problems of the angles of the laser beam on the walls of the narrow passage tunnels.

In order to optimise laboratory processing a network of reflecting targets was used: 29 targets were scattered across the surface of the walls, and they were detected and acquired by the scanner (minimum of 4 targeted control points for each point-cloud).

2. Data processing

After completion of the metric data acquisition on site the post-processing of the point-clouds was undertaken in the laboratory, using dedicated software (Cyclone and CloudWorks by Leica Geosystems, Reconstructor by Gexcel):

- *Registration*. The alignment of scans in a single reference system was carried out in an automatic way thanks to reflecting targets acquired by the instrument on site (Fig. 11.11a). In the absence of a topographic survey and a closed mesh of stations, the alignment procedure was carried out in order to ensure a uniform error distribution. Specifically, the recording was performed using triplets of

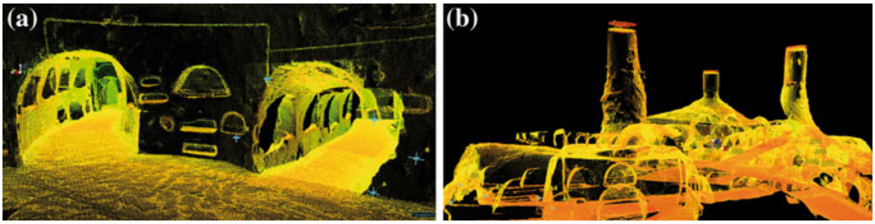

Fig. 11.11 Point-cloud where reflecting targets are scattered across the surface of the walls (**a**); the 3D model of the cubicles of Eusebius and Paul in RGB visualisation (**b**)

clouds, which had been adjusted during scanning of the rotunda of the Adelfia which, when compared with the others, is barycentric and in a transient position. Optimising the calculation parameters (sub-sampling percentage, maximum number of iterations), the 10 mm average initial maximum error of the individual triplets alignment was reduced to 4 mm. Instead, the overall model error is equal to 4 mm. The comprehensive model thus obtained consists of 6 scans and a total of 46,940,251 points (Fig. 11.11b).

- *Passage from the numeric model to the polygonal model*. Two different types of mesh were created. The first one was a tight mesh, in order not to lose important surface information. This was intended to be used to create products such as orthophotos. The other was a simplified mesh used to generate a lower number of polygons and required for better management and visualisation of the files in interactive virtual environments and the Web.
- *Correction and calibration of photographic images on the model*. The photographic acquisitions took into consideration the small areas and low lighting levels of the environment. Specifically, we used a Canon EOS-1Ds Mark III digital camera with 24–105 mm and 14 mm objectives and a maximum resolution of 21 MP. After several attempts to identify the optimal acquisition conditions (with or without the spotlight, with or without a flash, with or without a wide angle, mediating exposure and ISO sensibility), it was used on a tripod and for remote control distance acquisition, operating in a semiautomatic way and using a focal distance equal to 14 mm, an ISO sensitivity of 800 and depth of field equal to *f*/18 by varying the exposure time between one acquisition and the other. Barrel distortion of photographic images was corrected using PTLens software. The calibration of the images to be re-projected on the model was performed by the Cyclone software through the selection of homologous points, between the photos and the cloud of points. The average deviation of re-projection was equal to 1.5 pixels (Figs. 11.12).
- *Texture mapping of the model*. The images were projected on the mesh model, and a radiometric correction was carried out as the images were acquired in various light conditions.

Moreover, a graphic analysis of the point-cloud was needed in order to document the geometry of the archaeological complex in plan and elevation. To draw

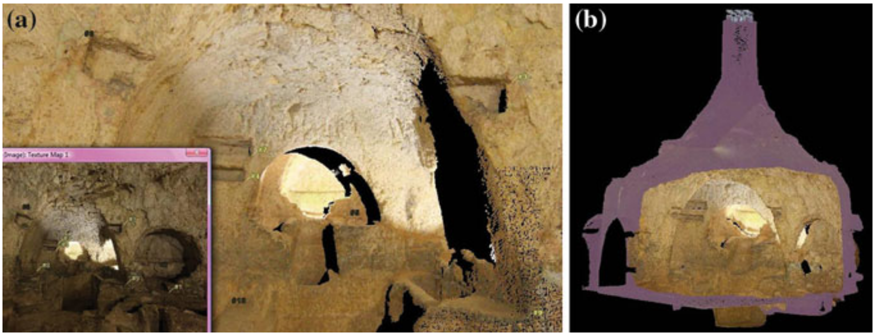

Fig. 11.12 (**a**) Texture map phase and (**b**) re-projection of the calibrated image on the point-cloud

the site plan two horizontal planes taken at different levels of the archaeological site were used, so as to be able to document the most representative typological elements (*arcosolia*, *sarcophagi*, niches, secondary galleries) as accurately as possible (Fig. 11.13). Also, several offset vertical cross-sections were carefully selected, each of them showing specific views of the complex: the axis between the entrances to the galleries, the skylight's axis, the centre of the rotundas and the quadrangular cubicula. Therefore, section planes of the surface of the ceiling intrados were also obtained, as well as the width and depth of the skylights (Fig. 11.14). The arching of the intrados that cover the rotunda has the shape of a somewhat irregular, wrinkled inverted cone, in contrast to that documented in the literature which depict the curved ceiling intrados as a dome (Galletta 2001).

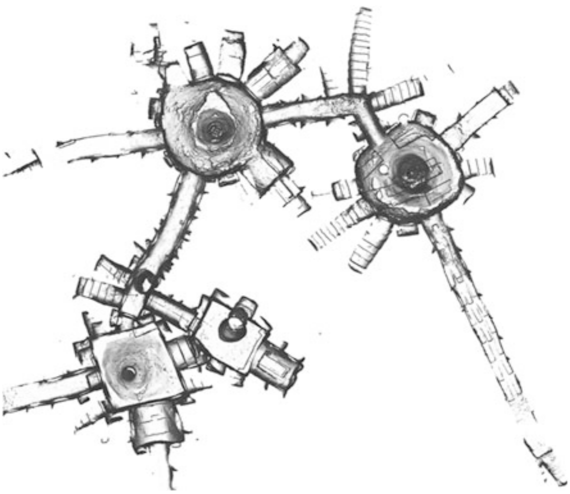

Fig. 11.13 Top view of the point-cloud

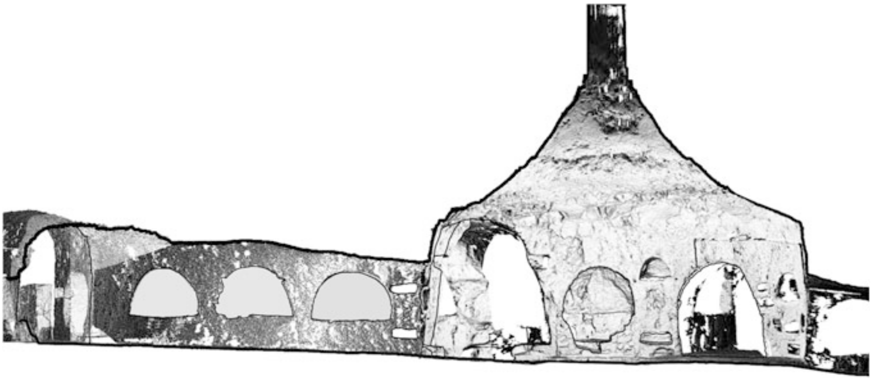

Fig. 11.14 Vertical section of the Rotunda of Adelfia

Work on the complete 3D surveying of the San Giovanni archaeological complex is still underway. To date only a small portion has been surveyed and analysed by means of laser scanning. To complete the project large amounts of data will have to be acquired, modelled and processed using specific procedures and advanced data processing technology.

The 3D data now available allows us to appreciate the spatiality of the rooms and their material characteristics. It provides high quality documentation on which to conduct multi-disciplinary research.

The digital model is also the basis for structuring a 3D information system that contains the available dimensional, archival, bibliographic, documentary, literary, epigraphic, historical, religious, economic and social information. Moreover, it can help retrace the timeline of the various phases of the complex (De Luca 2011), as well as the lighting and ventilation of these underground spaces through interactive 3D visualisation projects, Web-based applications (Pecchioli and Mazzei 2011) or through augmented reality (Inzerillo 2011, 2013; Stanco et al. 2012).

11.7 Discussion and Future Work

The three documented examples are particularly interesting for their various distinctive characteristics. Together they represent a valid example of methodological procedures following the principles of the Seville Charter including the preliminary identification of the final objectives (principle 2); the interdisciplinarity of the work groups (principle 1); the complementarity and integration of instruments (principle 3); and technological sustainability and efficiency (principle 6).

Such protocols are also implemented during the data acquisition phase and are already partly standardised. During the post-processing phase a common pipeline, customised according to the aims of the study as well as the peculiarities of the site/monument, was used and verified.

These experiences highlighted the need to use both traditional and innovative approaches and instruments which, integrated together, contribute to the documentation and understanding of the archaeological heritage. The data obtained through the laser scanner, unlike traditional representations, provided a 3D visualisation which documents and analyses the object being studied through high-resolution photo-realistic models. This latter feature allows us to appreciate the material characteristics as well as the state of preservation of the archaeological structures.

Finally, digital models were obtained which made it possible to carry out detailed studies, to extract sections/profiles and to represent them at according to various scales. In respect of "Torre Rossa," which was concerned with the conservation of the structure, the data obtained through the 3D laser scanner were compared with available iconographic documentation. The only available studies are attributed to the French traveller Houel: guaches in which, despite the well-known rigour of the French scholar, contain evident incongruities (principle 5: Historical rigour). Moreover, by use of 3D models it was possible to interpret deterioration and instability in both qualitative and quantitative terms, and according to various points of view. Also, the accuracy of the metrical data made subsequent geometric analyses possible. The geometry of the vaults/cupolas of the ''Terme dell'Indirizzo'' was studied through the extraction of vertical and horizontal profiles.

Finally, several vertical profiles were surveyed across the Catacombs of San Giovanni in order to understand the geometry of the excavation of the bedrock, which suggested a precise curvature and a possible original use as cisterns for the collection of water. In addition, the 3D model provides the base on which to create an interactive information system. The rigour of the approach makes the cognitive process one which can be repeated and tested by other researchers (principle 7: scientific transparency).

11.8 Conclusions

This work demonstrates that, using 3D laser scanner survey, it is possible to manage high-definition photo-realistic 3D models which, besides revealing the complex morphology of the structure and discontinuities of the material which characterise them, are models on which material, dimensional, geometric and structural research can be carried out through the creation of profiles, sections and orthogonal projections.

The reliability of the data compared with the existing documentation was also demonstrated. For each case study such a methodological approach led to unexpected and new outcomes going beyond the original expectations. Therefore, the 3D digital models thus obtained provide new opportunities for interpretation, conservation and re-presentation in the future.

Acknowledgments The study on “Torre Rossa” was conducted in collaboration with the Superintendency of Cultural Heritage of Catania within the project for the “Works for making secure and restoring the Roman sepulchral monument named “Torre Rossa” in Fiumefreddo di Sicilia (Catania)”: Director Architect Giovanna Buda, Director Archaeologist Dr. Francesco Privitera and Surveyor Salvatore Vitale. The 3D data acquisition and processing were carried out by Cettina Santagati and MariateresaGalizia.

The study on the “Terme dell’Indirizzo” was conducted within the research of the Laboratory of Architectural Photogrammetry and Survey. The in situ acquisitions and the alignment of the scans were carried out by Alessia Giuffrida, Mariangela Liuzzo and Cettina Santagati. The following processing included in this publication was carried out by Cettina Santagati.

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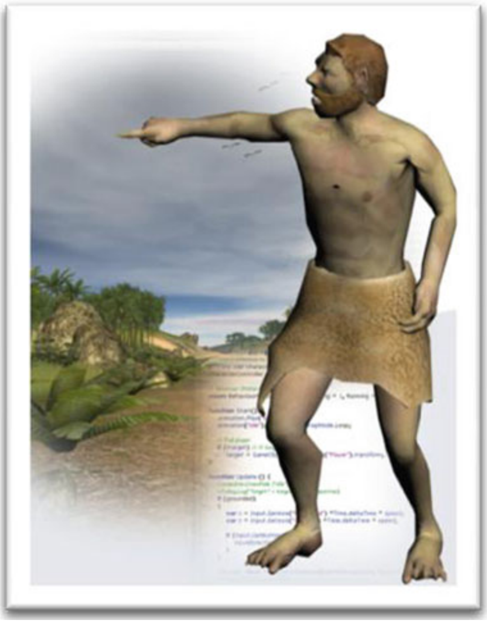
Part III
The World's a Stage
Agents and Agency in a Digital World

There has been considerable debate about the validity or adequacy of digital representation of society or even individuals. These issues manifest themselves in a variety of manners ranging from concerns regarding the Cartesian nature of spatial analysis (Tilley 1994, p. 7–11) through to daunting theoretical finessing of the complexity of human action (Hodder 2012). Despite such a situation we cannot sidestep the subject as, almost inevitably, heritage studies must consider the complexities of society as represented by the object of study or through consideration of the impact of digital technologies upon the observers themselves. Chapters here represent different approaches to the subject and demonstrate our increasing capacity to integrate disparate quantitative and qualitative data within



computational modelling of societies and environments. The purpose of such studies is to generate data that fill gaps in our information space and create situations where previously unrecorded knowledge, may become manifest. Such computational modelling and simulation, which may represent the leading edge in Digital Heritage (Costopoulos and Lake 2010), often incorporate the application of Complexity Theory, and models can involve the production of sophisticated, quantitative maps or emergent complex systems generated from semi-naturalistic environments and utilising the actions of potentially millions of autonomous agents.

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Chapter 12
Simulation and Visualisation of Agent Survival and Settlement Behaviours in the Hunter-Gatherer Colonisation of Mesolithic Landscapes

Eugene Ch′ng and Vincent L. Gaffney

Abstract Agent-based modelling and simulation of survival and settlement behaviour via interactive visualisation could potentially become a useful technique for generating new knowledge in those areas that sparse information, acquired through traditional methods, does not allow researchers to make informed decisions about past behaviour. This is particularly important following the development of remote sensing technologies that, in marine environments, are permitting novel exploration of previously inaccessible historic landscapes. This article explores and develops an agent-based model for basic survival and settlement behaviour for Mesolithic communities based within a marine palaeolandscape. It discusses the issues regarding how agents can be created to react to resource and environmental needs and limitations. The methodological study examines individual agent behaviour and sets the foundation for future, more complex scenarios that span large spatio-temporal landscapes including the North Sea and European coastal shelves. The article also considers the key technical challenges that must be met if large complex scenarios emerge in which the modelling of interaction between vegetation, animals and human groups becomes a priority.

Keywords Agent-based modelling · Simulation · Hunter-Gatherer · Mesolithic · Landscape archaeology

E. Ch′ng (✉) · V. L. Gaffney
IBM Visual and Spatial Technology Centre, Digital Humanities Hub,
The University of Birmingham, Edgbaston B15 2TT, UK
e-mail: e.chng@bham.ac.uk

V. L. Gaffney
e-mail: v.l.gaffney@bham.ac.uk

E. Ch′ng · V. L. Gaffney
Centre for Creative Content and Digital Innovation, Universiti Malaya,
50603 Kuala Lumpur, Malaysia

E. Ch′ng et al. (eds.), *Visual Heritage in the Digital Age*,
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12.1 Introduction

The only lands on Earth that have not yet been explored in any depth by science are those that have been lost to the oceans. Rising global sea level at the end of the last Ice Age inundated vast landscapes on continental shelves that were home to thousands of people. Across the world, they represent one of the last frontiers of geographical and archaeological exploration (Bailey 2004). Doggerland, occupying much of the North Sea between continental Europe and Britain, is amongst the most significant of these lost landscapes.

The central importance of Doggerland to understanding the earlier prehistory of north-west Europe has only truly been appreciated in recent decades (Coles 1998; Peeters et al. 2009), brought home by the quantities of prehistoric faunal remains and artefacts recovered from the seabed in the course of trawling and dredging for minerals (Flemming 2004). Undoubtedly, a vast and extraordinarily well-preserved prehistoric landscape—larger than many present-day European countries—lies substantially intact beneath the North Sea and a mantle of marine silts. Its progressive inundation has preserved this ancient landscape from the many forces of destruction which apply on dry land. However, what Doggerland gained in terms of preservation it lost in terms of accessibility, and until very recently it remained a tantalising *terra incognita*. Work by the University of Birmingham over the past decade has changed this situation significantly (Gaffney et al. 2007, 2009; Cuttler et al. Forthcoming). Following this the Birmingham team has embarked upon the ambitious goal of bringing Doggerland 'back to life' through a combination of remote sensing technologies, computer-based modelling, simulation and real-time interactive visualisation that go well beyond the state of the art, and this article is part of the computational aspect of such a goal. The project will permit archaeologists not simply to reconstruct landscapes, but to explore them interactively through the actions of simulated hunter-gatherer societies, and the outputs may also inform and transform our understanding of this 'lost world' exponentially.

The research aims of the emerging project may be divided into 'primary aims' and 'methodological aims' as follows:

Primary research aims

- To produce a near complete topographic map of early Holocene Doggerland using seismic reflection data, fully integrated with other data sources (e.g. sea-level curves, seabed cores).
- To model and simulate, using multi-agent systems inspired by the decentralised, 'bottom up' and emergent phenomenon of nature, possible dynamic scenarios for the geomorphological, ecological and human history of Doggerland.
- To use this mapping, modelling and hypothesis generation to inform a programme of seabed coring for palaeoenvironmental and dating evidence which will, along with other proxy data sources, test, or at least constrain, aspects of the models.
- To use computer models and simulation-generated data as a basis for real-time, interactive exploration of the virtual landscape and visualisation of the individual

and collective behaviour and emergent patterns, of the flora, fauna and people affecting the ecosystem.
- To provide a robust framework for future research into and management of this extraordinary scientific, heritage and educational resource.

Methodological aims

- To develop novel methods of using 'legacy' 3D and 2D seismic reflection data to achieve maximal, near complete topographic mapping of Doggerland, overcoming problems of variable data coverage, quality and type.
- To develop innovative methods that will address the numerous challenges related to Agent-Based Modelling on such an ambitious scale. (With agents covering the spectrum of organisms from arthropods to plants, and from vertebrate fauna to intelligent human actors, issues will include the bi-directional relationship of the global and local environmental modelling from a bottom-up perspective; efficient optimisation of agent interaction between the different layers of the trophic networks; agent adaptability and learning; and time compression of multiple levels of simulation).
- To develop new approaches in distributed simulation methodologies which will overcome the enormous computational demands of modelling multi-agent systems at this scale.
- All of the methodological aims involve research that goes beyond the state of the art and will be transferable to other research projects, whether these involve mapping other inundated landscapes or developing very large-scale multi-agent simulations.

12.2 Mapping Doggerland

Until recent work by the Visual and Spatial Technology Centre (VISTA) at the University of Birmingham, maps of the majority of the area of Doggerland were based on little more than informed guesswork. A breakthrough came when members of this team were able to show that extensive seismic reflection surveys carried out for other purposes, notably petroleum exploration, could be used to map the topography of ancient drowned and buried landscapes. This led to the initiation at Birmingham of the North Sea Palaeolandscapes Project, which initially mapped an area of 23,000 km^2 of inundated prehistoric landscape using 3D seismic data donated by Petroleum Geo-Services (PGS) from the western half of their 'Southern North Sea Mega Merge' (Gaffney et al. 2007). The Mega Merge stretches between the UK and the Netherlands and combines more than 60 different surveys, carried out at different times and by various groups, migrated into a single data set. The resulting mapping, covering an area about the size of Wales, has revealed the rivers, lakes and hills, coastlines and estuaries, wetlands and salt marshes of this part of Doggerland, sometimes in extraordinary detail. It must be stressed that the seismic reflection data used cost the companies involved several hundred millions of Euros to collect. The use of this data for a purpose that was not intended—the mapping of Holocene landscapes is currently unique and constitutes incredibly cost-effective research.

At present, mapping of the eastern half of the Southern North Sea Mega Merge is underway at Birmingham, and due for publication during 2013 (Cuttler et al. Forthcoming). This will bring the overall mapping coverage of Doggerland to some 45,000 km^2, an area somewhat larger than the Netherlands. The completion of mapping the Southern North Sea Mega Merge will represent the state of the art. It brings the ultimate goal, near total mapping of the lost Mesolithic country of Doggerland, within reach. One aim of the proposed project is to extend the mapping of Doggerland to achieve the maximum coverage possible. This cannot be achieved, however, just by doing 'more of the same'. The coverage of 3D seismic data (the type of data largely used for the mapping so far) is incomplete. Much of the North Sea is covered only by 2D seismic data, and the intensity of this coverage is variable. As the name suggests, 2D surveys comprise single lines of seismic reflection data (a single streamers is towed behind the survey vessel) producing single vertical profiles through the seabed geology. By contrast 3D survey comprise multiple lines of seismic reflection data collected simultaneously (multiple streamers are towed behind the survey vessel), a method that readily facilitates horizontal mapping.

Over recent years, the Birmingham team has devoted considerable research effort to exploring the possibilities of using the extensively available 2D data both to map areas not covered by 3D data and to enhance the interpretation of 3D data (in general the 2D data has better vertical resolution). This work has shown that, with the development of appropriate methods, the 2D data can be used to produce adequate mapping; it has achieved proof of concept (Fitch et al. 2011). Building on this research, the larger project will attempt to achieve the maximum possible mapping coverage of Doggerland using all available seismic data. A successful outcome would be a major research achievement and a global 'first' opening up new research horizons wherever such landscape exists across the world.

12.2.1 The Complex Systems Science Route to Agent-Based Modelling

The mapping of Doggerland opens up the possibility of bringing it back to life, virtually, through experience gained within the Birmingham research groups in large-scale computer modelling and simulation (Ch′ng 2007a, 2009a, b; Craenen and Theodoropoulos 2010b). This work is crucial as the possibilities for exploring Doggerland using conventional means applied by archaeologists and palaeoecologists are limited, and for much of the area completely impractical. Where traditional fieldwork can operate costs remain exceptionally high, and to be cost-effective such work must be hypothesis-driven and maximally informed by the insights that remote sensing and computer modelling can offer.

The main thrust of the research is therefore to use innovative mapping as a foundation on which to develop dynamic computational models of the changing geomorphology, ecology and possible human settlement of Doggerland, from the opening of the Holocene around 10,000 BC until its eventual total inundation around 5500 BC. The development of computational methods such as agent-based modelling and simulation in this chapter will lay the groundwork for the future exploration of the impacts of gradual change and catastrophic events on prehistoric society, such as the mega-tsunami caused by the Storegga submarine landslide about 6100 BC (Weniger et al. 2008). As Doggerland is being mapped extensively and in detail, the computational methods developed here will be tested against a programme of ground truthing, guided by the mapping and behavioural modelling.

In an ambitious departure from conventional approaches, the intention is to use techniques in Artificial Life for modelling biological processes, Artificial Intelligence for human intelligence modelling and Agent-Based Modelling to simulate the interaction of the biotic and abiotic factors in the ecosystem—vegetation, fauna and people—and its dynamic interactions. It is essential that the models leverage concepts from Complex Systems Science, the study of Complex Adaptive Systems (Holland 1995; Kauffman 1993; Mitchell 2009; Waldrop 1993) as the basis for the simulation as the various levels of interaction and population produces very different self-organisation and emergent behaviour (De Wolf and Holvoet 2005). For example, if a hundred army ants (*E. burchelli*) are placed on a flat surface, they will walk around and around in never decreasing circles until they die of exhaustion. But if you put half a million army ants together the group as a whole becomes what some have called a "superorganism" (Mitchell 2009). As the notable physicist Phillip Anderson (Anderson 1972, p. 1) puts it "The behavior of large and complex aggregates of elementary particles, it turns out, is not to be understood in terms of a simple extrapolation of the properties of a few particles. Instead, at each level of complexity entirely new properties appear, and the understanding of new behaviors requires research which I think is as fundamental in its nature as any other". Anderson's reference to elementary particles in this case gives insight into the varying complex interactions that occur in biotic relationships, which is similar in other physical systems in the appearance of new properties (see Camazine 2001) except that living organisms have a higher more complex level of principle rules possibly from their belief, desires, intentions, or intelligence. The ability to repeatedly run simulation with varying parameters and initial conditions will allow us to observe general trends of global states resulting from the aggregate interaction of individual entities and environmental conditions. The introduction of organic and intelligent properties into models will make development more difficult than particle simulation. However, in the longer term, the data generated will be worthwhile for the effort. The Complex Systems Science route to palaeolandscape modelling and simulation we believe will revolutionise analysis and interpretation in landscape archaeology.

Conventional modelling is typically static and 'top-down', with species' ranges and population dynamics predicted on the basis of state variables (Otto and Day 2007). State variable models (systems of differential or difference equations) in most cases cannot generate specific information, much less predictions on the local and global level behaviour arising from the local interactions (see Lynch 2006, 2008 for a comparison). Agent-Based Modelling, particularly Individual-Based Ecology, is fundamentally different. It is nature inspired and mimics nature's decentralised, 'bottom up' processes, taking individual organisms as its building blocks (Grimm and Railsback 2005; Resnick 1994). The focus of the approach is on the rules that govern the behaviours of individual organisms (the complexity of human behaviour represents a particular challenge) and on their interaction with biotic and abiotic factors (Ch′ng 2009b; Langton 1986; Resnick 1994). As observation of nature suggests, higher level patterns emerge from the individual behaviours of organisms and their interactions (Camazine et al. 2001; Sole and Goodwin 2002). Such a modelling approach is state of the art and was early recognised by researchers in the Ecological Modelling community to be a potential method for the unification of ecological theory (Huston et al. 1988).

Agent-Based Modelling allows different hypotheses and scenarios to be explored through dynamic simulations, and processes such as colonisation and the interactions between flora and fauna to be modelled in detail, from the perspective of individuals. For example, altering a number of conditions within the model, relating to the individual organisms or to abiotic factors, will allow the exploration of a number of alternative reconstructions of early Holocene forest structure, dynamics and landscape development. Overall, the strength of the approach lies in its ability to simulate the effects of individual variation, spatial processes and variation in growth patterns, cumulative stress and natural complexities that are difficult or even impossible with conventional models. Departing from traditional state-variable models will allow us to manage the complexity of the model in a way that does not isolate the different layers of behaviour related to physiological ecology, behavioural ecology and so on up to community ecology and ecosystem ecology.

While the principles of Agent-Based Modelling are well established and the approach is used by several research groups at Birmingham (Ch′ng 2009b; Theodoropoulos et al. 2009), the scale of the modelling which will be attempted for Doggerland has little precedent, and researching the appropriate methodologies will form a significant part of the work.

12.2.2 Distributed Simulation

A particular challenge of the proposed research is that the simulation of multi-agent systems of this scale and complexity is enormously demanding in computational terms and this means that parallel and distributed simulation is the only viable approach. Here the project will take advantage of pioneering work undertaken at

Birmingham on the distributed simulation of multi-agent systems models. The EPSRC-funded PDES-MAS framework provides multiple agents concurrent access to the shared state of the simulation in a scalable manner by a balanced distribution of state variables around a tree-like network of peer-servers (Craenen and Theodoropoulos 2010a; Craenen et al. 2010b; Gaffney and Murgatroyd Forthcoming). This research is built upon the framework for the Doggerland project, and algorithms developed for the partitioning, data distribution and synchronisation appropriate for the simulations utilised in the project. These algorithms will be integrated in a distributed simulation kernel, advancing the state of the art in this area.

12.2.3 Agent Design

All living and animated non-living entities at some point will have different conditions (states) and transitions between those conditions. A predatory animal may have states such as being in hunger, exhaustion, energetic, aggressive, hunting, resting, etc. A logical but basic way of modelling states and representing them in a manner that can be easily understood and analysed, is by using a mathematical abstraction employed in computer program design called Finite State Machine (FSM). In our case, the context is Artificial Intelligence. FSM is first presented by Mealy (1955) and Moore (1956) is a software process that is composed of at least four interrelated elements—States, Transitions, Transitional Rules and Events. For example, the transition from and the state of exhaustion to energetic fulfils the transitional rule of rested via the resting state. The transitional rule of being "rested" is Boolean in nature and is not necessarily represented in the relative condition between exhaustion and rest, but this is an easy way to explain the concept. The issue of relativity can be solved by various other techniques, one of which is Fuzzy Logic (first mentioned in Zadeh 1965, 1996). Events may be internal or external. The state of hunger is an internal event which fulfils a transitional rule and triggers the animal into a hunting state. On the other hand, the external event of the proximity of an enemy fulfils a transitional rule and brings the animal into an aggressive state. Those who are experienced in programming agents will agree that the fundamental building blocks of agents are FSM, and only when we have such a foundation can we introduce other more complex techniques that allow agent learning, adaptation and evolution, such as in (Weiß 1996; Hinton and Nowlan 1987; Ackley and Littman 1991).

Figure 12.1 is an illustration of the internal and external processes that occurs within an agent's lifecycle. Agents of different types (Human, Animals, Vegetation, etc.) possess the same high-level abstract processes (Sensors, Internal Structures, and Actions) but with very different ways in which the processes work. The processes are polymorphic in different agent types. For example, humans and animals move but they move in very different ways, reasoning between humans and animals are affected by a variety of issues, states are different between animals

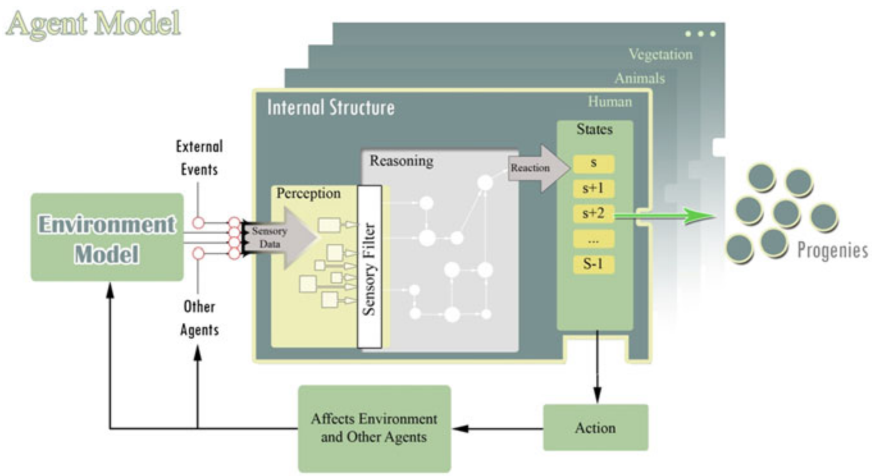

Fig. 12.1 A generic agent model—external factors and internal processes

and vegetation, etc. The figure shows that agents have the ability to sense the environment and are affected by other agents. These external factors affect the internal processes, which in turn influences the action that will affect the environment and the agents. In the pilot study (see Sect. 12.3), agent senses temperature, but any environmental factors can be included with the Adaptability Measure (Ch′ng 2007a, b) and a flexible Fitness Measure (Eq. 12.7). Agents also interact with objects, consume resources, and communicate with other agents. At the appropriate time, agents reproduce progenies and traits are passed on to them. Other capabilities of the agents are the mental model of the environment and the memory capacity. The section where future inclusion of learning and adaptation mechanisms resides is the reasoning block. In this study, the reasoning capacity is limited to simple survival strategies. The model designed for flexibility and extensibility, from which Artificial Neural Networks (ANN), or other learning and adaptation AI may be built in the future. It is also important to note that the model presented here is sufficiently generic to allow for diversity in multi-agent simulation by simply changing the input parameters (mobility speed, strength, fitness, memory retention, etc.).

12.2.4 Agent State Machines and Simple Rules

Figure 12.2 uses a conventional FSM diagram to illustrate the states (circles) and transitions (line arrows) of a logical but functionally limited diagram of a single agent in the Mesolithic. The start arrow sets a state for building a house, and, if necessary to also build a campfire. Notice that the identification of a suitable

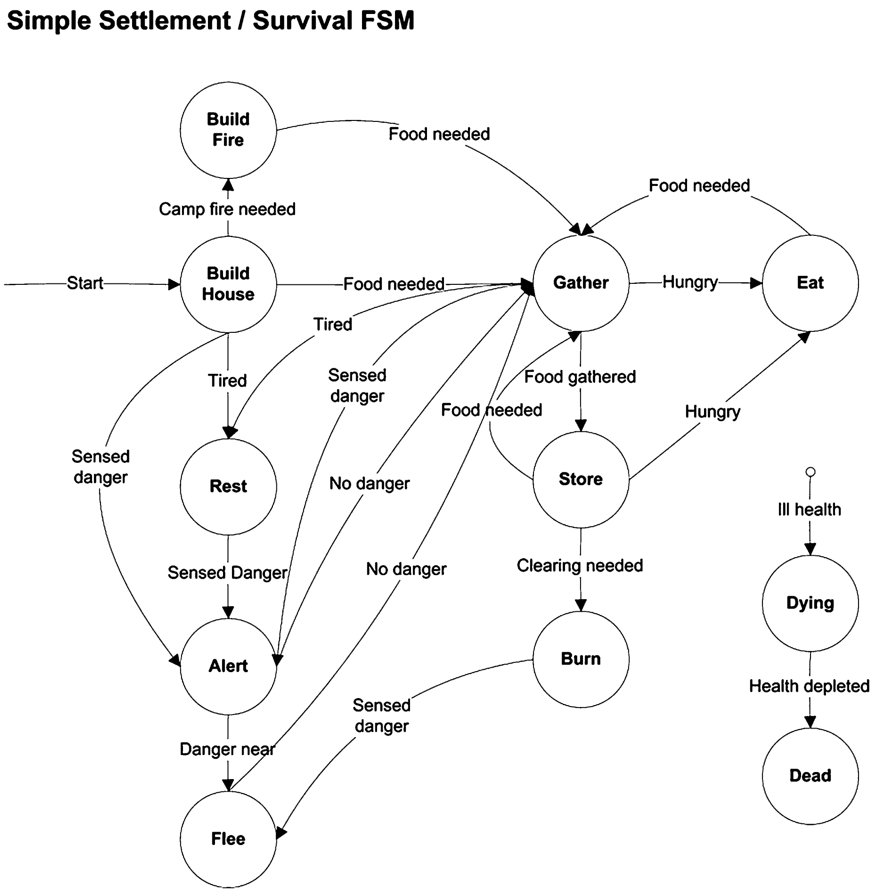

Fig. 12.2 Conventional FSM describing state transitions of a Mesolithic agent

location and the navigation to that location to build a house is not included, as it will greatly complicate the diagram. Other limitations seen for using FSM are the state for *rest* and the *dying* state, rest and dying is necessary to all states. If transitional arrows are connected to the *rest* and the *dying* state, the diagram becomes overly complicated. The *dying* state is therefore separated from the other connections on the lower left of the diagram. A more serious problem occurs after the *rest* or *dying* state. What state must the agent go back to after they have been rested, will the agent remember its previous states? There are too many states that the agents can transition to from the present state. When an agent builds a house or gathering food, there must be a condition of relative ease (rested, fed and in no immediate danger), the conventional FSM will not integrate these conditions without complicating the diagram. The examples showed that even though the agent is a simple model of a Mesolithic man, the process could be very complicated. There are clearly some limitations in conventional FSM shown in this simple example. Perhaps FSM is useful for simple animals, but highly intelligent beings require a more complex modelling procedure.

Figures 12.3, 12.4, 12.5, 12.6 are modified versions of the diagram in Fig. 12.2. The new FSM model introduces memory states, conditions, navigation target, objectives and self-preservation (priority). Each image is categorised as logical block (chamfered box), which is composed of multiple states. Each block with its composition of multiple states can be added to First In First Out (FIFO) queues in Discrete Event Simulation models with an added 'intervention' algorithm that transitions the states into other states when danger is sensed, for example. States are shown as shaded circles, next states are shown as dotted-circles, transitions are solid-line arrows, tasks and objectives are rectangles and memory states are ellipses. The dotted-line arrows are possible transitions from multiple states. Programmatically, the algorithms differ slightly from conventional ways of programming. The topic, however, is beyond the scope of this article. The diagrammatic logic blocks may evolve as we deal with more complex scenarios and acquire experience in modelling agents for ancient landscapes.

Figure 12.3 is the mobility block for an agent. Tasks require navigation from one location to another, with a set target and a state of what to do. Urgency is build into agent mobility by the introduction of a run state. After a task is accomplished, the agent moves on to the next state with a set target.

Figure 12.4 illustrates a survival block composed of these states—*eat, rest, alert and flee, dying* and *dead*. Eating, resting, being alert, fleeing and dying will

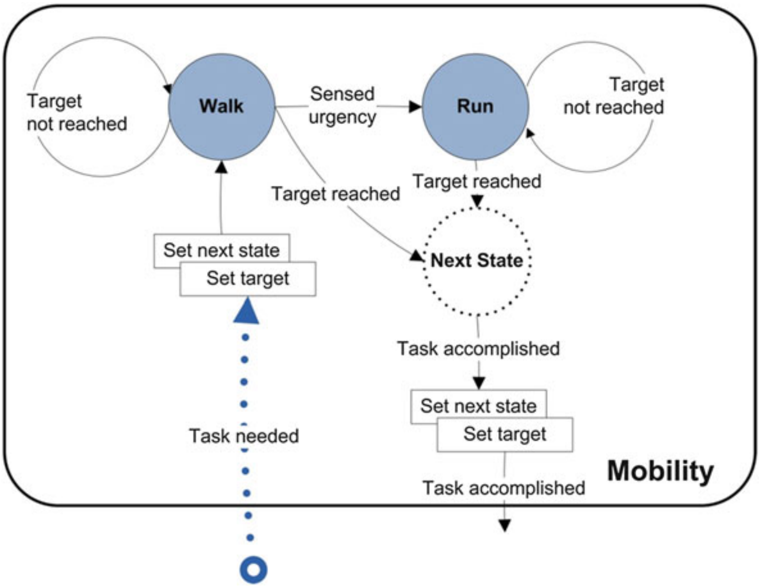

Fig. 12.3 Modified FSM depicting rules for mobility for an individual agent

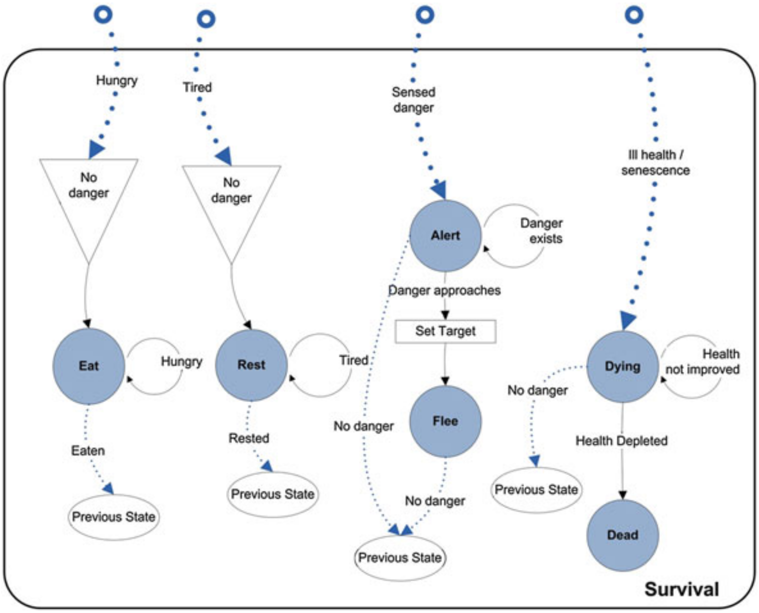

Fig. 12.4 Modified FSM depicting rules for survival for an individual agent

most definitely have a previous state that the agent will go back to once transitional conditions are fulfilled, with death as an exception. Loop conditions (looped line-arrows) are necessary for most of the states. The *alert* state has a special condition transitioning to the *flee* state, and that is to have a set target location to flee to. Transitional hindrances (triangles) are necessary for *eat* and *rest* states because an agent will only eat and rest when there is no immediate danger.

Figure 12.5 is the Settlement block with states *burn*, *gather* and *store* and *build*. The states are similar to the Survival block. The task for burning and building requires mobility, therefore the inclusion of objective blocks after the triangles. The gather state has an additional need for a set target objective and a transitional diagram which iterates. As gathering hazels or clams does not happen in a single location, this iteration resolves the issue.

Figure 12.6 illustrates the Priority block. Priority focuses on self-preservation of the agent and is designed for simulating the conditions that will threaten the survival of the agent. Burning and building may be a low priority as compared to states such as gathering food, resting, and eating. The state priority also means that the processes that are at a lower priority are not checked in the algorithm, this contributes slightly to the efficiency. For example, when the agent is dying, the algorithm does not need to check transitions to the lower priority states such as being alert and fleeing.

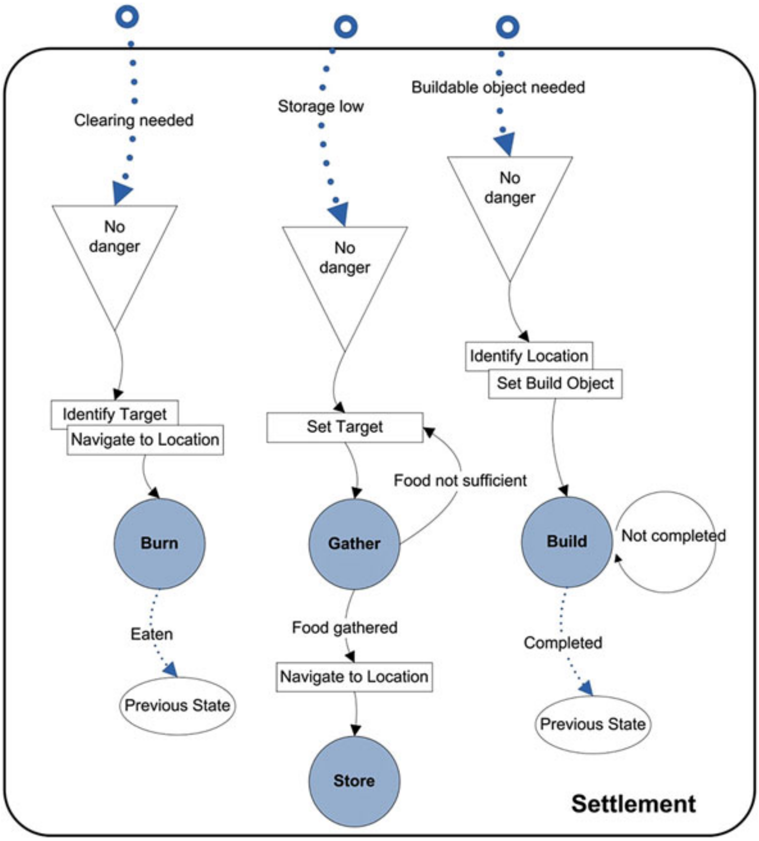

Fig. 12.5 Modified FSM depicting rules for settlement for an individual agent

12.2.5 Agent Memory

As human beings build mental models of their environments (Gentner and Stevens 1983), agents should also have the capability of forming models of their environments. Mental models of the environment can be very complex to build programmatically, but some important processes may be simple. In the long term, we aim to build mental model capable agents. Here we begin with memory and perception.

In our model, agent must form mental models of priority locations—home and resources. This means remembering house locations, and food sources such as where shellfish and hazelnuts are in abundance. Figure 12.7 illustrates the memory data structure with its associated variables. The memory structure for monuments and objects, and resource is:

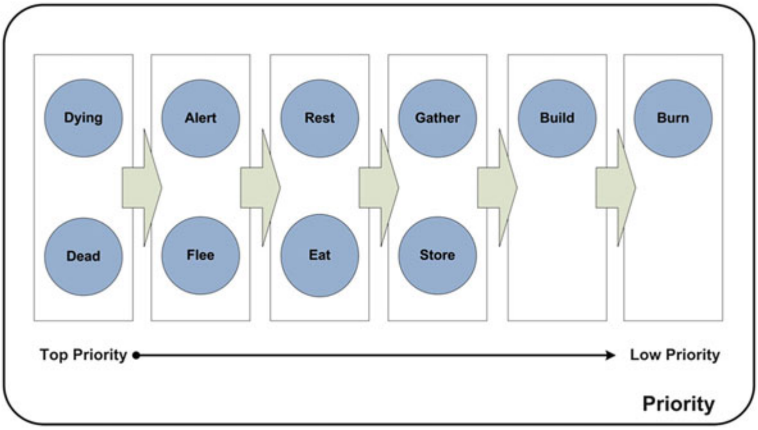

Fig. 12.6 A state-priority diagram illustrating the priority of process and decision making for an individual agent

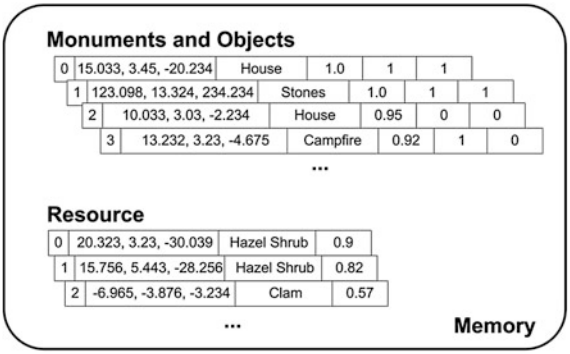

Fig. 12.7 A diagram illustrating the memory data structures for monument and resource locations and types

$$\delta_{\text{object}} = \{\text{id}, \text{Vector3}(x, y, z), \text{type}, \text{weight}, \text{ownership}, \text{short term/long term memory}\}$$
$$\delta_{\text{resource}} = \{\text{id}, \text{Vector3}(x, y, z), \text{type}, \text{weighting}\}$$

Long-term memory has a permanent value of 1 in the Boolean variable, which gives a weighting of 1.0. Larger value of weightings gets priority in the memory process. The weighting models memory fading μ_δ at time $t + \Delta t$ where the condition $\mu_\delta^t < 0.1$ renders it unimportant and removes the memory from the array,

$$\mu_\delta^{t+\Delta t} = \frac{1}{1 + e^{-\alpha + t^g}} \tag{12.1}$$

Where $\alpha = 10t$ is the time span in days, months or years before the memory weighting descends to a value of 0.5, and $g = (0.5, 0.1)$ is the gradient which lengthens the diminishing time of the memory.

12.2.6 Agent Perception

Agents perceive objects in the environment and makes decisions based on the resource availability in the landscape. Let γ_p^t be the set of target resource p (e.g. a collection of visible hazel shrubs) at time t within the visible range (eye-sight) $\sqrt{(x_b^t - x_j^t)^2 + (y_b^t - y_j^t)^2} < r_j$ of the agent j where the points $\left(x_b^t, y_b^t\right)$ and $\left(x_j^t, y_j^t\right)$ represents the position of each target resource b and of the agent j at time t, r is the visibility radius of the agent.

Once the perceived 'fitness' of the resource cardinality ρ_p^t (Eq. (12.4)) reaches a threshold, the agent stores the location in memory. Appropriate location where there is maximum resource yields a suitable location to build a house for settlement. The abundance of certain types of food as perceived by the agent at a location is stored as memory for future gathering activities,

$$\upsilon_j^t = \left[\rho_p^t > B_p\right] \tag{12.2}$$

where υ_j^t is the decision of agent j to store the location or object as memory, and ρ_p^t is the perceived 'fitness' of the cardinality of the resource that prompts a decision for memory storage, B_p is the decision threshold for that resource.

12.2.7 Agent Settlement Decision

Settlement decisions are made on the product of the 'fitness' ρ_p^t of a resource cardinality $\left|\gamma_p^t\right|$ and the environmental factors $\varepsilon_1^t, \ldots, \varepsilon_q^t$ important to settlement. These are measured by the Adaptability Measure (Ch′ng 2007a, b) as the 'fitness' f of the location for settlement,

$$\Phi_{\text{loc}}^t = \frac{1}{m}\sum_{p=1}^{m} \rho_p^t \left(\prod_{q=1}^{n} \varepsilon_q^t\right) \tag{12.3}$$

$$\rho_p^t = f_{\text{lower}}\left(\left|\gamma_p^t\right|, L_{pj}, P_{pj}, U_{pj}, c_{pj}\right) \tag{12.4}$$

$$\varepsilon_q^t = f\left(\text{E}_q^t, L_{qj}, P_{qj}, U_{qj}, c_{qj}\right) \tag{12.5}$$

where f and f_{lower} are, respectively, the adaptability measure and its lower bound variant, γ_p^t is the set of a particular resource or object, m is the number of sets of resources or objects perceived by the agent. L_{pj} and U_{pj} are the lower and upper boundary of resources p of agent j of the fitness measure, P_{pj} is the preference and c_{pj} is the cut-off range of agent j for a set of resources ρ_p^t. L_{qj} and U_{qj} are the lower and upper boundary of the environment q of agent j, P_{qj} is the preference and c_{qj} is the cut-off range of agent j for an environmental condition E_q^t at time t of the site ε_q^t, such as the closeness of the site to water, etc. n is the total number of primary environment conditions 'felt' by the agent. A fitness condition of $\Phi_{\text{loc}}^t > \Phi_{\text{threshold}}$ sets the location as habitable.

The equation for the settlement decision can be extended to manage environmental factors that are secondary for settlement therefore refining the sensitivity of the agent,

$$\Phi_{\text{loc}}^t = \frac{1}{2}\left(\frac{1}{m}\sum_{p=1}^{m}\rho_p^t + \frac{1}{S}\sum_{s=1}^{S}u_s^t\right)\prod_{q=1}^{n}\varepsilon_q^t \tag{12.6}$$

where u_s^t is the secondary environmental factor (e.g. temperature, natural barriers, etc.), and S is the number of secondary factors calculated.

12.2.8 Agent Fitness, Death and Senescence

Fitness β_j^t at time t of agent j is measured using the Adaptability Measure f [2].

$$\beta_j^t = \frac{1}{l}\sum_{g=1}^{l}\tau_g^t\left(\prod_{h=1}^{u}\eta_h^t\right) \tag{12.7}$$

$$\tau_g^t = f(E_{\text{sec}}^t, L_{\text{sec}}, P_{\text{sec}}, U_{\text{sec}}, c_{\text{sec}}) \tag{12.8}$$

$$\eta_h^t = f(E_{\text{pri}}^t, L_{\text{pri}}, P_{\text{pri}}, U_{\text{pri}}, c_{\text{pri}}) \tag{12.9}$$

where η_h^t is the fitness of the primary environmental factor h at time t affecting the agent j and τ_g^t is the 'fitness' of a secondary environmental factor g. The corresponding variables for primary and secondary environmental factors L, P, U, c are the lower L and upper U boundaries of the measure, the agent preference of the respective conditions, and c as the cut-off range. Agent transitions into the state of *dying* when $\beta_j^t < 0.3$, and death occurs at $\beta_j^t \leq 0.0$. The age A of the agent contributes to senescence when $A_j^t \geq A_{\max}$.

12.2.9 Character, Resource Modelling and Visualisation

The Mesolithic monuments, objects, and resources can all be modelled and represented appropriately both in terms of their behaviour and as 3D models in the visualisation. In the simulation, all monuments, objects and resources are modelled as agents. All objects are real-time physics bounded and certain objects requiring special effects such as the campfire are integrated with particle systems. Resources such as shellfish, hazel shrubs and hazel nuts have agent behaviour programmed into the models. This section discusses the techniques used for modelling the characters, vegetation, resources, house and objects that resides within the virtual world. A pipeline of tools is used for sculpting, mesh retopology, UV mapping, texturing, character rigging, animation and export. These include ZBrush, 3D Studio Max, and Photoshop. Real-time visualisation uses the Unity 3D engine with appropriate conversion of the agent model algorithms covered in Sect. 12.2.3.

Mesolithic Character. For visualisation of real-time agent behaviour, task and mobility, it is important to create 3D virtual characters with different behaviours. Characters are modelled in high quality before producing a real-time optimised version and retopology of the mesh, rigging, Inverse Kinematics setup, animation and mapped to agent behaviour covered in the preceding text.

Mesolithic House. The Mesolithic house has behaviour for simulating various stages of building development. Each stage of the building has a set interval, after each interval the representation of the building changes appearance. The appearance changes in this order: Pile of Materials ≫ Foundation ≫ Structures ≫ Cover ≫ Completion. Figure 12.8 is a representation of a Mesolithic House, following Waddington's work (Waddington 2003) at Howick Northumberland in various stages of development.

Mesolithic Diet. Trees and other irrelevant plants in the landscape do not grow or reproduce; they merely act as natural barriers. Other resources, such as hazel shrubs and hazel nuts however, have agent behaviours attached to them. Each hazel shrub agent is able to produce hazel nuts at set intervals. Each hazel nut agent persists on the landscape and is destroyed after a set period of time if uncollected by the agents. Two separate agents are needed for shellfish reproduction. The Shellfish Spawn is strategically positioned around the coasts and produces a number of shellfish agents at set intervals. The number and the intervals are probabilistic with a normal distribution $N(0, 1)$. Each spawn point has a limited set of shellfish it is able to produce and once this is exhausted, the spawn point is destroyed. Shellfish agents are bound to the laws of physics and reside on the location if they are not swayed about by the waves or tumble down the topology of the landscape. Shellfish, which are not collected after a set interval, are destroyed.

Fire. Resources can be burned/cooked by the agents. The fire itself has embedded agent behaviour. Once a hazel shrub is being burned, the AI of the fire seeks the nearest hazel shrubs and propagates a new set of fire on that shrub. If no other shrubs are at proximity, the fire stops.

Fig. 12.8 Mesolithic agent building a house—seen in sequential stages of development

12.3 Pilot Simulation: A Mesolithic Scenario

In previous sections, we looked at the model of an individual agent and explored agent design using FSM with transitional rules, memory and perception, and settlement decisions. We also modelled the environment, a Mesolithic house, and a set number of resources. The agent model itself could be replicated into as many individual agents as needed with different parameters as inputs such as roles, capability, mobility speed, perception, memory retention, etc., so that there is diversity amongst them. The pilot study conducted here provides a foundation for building a complex system of flora, fauna and humans from the bottom up, i.e. from modelling individuals and providing extensions by which they interact with other agents and the environment (see Ch′ng 2007b, 2009a, b, d, 2011; Craenen et al. 2010; Gaffney and Murgatroyd Forthcoming, for related examples of complex systems simulation).

The pilot simulation aims to test the agent model against an arbitrary landscape. The environment is deliberately set as an island scenario with summer temperatures averaging 16 °C. It is created as an established landscape with a stable ecology so that we could observe the agent behaviour. Hazel shrubs and shellfish spawn points are randomly scattered around the island to simulate environmental niches where these resources thrived. The actions of the agents are autonomous and depended upon resources in the landscape and the environment. One of these events may be that in an arbitrary location where the condition is ideal, more shellfish spawn points or Hazel shrubs occur, it may also be that these resources appeared closer and at a location where the agent will find it safe for settlement—a distance away from the shores. The aim is to test the agent behaviour to see where their autonomy would lead them to the best location for settlement.

Figure 12.9 depicts an agent exploring different parts of the landscape for resources that will contribute to a potential settlement site. Memory markers are used for notifying to us, the observers, what the agents think. Two memory markers are shown at the bottom right. The house marker indicates the site as potentially suitable as a settlement area. This is due to the adequate existence of Hazel shrubs nearby, as indicated by the tree marker, and also the distance from shore. Navigation waypoints (insert) are created around natural pathways for agent travels. Each waypoint node has a radius within which the agents could explore. The boundary around the nodes gives freedom to agents to explore the surrounding as would a human when they roam the landscape. The boundaries with radius of different sizes also help cover grounds for exploration where there are no nodes.

Figure 12.10 shows a settlement map of the entire island after the agent has explored the landscape. The inner circle depicts the range of the availability of hazel shrubs where the 'fitness' is measured and the outer circle is the range of the availability of marine resources. The ranges are adjustable for different resources. The figures within the circles showed the fitness of the location for settlement; these are based on the availability of the resources and environmental factors. In the pilot study, only the availability of hazel shrubs, shellfish and the proximity of

Fig. 12.9 Scenes from the interactive visualisation showing the agent exploring the landscape for resources that will contribute to a potential settlement site. The image at the *lower left* shows the memory marker for vegetation resource (hazel shrubs) and a '*house*' marker demonstrating the fitness of the site for settlement. The *inset* shows the strategically positioned navigation path nodes

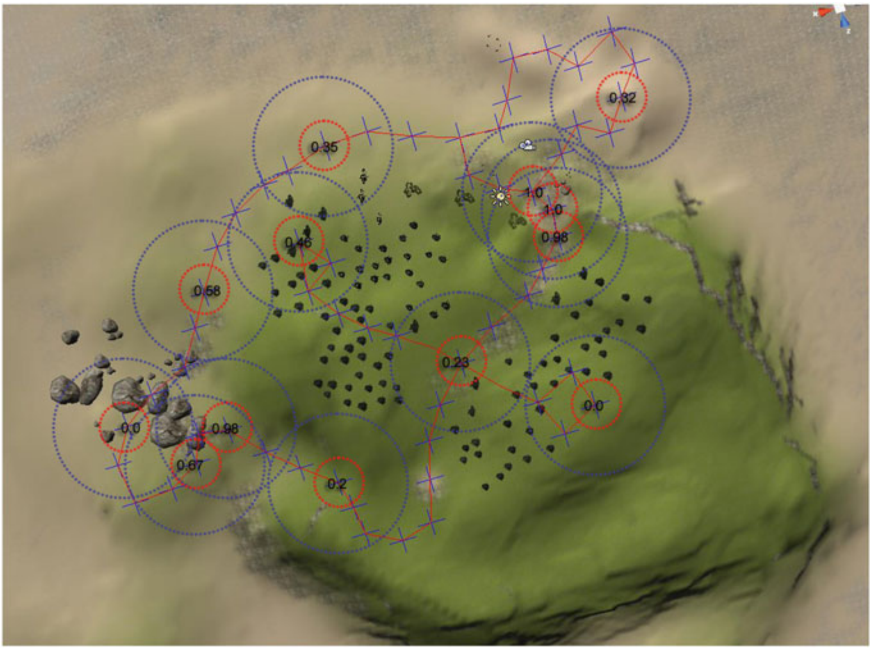

Fig. 12.10 A settlement map showing the 'fitness' of various sites for settlement, fitness is generated from data captured during the agent exploration of the landscape. The *inner circle* depicts the range of the availability of hazel bushes where the 'fitness' is measured and the *outer circle* is the range of the availability of marine resources. The ranges are adjustable for different resources

the coast are measured, but Eqs. (12.2)–(12.6) makes it possible for any amount of resources and environmental factors to be included and measured. Figure 12.11 is a scene depicting agents building houses on a settlement site (top) after roaming the landscape. The bottom half of the figure shows a separate simulation of agents gathering and depositing shellfish around the settlement areas.

Figure 12.12 shows two different agent roles in a land-based scenario. The top left figure shows agents walking away after building a camp fire when we the environment is made colder by adjusting the temperature slider. The top right figure shows an agent harvesting Hazel nuts. The agents measure the site at intervals to check if the food storage is sufficient, food sufficiency prompts the

Fig. 12.11 Agents building houses in the settlement location (*top*). The *bottom half* of the figures shows agents gathering and depositing shellfish in another simulation

Fig. 12.12 Other scenes—from clockwise, agents build a campfire and walk away, agent harvesting hazel nuts, burning a clearing, and suffering a sudden temperature change

agent to change states to meet the needs. The image at the bottom left shows forest clearing via burning. Fires spread if other vegetation is sufficiently near, agents can be hurt by fire. At the bottom right, turning up the temperature abruptly causes the agent to react to the threat.

The simulation and visualisation of agent-based models clearly offer great potential for exploration of sparse data sets of the sort available for the southern North Sea Indeed, it is doubtful, given the inaccessibility of the archaeological landscape whether this region, and period, can be explored adequately in any other way.

12.4 Conclusion

The team at Birmingham University will soon publish the results of the study of nearly 43,000 km^2. Of the surface of Doggerland (Cuttler et al. Forthcoming) and these data will represent the state of the art for marine palaeolandscape studies. This will open up new research horizons, with the possibility of bringing the landscape back to life, virtually (Ch′ng 2009c). For a number of years, key research being carried out in Birmingham has also explored large-scale computer modelling and simulation (Ch'ng 2007b, 2009a, b; Craenen and Theodoropoulos 2010b), and interactive visualisation (Ch′ng 2007a). These studies focus on the investigation of complex algorithms and data structures required for exa-scale multi-agent systems simulation. It is these fundamental studies, together with the interpretation of remotely sensed data that will make exploring Doggerland using unconventional approaches possible.

Our research strategy aims to use innovative mapping as a foundation on which to build dynamic models of the changing geomorphology, ecology, catastrophic events and possible human settlement of Doggerland, from 10,000 BC until its eventual inundation around 5,500 BC. This hypothesis-driven research simulates dynamic models and events and tests the trends of global states against programmes of ground truthing guided by mapping and simulation results. As we have seen in the introductory sections, modelling complex interactions and dynamic systems in geomorphology, ecology and human behaviour requires new research paradigms as differing population levels and collective behaviours give rise to very dissimilar macroscopic structures of self-organisation and emergent phenomenon within those levels. The field of Complex Systems Science—the study of complex adaptive systems, whilst considered a new scientific frontier, has provided valuable insights into how complex systems work. By adopting the lessons learned from the discipline, our modelling of agents and behaviour will help reconstruct past spatio-temporal events acquired through traditional methodologies. The strength of this approach lies in its ability to simulate the effects of individual variation, spatial processes, variation in growth patterns, cumulative stress, and natural complexities that are impossible with traditional methodologies such as state-variable and other conventional predictive models. The advantage, however, comes with a price. Whilst traditional approaches utilise state variables, multi-agent systems model the properties and behaviour of each individual, and in relation to other entities. The approach, whilst revolutionary, demands a huge computing resource. Take for example, the agent-based model of the present research (see the "Agent Design" and following sections). The model considers multiple instances of a single human agent, each as a separate process with their own states, interaction rules, task queues, memory structures, perception of the environment, fitness and adaptability, and decision making. Within those subprocesses are mathematical calculations that consume significant computing resource. Furthermore, agent relationships and trophic network warrant a multiplication of interaction within a relationship network n at $n(n-1)$. This easily raises the complexity of the algorithm (execution time and space used) to $\Theta(n^2)$ and probably $\Theta(n^2)$ or even $\Theta(n^4)$ in deeper interactions, unless more efficient parallel and distributed algorithms are used to reduce the performance to $\Theta(\log n)$. Simulation studies (Ch′ng 2009b, 2011) of hundreds to thousands of agents (largest population at over 12,000) consumes computing time as population levels grow exponentially to the extent that special algorithms (Ch′ng 2009a) need to be developed to allow for efficient optimisation of interaction. Other digital data processing and management requirements are real-time visualisation and data capture and storage of simulation states.

At the agent behaviour and societal level, various challenges await. How can we model learning, information sharing, and territorial clashes at the intra and extra-community level? How can we represent cultural behaviour, inheritance (parent to children) and spread within the computer? Other issues that need resolving are natural and man-made barriers hindering the distribution of species, and catastrophic events that bRecreating the past fromring destruction to natural habitats. Although the work presented here has laid a foundation for simulating and visualising ancient agents, the issues listed remain a challenge to be investigated by computer scientists. Only when we have sufficiently investigated the mechanics of the agent-based modelling approach will we be able to see the fruits of our endeavours. The overcoming of computational barriers may not physically bring us back to the past, but it will at least provide us a means to prove or disprove competing hypotheses. With interactive visualisation, there may even be the possibility to take on the role of one of the hunter-gathers, as an avatar living, working, and evolving the landscape, or look through the eye of a hunted animal as it is being pursued across the woods. Not actually reality—but getting closer!

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Chapter 13
Visualising Large-Scale Behaviours: Presenting 4D Data in Archaeology

Philip Murgatroyd

Abstract Agent-based modelling (ABM) is an excellent technique for investigating certain types of complex behaviours. Archaeologists have started to explore the possibilities of ABM as a means of simulating the processes that shape past human societies, processes that can be hard to reconstruct by other means. However, the complex nature of these models and the four dimensional (4D) nature of the data they produce can be problematic to present via traditional archaeological means of publication such as journals and monographs. This article reviews the problems faced when presenting 4D data via 2D media and presents some ways in which the Medieval Warfare on the Grid project attempts to solve those problems.

Keywords Byzantine · Military logistics · 3D modelling · Visualisation · Agent-based modelling · Archaeology

13.1 Introduction

Agent-based modelling (ABM) and archaeology seem like the perfect complement to each other. ABM uses spatial data to create models of complex systems that change over time based on the interactions of discrete entities simulated within, the "agents" of the title. Archaeology also looks at changes over space and time, wrought by the interactions of discrete entities, usually humans, with each other and their environment. ABM as a computer modelling technique has grown in popularity during the past 30 years as increased processing power and code manageability in object-oriented programming languages have rendered it viable

P. Murgatroyd (✉)
IBM Visual and Spatial Technologies Centre, The University of Birmingham, Edgbaston B15 2TT, UK
e-mail: P.S.Murgatroyd@bham.ac.uk

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across a whole range of disciplines but even before the widespread adoption of ABM within the wider scientific community, some archaeologists had noticed the overlap (Doran 1970). Whereas archaeologists were largely restricted to inferring processes from patterns, simulation was an excellent tool to enable the inference of patterns from processes (Kohler and Varien 2012, p. 9). Yet if the form of an ABM mirrors that of some of the problems that archaeology is tasked with investigating, the format of the data produced can be a very poor fit with the publication methods commonly employed in archaeological projects.

Despite recent responses to the technology of the World Wide Web, archaeology publications remain primarily paper-based. Journals and books still form the bulk of outputs from archaeological projects. These are static, sequential, 2D. The increase in use of portable document format (PDF) files does nothing to change this, being more associated with improvements in the efficiency of distribution. In contrast, an ABM is commonly not just a means to a conclusion, the process of arriving there itself can be useful (Ch′ng et al. forthcoming). ABMs commonly require multiple runs with varying parameters to quantify the interactions modelled within the system. This result is not only in a set of 4D data, 3D spatial data modified over time, but multiple sets of 4D data to be compared in a variety of ways, often with a bewildering number of combinations. It is dynamic, fungible and often very, very large in its raw state. Merely explaining the workings of an ABM can be a verbose and unwieldy process, showing the results satisfactorily sometimes seems nigh on impossible.

Another complicating factor in presenting an ABM involves the intended audience, a group that may include people with very different interests and levels of expertise, but will also include the creator of the ABM themselves. A researcher using an ABM will need some way of viewing the running of the model during operation in order to verify its behaviour. An extensively cited early ABM, the Schelling model (Schelling 1971), was recommended by its creator to be resolved on a checkerboard with actual counters rather than on the computers of the time precisely because their visualisation capabilities could not satisfactorily show the process of the model at work (Hegselmann 2012).

Once the simulations have been run, the results need to be shown to others. ABM researchers are accustomed to producing and interpreting graphs, 2D still images and animations of basic shapes in sparse landscapes. General archaeologists may not necessarily have that background and may need more visual cues to understand the processes at work within the model. Interested members of the general public may have even less experience of interpreting the outputs of models and may need more context and possibly different forms of publication altogether. With archaeological ABMs it is not just the results that are of interest, the passage of the agents through the process can give us an insight into past lives. The path of an individual agent through the simulation can act as the basis for visualising, via words, images or animations, an individual person's experience of the system being modelled. These "simulated biographies" are an attractive tool when dealing with a non-specialist audience who are often interested in what the lives of individuals were like. Just as a model needs to be created with only appropriate processes simulated, so the output should focus on the message that is being communicated and be disseminated via a useful medium.

13.2 Visualisation of ABM in Archaeology

Publication within the simulation community operates under some of the same restrictions as it does in archaeology. Traditional paper publishing still forms a large part of academic publishing within computer science and so even here complex 4D behaviours are presented as 2D stills and/or aggregated statistics and graphs (e.g. Cioffi-Revilla 2010). These outputs are well suited to presenting behaviours that can be reduced to formulaic expressions. A defining characteristic of complex behaviours however is that they can't be reduced to a single, simple formula (Holland 1998, p. 14) and as such their presentation presents a challenge for traditional publishing. Visualisation within the ABM community tends towards simplicity and clarity, often consisting of 2D images or, where possible, animations. An audience of researchers experienced in simulation will be comfortable with the interpretation of these outputs. Few archaeologists have experience of the process and results of ABMs and how the practise of simulation can be translated into archaeological data and therefore the approach to presenting results may need to be revised. Archaeology also frequently has to present its results to a wider audience, including interested members of the general public with no specific experience of the outputs of either archaeological research or ABMs.

Axelrod (2007, p. 96), in an article designed to suggest how simulation can be moved forward from the early stages he sees it in, presents three reasons why disseminating the results of simulations can be problematic.

- Simulation results are highly dependent on the detail of the model so, if the model is not described in detail, the results may be open to misinterpretation or misunderstanding.
- Although results can usually be summarised via statistical methods, the results often also include a narrative description of the run of a model. This commonly takes up a lot of space.
- Simulation results are often presented to an interdisciplinary audience, necessitating detailed explanation of parts of the model that some of the intended audience will find unnecessary.

The problems highlighted by Axelrod all apply to ABM within an archaeological framework and as yet no method of dissemination has presented a satisfactory solution to them. Thankfully the rise in popularity of ABMs has coincided with the rise of the World Wide Web and many ABMs have been made available to download, in some cases also including animations showing their results.

Nevertheless, there is a lack of a standard method of describing the workings of ABMs with the same degree that mathematical notation can be used to describe top-down systems. This is largely due to the complexity of multi-agent simulations and the relative youth of the field.

Within archaeology, the history of ABM visualisation contains comparatively few examples to examine. After an initial spurt of enthusiasm in the 1970s, when computing power was rare, arcane and expensive enough to not be of much use, it wasn't until the 1990s that archaeological ABMs became more widespread (Costopoulos et al. 2010). Early efforts tended to present their results in statistical format (Wobst 1974), comparing the data from each run of the simulation via aggregated indicators of performance. More recently, models have failed to take advantage of increases in computing power and visualisation technology.

One of the largest and most complex archaeological ABMs, a simulation of Bronze Age Mesopotamian settlement system dynamics (Wilkinson et al. 2007), relies on presenting the summarised results of many runs of the simulation as a way of addressing specific research questions regarding the system's resilience to various stresses. The source code of their ABM is unavailable and highlights a problem with ABMs modular nature, their ENKIMDU framework relies on data from systems from other organisations which may not be openly available. Access to source code from non-open sources may become a potentially damaging factor limiting the spread of successful models in the future.

The Village Ecodynamics Project (VEP) (Kohler and Varien 2012) is probably the largest, most complex archaeological ABM implemented so far. It consists of over 17,000 lines of code and draws in evidence from pollen cores, tree-ring dating, hydrology and a series of pre-existing modelling work dating as far back as the 1980s. The project examines the processes of population fluctuation in the Pueblo societies of south-western Colorado. It has produced a prolific range of publications across a variety of traditional journals (e.g. Kohler et al. 2007, 2008; Varien et al. 2007) along with a monograph dealing with the first phase of the project (Kohler and Varien 2012). The traditional nature of these publications, mainly produced in paper format albeit sometimes with an electronic copy, restricts the presentation of data. Illustrations are also limited and are usually in the form of graphs. There seems to be no easy way of extracting map-based outputs from the model, much less animations that require change over time. The VEP has published its models in their most primitive form, making the source code available for other researchers to simulate the same experiments, and run different experiments with the same model but different parameters or to expand the model in whichever way they see fit. This allows additional visualisation methods to be added by others and, although examples of published models being reused to verify results are rare (Janssen 2009 being a notable exception), publishing the model itself also acts as documentation of its workings.

MASON (Luke et al. 2005) is an attempt to provide an ultra-lightweight multi-agent simulation toolkit. Produced at George Mason University, it was written by computer scientists with considerable input from social scientists and provides a Java infrastructure and set of tools that can be used to build ABMs. It has the advantage of separating the model from the visualisation so that different forms of visualisation, both 2D and 3D, can be attached to a simulation while it is running and can be unplugged and changed at will.

13.3 The Medieval Warfare on the Grid Project

The Medieval Warfare on the Grid project (MWGrid) was funded by a joint AHRC-EPSRC-JISC e-science grant and attempts to use ABM to investigate the complex relationships involved with medieval military logistics (Craenen et al. 2010). Due to its scale and intended audience, the project needs to visualise the running and results of its ABM in both traditional and non-traditional ways. Using the march of the Byzantine army across Anatolia to the Battle of Manzikert in AD 1071 as its case study, it serves as a framework to quantify the supply implications of moving over different routes and with different forms of organisation. This case study was chosen as it was an excellent example of a historical question needing new sources of data. The Byzantine army marched over 1,000 km across Anatolia to face the Seljuk Turks at the battle of Manzikert and yet key data is not recorded in the historical sources available to us. The size of the army is unknown and although some aspects of the route it travelled are recorded, the logistical organisation needed to ensure it reached its destination is ignored in first-hand accounts. Anecdotal stories of events on the route take precedence over quantitative data regarding army speed, supplies required or number of participants and the hypotheses generated by historians has suffered from a lack of testability (Haldon 2006).

The MWGrid ABM allows the simulation of a day's march of a force of any given size, consisting of both cavalry and infantry using several different types of organisation. This allows quantitative analysis of how the size, composition and organisation of the force affects its overall movement speed and expended energy. This has a consequent effect on the supplies required from the settlements through which the army passes. The ABM represents members of the Byzantine army at a 1:1 resolution with each environment cell measuring approximately 5 m square and each tick of the simulation representing approximately 3.7 s of real time. Thus each day's march consists of up to tens of thousands of agents moving over thousands of environment cells over the course of around 10,000 ticks. The ABM records the location of each agent during each tick of the simulation as well as providing a summary file detailing each agent's distance travelled and calories expended during the day. This represents a large amount of data that has to be visualised, initially to the programmer in order for software errors to be detected and resolved, and subsequently for the researcher in order to draw conclusions from the model. Finally, the project is disseminated to a wider audience of interested parties.

13.3.1 Issues in Visualisation

Depending on the numbers of agents and length of the simulation, the ABM can take anywhere between a couple of minutes to a number of days to run. This presents problems to the production of working code. Some method of visualising the results of the model is required to ensure the ABM is running as intended, yet real-time methods of visualisation take up resources that could be used in the processing of the ABM itself. Also the scale of the environment and the large numbers of agents mean it can be problematic to display the behaviour of the model within a single display. Either the whole army can be shown in which case it is difficult to determine the behaviour of individual agents or only some of the agents can be on screen at any given time.

Any visualisation method also needs to be able to satisfy the need to present the data to the project's intended audience. This includes simulation researchers along with military historians, Byzantine historians and members of the public. The visualisation needs to be flexible enough to produce quick, low quality output that nevertheless enables all the workings of the ABM to be accessed for debugging purposes in addition to high quality output for presentation of the wider community of interested parties. It needs to be able to present the movement of the army as a whole in order to highlight macro-scale patterns whilst also being able to focus on individuals and to track an agent's path through the simulation. It needs to produce still images for traditional publications as well as animations that can present the movement of the army as a whole. As the effects of organisation and size on overall speed and energy consumption are also being investigated, statistics and graphs are required to communicate aggregated information on both individual runs of the simulation and multiple runs with different parameters.

13.3.2 The Architecture of the Project

Although it would be possible to design a bespoke visualisation method which will allow the user to move about the environment and focus on areas of interest while the ABM was running, no attempt at real-time visualisation was made due to the development time involved and the likely impact on the performance of the ABM. A modular system was designed (Fig. 13.1) in which the ABM outputs trace files that can be visualised outside the ABM by various means. This modular nature ensured that once run, a simulation did not need to be rerun for a different method of visualisation to be used. It also meant that any visualisation could be produced in parallel by copying the trace files onto a different machine while the ABM gets on with running the next simulation. The lack of real-time visualisation was partially mitigated by having continuous and customisable levels of text output on screen during the running of the ABM allowing the user to know at which point the

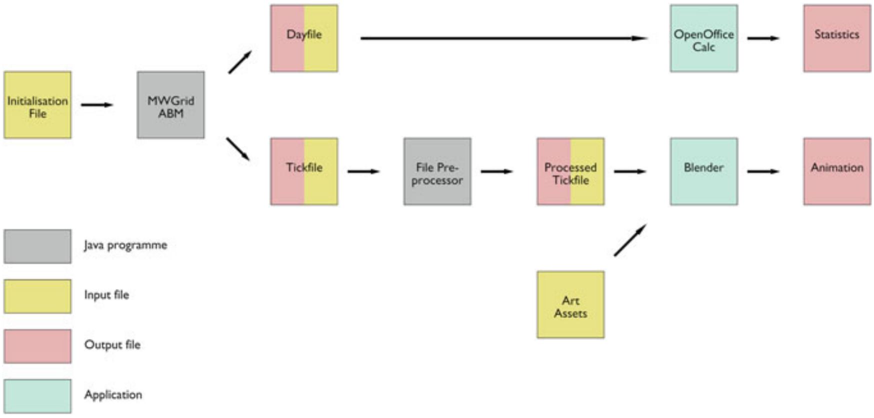

Fig. 13.1 The architecture of the MWGrid software

Table 13.1 Description of values contained on each line of the MWGrid tickfile

Value	Description
Tick number	The tick number of the simulation to which the data refers
Agent number	The agent's unique id number
Agent type	A numerical representation of the agent's type (1 = Column Leader, 2 = Cavalry Officer etc.)
X location	The agent's position along the environment's X axis
Y Location	The agent's position along the environment's Y axis

model was of its run at any given time. This proved sufficient to detect most problems.

The MWGrid ABM itself is a Java programme written specifically for the task. It takes in the parameters of its operation from the initialisation file, a plain text file containing a list of variables and their values. The ABM creates two output files during operation: a tick file (Table 13.1) containing the location of every agent at every tick of the simulation and a day file (Table 13.2) which contains one entry per agent summarising the activities that agent has engaged in, including distance travelled and calories expended. The day file is imported into an OpenOffice Calc spreadsheet which automatically summarises the information on one screen (Fig. 13.6). The tick file is used for visualisation but can be several gigabytes in its raw state if tens of thousands of agents are involved. For this reason a separate Java programme was written, the file pre-processor, which removes entries for ticks in which an agent does not move. These ticks are only used for debugging purposes and have no effect on the visualisation of agent movement. The processed tick file is then read by a Python programming script into Blender, an open source 3D modelling package. This creates each agent as a simple geometric shape

Table 13.2 Description of values contained on each line of the MWGrid dayfile

Value	Description
Agent number	The agent's unique id number
Agent type	A numerical representation of the agent's type (1 = Column Leader, 2 = Cavalry Officer etc.)
Arrival tick	The tick number on which the agent arrives at the destination camp
Total distance moved	Total distance moved by the agent in metres
Start tick	The tick on which the agent started its march from camp
Calories expended	The total number of calories expended during movement

or as a more complex animated figure depending on a series of art assets contained in separate Blender files. The result can either be rendered as 2D still images or animations depending on the requirements of the modeller.

13.3.3 Data Processing with Blender

The processed tick file is imported into Blender via a bespoke Python script. The Python programming language was chosen as it is the default scripting language for Blender and is heavily integrated with the application. The script creates an object for each agent based on its type and moves this object on a tick-by-tick basis depending on the location specified in the tick file. The object it creates can either be a simple geometric shape or a rigged, animated character depending on the requirements of the visualisation.

An initial version of the ABM focussed on individual agents performing complex behaviours involving item manipulation. It used as a case study, the setting up of the army's camp at the end of a day's march and included such behaviours as setting up each squad's tent and setting fires to cook food. As this involved behaviours that require multiple steps performed by multiple agents, a visualisation system was implemented to show the agents' behaviours in more detail, such as the tasks the agents are performing and the tasks they intended to perform in the future. The Python script used for reading the data into Blender inserts fully animated, humanlike models into the virtual scene to represent each agent. These humanlike models contained the mesh data for the agent itself and data for each animated action they could perform, along with speech and thought bubbles for tasks each agent was performing or intended to perform in the future, respectively. The Python script also imported 3D models from other Blender files for each type of item such as firewood, food and tents in both packed and erected forms.

The output worked well from a debugging point of view, as it was easy to identify each agent's behaviour at any given time. The modular nature, with the models being held in separate files, meant that it was easy to create two different types of 3D models, such as basic, low-polygon stick figures (Fig. 13.2) and more

Fig. 13.2 Low-polygon 3D models of a squad setting up camp

realistic 3D models (Fig. 13.3). This modular nature also allows professional 3D models to be integrated within the visualisation system if required. Although the system worked well for small numbers of agents, the details involved with this visualisation resulted in computational times that were unacceptable for large-scale simulations.

Users have the flexibility of manual positioning of the virtual camera within the display viewport, so that they can decide which agent behaviours to show in the final output. As the Blender file created by the Python script can be saved and easily "re-edited" by moving the camera into different locations around the scene, the same simulation datasets can be viewed from different angles for the users intended purpose.

As the focus of modelling shifted from setting up camp to simulating large-scale movement of thousands of agents, a much faster way of visualising ABM output was required. The Python script was pared down to represent each agent as a 2D geometric shape. Blender's camera can be set to orthographic projection, this removes perspective distortions that may occlude the results. The end result was a 2D representation of the agents' movement familiar to ABM researchers (Fig. 13.4). This meant that tens of thousands of agents could be modelled in a reasonable timescale. At this point of the development the focus had shifted to the movement of the agents over the day's march and so the extra mechanisms used to

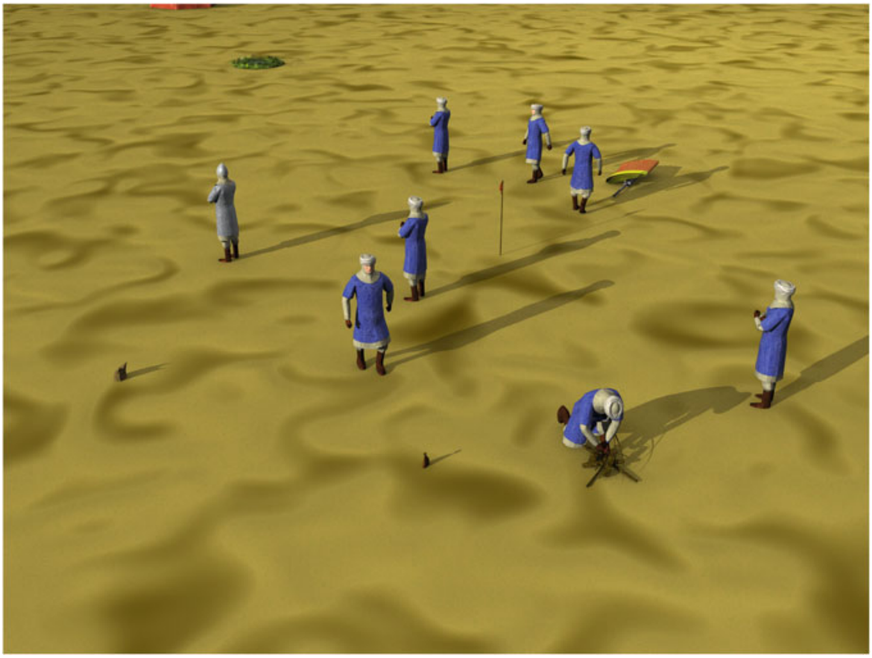

Fig. 13.3 Higher detail 3D models visualising the same tick of the simulation

indicate items or the intention of the agents were not necessary. The result shows movement well but has no way of representing the underlying terrain.

This type of output that is represented by simple geometric shapes, represented orthogonally on a plain background is commonly seen in academic publications related to ABMs. It, however, provides no indication of the way route finding works within the model. Within the MWGrid ABM, each column of the army, by way of its behaviour, selects a route based on the terrain and create the shortest possible route to their destination while avoiding unnecessary climbing of hills. A better way of visualising the route planning algorithm is to represent the agents' movement in a 3D landscape (Fig. 13.5). The existing Python script used earlier for producing the 2D representation of the agents' movement was modified to create 3D geometric shapes for each agent. The landscape was created in a separate script which simulated a 3D landscape of blocks representing the actual terrain data that is used in the ABM. The orthogonal camera view used in the 2D representation does not adequately show the 3D nature of the terrain so a perspective-based camera view is used. This allows freedom to create multiple visualisations from the same Blender file but requires the user to decide which behaviours in the model are most important and from which angle they can best be visualised.

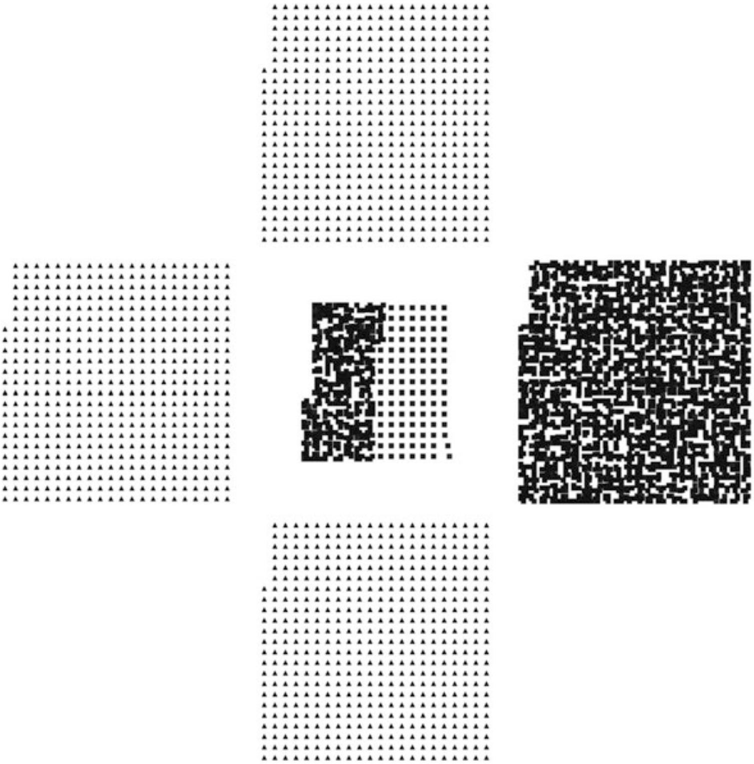

Fig. 13.4 A 2D representation of MWGrid agents

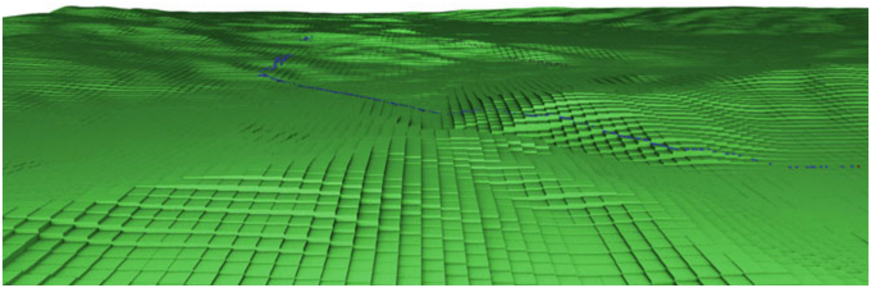

Fig. 13.5 A 3D representation of MWGrid agents moving across the landscape. The *lined dots* represent agents

13.3.4 Data Processing with OpenOffice

The model involves tens of thousands of agents all moving via subtly different routes at different times and expending different amounts of energy. Presenting this to others poses a problem as different aspects of a model's results are of interest to different people. One of the key points of using ABM is that the idea of what an army does, how far it moves and how much energy it expends, is an abstraction covering a lot of complexity in the behaviour of individual agents. The raw data is too complex to investigate and therefore, some form of data aggregation has to be conducted. A statistical summary of the simulation is needed at this point. The summary is derived from the day file, a text file output from the ABM showing aggregated data for each agent from the whole run of the simulation. This includes the total distance moved, ticks spent resting and energy expended in calories. An OpenOffice Calc spreadsheet was created which took this data and aggregated it into a series of statistics in table format (Fig. 13.6) illustrating the average, highest and lowest values for a range of values. It also shows the number of agents and the time used to complete the march. The unit of time the last agent arrives in camp provides an indication of the total amount of time taken by the army.

Fig. 13.6 Aggregated statistical output of a day's march

Average arrival time	6446.21
Average distance covered	27009.46
Average arrival time (Officers only)	6156.22
Last arrival tick	8197
Squads	1260
Agents	7061
Column Leaders	1
Cavalry Officers	1060
Infantry Officers	200
Cavalry Soldiers	4000
Infantry Soldiers	1800
Average Calories Expended	1480.98
Average travel time	4876.69
Column Leader cals	1037.36
Cavalry Officer average cals	1252.1
Cavalry Officer high cals	1467.06
Cavalry Officer low cals	1056.64
Cavalry Soldier average cals	1288.15
Cavalry Soldier high cals	1447.48
Cavalry Soldier low cals	1087.22
Infantry Officer average cals	1983.8
Infantry Officer high cals	2041
Infantry Officer low cals	1948
Infantry Soldier average cals	1988.64
Infantry Soldier high cals	2110
Infantry Soldier low cals	1956

13.3.5 Formats of Visualisation

The MWGrid ABM and its associated programmes are able to generate structured and highly visual datasets via Blender and OpenOffice Calc. This allows the presentation of the data as either statistical tables and graphs, or still images and animations. Different formats have different uses. Still images can give a snapshot of the model at work and can be a good way of examining spatial distribution of agents and resources, animation is often the most effective way to visualise behaviour over time, tables can show large amounts of data at the same time and graphs can track individual values over time. By using Blender as a rendering engine, still images can be made of any tick of any simulation. If the end result is to be reproduced in a printed journal then, given the scale of the Manzikert model and the number of agents used, any image that reproduces the complete army on the march will be at the wrong scale to identify individual features but can show patterns in the movement of the army as a whole. However, there is no reason for the output to be restricted to paper publications. Publication via the Internet allows much higher resolution images in which macro-scale patterns can be seen but each individual agent's movement can be focused on by zooming into an appropriate scale. Once the data is imported into Blender and the appropriate frame of the animation chosen, a high resolution still image can be generated.

In order to see the movement of agents within the model during its operation, animations must be created. Unlike stills, animations cannot easily be created so that the user chooses which parts to focus on, there needs to be an element of directorial control at the point of creating the animation. The virtual camera through which the animation is seen needs to be placed in appropriate locations and to have appropriate scale to visualise the required activity. This may result in interesting behaviour elsewhere in the model being missed due to the camera being elsewhere. Animations however are ideal for illustrating the actual micro-scale behaviours which make up the macro-scale results that are more often shown via statistics and graphs. Graphs can more accurately show data but they are not good ways of illustrating what an army on the march actually looked like.

The most complete way of visualising the behaviours of complex systems is to provide access to the systems themselves and allow users to perform their own simulations. If the system is published with full featured visualisation it allows users to specifically create the information they wish to see. They may be able to see the simulation running in real time or they may produce data from which visualisations can subsequently be made. This is an ideal scenario for simulations which require minimal processing time and small numbers of complete runs of the simulation but will be impractical for models requiring parallel processing, many thousands of iterations or days or even weeks of processing time. In these cases aggregated data is usually much more practical. The modular nature of the MWGrid system enables, for instance, the tick files from certain simulations to be made available so that they may be visualised in different ways by different people.

Others may even create their own Blender models which, as long as they adhere to certain naming conventions, can easily replace the models used in the visualisation seen here.

The production of statistics, stills and animations allows the project to present its data in traditional paper-based publications as well as via the Internet. In addition to using the outputs of the model to explain the results of the project, the art assets and initial Python script were used to produce an explanatory video in the design stages of the project. The Road to Manzikert (Murgatroyd 2009) was part of a university-funded pilot scheme to provide the equipment and technical expertise to allow Ph.D. students to present their research in a short film. The result has been a useful introduction to the project and although it describes the project in an earlier form rather than as it subsequently developed, it was a useful exercise in presenting a specialised project to a lay audience.

13.4 Conclusion

As can be seen from the MWGrid project, ABMs can produce complex data involving large numbers of agents performing a variety of actions over long periods of time. The raw data requires some form of visualisation to make sense but the appropriate form of this visualisation depends on the target audience, the method of distribution and the technical skills available. Due to the fact that it is not only the results but also the process used to produce them that is important, multiple methods and media are required to completely document an ABM. As ABMs are still a relatively new investigative technique within archaeology, existing work is presented in a variety of ways, sometimes as graphs, sometimes with 2D or 3D graphics and sometimes the whole model is available to use and alter.

In order to communicate both the process and results of an ABM, non-traditional outputs can widen the usefulness of research as well as the scope of the audience although traditional publishing is valuable in order to use the audiences that journals and books have access to. Some electronic supplemental data can provide access to more detailed still images, animations and the actual model itself, the most complete method of documentation and presentation. With the easy availability of Internet publication of text and images as well as large audiences for animation and video via services such as YouTube and Vimeo, traditional publishing methods need not, and arguably should not be the only method of dissemination.

There is as yet no fully featured way to produce and visualise ABMs without some technical knowledge and so the techniques used to create archaeological ABMs will depend on the skills available within a project. Issues with visualisation will exist regardless of whether technical solutions are provided by existing toolkits or with bespoke software. Publication via static 2D methods will prefer static 2D data. Data generated from ABMs are dynamic, and in 4D. It shows the processes involved in the agents operations. Any proposed technical solution will have to be able to cope with the variety of scales, topics and levels of detail possible within archaeological ABMs.

At present, the MWGrid project is in the final stages of data collection and analysis with a view to publication via a variety of media. Traditional publication remains an important part of a research but additional publication via methods more suited to 4D data will be key if a proper representation of the processes involved with both producing the ABM and moving the Byzantine army is to be achieved. Finally, the ABM and any accompanying visualisation methods will be freely available for researchers to use, reuse, improve and otherwise do what they wish with.

Simulation is a growing area of research and archaeological simulation will grow with it. The increasing use of simulation in archaeology means that there are an increasing number of archaeologists with the skills and experience necessary to create, reuse and alter ABMs. As the number of archaeological ABMs increase with demands, the range and size of their audiences will grow in proportion, new ways of representing data through visualisation will need to be developed.

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Chapter 14
Time and Tide: Modelling the Effects of Landscape Change on Population Support in the Southern North Sea

Simon Fitch

Abstract The submerged landscape of the North Sea has long been known by archaeologists as an area of Mesolithic occupation yet, despite this, the nature of the occupation of this landscape has remained poorly understood due to its inaccessibility. This chapter presents a first attempt to use digital technologies and modelling to understand the nature of the human occupation of these currently inaccessible landscapes and their associated demography. The models aim to explore the impacts of sea level-driven landscape change upon the Mesolithic population, and further aims to reveal the diversity of resources that would have been present. As such the model will seek to take the first steps in developing an adequate representation of the past landscape and generate an understanding into how past landscape evolution may have served as a buffer to the effects of marine inundation.

Keywords Submerged landscapes · Palaeoeconomic modelling · Population modelling · GIS · Mesolithic archaeology

14.1 Introduction

Volume datasets provide perhaps some of the greatest challenges to archaeological computing, since their demands frequently go beyond the capacity of traditional mapping technologies. This is an issue as, whilst archaeological landscapes are frequently presented as traditional 2D datasets, many aspects of these landscapes demand representation in 2.5D or better. This issue is particularly critical in the developing study of submerged prehistoric landscapes, where large voxel volume

S. Fitch (✉)
IBM Visual and Spatial Technology Centre, The University of Birmingham,
Edgbaston B15 2TT, UK
e-mail: Si_fitch@yahoo.co.uk

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datasets are readily available, often with a supranational coverage. This situation is exemplified by the North Sea, where the study of the landscape has shifted dramatically, from traditional 2D paper studies of the past (e.g. Clark 1936; Jacobi 1976; Coles 1998), to more comprehensive landscape mapping through the use of 3D seismic data, such as those produced by the North Sea Palaeolandscape Project and its successor projects (Gaffney et al. 2007, 2009; Van de Noort 2011, p. 49). These studies have provided a detailed map of the Mesolithic landscape of that region and this study transforms the North Sea Palaeolandscape dataset from beyond simple 2.5D research to create a more holistic dataset capable of exploring not only geographical change, but also temporal data related to population and environment.

14.2 Background

In order to appreciate the scale and significance of the research within the North Sea, it is important to understand something about its geomorphology. The Southern North Sea is a marine basin that occupies a position between the European countries of Norway, Denmark, Germany, the Netherlands, Belgium, France and the United Kingdom, and is confined in latitude between 55° north and 51° north. The North Sea region covers some 574,980 sq km, although the results presented here relate to an area located in the Southern Sector covering 6,250 km^2 or approximately 1 % of the area (Fig. 14.1). Water depths within the North Sea range from 15 m at the Dogger Bank to 600 m in the far north. The landscape of this region owes its appearance in part to Late Pleistocene glacial erosion and subsequent deposition and modification during the Holocene.

Human artefacts and mammal remains have been dredged from the Dogger Bank and it is assumed that these finds have been retrieved from the seabed (Flemming 2002, p. 33). However, as many of these lack both dates and provenance they currently add relatively little to our understanding of the period. Those that possess such information demonstrate the presence of humans, wild boar, red deer and other fauna during the Early Holocene, from 9,870 ± 70 BP till at least 8350 ± 50 BP (Glimmerveen et al. 2004; Mol et al. 2006). Flemming (2002, p. 33) has suggested that suitable environments for the preservation of archaeological materials might include the Holocene fluvial valleys and vast lagoon which must have existed to the south of Dogger Bank at 8,000 BP. Many of these areas are, however, associated with extensive commercial geophysical datasets which have provided a valuable opportunity to explore the region and map the landscape, and this was realised in the mapping provide by the North Sea Palaeolandscape Project.

The North Sea Palaeolandscape Project (hereafter referred to as NSPP) provided a significant advance in the scientific understanding of the British sector of the southern North Sea (Gaffney et al. 2007). However, whilst the NSPP was a major step forward in the technical location of broad landscape features and the

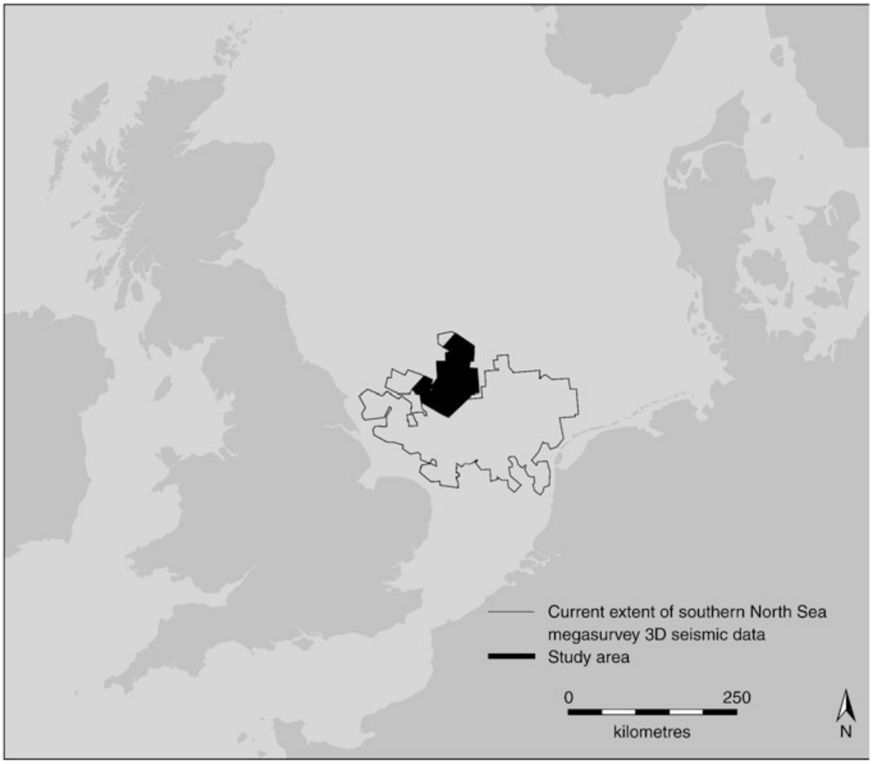

Fig. 14.1 The location of the study area

application of new technologies to 3D seismic data, the project did not seek directly to investigate the scale and nature of Mesolithic occupation or the social and resource impacts of landscape change within the region. This chapter seeks to investigate these unresolved questions. This is largely the consequence of the landscape data available through the NSPP which permits an initial quantitative analysis of the potential nature and scale of human occupation of region (e.g. van Leusen et al. 2005; Peeters 2007).

A variety of models is currently available to determine foraging behaviour, and ultimately, population density within hunter-gather societies (e.g. Mithen 1990; Ebert 2004). These models usually seek determine the supportable population size through analysis of food procurement strategies. Although it is not the purpose of this chapter to discuss the relative merits of such methodologies, it is important to note that at this stage of research in the North Sea, the available datasets are constrained largely to geophysical data and limited environmental evidence. Direct archaeological evidence suitable for use within such models is extremely rare for the North Sea.

Given these limitations, the research presented here uses a modified version of Jochim's 1976 model for hunter-gathers in Northern Europe and utilises qualitative measurements of prey weight, aggregation size and mobility to resolve subsistence issues. As the model uses qualitative measurements, it does not seek absolute values, but rather seeks to display general relationships through ranking of resources and their efficiency of exploitation. Originally developed by Jochim from ethnographic research and archaeological studies, the model is primarily based upon the ecology and resources available within North Germany. Jochim's model examined the factors that determine the exploitation of resources by hunter-gathers. These data were used to generate a mathematical model which predicted and mapped the probable resource utilisation seasonally, as well as effects on settlement. As such, the model relies upon indirect measurement of foraging practices and is much simpler in structure than most quantitative models. It is, consequently, suitable for application within the North Sea despite the limitations imposed by the scarcity of direct archaeological evidence.

14.3 Methodology

For the purposes of this chapter a focus area of 4,500 km^2 was chosen for the implementation of the model. The study covers both flanks of the main depression within this region, the Outer Silver Pit, some 120 km from the nearest landmass. The main source of data for the chapter is a 3D MegaSurvey seismic dataset which was kindly provided for the purposes of this research by PGS UK Ltd. (www.pgs.com).

Initial visualisation of this data was achieved by time-slicing a 3D seismic data cube at 4 ms intervals from 60 ms, the first seabed multiple images, through to 200 ms where clearly resolvable glacial features appeared. Where the seabed was poorly resolved, multiples were used in the time slicing to gain a full understanding of the features at, or near, the seabed (see Gaffney et al. 2007 for more detailed information on the seismic analysis).

In addition to time-slicing the data, archaeologically relevant horizons were identified within the cube and exported as surfaces into a GIS to facilitate the building of a terrain model associated with the Mesolithic land surface. The integration of seismic data in the form of interpreted surfaces into a GIS permitted further opportunities for analysis and interpretation of the data. In conjunction with the terrain model it became possible to accurately position landscape features within the dataset. Additional benefits included correlation with other non-seismic datasets (e.g. core location databases or geological mapping). This analysis permitted a range of Holocene landscape features to be identified and their interpretation provides evidence for the contemporary coastline, estuaries and fluvial features including major river systems that were active during the Mesolithic period. Further details on the processes and techniques of landscape generation are described by Gaffney et al. (2007) and Fitch (2011).

14.3.1 Generation of a Support Model

For the purposes of this project, the values for mobility, aggregation and weight are expressed as dynamic values that change monthly using Jochim's 1976 model of resource use (see Fig. 14.2). For terrestrial species, these values are primarily based on the existing model values (Jochim 1976), with modifications to take into account northern European conditions, such as the timing of fish runs. Modifications were made to include marine species and the weights and aggregation values were expressed using values from modern British populations from data provided by the Natural History Museum (2005). However, the aggregation values for seal populations, and possibly the densities for all resources are, if anything, an underestimate, due to modern interference in these populations. These calculations were then repeated utilising prey species density values that typified both Boreal and Atlantic environmental conditions. This generated data for each prey species' environmental preferences and then allowed the selection of suitable analogues for the model. The final output is grouped seasonally to reduce any monthly bias.

Once the figures for the maximum possible resource yield were determined, and the availability of the resource for human use calculated, Jochim's equation was then applied to the resource matrix. The resource matrix calculates the number of people that the resource could support per square kilometre. To this, a binary matrix is applied within the GIS that allows the calculation of the presence or absence of a resource species. Once factors, including hunting intensity (Jochim 1976; Smith 1992, p. 15) are applied and the resource yield is calculated, it was then possible to calculate the maximum resource energy available for human usage. The energy requirements for a single person in a year are defined by Jochim as 730,000 Kcals per annum. Using this value it is therefore possible to calculate

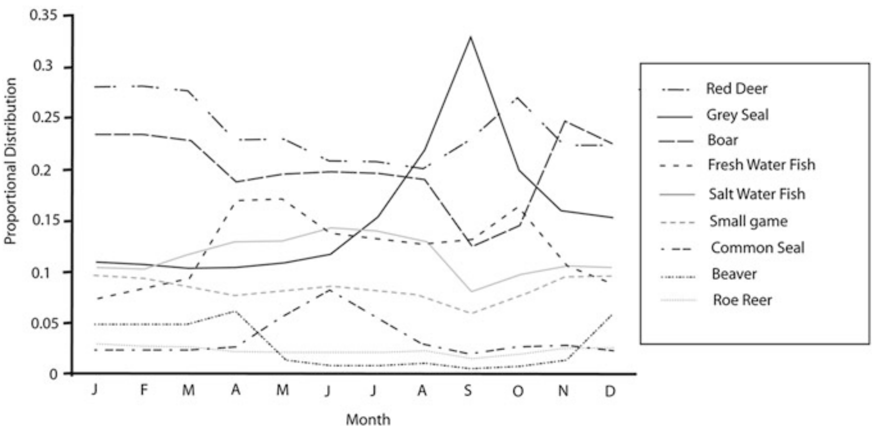

Fig. 14.2 The resulting values of resource use for the Atlantic environmental stage. Note the significant spikes related to the exploitation of seal resources. If the model is indicative, then this would encourage a reliance on terrestrial resources during the winter months

the number of people per square kilometre. This calculation is performed by adding the total resource values for the schedule over the year, less a hunting efficiency constant (given by Jochim (1976) as 20 %), and dividing by the total energy requirements of a single human individual.

For example, for the resource common seal for the winter season, a calorific value of 1294264.78 Kcals per km^2 of coastline is calculated. Of these, only 258,852.95 Kcals are available at a 20 % hunting strategy. Since one person requires 730,000 per year, to calculate the number of people this could support, we must divide the Kcal value (258,852.95) by the requirement value (730,000). This gives us a maxima value of 0.35 persons per km^2 of coastline.

14.3.2 Generation of a Location Model

Any model for site location of hunter-gather communities in the North Sea region must take into consideration the variety of factors noted earlier in this chapter. First, the scarcity of archaeological information from the North Sea itself makes it difficult to generate a suitable strategy. Any model must therefore take into consideration information from the surrounding terrestrial and marine spheres in which comparable societies lived. Fortunately, analysis of Mesolithic data in adjacent areas (e.g. Waddington 2007), suggests that there are comparable areas which can be drawn upon to provide relevant information.

Following this, it is worth stating that most of the required topographic information for the model (e.g. fluvial features, shorelines) can be easily acquired by using the 3D seismic information (see Gaffney et al. 2007 and Fitch et al. 2011). This information was readily available for the southern section of the study area and a subsection of this was chosen for the development of a predictive model. Fischer's Danish fishing model (1988, 1995) also provides a predictive model for submerged sites that exist in the Danish sector of the North Sea. This model is derived from observations on known sites that suggest that topographic position influences site location, and testing of the model has occurred over a long period of time and has gained some degree of veracity as a result (Fischer 1988, 1995; Fischer and Pedersen 1997 and Fischer 2004). However, although the model has been published in part (Benjamin 2010, p. 257), the full detail of the general model has never been published. Indeed, Benjamin (2010, p. 256) notes that "the term 'model' could be inappropriate for the procedure in comparison with substantial studies like that of Jochim (1976)".

This research therefore generated a GIS model based upon the "*principles*" underlying the Danish fishing model. The model utilised a simple inductive layer model approach with important factors being 'weighted' according to their relevance to settlement. Topographic data for the model was derived from a pick of the land surface in the seismic data which was converted to depth (Fitch 2011, p. 94). The initial stage of the model required the contouring of slopes at one degree intervals to satisfy any settlement preference for gentle slope as suggested by the Danish fishing model. A classification of the slope model was generated giving the heaviest weighting to slope values below 5°, which are generally regarded as attractive for prehistoric settlement (Kuiper and Wescott 1999; Waddington 1999).

The relative sea level heights used to generated coastlines were extracted from Shennan's (2000) sea level curve for the study area. This information was applied to the Digital Elevation Model (DEM) generated from the topographic data. Topographic lows that fell below the sea level curve were then deemed to be submerged, whilst those above were considered to be land. Tidal variation was taken into account by assigning a height of 5 m above sea level as the minimum height at which a site could be located. As a further restriction, a distance model was applied whereby all sites over 0.5 km from the sea were scored at a low value (1) to compensate for distance from the coastline. In addition to this coastal effect, the presence of islands and safe waters was indicated by a weighted score and was overlain in a summative manner with the fluvial and coastal distance models (see Fig. 14.3) in a manner which replicated the Mesolithic preferences observed by Fischer (Fischer 1995, p. 374).

The Danish fishing model suggests that the presence of fluvial features near the coastline influences site location. Since the fluvial features located by the seismic data are likely to represent the flood plain of a river rather than the channel itself (see also Posamentier 2000), it was decided that distance from these features would be sufficient to reflect their influence within the model. Scores were therefore ascribed which placed the highest value in the floodplain itself, whilst the score decreased over a distance of 0.5 km from the feature. Areas beyond 0.5 km were ascribed a low value (1). Once all the layers had been compiled, they were reclassified on a scale of 0–255, where 0 is least attractive to hunter-gathers and 255 most attractive. The resulting outputs were added together to allow a quantification of probable site location. The resultant output layer offers a modelled significance of the importance placed on the coastal areas. Catchment analysis was then performed on the output as a final stage of the methodology (see Fitch 2011 for more details).

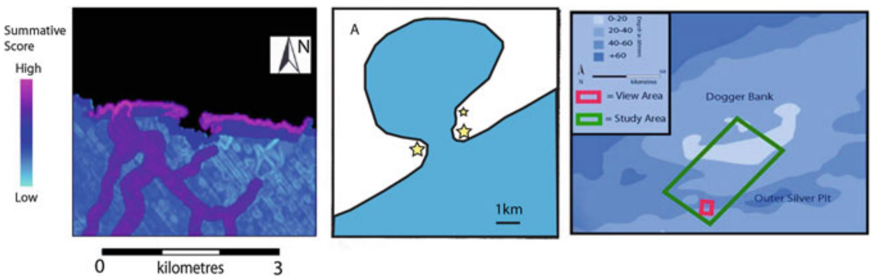

Fig. 14.3 Summative distance mapping for coastline and fluvial features. It is apparent that the locations where the coastline is met by a river score highest (*purple*). A similar effect is seen in the embayment—this is comparable to the effect seen in settlement locations predicted by the Danish fishing model (labelled 'A'—adapted from Fischer 2004)

14.4 Results

The resource values provided were converted to population carrying capacity and generated at 500 year intervals across the available land within the study area. It must be stressed again that the values presented represent population maxima values rather than a real figure, and it is therefore the relative change in ratios between time-intervals that have the most significance. If this data is examined by species then grey seal appears to be able to support a larger population than any other prey species. This is a product of the size and calorific value of a grey seal, which suggests that even a relatively small catch will support a large number of people. Thus, it could be expected that a large population could be supported on the coastline. However, the relatively small overall area of the coastline (Fig. 14.4) should be taken into consideration as the result is likely to only have localised significance.

If the results are examined as a seasonal maximum population over time, then further insights are provided (Fig. 14.5). Whilst both the spring and summer maxima population values broadly reflect the overall downwards trend in population over time, there are significant variations in the autumn and winter values (Fig. 14.5). The autumnal figures do not deviate greatly but show a pronounced peak in population at 9,500 BP. This rise is almost certainly due to the appearance of marine resources in the model, associated with sea level rise, and associated in part to the availability of grey seals during pupping. After 9,500 BP the population values return to a downward trend. This is significant, given the change in available coastline (Fig. 14.4), and this suggests that the resources made available by the new coastline were not sufficient to make up for the terrestrial resources lost to inundation during this time.

Within the seasonal data the winter values are more significant. If the values for all the seasons are examined together (Fig. 14.5), then it is apparent that the winter value is likely to be the controlling factor on population. If the winter results are expressed as a percentage of the summer population values (Table 14.1), then the

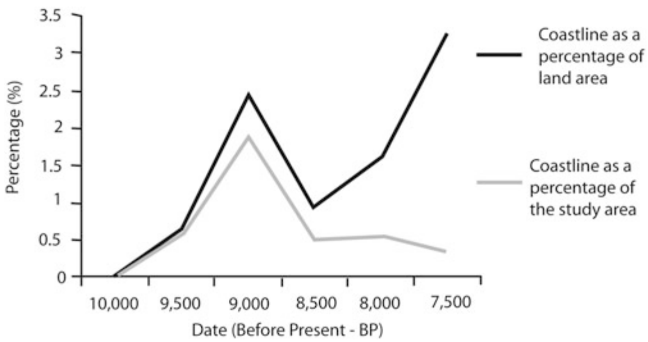

Fig. 14.4 Coastline as a percentage of the total habitable land area

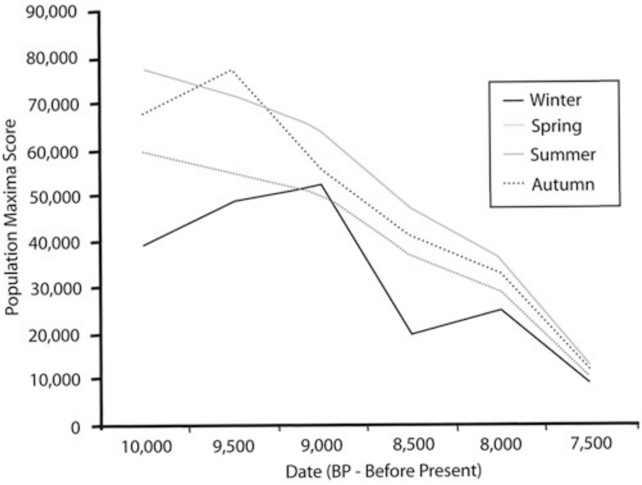

Fig. 14.5 Total maxima population over time (all seasons). This suggests that, with the exception of the period centred on 9,000 BP, the winter total population value is likely to be the controlling factor

effects of seasonal changes on the population supportable by available resources can be clearly identified. At 10,000 BP, winter population value is only 50 % of that supportable in summer. To the contemporary inhabitants of Doggerland the summer would therefore represent a time of plenty or as providing a surplus to be stored for the following winter. If the Mesolithic population were not storing foodstuffs then the maxima Mesolithic population would be expected to be controlled by the winter values. Even if storage was available, the differences between the other seasons and winter are sufficient enough to suggest that this would have not increased greatly beyond the winter value. For 9,000 BP the story is very different. The winter population value is some 81 % of the summer value, and is greater than the spring value. In this case the spring value may be the controlling factor. However, given the opportunities presented by food storage, and the similarity of the winter and spring values, it is likely that the higher winter value may

Table 14.1 Overall winter population as a percentage of the summer population

Ka BP	Land area	Population winter	Population summer	Winter population as a percentage of summer
10	4,377	39,359	77,662	50.6
9.5	3,814	48,571	71,975	67.47
9	3,317	52,218	64,012	81.6
8.5	2,464	19,630	46,919	41.8
8	1,410	24,571	35,870	68.5
7.5	484	8,734	12,458	70.1

Table 14.2 Percentage change in population relative to the maximum winter population

Ka BP	Land area	Controlling value	Density	Change in population	% of Maximum population	
10	4,377	39,359	8.99		75	Rising population
9.5	3,814	48,571	12.73	9,212	93	Rising population
9	3,317	52,218	15.74	3,647	100	Maximum population
8.5	2,464	19,630	7.96	−32,588	37	Falling population
8	1,410	24,571	17.42	4,941	47	Rising population
7.5	484	8,734	18.04	−15,837	16	Falling population

still be the controlling factor. There is therefore an opportunity for more a larger, possibly more stable population in the period centred on 9,000 BP.

Further information can be gleaned if the values are expressed as a percentage of the maximum population size for winter (Table 14.2). When examined, clear changes can be observed and quantified, with the population being seen to rise to c. 25 % of the maxima value between 10,000 and 9,000 BP, with the maxima population value reached at c. 9,000 BP. After this however, at 8,500 BP, there is a sharp fall in population to only 37 % of the maxima. This represents a decline of 63 % of the population, although by 8,000 BP the population rises again by some 10 % of the maxima value. This is due to the onset of Atlantic environmental conditions which support an increase in density of prey species.

It is clear from the data that there is a large fall in population at around 8,500 BP and a smaller one at 7,500 BP (Fig. 14.5). If we examine the population density results for the habitable land area (Table 14.3), then it is apparent that the picture is largely one of increasing population densities over time. Logically this would imply a larger population being required to live within an increasingly small area. The slowing down of such a trend towards the end of the inundation period would indicate that an optimum density, in terms of resources, is being approached. However, there is a major deviation from this at 8,500 BP, which requires explanation (see Table 14.3). Around this time the population falls from a density of 15.7 at 9,000 BP to 7.9 at 8,500 BP. It is important to note that this figure is even less than the value for 10,000 BP. Upon examination it is apparent that this decline also coincides with a major population loss (see Table 14.2), a loss in

Table 14.3 Percentage change in population density for winter

Ka BP	Density	Change in density	% Density change	
10	8.992232122	N/A	N/A	N/A
9.5	12.73492396	3.742691842	37.4	Gain in density
9	15.74253844	3.007614474	31.6	Gain in density
8.5	7.966720779	−7.775817659	−86.4	Loss of density
8	17.42624113	9.459520356	111.3	Gain in density
7.5	18.04545455	0.619213411	7.7	Gain in density

coastline, and an increased rate of sea level rise. This loss in population density is therefore understandable, as there are few people in the landscape, and because of the loss of coastline, fewer resources are available to support higher population densities. However, this should also be considered in light of the drop in total coastal area and a reduction in the length (and convolution) of coastlines. At 9,000 BP the coastal area represented some 2 % of the total study area; by 8,500 BP this had dropped to only 0.5 %. Since the coastline is capable of supporting high population densities any decline in coastline length also represents an important reduction in capacity. This combination of a reduction in overall landscape and coastline area results in a significant negative impact upon the Mesolithic populations within the region. The loss in overall population, combined with a reduction in population density over a relatively short period of time (500 years), suggests that a considerable portion of the population may have been displaced.

Such major changes in population numbers and density have obvious cultural implications. At 10,000 BP, with relatively low population densities spread across the whole study area, it may be surmised that a mobile economy is predominated in the area. However, from 9,500 to 9,000 BP, with the increased availability of marine resources, the opportunity for a more sedentary population occurred. The population densities in areas without access to the coast remain unchanged from 10,000 BP (Table 14.4) until 9,000 BP, when the reduction in landscape becomes sufficient to cause this to fluctuate. This suggests that mobile lifestyles remained the norm within the interior, and may even have been required in later years following resource reduction. Conversely, the increase of high density coastline allows for greater population densities than in the terrestrial zones and such conditions may support the development of semi-sedentary settlement. This suggests that significant cultural, as well as settlement, differences may have occurred between the terrestrial and coastal populations. The values suggest that the terrestrial zone would have therefore been populated by high numbers of small groups that were relatively well dispersed within the landscape. For the coastal zone a different picture emerges. The results of this model suggest a small number of large groups, occupying relatively small areas in terms of the landscape.

Table 14.4 Population density compared to soil type

Population density	10K_BP	9.5K_BP	9K_BP	8.5K_BP	8K_BP	7.5K_BP
Alluvial soil	13.0	13.0	12.9	12.5	18.2	17.6
Calcareous soil	6.5	6.5	0	0	0	0
Well-drained basic calcareous soil	6.5	0	0	0	0	0
Well-drained basic soil	6.5	6.5	3.7	1.3	4.7	4.7
Wet basic soil	9.1	12.4	14.8	7.2	16.6	16.7
Coastline	0	58.5	58.3	57.4	63.5	64.4
Sea	0	0	0	0	0	0
Lake	0	0	0	0	0	0

This information is perhaps most useful when considered within the GIS analysis. This clearly show the effects of these changes (represented here as maxima values) over time and space. These can be found in summary form in Fig. 14.6 (full illustrations are located in Fitch 2011, Appendix 2) representing the mapping of total maxima population during winter. The GIS analysis allows for visualisation of the changes in population, in relation to the changes in the landscape. For example, the highest maxima population numbers are situated on wet basic soils (Fig. 14.6). This trend continues throughout the life of the landscape, and is primarily driven by the large area of these zones. Significantly, one of these

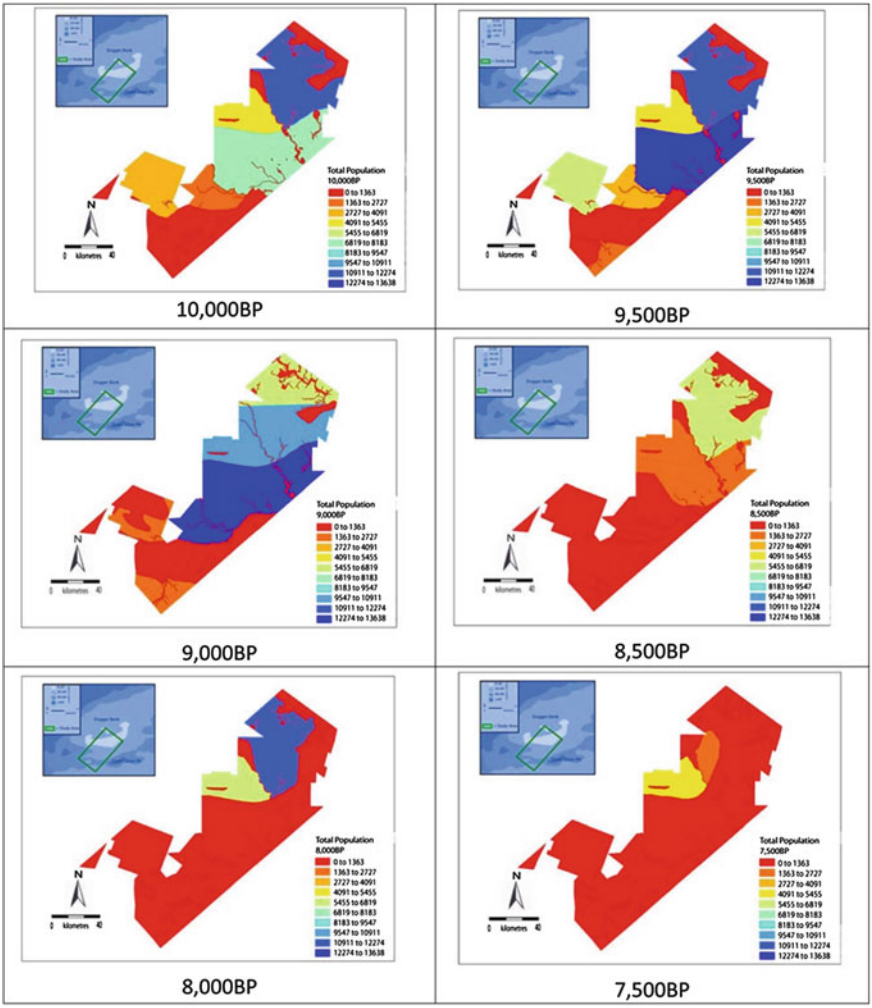

Fig. 14.6 Maxima population maps for winter over the time range 10,000–7,500 BP (detailed maps for all seasons can be found in Fitch 2011)

areas is largely lost to marine inundation at 8,500 BP and the associated loss of resource may be the principal cause of population loss at this time.

If the population density is further examined within the GIS, similar insights can be gleaned. Winter at 10,000 BP produces some unexpected results and the influence of overall soil type on plant species plays a major factor in the potential of specific areas for population aggregation. These data produce a regional high in the north of the study area. At 9,500 BP marine incursion has begun in the Outer Silver Pit, and the opportunities provided by a marine environment are emphasised by high potential population densities in the coastal zone. The population density values are considerably higher than purely terrestrial values. However, in relation to coastal population densities the terrestrial population density is significantly increased along river courses during the autumn and winter seasons. This is probably a reflection of seasonal fish runs and the hunting of beavers during these periods. As marine inundation continues through to 9,000 BP, only minor changes in the overall population density are observable in the data. Locally, the increase in coastline resulting from inundation leads to a spread of high population density areas. At 8,500 BP the GIS illustrates the effects of increasing marine inundation. Approximately 45 % of the study area is now submerged and rivers now appear as areas associated with an increased population throughout the seasons. This response is thought to be a reaction to the relative loss of terrestrial resources.

By 8,000 BP nearly two-thirds of the study area is inundated. The change to more Atlantic environmental conditions is seen to increase the supportable populations across the region. Due to the increase in the percentage of coastline relative to habitable land (Fig. 14.4), the effect of the presence of coastal areas is now very apparent. At 7,500 BP most of the landscape is inundated and only a very small area of habitable land remains. This is surrounded by a coastline with a high population density. It is apparent from the map that the marine inundation would have shut down almost all of the fluvial systems in the area. It is likely, therefore, that fresh water may have been a scarce resource, and this appears to be reflected in the alluvial population densities.

14.5 Results of the Location Model

Whilst the tables and base resource and population maxima maps produced in the previous section are useful, greater insight may be gleaned by looking at the effect on an individual hunter-gather territory. Since hunter-gather populations are frequently mobile it is likely that large-scale changes in available land must impact on hunter-gather bands. By looking at the effect of the introduction of sea level rise on a set of predicted territories, however, we can begin to observe changes which may affect hunter-gather decision making.

Upon examination of the quality of the datasets, it was felt that only the southern area possessed sufficient data quality to permit modelling of such factors. Topographic data was provided in the manner described above although additional

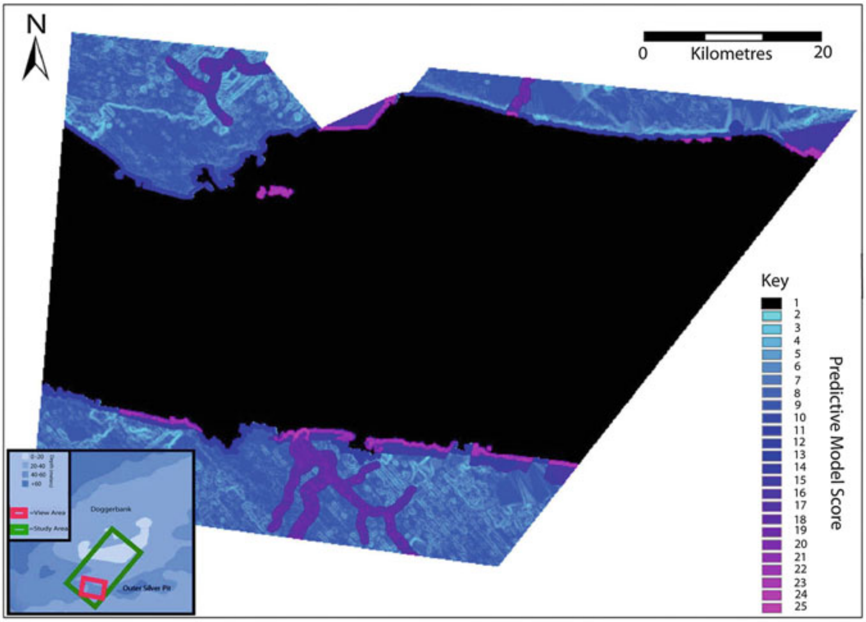

Fig. 14.7 Model at 9,500 BP illustrating the combination of the data layers. Note that whilst river valleys and the coastline score well (shown in *purple*), the areas most likely to be locations of archaeological sites are at the junctions of rivers and on small islands

weighting was provided through the use of the Strahler stream order to allow the model to consider the river size. The resulting outputs were summed to provide data on site preference, and the results of this process for 9,500 BP are illustrated in Fig. 14.7. Here the model outputs an area of optimal opportunity for settlement. The combined results for the period 9,500–8,000 BP can be seen in Fig. 14.8. The highest scoring areas within the data were manually selected as optimal site locations and converted to point data to facilitate additional analysis.

What the model clearly illustrates is a preference for coastal locations, and specifically areas of fluvial/coastal interaction. This is, perhaps, to be expected given the weightings within the model. Indeed, it is a limitation of this model is that it preferentially predicts for site location in coastal areas and not in more landlocked areas. While this initially may not seem a major issue, since preferential settlement is thought to have occurred in these areas, the very high values effectively mask areas of interest in the inland areas which may have equal archaeological validity and interest. One possible solution to this issue, which may be explored in future, is the inclusion of a second iteration with the coastal element of the model removed. Foley (1981) presents the possibilities of considering "off-site" archaeology, and a combination of this with the model would facilitate a more balanced prediction.

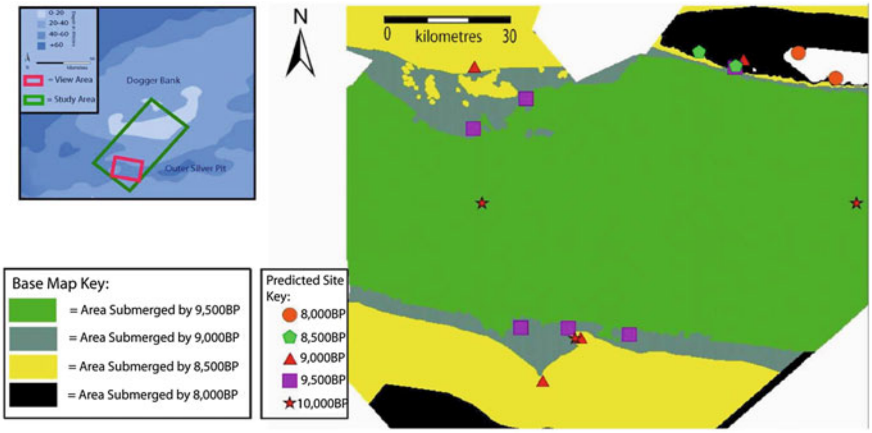

Fig. 14.8 Predicitive model output (by period) after core areas have been identified as points

14.6 Discussion

The overall trends derived from the model suggest a reduction in population through time as the landscape is slowly inundated. As submergence progresses so the population is forced into a smaller habitable landscape, thus the population density increases. However, there are deviations within the data from this trend and these may have archaeological significance. The maximum population figures clearly show that the loss in landscape did not necessarily result in a loss of population. The buffering effect caused by the presence of marine resources can be seen to stave off loss for a considerable period of time. It is only when the landscape fragments and the length of coastline is seriously reduced, that the relationship between landscape loss and population loss is established.

The maximum population figures also show that much large numbers of people were probably present in the terrestrial zones of the landscape, in comparison to the coastal zone. If this is taken in isolation then it would suggest that the terrestrial areas were more attractive areas for habitation. Yet when we consider the population density figures the picture becomes more complex, and from the density figures the coastline appears to the optimal area for settlement. How then are we to interpret these two observations? If the datasets are considered together it is clear that the terrestrial areas are capable of supporting large numbers of people, primarily due to the large area involved. However, this is at the expense of population aggregation (density). Thus, the data suggests that there are large numbers of people moving around an extensive landscape in small groups. This would support a hypothesis that the "people of the interior" were nomadic in nature, and less likely to aggregate in order to produce structures such as houses (e.g. Waddington 2007). Conversely the coastline, whilst being smaller in area and supporting fewer people than the terrestrial zone, actually supports a population that can achieve relatively large group sizes (and hence population densities) within the given area. Such an aggregation of people would support more complex social interaction and behavioural change. Furthermore, the density of the resources in the coastal zone would require smaller movement across the landscape for the purposes of resource acquisition, presenting an opportunity for sedentism. Such a result suggests that if coastlines are present there may be two patterns of settlement, and Nordqvist (2000) has reported such a situation in Sweden.

The model also demonstrates significant reductions in population and population density at around 8,500 BP. This is caused by acceleration of marine inundation and the loss of coastline. As such, the model suggests that 8,500 BP represents a tipping point where the new resources generated by access to the coast are outstripped by the pace of landscape loss. The effect of this on the resident population must have been significant and potentially discernible within the archaeological record. A fall representing the loss of over 62 % of the population over 500 years could only be achieved through higher mortality/lower birth rates and/or migration. Given our knowledge of Mesolithic mobility, it is likely that migration is the most likely response to landscape loss of this scale.

When considering these data, it is important to balance this information with the fact that the opportunity for increased population densities may not be fully utilised by hunter-gather groups. As noted by Joachim (1976), ethnographic hunter-gather groups rarely exploit available resources to the full and consequently have a comfortable resource reserve for lean years. Consequently, if the increased potential population density observed for the coastal zone is considered to represent resource surplus then it is possible that these coastal communities may have been buffered from the effects of landscape and resource loss. Again this would have provided further opportunities for sedentary occupation. However, even if this strategy were to have occurred, it is most probable that the dramatic decrease in resources suggested by the model would have impacted upon these coastal communities.

Gradual submergence would have had other, more immediate effects, upon the occupants of the area. At a small scale, the loss of a village during the Mesolithic, perhaps precipitated by a storm breaching a sand bar, would have had immediate consequences. Although inconvenient, this would have represented only a small risk to mobile hunter-gathers. Lost tools and houses could be remade, whilst lost foodstuffs could be replaced from resources in the surrounding landscape. The overall impact would, therefore, have been much less than one might expect. However, the large-scale loss of extensive tracts of lower lying land would have exerted pressure upon Mesolithic peoples to move to new territories. Waddington (2007, p. 205) contends that the construction of the large structure at Howick was a direct consequence of this pressure and the need to delimitate ownership within a landscape where groups were competing for space.

This evidence for pressure resulting from marine inundation, although currently unavailable from Dogger bank itself, can be demonstrated from other areas. The evidence for violence from Skateholm (Mithen 2003, p. 174–175), although from a slightly later period, is of particular significance. Indeed, there is a growing awareness that violence may have been endemic amongst communities experiencing such pressure (Roksandić 2004). Mithen (2003), for example, notes southern Sweden was already losing large areas of its coastal strip to rising sea levels during the period when the cemetery at Skateholm was in use. The tension between competing communities under pressure from landscape loss must have been significant, and is perhaps reflected in the number of injuries to the dead including head wounds and arrows embedded in bodies (Midgley 2005; Spikens 2008).

The results of this model are significant in the light of such evidence. The data clearly shows a rapid population loss after 9,000 BP. Although the qualitative model is unable to produce absolute figures for this loss, the ratios are large. The figures suggest a 63 % loss in population between 9,000 and 8,500 BP (Table 14.2), and an 86 % loss in population density (Table 14.3) for the same period. Such a figure represents a huge change in the population in this area. If, for example, an optimal environment figure of 0.1 persons per km^2 (Smith 1992) is utilised over the entire study area, then a population of 332 people would be expected within the research study area at 9,000 BP. If the losses stated above are applied, then only 123 people would have remained in the study area by 8,500 BP. If we consider the figures for 9,000 BP, assuming no population change due to changes in mortality, this would suggest that 209 people would have been displaced over a 500-year period. Whilst this may not seem like a large figure, in terms of a hunter-gather society, these figures would have been as large as entire tribe recorded in the ethnographic literature for Australia (Birdsell 1968, p. 229). Even with respect to an average ethnographic band of 25 (Lee and Devore 1968, p. 11), the figure represents the loss of at least 8 major social groups. The numbers of displaced persons moving into the surrounding areas of Britain and Europe could well generate the pressures documented in the archaeological record of adjacent terrestrial zones.

The scale of changes may have generated social adaptation and the requirement to emphasise ownership of the land and its resources. This would have become even more urgent as yet more people were displaced by the emerging North Sea. If we scale the figures up from the 4,500 km^2 of the study area to consider the area of the emergent landscape covered by the marine 3D geophysics (46,000 km^2, Fig. 14.1), the 63 % loss figure for 8,500 BP reveals a displaced population of perhaps some 2,898 persons. When we compare this to the likely population numbers for much of northern Europe at this time (thought to be in the tens of thousands: Smith 1992), this figure is very large. Indeed, as this only represents approximately half of the emergent landscape at that time, the actual figure is likely to have been much higher.

Given the buffer to change represented by the marine resources, it is perhaps no wonder that structures such as Howick appear in the landscape at about the time of this population displacement (8,715 BP ± 45, OxA-11831, Waddington 2007). As the results show, the resources available from marine sources provide an incentive to reduce movement in the landscape, and the need to protect such resources from a migrant population may have been a real requirement. One of the main questions raised by Waddington (2007, p. 207) was that of why Mesolithic house structures seem to disappear from the archaeological record some 500 years or so after they appeared. The model suggests that this question may have a simple solution and is linked to the reduced displaced population numbers after the initial events centred on 8,500 BP. If we examine the results from the study area, we can see that after the initial displacement of 209 people between 9,000 and 8,500 BP, displacement stops during the next 500-year period. If we consider this in simple terms, the period 9,000–8,500 BP sees a population migration of 0.4 persons per year, while the period 8,500–8,000 BP sees the emergence of increased resources associated with available coastlines and therefore no population loss. It is apparent from these figures that the impact of migration during these two 500 year periods would have been significantly different.

Perhaps what the model and the information on the creation of house structures during this period tell us, is the scale at which Mesolithic society responded to climate change and the nature of such change. The modelled data suggest that the Mesolithic response may have been relatively rapid and the response equally dramatic. The creation of structures such as Howick required a major and sustained effort to create (Waddington 2007) and the occupants of the structure obviously felt that this was required. However, after 500 years of house building something changed, and the response was to discontinue house building. The model suggests this may have been a reaction to a decrease in migration. Indeed, the increasing marine resources during the preceding period suggest that the new convoluted coastlines' marine resources acted as a buffer, slowing the impact of landscape loss on resource availability.

If this is applied at a greater scale across Doggerland, then the pressures on the surrounding population must have decreased. Whilst Waddington (2007) observes that the pressure is less when Britain is finally isolated from continent, the results of this research suggest that the increase in coastline may have provided sufficient resources to reduce the pressure before separation occurred. Significant proportions of the landscape would have continued to be flooded after this date, and the pressure must have continued, but at lower levels. However, the overall scale of movement must have been far less than the initial loss at 8,500 BP. The effective need for delimitation of territories remained, but the lower numbers of displaced persons suggest that permanent structures were not required, and that these changes may provide a possible explanation for the end of house construction along the British coast.

14.7 Conclusion

The results of the model suggest that the inundation of the study area may well have driven social change over a large area, and that these changes must have rippled outwards from the region as inundation proceeded. It can be argued that this must have been a turbulent time socially and that the nature of the landscape change would have shaped and moulded the character of Mesolithic communities across the region and beyond. This first pass model, therefore, has demonstrated that the application of digital technologies has the potential to offer real insight into this remote period and inaccessible landscape. This has, of course, also been the result of the availability of new technology and data sources. The ability to examine and model environmental and landscape impact upon prehistoric populations using information derived from new and emerging volume datasets is now possible at a scale never previously thought impossible. The significance of such a development should not be understated. The inclusion of such data offers archaeologists the opportunity to revolutionise our understanding of submerged prehistoric landscapes, their populations, and to understand their place in prehistory both in Europe and elsewhere in the world.

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Chapter 15
"There's an App For That": Building Smartphone Applications to Improve the Ergonomics of Landscape Study, Analysis and Interpretation

Lawrence Shaw and Keith Challis

Abstract In the past few years, the widespread availability and use of Smartphones and mobile applications has become ever more prevalent in daily life; but how can these powerful, compact, user-friendly devices be used to improve an individual's interpretation and understanding of a landscape? This chapter discusses the development and testing of a dedicated Smartphone application for Apple's iOS, which allows users to explore archaeological information relating to the Stonehenge World Heritage Site. We describe the design and development of the application and assess how individuals interact with the software and ways in which it aids with the interpretation and understanding of the landscape.

Keywords Landscape archaeology · Landscape theory · Thomas soja · Third-space thinking · Applications · Apple iOS · Stonehenge · Archaeology data service

15.1 Introduction

In recent years a number of powerful, interactive and informative heritage-based applications have been produced as a response to the Smartphone revolution. In the UK, organisations such as English Heritage and the National Trust have produced map-based applications that provide users with information on their surroundings and associated properties and monuments. This chapter utilises a case study to assess ways in which Smartphone applications (usually abbreviated to Apps) can be

L. Shaw (✉)
New Forest National Park Authority, Lymington, UK
e-mail: lawrence.shaw@newforestnpa.gov.uk

K. Challis
Department of Archaeology, University of York, York, UK

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used to improve the ergonomics of landscape study, analysis and interpretation. After setting a broad disciplinary context, we discuss the development and testing of a simple App using Apple's iOS and conclude with some observations on the use and effectiveness of our App and the theoretical context for such endeavours.

To assess ways in which Smartphone technology could be used in landscape studies, we developed a dedicated Apple iOS application using data provided by the Archaeological Data Service (ADS), and focused on the Stonehenge World Heritage Site. By assessing the influence, this application had on individuals moving within the Stonehenge landscape, this chapter will examine ways in which Smartphone technology can benefit landscape studies.

15.1.1 Smartphones and Applications

The use of mobile phones to interact with function-specific software applications (Apps) took off in 2007 with the introduction of the Apple iPhone. To date, the Apple App Store provides the world's largest application marketplace with over 350,000 applications available to download (Apple 2011). Increases in processing power, memory and the ability to use wireless connections have allowed mobile devices to run highly complex and interactive applications that were once only available on desktop computers (Onal 2007). The production of an intuitive software development kit by Apple has also helped to fuel the growing App market, making it easier for inexperienced developers to develop their own application. The innovations led by Apple and iOS have been matched by the development of Google's Android operating system for mobile devices, also supporting small, downloadable software applications accessed via an online marketplace. These two compete for the lion's share of the Smartphone market worldwide.

In the UK, the National Trust and English Heritage created two of the leading heritage-based applications. These map-based applications provide an interactive gazetteer of the respective organisation's visitor attractions. GPS receivers built into many Smartphones also allow users to identify their location and to search for attractions in their locale. The key aims of these applications were to increase visitor numbers and to keep up with the mobile market within the heritage sector. The National Trust App alone has had over half a million downloads to date, and the newer English Heritage application is receiving 5,000 downloads a month (Holly Wright, National Trust, Anne Wright, English Heritage).

15.1.2 Archaeological Data Service

The ADS aims to 'support research, learning and teaching with a high quality and dependable digital resources'. (Archaeology Data Service 2011a). The service's web site receives over one million hits every month (Archaeology Data Service

2011b). Relying on data provided by research and commercial heritage projects, the service provides a central location for all UK heritage related data to be stored. The ADS also actively promotes standards of good practice in data collection, management and maintenance, with the aim to allow as much of the information and data that they receive to be accessed by the public. Over a period of 7 days in April 2011, the ADS saw 527,484 successful requests for data from around the globe, with 67.04 gb of data being downloaded (Archaeology Data Service 2011c). This hugely popular and rich resource of heritage data is clearly well used worldwide and provides detailed and useful information for personal, professional and academic research.

15.1.3 Stonehenge

Located on Salisbury Plain, Wiltshire (Fig. 15.1, NGR 4117 1420), Stonehenge became a World Heritage Site in 1986 for its outstanding prehistoric monuments dating between 3,700 and 1,600 B.C., (English Heritage 2011). This prehistoric landscape covers around 2,600 hectares and contains a wealth of archaeological remains with the ADS ArchSearch database holding around 1,900 individual records for features and events within our area of interest (a 38.6 km^2 box around

Fig. 15.1 Map showing the location of the Stonehenge World Heritage Site. *Left panel* shows the county of Wiltshire within Great Britain and the approximate location of Stonehenge, *right panel* shows the County of Wiltshire and the boundary of the Stonehenge World Heritage Site, with the boundary of the study area indicated in *red*

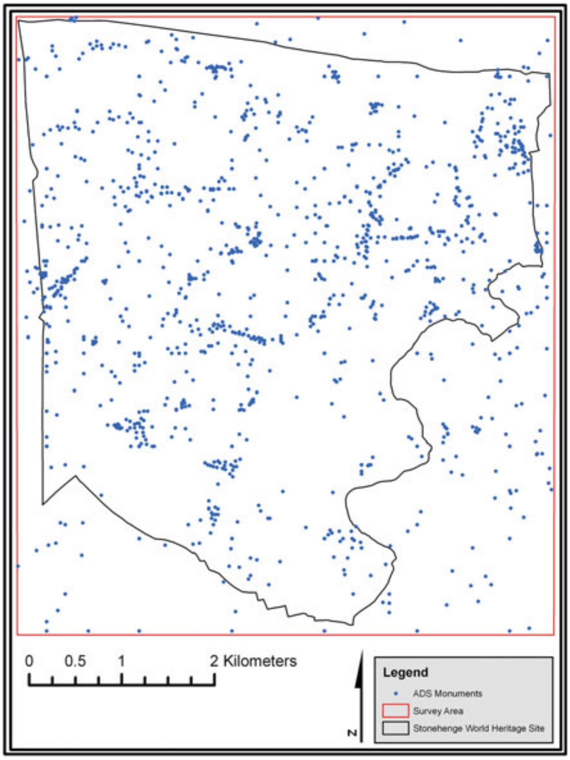

Fig. 15.2 Map showing the spatial locations of individual records held by the ADS for the study area, the boundary of the Stonehenge World Heritage Site is indicated in *black*

the world heritage site, Fig. 15.2). In 2008, Stonehenge saw 887,000 visitors (English Heritage 2008). This number has grown by 100,000 every 10 years since 1990 and only includes people visiting Stonehenge itself. As one of the world's iconic heritage sites and one of the most visited World Heritage Site in the United Kingdom, Stonehenge provides an ideal case study for research investigating public engagement with landscape. In our research, we adopted the Stonehenge landscape as the theatre of study for an Apple iOS App designed to run on the iPhone which draws upon the data available within the ADS to mediate information on the archaeological aspects of landscape.

15.1.4 Landscape

The interpretation and understanding of landscapes has a wide and multidisciplinary interest (Johnson 2007). Edward Soja, an American urban geographer explored the dichotomies of landscape study identifying two key approaches to thinking about landscape, which he defined as first and second space. Firstspace thinking focuses on local landscape experiences, understandings and interpretations such as phenomenology. Contrasting this, Secondspace thinking is a theoretical school that provides conceptualisation of space and landscapes, looking at aspects such as spatiality in mental or cognitive forms (Exon et al. 2000). Soja (1996) went on to define a third approach to landscape, his so-called Thirdspace which 'aims to critically, but sympathetically, deconstruct and reconstruct First and Secondspace thinking to an ontology associated with historicality, sociality and spatiality'. (Soja 1996). This school of thinking is in relation to, but not opposition to, the current spatial duality and seeks to open new positions not offered by First and Secondspace thinking (Exon et al. 2000). We are interested in ways in which the use of mobile technology may integrate first and second space ways of being within the landscape, thus providing access to Soja's third paradigm.

15.2 Methodology

The objective of our research was to develop a user friendly, informative heritage-based application for the Stonehenge landscape, from data provided by the ADS, utilising a map-based interface to mediate information on monuments in the users' locale.

15.2.1 Development

Software development took place within Apple XCode using Objective C, a pure superset of C acquired by Apple in 2005, and their preferred developing language (Chisnall 2009). We chose XCode to develop the application for our research because of its intuitive nature and the array of pre-set tools it provided for interface building. The software also supports a selection of file types, broadening developer's options. This proved invaluable when looking at ways to incorporate monument data from the ADS. An important limitation to using XCode is its limitations to Apple products only. This meant that the application developed for our research could not be used on non iOS platforms. The Android operating system has recently been acknowledged as supporting nearly 50 % of the world's Smartphones, with Apple only supporting 19 % (Albanesius 2011) and this limiting software choice, while acceptable for a research application, would not be sustainable in real world use.

15.2.2 The Application

We chose to adopt a similar approach to that used by English Heritage and the National Trust, in adopting a Google Maps-based interface to provide the spatial context for presentation of information and user location (Fig. 15.3). The MapKit function within Apple's iOS SDK allows the use of a Google Maps-based interface for their application (this has since changed to Apple Maps with the introduction of the iOS 6 update in 2012 (Apple 2012)) within which the map style can be customised. We adopted Google's hybrid style map as it was felt that the use of annotated aerial imagery provided information, which enhances the user's experience allowing them to gain further insight into their surroundings. Our application included the ability for uses to access the iPhone's on-board GPS to identify their location within the landscape. Thus, the basic architecture of the App comprises a location aware image-based map, generated in real-time using Google Maps, upon which data may be superimposed.

Information on individual sites is represented on the map interface as standard Google pins, the pins were geo-located, using information on individual monument records provided by the ADS, and each pin contained embedded data relating to the monument name and types where available, as well as the monument ID (Fig. 15.3). While limited in its content, this simple approach allows users to identify exactly what a monument is and provides an insight into how monuments

Fig. 15.3 Screen grab from the working iOS application showing the user location (*blue symbol*) with *black pins* indication nearby ADS records. The *background* aerial imagery is provided by Google maps (© Google)

and features relate to each other spatially. Since the map interface provides information on monuments around a user's location as well as at their particular point in the landscape, users gain insight into the spatial distribution of monuments in their locale. Management of pin distribution was handled using the REVClusterMap API (Bart Claessens of Revolver (Revolver 2011). (http://revolver.be/blog/mapkit-clustering-with-ios/) Fig. 15.4), which allowed progressive clustering of pins as the user view becomes wider and prevents cluttering of the map screen with excessive pin numbers.

15.2.3 Data Integration

The data used for this project played an important role in how the application was produced. One problem within the data used was that of its quality. The ADS provided 1,942 records for the area of investigation. However, after reviewing these data, it became clear that a number of these records needed to be removed as they were either erroneous or irrelevant. Additionally, problems were encountered with the georeferencing of some records, as a number of them only had six figure

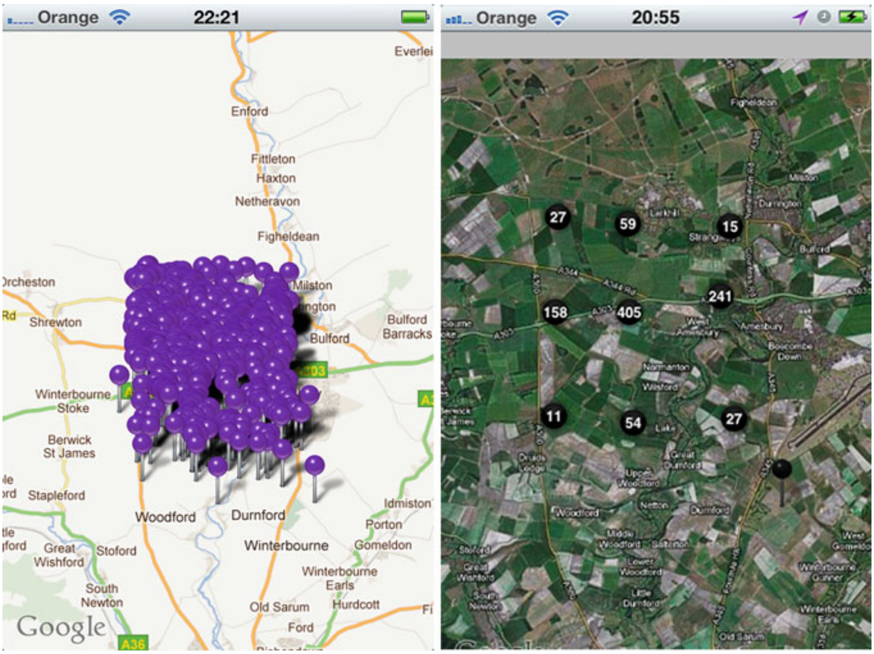

Fig. 15.4 *Two* screen grabs demonstrating the results of pin clustering algorithm on distant views of the data. *Left*, un-clustered monument pins *Right*, the results of clustering of monument pins, where each pin represents a number of adjacent records, with the quantity of records represented by each pin shown by the *white* numbers

Table 15.1 Examples of records with rounded up Eastings and Northings, in each instance additional zeros have been added to convert a six figure grid reference to a 12 figure reference of spurious accuracy

Record ID	Record name	Easting	Northing
1136020	Yew cottage	415000	141000
1135994	No title	415000	141000

or less national grid references (Table 15.1) This resulted in a number of the records being placed in the bottom left corner of a grid square, essentially in a fictitious location. Consequently, data were cleaned by removing any record with a grid reference less than 10 m precision. With the removal of these records, the number of records available for our research fell to 998, still a useful sample.

Data were included within the application as a CSV file rather than using the more problematic approach of dynamically accessing data from an external database through an internet connection. A number of factors suggested this approach. Firstly, as noted by Ancona et al. (2008), applications that rely on obtaining information through internet requests from devices to servers, tend to work slower and have more issues associated with them. 'Basic advantages are mobility (working while moving) and ubiquitous data access. These advantages gain their complete effectiveness only when supported by context location awareness, which simplify the user interface design and minimise the need of data exchange over the network' (Ancona et al. 2008). Embedding data within the application also eliminates the need for a mobile internet connection, which varies between networks across the Stonehenge landscape. While embedding data provided an efficient means of developing a demonstration application, the limitations this method are manifest, in particular preventing updated output that changes as record are improved or added by ADS.

15.2.4 Field Testing

Field testing of the completed application was undertaken within the Stonehenge landscape using five volunteers, including individuals from non-archaeological backgrounds, archaeology undergraduates and professional archaeologists. The volunteers were individually taken to the Cursus Barrow Group and asked to use the application to answer a number of questions (Fig. 15.5). These questions were deliberately chosen to gain an insight into what the individuals thought of the ergonomics of the application, if it was useful in informing them about their surroundings, if the application influenced or helped their understanding and interpretation of the landscape, and what they might use the application for.

To gain feedback from the volunteers, a questionnaire was provided to assess how the different individuals engaged with the application and how it affected the way they understood and interpreted the surrounding landscape. Although only a

Fig. 15.5 Screen grab of the working iOS application showing field testing adjacent to the Cursus Barrows. User location is shown by the *blue symbol* while *black pins* indicate adjacent ADS records

small sample of individuals undertook the field test, their feedback helped to provide an insight into how users may use the application depending on their background. This feedback is of use to aid any further development of the research. By allowing the application to be downloaded by the general public in the future, a broader and more detailed picture of the success of the application could be gained. However, the field testing did prove some insight into how the application may be used by different individuals.

15.2.5 Results

The field testing provided positive feedback about the application and its use within landscape archaeology. However, it also highlighted a number of issues with the methodology used for the present application, which would need to be address should the application be developed further.

In general, feedback on the application was positive as users found that access to monument specific data within the landscape enables a better appreciation of monuments in their context and the broad spatial patterns of monuments. Access to monument information overlain on overhead imagery was considered particularly useful. One issue noted about the application was its essentially closed nature; there was no facility for users to add to or update information on monuments for example to discuss and share their interpretations and understanding further with other users. Bender identifies that 'standard archaeological text creates a closure on the subject and debate shuts down'. (Bender et al. 2007). In effect, a closed application with no facility for user interaction represents an example of a 'standard archaeological text' with no option to discuss interpretations and understandings. It seems possible that interactive mobile applications will offer the potential to overcome the limitations of the closed text. Web and mobile services such as TOTeM Labs Tale of Things (2012) allow user creation a modification of on-line data attached to objects tagged with a unique QRCode. Such an approach might easily be adapted to allow users to contribute to the interpretation and understanding of monuments and the elements of landscape architecture creating an open debated text in the spirit of Bender and reminiscent of Soja's Thirdspace.

Expanding upon Soja's thesis, the paradigm within which users work can be considered to be highly influenced by their physical location when accessing the app. Use in the field, where mobile data enhances the physical experience of a monument or landscape is very much in the spirit of Firstspace where sense and the phenomenological approach dominate. However, the same App and data accessed away from the landscape which it mediates is more likely to be seen as providing factual information in a rigorous, data-driven positivist framework inhabiting Secondspace. The theoretical ability of a single tool mediating the same data to exist in either theoretical paradigm depending on its means of use is in itself a vindication of the "coming together" of Thirdspace.

15.3 Discussion and Conclusion

The use of Smartphones and mobile applications that underpins this research demonstrates an effective method of data dissemination for landscape studies, interpretation, and understanding. We argue that, in the great tradition of British landscape archaeology, tools such as that produced by our research actively encourage individuals to "explore England on foot" (Hoskins 1955) by engaging with landscape and enhancing the experience of exploration both sensually (uniting locale with context) and factually (through conveying information about place).

At the conclusion of our research, it is clear that there is much that could be done, both to improve and expand our application and more broadly in the application of Smartphones and mobile applications to landscape studies. With constant improvement in technologies, it is clear that Smartphones have the potential to play an ever more powerful role in the way we look at landscape, its study, interpretation and analysis.

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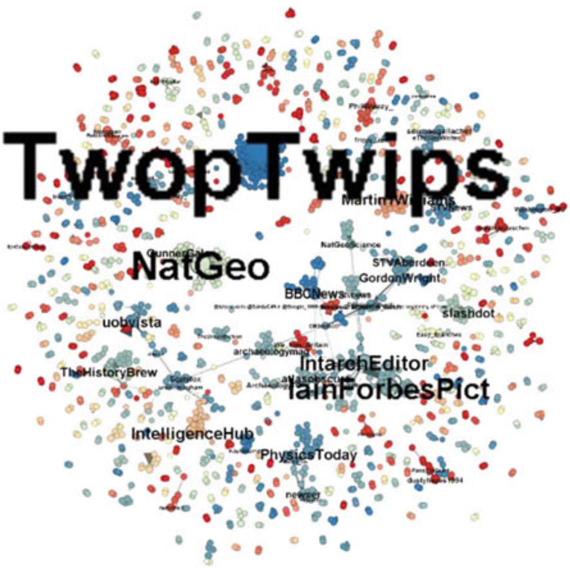
Part IV
Onwards and Upwards
The Never-ending Paradigm of Digital Heritage

The end of history was, as it turned out, much exaggerated (Fukuyama 1992) and the future histories of digital heritage may well be viewed in a similar light. As emphasised in the introduction (Fig. 1), digital heritage has witnessed a series of revolutions that show no signs of stopping or even stalling. It appears that enhanced or novel digital data sources, distributed storage and analysis, pervasive and mobile technologies and social media contribute to this position. Whilst the development of existing and future technologies remains central to the development of the discipline it may yet be the case that the spread of social media in its multifaceted guises will prove to be of the greatest significance to the advance of digital heritage. This does not simply reflect growing access to data, although that is a critical change. Rather this reflects attitudes to digital ownership and the



sophisticated manner in which digital heritage is both produced and recombined in a multitude of user-defined states and permutations. To demonstrate this point, the illustration above is a map of tweets responding to the publication of a single digital article over a 5-hour period (Gaffney et al. 2013). A detailed understanding of the manner in which such data are cascaded and the nature of communities who apparently see academic events as significant or worthy of comment is something that heritage practitioners rarely understand or currently consider. An appreciation of such data and the provision of responding strategies may well be our next great challenge.

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Chapter 16
Preserving Our Digital Heritage: Information Systems for Data Management and Preservation

Julian D Richards, Kieron Niven and Stuart Jeffrey

Abstract It is essential that we develop effective systems for the management and preservation of digital heritage data. This chapter outlines the key issues surrounding access, sharing and curation, and describes current efforts to establish research infrastructures in a number of countries. It aims to provide a detailed overview of the issues involved in the creation, ingest, preservation and dissemination of 3D datasets in particular. The chapter incorporates specific examples from past and present Archaeology Data Service (ADS) projects and highlights the recent work undertaken by the ADS and partners to specify standards and workflows in order to aid the preservation and reuse of 3D datasets.

Keywords 3D laser scanning · Close range photogrammetry · Data management · Digital archiving · Digital repositories · Research infrastructure

16.1 Introduction

There is a pressing need to preserve and integrate existing archaeological research data to enable researchers to use new and powerful technologies. Large numbers of archaeological datasets span different periods, domains and regions; more are continuously created as a result of the increasing use of computer-based recording. They are the accumulated outcome of the research of individuals, teams and

J. DRichards (✉) · K. Niven · S. Jeffrey
Archaeology Data Service, University of York, YO1 7EP York, UK
e-mail: julian.richards@york.ac.uk

K. Niven
e-mail: kieron.niven@york.ac.uk

S. Jeffrey
e-mail: stuart.jeffrey@york.ac.uk

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institutions, but they form a vast and fragmented corpus and their potential is constrained by difficulties of access and lack of integration. Furthermore, these data are fragile and they will be lost unless they are actively curated.

In particular, the tremendous growth in the use of 3D data in archaeology over the last 10 years can be seen not only in the increasing availability of services and technologies that allow the collection of such data but also in the way in which such datasets often play a key or uniting role in larger, more diverse projects. The generation of 3D data occurs at numerous different scales, from landscape or seabed survey, through the laser scanning or photogrammetric survey of buildings and monuments, all the way down to the digitisation of small objects.

With such a pervasive and important role, the issue of preserving such data for future reuse and reinterpretation comes to the forefront. This is particularly relevant where the data are expensive to acquire or where they are used to monitor or 'digitally preserve' sites or objects that are either inaccessible or subject to deterioration.

The objective of this chapter is to outline the key issues of data management and preservation, with particular reference to some of the large and 3D datasets developed by the applications described in many of the other chapters in this volume. The chapter begins by discussing the major issues and challenges, including digital preservation, access, synthesis and integration, and the increasing requirements and demand for open data. It describes existing efforts to establish research infrastructures in the heritage sector. Finally, it looks at work by the Archaeology Data Service (ADS) and partners to deal with the particular challenges of large 3D datasets.

16.2 Background: Major Issues and Challenges

The current situation in the heritage sector is characterised by a high degree of fragmentation and difficult access due to the fact that:

- There are different actors involved in data creation and management, including research groups, museums, scientific laboratories, cultural heritage administrations, contract excavators and others.
- Data are created and/or need to be consulted in different stages of the archaeological investigation from excavation or field survey to publication of data analysis and interpretation.
- Data may be embedded in, or attached to, monuments records, documentation of excavations or field surveys, scientific laboratory analyses, museum reference collections and others.
- Data types are varied and comprise, for example, textual descriptions, drawings, photographs, maps at diverse scales, 3D models derived from photogrammetry or laser scanning, grey literature (i.e. unpublished reports of contracted excavation work), as well as traditional academic publications.

- Data are increasingly born digital, and the functionality of a GIS or 3D model is not available in a traditional paper publication format.
- Data are fragile, and without adequate documentation and active curation they will not be available for future generations of scholars.

Furthermore, archaeology is unusual in that the creation of knowledge results from the physical destruction of primary evidence, making access to data all the more critical in order to test, assess, and subsequently reanalyse and reinterpret both data and the hypotheses arising from them.

16.2.1 Digital Preservation

The issues associated with the long-term preservation of digital data—together with the advantages of doing so—are becoming increasingly well-known across a wide range of fields. As a result, in recent years guidance and support have been developed at both national and international levels through a number of organisations and projects such as the Digital Preservation Coalition (DPC) and Digital Curation Centre (DCC) in the UK, the National Digital Information Infrastructure and Preservation Program (NDIIPP) in the US, and Digital Preservation Europe (DPE) and the Open Planets Foundation in Europe.

Within Archaeology, although awareness of the need to actively manage digital data is growing, practical developments towards doing so in a secure and standardised fashion are still some way behind other disciplines. As in the wider digital preservation sphere, the issues that are pertinent to the preservation of archaeological digital data revolve around the definition of standards and best practice, i.e. what should be preserved and how this should best be done. A significant element of digital archiving focuses on the use and suitability of data file formats for the preservation and dissemination of data and involves such considerations as binary versus ASCII data types, proprietary versus open file formats, and the management of data compression. In addition, all data requires some form of documentation in order to be understood, not only in terms of how it came into being, but also what it represents and how it can be used. The specification of documentation and metadata standards, and their applicability to archaeological data, remains a significant digital preservation issue.

One of the most widely acknowledged approaches to the practical matter of preserving digital data for the long term is the Open Archival Information System (OAIS) reference model. OAIS comprises hundreds of pages of guidance and good practice and makes clear the importance of open file formats, data migration, robust and distributed hardware infrastructure and the necessity of discovery, access and delivery systems (CCSDS 2012). It does not, however, define the practical implementations of the recommended processes. Actual digital preservation based on OAIS can be enormously complex. In archaeology, preservation processes may have to deal with hundreds of file types, from hundreds of types of devices, using a plethora of software packages and the whole broad range of archaeological techniques. In addition, for a digital archive to be considered credible, and thereby attain 'trusted digital repository' status, it must be able to demonstrate well-documented preservation policies and processes as well as having a robust long-term sustainability plan. The accreditation of digital repositories is still in its early stages although the Data Seal of Approval (DSA) provides an internationally recognised kitemark for repositories and a new ISO standard was recently published (ISO 2012). In 2010, a number of European organisations signed a Memorandum of Understanding that links these into a wider European framework for certification (TDR 2010).

16.2.2 Access and Value

Despite some notable exceptions in one or two countries, most archaeological data is still not accessible because the traditional approach to research also protects the intellectual property rights of researchers—sometimes beyond any reasonable term, as in the case of excavations unpublished for decades and still 'under study' by the archaeologist. It does not favour, or even consider, the publication of primary data. By contrast, access to data and data sharing is generally perceived as important. In a survey undertaken by the ADS in 2007, 70 % of respondents had somehow reused old data and 80 % would allow access to their data; one commented that 'having such data available will assist any longer-term monitoring projects or even cast new light on a previously recorded subject' (Austin and Mitcham 2007, p. 36).

Nevertheless, and although initiatives to create public archives of heritage data such as ADS have existed for a long time, heritage data sharing is not yet common practice in Europe. Public data repositories and the related standardisation are also the best solution for long-term preservation. Reinforcement for this practice may come from implementing a recommendation that public funding agencies 'should incentivize a scientific culture in which sharing of data becomes an accepted norm of professional behaviour' (Kintigh et al. 2010, p. 4). In other words, researchers who want public money must share their data. It should also be noted that data (and not only scientific reports) are part of the EU Open Access initiative, as clarified by *Sharing Knowledge: Open Access and Preservation in Europe*, the conclusion of a 2010 EU strategic workshop (Swan 2011). Section 2.5.2 of the *Digital Agenda for Europe* states that publicly funded research should be widely disseminated through Open Access publication of scientific data and papers (European Commission 2010). In May 2011, the UK's Engineering and Physical Sciences Research Council (EPSRC) gave research organisations 12 months in which to develop individual roadmaps to put policies and procedures in place to ensure the preservation and availability of digital research data for at least 10 years. Applicants for UK research council funding are also generally required to submit Data Management Plans as part of their proposals (Higgins 2008; Jones 2011).

Other European countries are also working individually, or in combination, to develop data preservation and access policies. ESFRI, the European Strategy Forum on Research Infrastructures, is a strategic initiative to develop the scientific integration of Europe and to strengthen its international outreach. One of its key goals is to facilitate multilateral initiatives leading to the better use and development of research infrastructures, at EU and international level. The ESFRI programme has provided funding for scientific research infrastructures across a range of disciplines. It provided start-up funding for the preparatory phase of Digital Research Infrastructure for the Arts and Humanities (DARIAH), which is now in the construction phase with support from a number of EU countries.

The primary nature of archaeological data makes it particularly vulnerable to data loss and the importance of heritage to cultural identity across many European nations should make it a key priority for support. But how well placed are European repositories to meet this challenge? In many countries it has been assumed that libraries and archives, the traditional custodians of records, will simply take on this additional role, although few are adequately resourced, or staffed, to deal with the scale and complexity of digital data, particularly with 3D data. Several studies have recognised the value of discipline-based repositories in developing stakeholder communities, avoiding fragmentation and establishing discipline-specific data preservation expertise (e.g. RIN 2011).

16.2.3 Synthesis and Integration

To date, synthetic research has often comprised the summarised results of specific research projects. In the words of Kintigh et al. (2010, p. 2), researchers: 'desperately need to foster synthetic research that transcends the spatial and temporal scales of individual research projects'. This requires tools and methods to integrate and synthesise data collected by researchers in different investigations (Kintigh 2006; Snow et al. 2006). Researchers have to handle an enormous amount of information, but it is not storage resource or processing performance that are required. The purely technological approach of providing more petabytes or guaranteeing more teraflops is insufficient; the diversity of archaeology requires fundamental research encompassing many disciplines, and developing innovative approaches. Integration also represents a challenge when considering the diversity of contexts, collecting protocols, relevance and goals under which data are collected.

A special role in synthesising information is played by innovative visualisation technologies. 3D digitization applications in archaeology are eased by new low-cost devices, improved accuracy and speed, emergence of new image-based solutions to process raw data, more sophisticated algorithms and the consolidation of open source solutions (e.g. the Italian Research Council's *MeshLab* platform, totalling several thousands of users worldwide). The recent introduction of HTML 5 and WebGL makes it possible to use 3D models on web pages and to distribute those representations on the Internet. These technologies are now able to produce excellent digital replicas of heritage assets and can be considered as a mature resource. The availability of sophisticated digital clones may extend archaeologists' ability to use a number of computer-assisted tools in order to compare, measure, comprehend and gain new insights (e.g. Scopigno et al. 2011).

16.2.4 Increasing Demand for Data and Interest in Data Sharing

While the data landscape is fragmented, demand from archaeologists to access existing data for consultation, comparison and reuse in current research is widespread. For example, in the UK, the ADS had over one million downloads of unpublished fieldwork reports in the 12 months from February 2011, with an increase of interest as more data are made available. In the United States a recent survey by Archaeoinformatics.org among members of the Society for American Archaeology (SAA) shows that 94 % of respondents would use electronic data more, if they were accessible. The 2011 RIN/JISC report on *Data centres: their use, value and impact* revealed that 84 % of users believed that the existence of the ADS had made a positive impact on the culture of data sharing, 79 % reported that it had improved the efficiency of their research and 65 % said that it had reduced the cost of data acquisition (RIN 2011).

Data sharing has also gained momentum through the promotion of Linked Open Data. Several countries, including the USA, UK and France are moving towards open governmental data and this will inevitably have implications for data provision by state public heritage bodies. The development of an archaeological semantic web has been a long-held vision (Richards 2006) but, until recently, there were few working examples. A number of the basic building blocks are now in place, including mappings of data schemas to standard high level ontologies such as the CIDOC CRM and the provision of classification systems, thesauri and authority files as Simple Knowledge Organization System (SKOS) web services, through projects such as STELLAR and STAR (Binding et al. 2008; Binding 2010; Tudhope et al. 2011).

16.2.5 Research Infrastructures

In summary, there is therefore, a strong case for the development of research infrastructures, generally at a national level, to provide leadership in information management, data access and preservation, but with collaboration at an international level to facilitate the development of common standards and interoperability. Many of the big archaeological research questions transcend modern political boundaries and research will be enhanced by integrated user access, whilst responsibility for preservation needs to be distributed (Kenny and Richards 2005).

The UK's Archaeology Data Service is the longest standing digital archive for archaeology, and recently enjoyed its fifteenth birthday. The ADS was established in 1996 as one of the five discipline-based service providers making up the UK Arts and Humanities Data Service (AHDS). It is hosted by the University of York. Funding for the ADS came initially from the UK Arts and Humanities Research Board (now AHRC) together with the Joint Information Systems Committee (JISC) but currently consists of elements of core funding from the AHRC together with the Natural Environment Research Council (NERC) alongside a range of project-based funding from a variety of UK and European project and organisations (Richards 2008).

The ADS is the mandated place of deposit for archaeological research data for a number of research councils and heritage organisations and makes all its holdings freely available for download or online research. At the last count, it provides access to over 17,000 unpublished fieldwork reports (the so-called grey literature) and over 500 data rich digital archives. The ADS was the first archaeological digital archive in Europe, and was only preceded by the now defunct Archaeological Data Archive Project (ADAP), in the United States (Eiteljorg 1994). In recent years, however, there have been related initiatives in several other European countries, although admittedly these are concentrated in Northern Europe and Scandinavia.

In 2007 the ADS was joined by EDNA, the e-depot for Dutch archaeology, which was established as part of DANS (Data Archiving and Networked Services), and funded by KNAW, one of the main Dutch Research Councils. Like the UK Data Archive, DANS originated as a social science data archive but from there it expanded into archiving historical data sets and then, in collaboration with Leiden University, into Archaeology through a 2004–2006 pilot study. As of 2007, agreements to deposit archaeological data at DANS were formalised in the quality standard for Dutch archaeology, making archaeology one of the largest components of the digital resources hosted by DANS. By the end of 2011, the EDNA provided access to over 17,000 reports and excavation archives, although some are only downloadable by registered archaeological users. EDNA employs two archaeological archivists, but also benefits from input from the much larger staff of DANS.

Recently, the Swedish National Data Service (SND), based at the University of Gothenburg, decided to extend its collection policy to focus on Archaeology. It has worked with the Department of Archaeology and History at the Uppsala University to archive a number of archaeological reports. At present, SND is starting the publication of over 200 GIS files with the excavation data from Östergötland. SND is a service organisation for Swedish research within the humanities, social sciences and health sciences. A second Swedish infrastructure initiative focuses upon access to data pertaining to environmental archaeology. The Strategic Environmental Archaeology Database (SEAD) is based at Umea University, in northern Sweden. The SEAD project is funded by the Swedish Research Council and

Council for Research Infrastructures. It aims to facilitate the online storage, extraction, analysis and visualisation of data on past climates, environments and human impact, by providing online tools to aid international researchers in these tasks, and by providing access to data that are currently not accessible online (Buckland et al. 2011).

The most recent initiative to establish a national archaeological digital research infrastructure in Europe has been led by the German Archaeological Institute (DAI), which is part of the DFG, funded via the German Foreign Ministry. In 2012, the DAI established a new project, IANUS, with an initial staff of two, to scope what would be required to set up a digital archive for German archaeology.

In North America, there have been a small number of significant initiatives which seek to provide cross-institutional support for digital archiving. Although seen primarily as a data publication tool, *Open Context*, based at the Alexandria Archive Institute, has developed a relationship with the California Digital Library to provide for long-term citation and preservation, and it is now one of two repositories mandated by the National Science Foundation (Kansa and Whitcher Kansa 2009, 2010). The other is *tDAR*, hosted at Arizona State University, and supported since 2009 by a 4-year start-up grant from the Andrew W Mellon Foundation to the Digital Antiquity consortium (McManamon 2010). In Canada, the Canadian Foundation for Innovation and the Ontario Ministry of Research and Innovation have funded *Sustainable Archaeology*, a 9.8 million Canadian dollar joint initiative between the Western University and McMaster University, with the initial aim to digitally consolidate archaeological collections that are currently scattered across the Province of Ontario, Canada. These initiatives make Northern American archaeology better placed to address growing pressure from governmental and research bodies to make the results of research and the data underpinning scientific research freely and publicly accessible.

In Australia too, there have been numerous attempts to develop a digital research infrastructure for archaeologists. The latest of these is Federated Archaeological Information Management System (FAIMS), a highly ambitious project led by the University of New South Wales, and funded by the Australian Government's NECTAR programme. FAIMS is a 12-month project which aims to 'assemble a comprehensive information system for archaeology. This system will allow data from field and laboratory work to be born digital using mobile devices, processed in local databases, extracted to data warehouses suitable for sophisticated analysis, and exchanged online through cultural heritage registries and data repositories'.

16.3 Dealing with 3D Datasets

3D datasets are now routinely generated by a range of techniques in many archaeological projects, as demonstrated by the case studies in this volume. They can be used to integrate data derived from multiple sources but they can raise new or unique problems for data management, digital preservation and access. The following examples, derived from the ADS experience, highlight the development of archival processes that address a number of these problems.

16.3.1 The Big Data Project

Many datasets generated by techniques such as marine bathymetry, laser scanning and LiDAR present specific challenges in that the volume of data created is frequently very large and therefore has storage implications (including the cost of buying and maintaining hardware or purchasing separate storage). In addition, beyond the actual storage of data, the physical size of such datasets can often create problems in terms of data access or reuse. The 2006 Big Data Project, funded by English Heritage, looked specifically at the practical issues raised in storing and disseminating large 3D datasets through three case studies: marine survey data from Wessex Archaeology, laser scanning data from Durham University and LiDAR data from English Heritage (Austin and Mitcham 2007). The project started with a data audit and culminated with the deposit of data from each case study with the ADS. In addition, the project also carried out a questionnaire survey and workshop aimed at ‘Big Data’ creators in order to quantify and assess the types of data being created alongside the options available for dissemination and reuse. As a result of these activities, the project produced a final report aimed at raising awareness of the issues associated with creating, storing and accessing ‘Big Data’ as well as providing guidance in terms of both policy and practice.

The project report also provided a key set of recommendations for future research which has subsequently informed the recent Guides to Good Practice project (discussed) with the findings incorporated into the relevant individual guides (Austin et al. 2008).

16.3.2 The VENUS Project

In addition to the issues of storage and dissemination highlighted by the Big Data Project, ADS involvement in the 2006–2009 European VENUS project looked at the preservation of large, complex marine survey datasets, often featuring multiple streams of data combining to form various different data ‘products’ (Alcala et al. 2008). One key aspect of this project was to demonstrate how data selection plays a key role in producing a robust and reusable digital archive. The VENUS project itself aimed to develop scientific methodologies and deliver technological tools for the virtual exploration of deep underwater archaeology sites with the ADS role being focussed on the long-term preservation of the project’s digital outputs. The ADS specifically focussed on the publication of a VENUS Guide to Good Practice (Austin et al. 2009) alongside an exemplar digital archive (Drap 2009).

A significant outcome of the project was the identification of ‘Preservation Intervention Points’ (PIPs) in the data lifecycle of the project. The VENUS underwater missions themselves surveyed shipwrecks at various depths by employing a complex data acquisition process using remotely operated unmanned vehicles with innovative sonar and photogrammetry equipment. Subsequent data processing stages also included the plotting of archaeological artefacts and the production of 3D models. At various stages in the data lifecycle, ADS identified PIPs where data were transformed by processes such as decimation, aggregation, recasting or annotation, in addition to data being migrated from format to format. These stages were then evaluated in terms of whether, for the purposes of preservation, it might be appropriate to intervene and take a preservation copy of the data to be archived. The evaluation process itself was based on a number of broad criteria, seven in total, which allowed each point to be weighed up in terms of categories such as reuse potential, repeatability, value (cost) and available metadata (in terms of both data reuse and the repeatability of specific processes). Interestingly, the PIP criteria highlights that, although it is generally considered good practice to archive data in as raw a state as possible—because often the subsequent transformations applied can be recreated—this is not—always the case for certain 3D datasets where data are subsequently merged (e.g. meshes) or processed (e.g. cleaned or decimated) to create ‘new’ interim datasets, often via a proprietary or automated processes (Fig. 16.1).

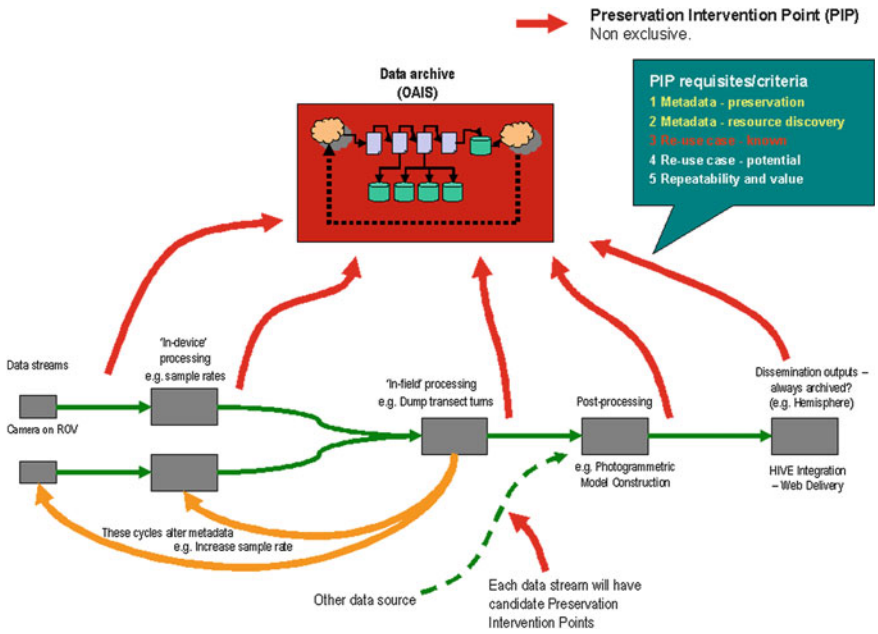

Fig. 16.1 Preservation intervention points in the digital workflow

As with the Big Data Project, the VENUS project has also made a significant contribution to the subsequent revision and expansion of the Guides to Good Practice through the further development of elements of the VENUS guide into a new general guide looking at marine survey data. In addition, the concept of PIPs is equally applicable to other datasets including laser scanning and photogrammetry and this conceptualisation of the process of data selection has been incorporated into these guides.

16.4 Guides to Good Practice

The research that emerged from the Big Data and VENUS projects, as mentioned above, was incorporated into a wider suite of guidance material in the 2009–2010 Guides to Good Practice project (Mitcham et al. 2010). The 2-year collaborative project, funded by the US Mellon Foundation and English Heritage, aimed to revise, update and expand the original ADS series of Guides to Good Practice. The six guides originally authored between 1998 and 2002 (Gillings and Wise 1998; Bewley et al. 1998; Richards and Robinson 2000; Schmidt 2001; Eiteljorg et al. 2002; Fernie and Richards 2002) were integrated and updated within an online wiki and extended to cover a number of additional techniques including close range photogrammetry (CRP), marine survey and laser scanning (Fig. 16.2).

Fig. 16.2 Guides to Good Practice

As with the previous series of Guides, the new updated series aims to specify standards and ‘good practice’ for a variety of techniques used within archaeological projects and covers the data formats that they produce, the suitability of these formats for long-term data preservation and, importantly, the metadata and documentation (at a number of levels) required to archive, understand and reuse these datasets in the long term. Building on the work of the VENUS project, the new Guides also examine 3D techniques and data types such as laser scanning and photogrammetry within the larger project lifecycle of data acquisition, processing, reprocessing and the creation of various types of derived data such as CAD models, still images and video.

16.5 Current Projects

A number of recent and current projects are also contributing to the way in which the ADS approaches the archiving and dissemination of 3D datasets.

The deposit of data from the Virtual Amarna Project provided the first opportunity for the ADS to ingest and disseminate a large collection of 3D PDF files (Kemp 2011). A number of artefacts held in the site museum at Tell el-Amarna in Egypt had been scanned by a team from the University of Arkansas, working with Barry Kemp, the excavation director. As deposit of the archive coincided with the production of the laser scanning Guide to Good Practice, this provided the opportunity to create an excellent exemplar archive and highlight the various incarnations of data created within a laser scanning project together with the metadata required to understand and reuse these data (Limp et al. 2011; Payne 2011) (Fig. 16.3).

The ADS is also currently involved in the European CARARE project as a content provider mapping and adding—amongst other data—3D datasets to the Europeana portal. The use within the project of the 3D PDF format as the primary means of object dissemination has highlighted this format’s potential for easy and flexible dissemination of complex 3D models as well as allowing ADS to work with similar European organisations that are creating or disseminating data in what is a relatively underused format.

In addition to 3D-specific projects, the ADS has also undertaken work to ensure that the data it stores, regardless of type, is both secure and reusable. In 2011, the ADS was awarded the Data Seal of Approval verifying that it meets the standards of a trusted digital repository (Mitcham and Hardman 2011). In addition, in 2012, the ADS was also accredited as an official Data Archive Centre (DAC) for the UK Marine Environmental Data and Information Network (MEDIN). The ADS has also implemented the ISO standard Digital Object Identifier (DOI) system for its collections via DataCite (http://datacite.org/). From an ADS perspective, the availability of DOIs for its digital collections not only ensures that data citations remain stable and resolvable but also that they are quantifiable in terms of reuse and impact via metrics from the DataCite DOI resolver.

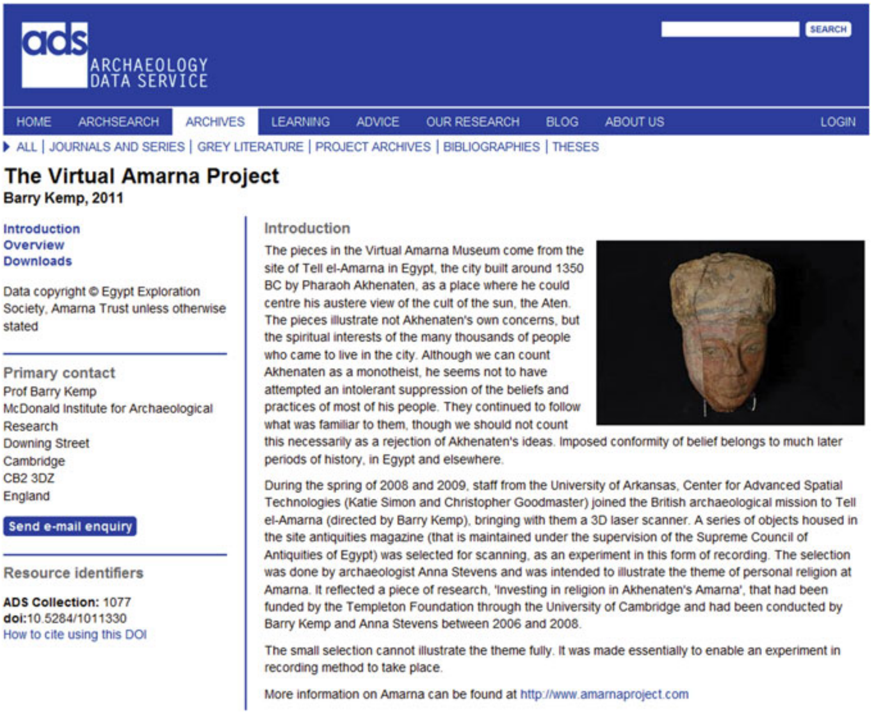

Fig. 16.3 The Virtual Amarna project archive

16.6 Conclusion

Archaeological data requires active management throughout the project lifecycle to ensure that it will be 'fit for purpose' for future preservation and access. A number of factors are encouraging researchers to think about providing open access to their data and to plan for its long-term preservation. These include policy recommendations from research councils and governments, as well as an increasing desire from researchers themselves to share data. A number of countries are now developing digital research infrastructures and data archives and there have been attempts to promote more integrated access.

3D data faces the same preservation issues as other archaeological datasets although, in some cases, certain problems are somewhat heightened, including issues of data storage, ensuring adequate metadata, documenting processing techniques and dealing with proprietary software. While, for example, the use, and even preference, for proprietary or compressed 3D data formats within the community is a well-recognised preservation issue, new complex problems in terms of access (due to the sheer size or number of files) is a particular characteristic of 3D data in archaeology.

This increasing volume of data produced by 3D projects has another aspect in that, when the larger workflow is viewed and multiple incarnations of the 'same' data are viewed as holding value, storing and providing access to these multiple sets of files becomes problematic. While storage capabilities continue to increase alongside decreasing hardware costs, indicating a possible solution to such data storage issues, it is worth noting that many technologies which capture 3D data continue to generate larger and larger volumes of data countering the perceived savings implied by lower hardware costs. It should also be noted that the most significant cost component of any digital repository is actually the labour required to ingest, migrate and subsequently manage the data. This cost is contingent on many factors, the least of which may be data volume (Richards et al. 2010).

The continuing growth and use of 3D data and the varied technical systems used to generate it will also hopefully continue to see a parallel development of both data format and metadata standards. Ongoing collaborative research at both a national and international level, as demonstrated by the projects discussed in this chapter, will be an important factor in developing systems that ensure that the data produced remain secure and usable for future generations.

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Chapter 17
Digital Heritage: What Happens When We Digitize Everything?

Harold Thwaites

Abstract Research that targets the re-presentation of culture and heritage using tools and techniques of digitization continues to develop worldwide. This chapter discusses digital heritage and what happens when we digitize everything. Society has acknowledged the urgency to capture heritage content in its various forms and the sites it is found in. At the same time, it begs the questions of what the impact of all this digitization will be and how useful or long-lived the results. A focus is placed on the audience, those who receive and experience the resulting digital output such as in a museum or gallery, website, interactive exhibit or any form of mediated digital heritage content. The concept of eternal themes is introduced along with human values related to digital heritage. The impact of digital heritage is discussed in relation to the mobilization of heritage content for diverse audiences. The vanishing virtual and considerations for the future of digital heritage are presented with some key points for conservation.

Keywords Digital heritage · Culture · Virtuality · Audience · Values · Information chain · Communication · Multimedia technology · Cyberception

17.1 Introduction

This chapter presents an overview of Digital Heritage (DH) from the side of the audience, receiver, viewer and the creators of the content. It brings together the various concerns of members of the heritage community; the archaeologists,

H. Thwaites (✉)
Centre for Creative Content and Digital Innovation, University of Malaya,
Kuala Lumpur, Malaysia
e-mail: hal.thwaites@gmail.com

H. Thwaites
University of Birmingham, Birmingham, UK

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technicians, historians, curators and media content specialists and it reflects on what it means and what are the implications for humanity and the cultural record when we digitize everything. The chapter begins with a framework for digital heritage, presents an outline of shifting cultures and the technologies affording digitization. Eternal themes are discussed from a humanities point of view leading into human values and digital heritage. Concerns about the vanishing virtual are presented ending up with smart heritage and cultural futures, concluding with implications and suggestions for conservation and archiving.

The following discussion is based on a very early paper (Thwaites 2001) wherein I outlined the impact that virtual heritage has on an audience or viewer, or user. It seemed fitting, after 12 years, that I revisit that work in light of the current focus on digital heritage around the world and an increasing focus on the digital heritage audience.

The title of this chapter derives from a talk given by Philip Rosedale (2006), the founder and creator of the Second Life on-line virtual world. In his presentation he posed the question "What do we learn IF we digitize everything?" I was fascinated by that concept when applied to digital heritage and thus came the inspiration for this chapter.

17.2 Thinking About the Past

The notion of time travel has always captured the human mind from the time of H.G. Wells' original novel Time Machine written in 1895. In his 1999 novel Timeline, Michael Crichton describes a future where time travel to the past is possible and entertainment is the past.

> At the end of the 20th Century, the artifice of entertainment, constant, ceaseless entertainment, has driven people to seek authenticity. Authenticity will become the buzzword of the 21st century. How do we define authentic? It is that which is not controlled by corporations, entertainment mega-conglomerates and media moguls. It that which is not devised and structured to make a profit. It is anything that exists for its own sake, and that assumes its own shape. What is the most authentic of all? The past.

In addition to looking into the past as a source of content, he poses some other excellent questions. "So what is it about history that is so appealing? History is the most powerful intellectual tool society possesses. History is not a dispassionate record of dead events, places and people. The purpose of history is to explain the present, to tell us why the world around us is the way it is. History tells us what is important in our world and how it came to be. It tells us why things we value are the things we should value and what is to be ignored or discarded."

This is not the only notion of time travel that has fired the minds of digital heritage professionals in recent years. Ch′ng (2009), Silberman (2005), Lowenthal (2002), Mosaker (2001), Sanders (2001), Davis (1997), Britton (1996) and Woolley (1993), have all theorized as to the impact of digital heritage "time travel" on the minds of an eager audience. Mosaker argues "virtual reality environments that present the past might be thought of a contemporary time machine".

It therefore becomes important to clarify the difference between *heritage* and the *past* (Silberman 2008). *Heritage* comprises a constantly changing collection of objects and symbols, a complexity of images, cultural artefacts, monuments and a varying assortment of ethnic customs that are significant and meaningful to us. The *Past* can be viewed as the most virtual reality that we contend with. It is the ghost of a once lived reality surviving in fragments that can only be experienced in hindsight. The past can never be re-created as it was and thus our fascination and dedication to come as close as we can to re-presenting it to contemporary audiences via digital heritage applications.

Lowenthal (1994) identified a key point when he said that "the more realistic a reconstruction of the past seems, the more it is a part of the present." This statement certainly highlights why digital heritage is both a timely endeavour and one fraught with so much challenge in our current digital-rich media environment.

17.3 Now and Why?

This book entitled, 'Visual Heritage in the Digital Age', seeks to address many key research areas such as social considerations and human behaviour, the technology and tools employed, the creation of information systems, visualization strategies, content interfaces and archaeological concerns focusing specifically on; Objects, Monuments, Landscapes, through case studies of applications and techniques and comparisons between technologies covering a global map of digital heritage sites or objects.

To frame the discussion of digital heritage it is first important to reflect on the beginnings and various terms that encompass the field. Virtual Heritage was discussed and defined in 1999 by Stone as "the utilisation of technology for interpretation, conservation and preservation of Natural, Cultural and World Heritage". It has since been written about extensively under a variety of other terms such as virtual culture, e-culture, e-heritage, new heritage, digital history and digital heritage (Smith 2006). An important additional defining component is "…to deliver the results openly to a global audience in such a way as to provide formative educational experiences through electronic manipulations of time and space", once again referencing the notion of time travel described above.

UNESCO in their Charter for the Preservation of Digital Heritage (2003), has clearly defined digital heritage as the "cultural, educational, scientific and administrative resources, as well as technical, medical and other kinds of information created digitally, or converted into digital form from existing analogue resources" and includes "texts, databases, still and moving images, audio, graphics, software and web pages." Due to the increasing complexity of heritage data, in addition to levels of interactivity, we can aptly describe this content in the form of digital heritage ‘datacubes’ (Thwaites and Malik 1998), or as comprehensive datasets represented by a 3D cube (Foni et al. 2010).

In 2013 heritage researchers and media creators continue to be fascinated with exactly what Crichton described for us. What impact will our research and production of Digital Heritage (DH) and multimedia cultural representations have on our audiences? How will we use DH? We do not yet fully know, as it has in the past failed to live up to expectations (Addison 2001). This failure has partly been the result of the influence of digital special effects in the film industry creating a perceptual stereotype in the audience, who eagerly expect digital heritage to equal or exceed the “spectacles”, designed by Hollywood.

However, as we continue to research, design and present digital heritage content we provide the receiver or visitor/audience with a representation of reality that elicits a certain information impact. This “impact” is created somewhat in fact and historical record, mixed with a possible fictional interpretation, while stirring that fleeting notion of fantasy through time-travel. It is these qualities that make our efforts at digital heritage so intriguing, as outlined in a discussion to follow.

17.4 A Brief Summary of Early Digital Heritage

As readers of this book may be aware, digital heritage (in its myriad of iterations listed above) has been developing in tandem with technology from the 1990 s when computers became more accessible and cheap enough for widespread application to heritage projects across a variety of disciplines and fields (Mahoney 1996; Dave 1998).

An early exhibition of digital technology applied to a heritage recreation was staged at the Imagina Conference in Monte Carlo in February of 1993. It showcased a real-time guided tour of a digital reconstruction of the Cluny Abbey, a building that has not existed for centuries. Following from that event 1995 saw the first Virtual Heritage conference held at the Assembly Rooms in Bath, UK. It showcased such projects as Virtual Pompeii (Jacobson and Vadnal 2005), Virtual Lowry (Stone 1996a), the Caves of Lascaux (Britton 1996) Palace of Ashur-nasir-pal II, Nimrud, Assyria modelled in 1999 by Learning Sites (Sanders 2001) and the Fortress at Buhen, Egypt (Barcelo Juan et al. 2000). Many heritage applications continued to emerge built on the work done in Japan at the Virtual Systems Laboratory at Gifu University including the VSMM (1995) International Conferences that followed each year from the first in Gifu Japan in 1995 and onwards (Stone 1996b).

Indeed each passing year added an impressive list of sessions to a wide variety of international conferences and meetings including (but not limited to); Europe’s VAST (International Symposium on Virtual Reality, Archaeology and Cultural Heritage), IEEE VR, ACM Siggraph to the CAA, ISPRS, CIPA, ICOMOS, ForumUNESCO, Virtual Retrospect, Museums and the Web, ICHIM and many others (Addison 2006). Within all these early, and some still continuing meetings, there has often been little coordination on timing and collaborative partnering. This led to the virtual reality (VR) or digital heritage community attending one set of meetings, the computer scientists another, and the archaeologists their own special sessions resulting in duplicated projects and less than optimal collaborations.

As has often happened with early digital heritage projects, many of the excellent and pioneering works have been lost to time and technology shifts, such as the web-based examples of Virtual Notre Dame Cathedral (VNRD) created by Vic DeLeon (1999, 2000), Fig. 17.1 and the seminal Lascaux Caves project by Britton (1996) shown in Fig. 17.2.

Most of these early digital heritage projects, among many others (Harada et al. 1998; Hamit 1998; Simo et al. 1999; Stone 1999) have all but disappeared from view. Now they may only exist in the minds of those who saw and interacted with them and wherever they are still stored on the hard drives of the researchers who built them. Or perhaps they are lost forever. This raises questions surrounding the archiving and curating of digital heritage work into the future as we move so rapidly between generations of hardware and software tools.

Rahaman and Tan (2011) present a review survey of online digital heritage examples wherein they discuss the technology used and levels of interaction (exploration, manipulation or contribution) available to the user. They argue that early projects tended to focus on the “faithful” representation of realism, making

Fig. 17.1 Virtual Notre Dame Cathedral project (reproduced from DeLeon 1999)

Fig. 17.2 Virtual Lascaux Caves (reproduced from Britton 1996)

them inherently quite static with little audience involvement. That early nascent quality of DH work has since become much more evolved both in terms of content and the technology used to present it.

17.5 The Information Impact of Digital Heritage

I would now like to describe an area that for most readers may seem to be out of place in a book that deals mainly with more scientific discussions of various research projects in digital heritage. However, given the scope and scale of applications being developed the world over, I feel that it is important to incorporate this discussion here. Much of digital heritage has focused either on the ‘process’ of creating work or the resulting ‘product’ but rarely does it consider the ‘receivers’, the audience (end-users) and their perception of the project content (Rahaman and Tan 2011; Russo and Watkins 2007).

This section argues that in order to build a complete and complex cultural representation via digital heritage technologies we must also understand how the users interact with the system or interface that is primarily ‘information’ based and thus through human interaction, elicits an ‘information impact’.

Within the fields of cybernetics and biocybernetics the concept of ‘information’ is understood in the systemic form of an information complex. Biocybernetics is formed by the application of basic cybernetic laws in biological systems. Heritage and cultural artefacts, in various iterations comprising the content of digital heritage, can be viewed as information complexes. They are the source of the information, the environment in which this source is situated, or transmitted and most importantly the audience or receivers, who are experiencing the information, processing it, responding to it and storing it in their memory. They are called "information complexes" because the information in them is complex, often very different in form, or can be perceived by different senses and in different time frames. This overall process is called an *information chain* as shown in Fig. 17.3 (Malik and Thwaites 1990).

The fundamental principle of an information chain is its connectivity (the reason for the name *information chain*). Each component of a digital heritage project (the content itself, the space and conditions by which it is perceived and the person(s) perceiving it) may contain pieces of the final message. If any part of the information chain is altered, the information itself is changed. It must also be understood that each part of the information chain could exist independently and that the connectivity is multi-layered (one information source could be connected to thousands of receivers, networks) or transmission conditions could vary across time and space or the receivers could change (a different audience in different cities for the same source) or the same receivers could change their viewpoint or thoughts about a particular piece of digital heritage work over time.

On a daily basis twenty-first century media "consumers" perceive great amounts of information detected by our senses, processed and often stored in our brains. This myriad of details is not perceived in isolation, one by one. Certain groups of information are perceived as entities, others as patterns, and others as mosaics. Some groups of information have their own complexities of space, time, structure and reflections in our sensory and mental processing system. They are carriers of many different messages or contents, all depending on our past experiences, cultural or personal backgrounds, particular habits and stereotypes.

Digital heritage (DH) environments in particular, are prime examples of information complexes. Since they must be communicable to diverse audiences spanning continents, cultural groups, time zones and different semantic and aesthetic experiences, a common ground is needed for data assembly, evaluation,

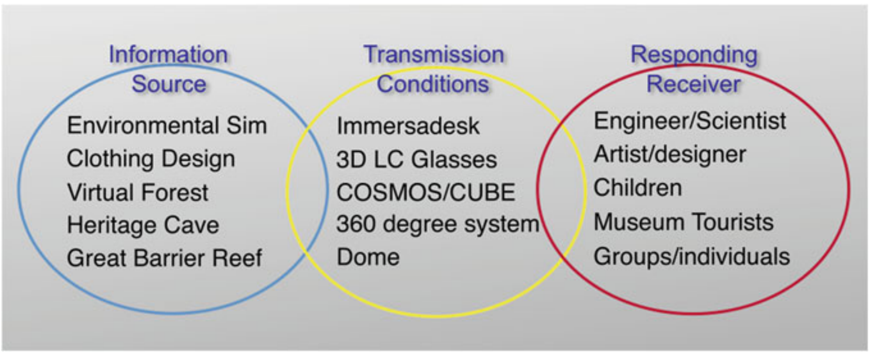

Fig. 17.3 Information Chain Scheme (reproduced from Malik and Thwaites 1990)

creation, transmission and storage (Thwaites 1999). This common ground is based on three key assumptions: teamwork with cooperative and non-competitive attitudes; a common language that is well understood by all members of the team and lastly the ultimate dependence on each team member's contribution to the overall production and creation process of any DH environment.

17.6 Eternal Themes

In 1973, Clynes described roughly three distinctive groups of human activities, from which an information impact could arise: (1) Egotropic group, where basic personal human needs are expressed; (2) Egosentic group, where the most basic emotional states of mind are expressed, and (3) Egospatial group, where most environmental and social needs are central. Each culture may have a different classification or priority within the "eternal themes", but most researchers more or less agree with these three major groups and find in each group several examples of values that are agreeable to them.

The presentation of thematic aspects of a media piece to the audience does not progress in distinctive steps, but in more of an uninterrupted flow even if the receiver of the information is not actively reading or viewing and only daydreams about the thematic stimuli (Churchland 1988). The process of segmentation of artistic information has increased in the twenty-first century, facilitated by the rapid speed of images, sounds and media works, perceived by enthusiastic "information grazers" (McLuhan and Bruce 1989).

From the opposite viewpoint, if a digital heritage work does not contain strong semantic content, the viewer may turn their attention to the more formal, stylistic details and actively engage with them. In this situation, the theme may replace the form and form may replace the content for the audience. It is often the case that what we may consider 'important' in a project becomes quite the opposite for the audience. Mosaker (2001) found a paradox arising from her work whereby "the part of the virtual environment that was based on less information was the one that the visitors liked the best and the one in which they felt the most presence".

Finally, the classification of themes has another more elusive sense. As the receiver of the information sorts the various heritage experiences according to themes or contents, the recall or "remembering" segment of the information chain (the receiver and their response) may work to merge several experiences together creating more of a feeling, inclination or attitude toward a certain theme (Thwaites and Malik 1991). This state of mind can easily enable new information input that can amplify an idea or a theme. This process is the primary cause for much of what we call the "the taste or preference of any given audience".

Today the audience of digital heritage presentations can be seen to follow in the footsteps of their forefathers, but with very different shifts of time and space that are warped by the digital electronic environment and a hierarchy of values heavily dependent on the technology and speed of information processing such as in the work of Sarah Kenderdine and Tim Hart (2011) comprising vast omni-spatial heterogeneous datasets.

Researchers and DH media creators now have access to unprecedented technological tools and a wide range of affordable hardware and software (Hemsley 2005). There has been a renewed and increased interest in digital world heritage, mostly due to the UNESCO initiative establishing the World Heritage list of sites. Additionally a more global sense of community and the decreasing access to heritage venues due to deterioration caused by "over-visiting" has raised an alarm to protect them by the implementation of pervasive computing applications at heritage sites and museums (Ch′ng 2011).

17.7 Shifting Cultures

The situation that results when we create digital representations of cultural heritage sites and artefacts is that we move towards virtuality and interactivity, both of which originate in abstraction. There has been a complete shift to the digital realm. Previously where analogue sought to transcribe, digital seeks to convert. The analogue media of the past stored cultural information in the material of physical objects. Digital media store it as formal relationships in abstract structures of zeros and ones. You cannot 'see' digital content in the same way we can see an image on a strip of 35 mm film or a photo negative, both of which are quickly becoming dead media. Our current ability to digitally model a heritage environment makes abstract coordinate space become object space while the computed information becomes the image space (Hayward and Wollen 1993). Ascott (2003) coined the term 'cyberception' that aptly describes this altered state we now embrace. Cyberception includes all the interfaces we use to connect to cyberspace. These digital tools afforded by the computer are cognitive extensions that underline the independence and further the creative abilities of the user.

Our interaction with reality itself is increasingly mediated by interfaces to computation (Holtzman 1997; Ioannides 2010). Digital media continue a tradition of a surrogate reality inaugurated with the development of the camera. Exploring digital heritage simulations can teach us a great deal about what reality is or was, while dramatically changing the reality in which we live (Kalay et al. 2008). Digital heritage relates back to an issue pointed to by John Searle in 1992, when he argued "simulating something is not always enough to make it the real thing". In addition I might add another question to consider, how complete does a simulation have to be before it is real, or to put it another way, how much information is enough?

As we create our digital heritage *datacubes*, we will force a dramatic challenge to our media-based culture as we try to comprehend the paradoxes of interacting with computed digital heritage representations. Marc Pesce, early in 1995 identified this process in what he called "electrification of imagination". It is now apparent that we have come full circle, back into an era where we seek to communicate the imagination. That is one of the things that cyberspace and certainly digital heritage is about, capturing our imagination with the past and bringing it back into the present. In order to make computers clear to our minds, we have to teach them to speak to out hearts.

Digital heritage can be considered to comprise facts and information (architectural plans, 3D scans of heritage artefacts or sites, photos of locations, etc.), fiction, interpretations or "best guess" (re-creations of landscapes, people, building adornments etc.) and fantasy (highly engaging for the audience) in varying forms and degrees with interpretive narratives of the past. The notion of fantasy is perhaps the strongest to appeal to the imagination of the viewer/visitor on certain levels. It may ultimately be the key to the widespread appeal of digital heritage as a public experience and help the goals of many projects succeed. That does not mean that a "fantasy" element is a bad or negative quality. It can be much more of a dynamic catalyst that sparks audience engagement with the digital heritage representation (Kwiatek and Woolner 2010).

Current work in digital heritage is also very much in keeping with what Janet Murray outlines in her recent book 'Inventing the Medium' (2012) that we are "shaping new digital artefacts and the systems of behaviour in which they are embedded" as a cultural practice. Sarah Kenderdine has spoken widely about "inhabiting the cultural imaginary" wherein the audience becomes an integral part of, and immersed into, the digital heritage experience. Her evaluation study of PLACE-Hampi revealed a wide cross-cultural appreciation of the project and that people are very forthcoming to report and discuss their experiences of digital heritage. Sadly, many digital heritage projects are never experimented or monitored with people, and instead just die in labs (Kenderdine et al. 2009). However, with many new projects the audience has thankfully become an increasingly important part of the overall research scheme whereby the receiver's feedback is incorporated back into the evolution or new versions of the work when presented again.

17.8 Multilayered Delivery

A common way DH media creators convey a certain story, idea, or content is to imitate or describe a certain situation in life or society, heroes and heroines, events, advantages or disadvantages, which happen(ed) in either real-time or were restricted or prolonged over time. All these *stories*, in a basic sense, are the subjects of what is referred to as the *mimesis* of life. What distinguishes them from real life is not their closeness or remoteness to the cultural or intellectual level of the audience or receiver, but the relative freedom with which the receiver can play, daydream or think of them in endless variations. This is quite contrary to real life, whereby events pass around us with a certain one-way direction, which cannot, or is usually not, interchangeable.

After a real-life event has occurred, it cannot be undone or changed according to our wishes. Within a digital heritage media project quite often the opposite is possible or even desirable. The event can be turned around not only in the media piece, but it can be endlessly replayed in the viewer's mind: forwards, backwards, sideways and in any real, daydreamed or night dreamed state of mind. Bachelard (1998, 1994) wrote extensively of 'poetic imagination' and 'reveries' as powerful states of dreaming.

The result of such a freedom of thinking is a centuries old craving for artistic mimesis of life as can be found in literature, theatre, movies or television and now within digital heritage multimedia presentations. The power of the artistic mimesis of life comes from a multilayer information delivery. Distinct cultures and nations may have different subjective values or preferences for content. Once an artist has created the mimetic information skeleton (outline), they can start to describe the people, events, situations and environment in a human perspective or "through human eyes". The audience then begins their own similar decoding patterns within his own memory thus imparting a great impact on a digital heritage mediated work (Malik and Thwaites 1994).

Any multilayer information delivery process initiates a very important effect: it can bridge a number of "missing connections" in the basic information design. Since the receiver follows the "path of life experiences", they can fill in any gap in the mediated reality using their imagination with ease and efficiency. They can fantasize. In a brief time the viewer can cross centuries, distances, social groups, peek into the private lives of many other characters and "survive" or experience imaginary wars, crashes, battles, and scandals, etc. (Malik et al. 1991). Digital heritage can easily incorporate many of these qualities by the very nature of the content and the technologies currently available and employed.

The human brain has a remarkable ability for multilayer information delivery (Alkon 1994). It can process incoming information in two basic modes: (1) A sequential mode: respecting the time and flow of events, characters, such as in books, and films and in (2) A Spatial mode: reflecting the incoming information back on their own experiential mindscape. Although each mode evokes activity in a specific brain hemisphere; (sequential processing in the left brain hemisphere and spatial processing in the right brain hemisphere) the whole brain is processing information in a parallel fashion (Small and Vorgan 2009) giving the viewer an amazing opportunity to move forward in the information flow or to adjust it according to their own cultural and intellectual experiences. This is why the addition of interactivity to digital heritage is so compelling to the user as evidenced in recent projects (Cameron and Kenderdine 2007; Champion 2008; Kenderdine 2010; Ch′ng 2011).

17.9 Digital Heritage and Human Values

Over time each society has developed a hierarchy of values resulting from its geographic location, interior and exterior social relationships with other human groups, and specific to its social structure. The distance or closeness of content to a particular set of human values may label the work as “national”, “tribal”, “personal” and as such, it facilitates establishing the information consumer’s attitude toward any mediated work (Malik et al. 1991).

Historically artistic works were most often destined for a specific audience (one’s own tribe, own community, or own nation). The codification of content in writing narrowed this function to only those who understood the specific language. From medieval times onward the concept of cross-cultural understanding and cross-cultural communication rapidly extended the information impact of artistic works globally. Marshall McLuhan’s vision of the “global village” (1989) signals a strong cultural importance in this sense. As we closed the twentieth century artistic works of all kinds, were increasingly shared by people of diverse countries, ethnic and cultural backgrounds, rising dramatically in the twenty-first century.

Basic human values are usually united into hierarchies and the expression of them in human behaviour is generally perceived as “value stereotypes” and “value archetypes”. Whenever a thought or idea is repeatedly processed along the same established, repeated pattern the result is a person thinking in his own “stereotype”. In addition, there are a number of human values that traditionally cut across cultural and national boundaries. Certain religious, political and humanistic values are of this nature. Those that are closest to *sentic* (Clynes 1973) human values will transfer across geographical, national or political boundaries easily (survival, home making, love, motherhood, jealousy, hate) and those, which are geographically or nationally specific, are usually perceived as “exotic”, or “strange” (Malik et al. 1991). Thus, human values are a key component of digital heritage content that can elicit a significant impact when digital heritage works are transmitted via cross-cultural applications and globally mobilized through expanded technology such as described here in this chapter.

17.10 Considering Style, Form and Content

A digital heritage information complex undergoes a transformation while being perceived within the domain of the human brain. Not only are the original shape, form and content subtly or substantially changed, but also the receiver’s own experiences, combinations and dreams begin to enrich the original content. The significant element here is not just the original stimuli (the content), but a whole mindscape of thoughts, recalls, memories, or fantastic dreams brought to bear on the content by the audience (Malik and Thwaites 1994).

At the end of twentieth century the time and space axes of information began to deform the content and form of an artistic work in the mindscape of information consumers (see Fig. 17.4). As a result, the designer of a digital heritage piece no longer has the complete ability to engage their audience. The person who perceives the work is freed from the conventions of traditional audio-visual form. They can start to move freely within his/her imagination due to the awesome capacity of human brain to combine the carefully designed elements of subjects, image and sound content, and interactive forms into a most fantastic, invisible pattern of thoughts, dreams, and personal imagination (Thwaites 2005).

Heritage, culture, our understanding and definition of it, is a vast and complicated human quality evolved through the centuries and manifested in language, art, architecture, writing, drama, etc. Digital representations of reality, either past or present, that by their nature embody culture, are currently tied to a myriad of technology schemes that can vary greatly in the presentation form and style of digital heritage information (Foni et al. 2010; Champion 2008).

The re-presentation of digital heritage via Internet websites, a popular content conduit, can provide only certain kinds of information and in certain ways subject to established protocols. The longstanding format of QuickTimeVR or other forms of 360° panorama interactions, combined with texts, images, databases and avatars are common. DVD delivery by nature of its high-density can take content further in scale and scope but are limited in interactivity. Stand-alone, immersive delivery platforms such as CAVES, Cubes, 360 Panorama Theatres, and touch-tables, to name a few, can further provide a more “true virtual” and interactive or immersive experience (Hemsley et al. 2005; Ioannides 2010).

Our quest for the optimum technology is the seeming “holy grail” of digital heritage, however it is often costly and limited to specific venues. No two applications are alike nor do they present content in the same style or form. The resulting information impact on the audience is, or can be, altered in each case. Such an outcome must be considered carefully in the overall content design whether it will be specific to a delivery system or across a variety of transmission conditions. A current iteration of this is manifested in the developing field of transmedia, comprising content of various media formats and technologies across new modes of delivery, often requiring redesign or reshaping before use.

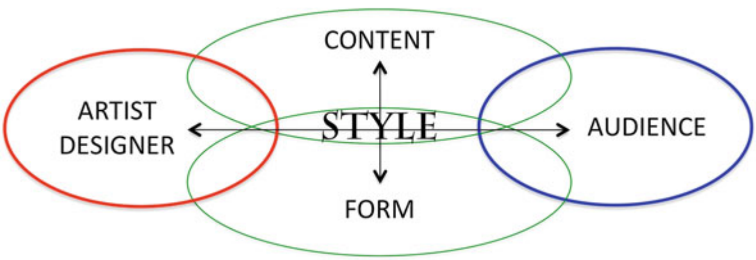

Fig. 17.4 Interactions of style, form and content (adapted from Dondis 1973)

17.11 The Vanishing Virtual or the "Disappearing Digital"

Many researchers have highlighted an urgent situation around the world, that digital heritage is vanishing or disappearing faster than actual physical heritage of all kinds (see Fig. 17.5) (Koller et al. 2009; Stodl et al. 2009; Addison 2008, 2006; Cohen and Rosenzweig 2006; Kuny 1997). How can this be and why is it happening at such an alarming rate? Mostly it is happening due to inappropriate standards, a lack of understanding and in some cases just a rush to capture, and digitize, in order to "save" it before it is gone, often resulting in the opposite result.

Addison has identified some of the broad areas where there needs to be consistency in characterizing information related to heritage. They are the following; capturing and digitizing, the use of metadata, the selection of technology, data quantity verses quality, and archival protocols. He has proposed a minimum 14 point basic template of metadata required to be added into each heritage asset such as photos, 3D scanning data, measurements, documents, sound and video recordings (Addison 2006). If all our digital heritage data were tagged accordingly it would move us towards a more comprehensive archiving of what we seek to preserve thus extending and expanding usability over time.

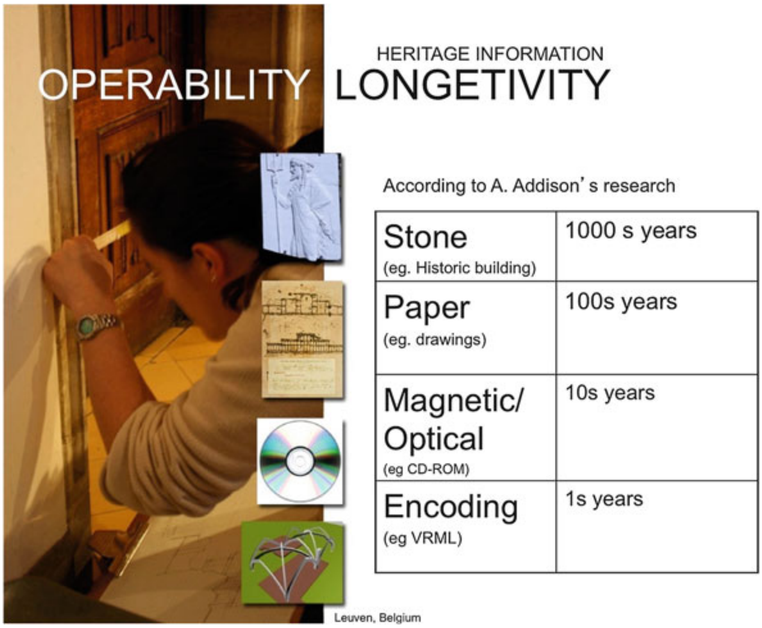

Fig. 17.5 Longevity of storage formats in years (reproduced from Santana-Quintero 2008)

17.12 Smart Heritage and Cultural Futures

The concept of smart heritage and cultural futures is comprised of applications that combine imagery and sound captured at locations of high cultural significance with animation, narratives and immersive sound and vision technologies to create hybrid virtual-real worlds rich in detail, interpretation, and aesthetic impact exemplified by the work of Kenderdine et al. (2009). This field of research is extremely promising because it seeks not only to create new experiences in digital heritage but also to have them live through into a "cultural future". Sarah Kenderdine's (2013) ground breaking work with the immersive panorama format displaying the heritage site of the Mogao Caves at Dunhuang has been seen by thousands of people in various locations (see Fig. 17.6). It is an example of what I would call 'mobilized' digital heritage since it was designed to be experienced across cultures in different environments and by diverse audiences.

Much of the future of digital heritage re-presentations lies in what Balsamo (2011) describes as "public interactives", "a category of exhibits that use interactive technologies to present content to a wide range of public audiences". These experiences can push the boundaries of digital creation to new styles, forms and content in venues such as galleries, museums, heritage sites, exhibitions and other public spaces. They immerse and involve audiences by maximising the components of the information chain; the source, transmission conditions and the response of the audience, capturing their imaginations in ways that were until now only dreamed of with early digital heritage presentations. Work continues to evolve in this exciting field each year with new installations appearing around the world.

Fig. 17.6 The Mogao Caves at Dunhuang 360° immersive panorama installation (reproduced from Kenderdine 2013)

17.13 Born Digital Content

Digital heritage content is created in many different formats as described and discussed above. What is now of increasing importance are the totally 'born digital' projects, those that are completely computer generated and presented with no analogue equivalent such as the work of Kwiatek on creating heritage stories (2010), Ch′ng and Stone on ancient landscapes (2006, 2005), Pletinckx et al. (2000) on archaeological visualization among many others.

UNESCO's charter for the preservation of digital heritage has indicated that such 'born digital' content should be given priority. Why, one may ask? Presumably it is simply that totally digital content stands an even greater chance of 'vanishing' than content that has been created from a digitization process of an existing reality.

Born digital content comprises the following formal aspects; it is original content that is entirely digitally generated and presented, and has no analog equivalent; it is easily replicated, altered, and destroyed, has networked or distributed storage, can be internet-based, and it is subject to instability (lost information is lost forever). In addition, and of critical note, it is subject to technical obsolescence and physical decay, thus not having a 'cultural future'. Lastly it is content having a lasting value and significance, being dependent on computers and related tools, with hardware and software always changing and thus by nature is dependent on storage media and format upgrades (Jianhai and McDonough 2009). All of these features need to be addressed from the outset by those creating born digital heritage content if we are to see it as 'Smart Heritage' that is carried forward into our 'Cultural Future'. Therefore, it must be curated, re-versioned, and updated to move forward in time.

17.14 What Do We Learn When It is all Digitized?

The year 2013 is a significant time and place in history, a time of the merging of technology and human will/needs in order to preserve world cultural heritage in its many forms. It is also intensified by the interest and encouragement of UNESCO to digitize endangered heritage sites (Smith 1998). In the process, what impact will these digital interventions have on our perception and understanding of heritage into the future? What follows below are some of the possible implications of this process that may shift in importance and scope over time and as technology and our research in digital heritage creation develops further.

As a result of digital heritage there has been increased interest in cultural heritage the world over. It can provide access to remote or closed heritage sites that are on the rise and open a wide variety of rich information sources. Digital heritage projects create an increased awareness of global humanity, encourage virtual tourism over mass tourism, and provide a means of recording, preserving, interpreting and educating thus fostering widespread cross-cultural and inter-cultural communication. Lastly it comes full circle to the beginning of this discussion by coming closer to satisfying our "fantasy" of time-travel into the past.

From the above discussion, it is apparent that digital heritage can be technologically intense and expensive to develop and present, often existing in an exclusive environment not easily shared across time or space. It can provide only a limited perception of the overall "cultural value" of a site, leaving certain ellipses in cultural information. It has raised public awareness of heritage sites often resulting in increased tourism to sites, putting them in danger of over visiting. There has been a huge diversity in the amount and accuracy of the information available around the world posing a risk of commercialism and low quality applications. The digital heritage audience has had an exposure to formative experiences creating pre-defined expectations of what digital heritage experiences 'should be'. Lastly of course, the content requires custodial care and maintenance as digital heritage technology evolves with increasing speed each year (Tan and Rahaman 2009).

In addition to the foregoing discourse on digital heritage, Lavoie and Dempsey (2004) have identified key issues to the understanding of digital archiving that readily apply to the overall digital heritage processes and could be seen as a minimum starting point. They describe it as an on going activity aligned to set of agreed outcomes, with a shared and understood responsibility. Preserving our digital heritage entails a selection process in order for it to become an economically sustainable activity. It must be built upon a cooperative effort that is often seen as an innocuous activity, or perhaps an aggregated or disaggregated service, while also being a complement to other services. Digital heritage has become an understood process, but it is just one of many options for heritage preservation. Most significantly it can overall be seen to be as a public good and a global initiative for humanity.

For additional guidelines that support digital heritage projects see the work of Letellier (2007) in the publication "Recording, Documentation, and Information Management for the Conservation of Heritage Places" as some clear indicators of what we need to consider as we move further forward in the process towards 'digitizing everything'.

17.15 Conclusion

From the foregoing discussion it is safe to say that Digital Heritage is still a relatively young but rapidly evolving field. This chapter has presented a broad summary and overview of issues, approaches and digital heritage projects across time and space. Many researchers and media artists around the world are working to find better ways to "digitize" our global cultural heritage sites and artefacts before they disappear forever. Millions of people comprise the twenty-first century media consumers who anxiously await the results of our efforts (Mudge et al.

2006). Technology advances faster than we can sometimes keep up with it. This double-edged sword provides us with the tools to create ever more engaging representations, while at the same time it creates challenges for the exhibition, access and preservation of digital heritage works.

So what now? How do we proceed forward so that the best of Digital Heritage can make its way into the public space given the constraints and considerations outlined in this chapter? The engineers, historians, archaeologists, digital media designers and artists must find new and useful ways to expand their work, share approaches and learn from each other (Cameron and Kenderdine 2007). In my opinion, very few projects should, or can now, be carried out in isolation, one specialized team working without the help or input from other disciplines. Digital heritage is indeed a transdisciplinary team endeavour that can only succeed through the meeting of minds and the sharing of ideas and research from around the world and across cultures. We are seeing many more examples with each passing year.

In the very near future some critical issues will need to be addressed; increased accessibility to (and sharing of) heritage data, consistent interface design for widespread public use and re-presentations of work, the formalization of a digital heritage database, establishment of a global infrastructure, institutionalized archival standards for digital heritage and most importantly the on-going curation of work forward in time as the technology evolves so that our current digital heritage projects will not be lost to future generations. We cannot afford to have our digital heritage disappearing faster than the real heritage or the sites it seeks to 'preserve' otherwise all of our technological advances, creative interpretations, visualizations and efforts will have been in vain. The solutions lie with the digital heritage community and with the readers of this book.

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Chapter 18
Digital Heritage: Concluding Thoughts

Eugene Ch′ng, Vincent L. Gaffney and Henry Chapman

Abstract Digital approaches to heritage and archaeology were in development since the 1980s and witnessed exponential growth throughout the 1990s. The successive decade saw the breadth and depth of digital technology being applied in heritage and archaeology, encompassing a more complete process in research and focusing on more practical methodologies. It is perhaps at this juncture that digital heritage can be said to be approaching a stage of maturity. The impacts of technological change on the process and dissemination of research witnessed within this volume have demonstrated just that. However, the combinations and permutations of existing and emerging digital technologies and the subject of study in heritage and archaeology are continually creating new areas of research. In this concluding chapter, we reflect upon the research presented in this volume and explore the notion of a continuum of digital heritage development and the recent changes in a more substantive manner.

Keywords Digital technology · Heritage · Blurring boundaries · Future trends

E. Ch′ng (✉) · V. L. Gaffney
IBM Visual and Spatial Technology Centre, Digital Humanities Hub, The University of Birmingham, Edgbaston B15 2TT, UK
e-mail: e.chng@bham.ac.uk

V. L. Gaffney
e-mail: v.l.gaffney@bham.ac.uk

E. Ch′ng · V. L. Gaffney
Centre for Creative Content and Digital Innovation, Universiti Malaya, 50603 Kuala Lumpur, Malaysia

H. Chapman
IBM Visual and Spatial Technology Centre, The University of Birmingham, Edgbaston B15 2TT, UK
e-mail: h.chapman@bham.ac.uk

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18.1 Introduction

The title of this book, *Visual Heritage in the Digital Age*, may perhaps be seen as pointing in two directions. Whilst the focus has been on the application of digital technologies and their recent developments within the broad realm of heritage, digital technologies themselves have their own legacy. Digital approaches to heritage and archaeology have been developing since the 1980s, but witnessed exponential growth throughout the 1990s and successive decades. In some ways, the examples of research presented in this volume illustrate the most recent stage of a continuum of development within a broader context of change, as illustrated by the notion of Web 2.0 in 1999 and, more recently, the development of the semantic Web (Berners-Lee et al. 2001), the Internet of things (Atzori et al. 2010), the need for big data analytics (Lohr 2012) and the data science associated with it, as well as the emergent domain of complex systems science (Byrne 1998; Holland 2012; Miller and Page 2007; Mitchell 2009; Page 2010; Sole and Goodwin 2002; Weaver 1949). The implications of these dramatic technological changes and the resulting new research areas have important implications for heritage study in the twentyfirst century (Barceló et al. 2000). In this concluding chapter, it is useful to reflect upon the research presented here and to explore the notion of a continuum of digital heritage development and to investigate recent changes in a more substantive manner.

In the 1960s, the Canadian philosopher and media theorist, Marshall McLuhan (1911–1980), provided the aphorism ‘the medium is the message’, noting within the context of digital media, that ‘we become what we behold that we shape our tools and thereafter our tools shape us’ (McLuhan 1964, p. 33). Arguably this observation on technological determinism was reflected, in some ways, in the earlier use of digital technology within heritage. The use of Geographic Information Systems (GIS) and in particular methods such as visibility analysis provides a specific example. The availability of tools for the analysis of visibility, although never actually provided for the purposes of heritage studies, may well have determined the trajectory of research within disciplines including archaeology and led to an overemphasis on visual approaches for understanding the past (Wheatley and Gillings 2002, Chap. 10) at a time when the importance of multisensory experiential analysis of landscape were being promoted (Gregory 1994; Tilley 1994, p. 7–11).

Further developments have occurred over the last two decades and, in this chapter, we can consider the question of whether the current state-of-the-art actually represents a continuum of trends within digital heritage, and perhaps the tyranny of technology, that might be identified in previous decades. We can also discuss whether digital technologies are being used in more imaginative or thoughtful ways and set this against current and future technology change. Firstly, the penetration of digital technology into our disciplines and, more generally, within society has become ubiquitous. This has also meant that a greater proportion of heritage practitioners may now be using these tools themselves in contrast to the past reliance upon the exclusive competence of digital technology specialists.

Furthermore, developments in hardware and software have revolutionised the ways in which data can be captured and processed in terms of both velocity and interconnectivity. For example, image processing and dataset management software now have user interfaces that are similar to standard PC applications and are available at a fraction of the cost in comparison to the specialist systems available several decades ago. As a consequence, in terms of access and ease of use, technology has appeared to achieve some level of satisfaction in respect of the ambitions and aspirations of heritage professionals. Technology has also offered new ways of engaging with data, whereby visualisation has become part of the process of archaeological investigation rather than reflecting the final stage of a process for wider consumption (Frischer and Dakouri-Hild 2008). This engagement is also being dramatically augmented includes new ways of exploring hypothesised models of our world includes the use of computational approaches such as Agent-Based Modelling (Bonabeau 2002; Parunak et al. 1998) within the context of complex systems science.

In effect, the process of digital representation, once a distinctly separate subdiscipline within heritage and its related disciplines, has begun to merge or blur the traditional boundaries of both the process of heritage research and of the relationship between the digital and traditional approaches for understanding, conserving, managing and presenting past and present heritage resources.

18.2 Ubiquity of Digital Technology and Data

In recent years, the accelerated global development and pervasiveness of digital technology has led to new levels of computing activity that enable the processing of larger, more complex datasets and their visual representations. However, the capacity to realise the potential of such technologies has fundamentally been based upon the increasing availability of digital data in vast quantities, much of which may never have existed except for the digital formats in which they were generated. From remote sensing datasets to the self-generative capacity of the web itself, first engagement with archive data is increasingly a digital event. The emergence of online databases, virtual museums and digital library catalogues have meant that access to information has expanded and deepened in terms of the quantity, and the quality of the experience of users in the digital domain. From the Archaeology Data Service (ADS), to Europeana and the numerous projects funded by national organisations, including the UK Joint Information Systems Committee (JISC), this has meant that an ever growing archive of online accessible information has become available. It is notable that this trend is also becoming supranational, not simply in terms of European-wide heritage initiatives, but in intercontinental data projects with shared technical concerns and data challenges (DataDig 2013).

The increasing accessibility of data has also demanded sophisticated interfaces which go beyond simple data discovery of the sort associated with early search engines. Heterogeneous Mashups combine digital knowledge in a dazzling constellation of networks that form links that could never have been achieved by local human action—information seems to have a life of its own. This phenomenon is also seen in the dramatic expansion of gaming technologies for use in behavioural or experiential modelling or for virtual engagement with data in novel ways. An example of ubiquity is provided by developments in digital cartography, once the realm of the GIS specialist, but now accessible through ubiquitous platforms such as Google Earth. Similarly, the development of positioning technologies now means that smart phones are able to provide geolocations for user-generated contents such as text and images, for example, which allows such content to be linked with spatial information.

These trends also include the enhancement of human engagement with heritage data through the use of mobile technologies, touch interfaces and 3D visualisation. From digital installations within museum spaces through to online *virtual museums* (e.g. Chapman et al. 2010) there has been a considerable growth in the digitisation of collections and the ways in which these are presented for wider consumption (Styliani et al. 2009). In addition to online virtual museums, engagements with both tangible and intangible cultural heritage are facilitated through a range of novel methods such as augmented and mixed reality (Khan and De Byl 2011). The increase in the digitisation of heritage collections and libraries is matched by shifts in the way that people consume online material. For example, the use of smart phones as a primary method for accessing the web has significantly increased over recent years and this is having a dramatic effect on the way in which knowledge is accessed, with dramatic effects on university library services (Paterson and Low 2011). In practice, the growth of digital content generated by institutions and the development of new ways of engaging with it is providing new opportunities and challenges for the sector. This, in addition to the increased capacity for the public to generate their own online content such as through social media applications, demonstrates the considerable shifts that show how the ubiquity of digital technologies is shaping how we engage with heritage (Fig. 18.1).

18.3 Data Capture

The capacity to capture data relevant to heritage studies has also changed significantly in recent years. The availability of digital imaging and mobile Global Positioning Systems (GPS) units through to the use of linked social media such as Instagram, Flikr, YouTube, Facebook and Twitter has generated huge quantities of user-generated data that can be mined and analysed to explore continuous themes produced by tourist activities and attitudes (Ch′ng 2013), or even crowd source 3D models of sites that one can embed within Google Earth through user-friendly

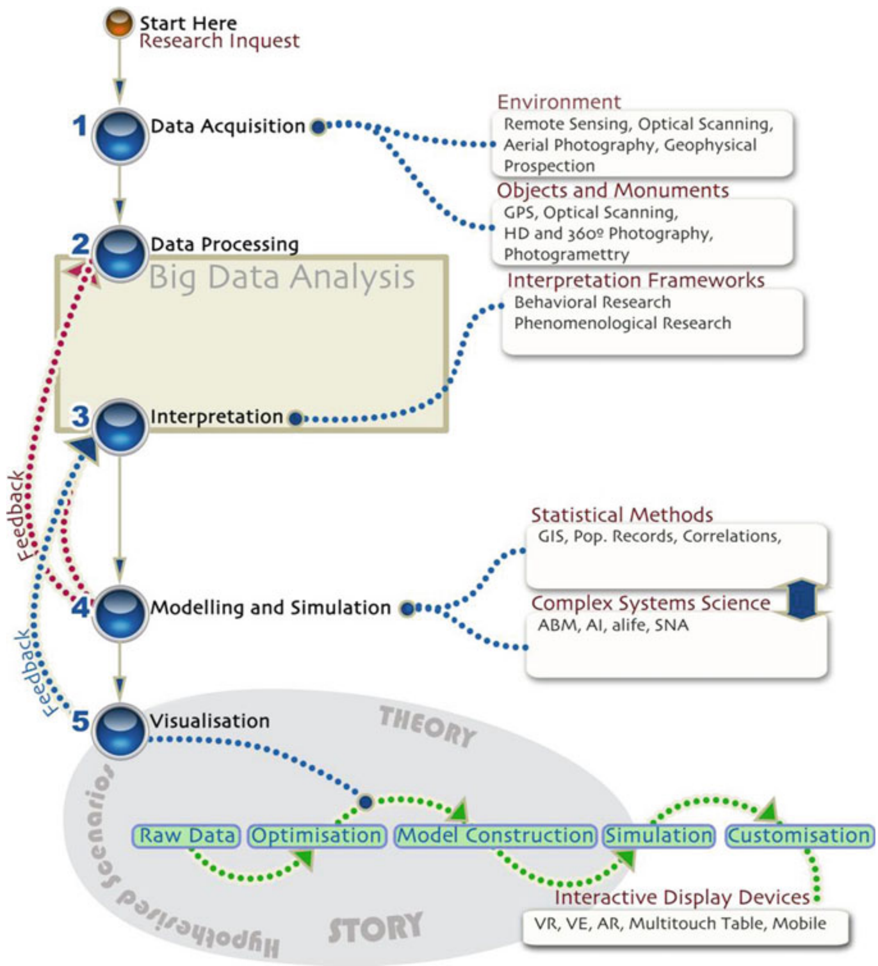


Fig. 18.1 The research process road map within heritage and archaeology

modelling software such as SketchUp. For the first time at a grand scale, the potential for user-generated content and real-time data about the nature of the heritage experience can be understood directly from these sources.

At a more specialist level, exponential developments in data capture have had a significant impact on the rapidity of survey of heritage sites, the representation of objects, the density and resolution of data and the spatial quality of outputs. Developments in optical 3D data capture technologies such as laser, structured light scanning and photogrammetry, have enabled the rapid collection of physical surface information, enabling reconstructions through 3D modelling and simulation for objects, monuments and environments. These developments have two main impacts on heritage research—volume and velocity. The velocity of incoming data captured is accelerated, and the volume of captured data has become so great that High Performance Computing (HPC) has to be employed for structuring the data in a way that informs our senses.

Data capture has also been revolutionised in recent years through the ability to collect spatial information relating to other data capture methodologies. For example, in addition to geophysical equipment being able to capture data at higher resolutions and at higher levels of detail and sensitivity, its combination with GPS means that data capture is no longer restricted to gridded surveys (Gaffney and Gaffney 2006).

The exponential increase in our ability to rapidly capture large quantities of highly accurate spatial data has been paralleled by hardware and software developments that enable the processing and visualisation of very large datasets. In turn this has led to an increase in the ambitions and expectations of data capture both at a demographic level, through to the capture of digital photography in social networks, to novel 3D content. Whilst this may suggest that content creators may be more ambitious with respect to the digital objects they generate these developments are not without issue. At a pragmatic level the sheer size of digital data has increasing implications including the ethical issues of power consumption and storage in increasingly isolated server networks (The Arts and Humanities Research Council, Big Data Workshop, London, 25 June 2013). However, there is also a tension between the digital objects as presented and what they may represent. Description is not interpretation, and infinitely finessing the resolution of data cannot actually explain or interpret the data we may generate for heritage purposes (Gaffney 2008). Whilst the velocity, volume and quality of data capture invariably add value to research, gaps remain with regards to the connections between one dataset and another. A complex systems science approach to modelling and simulation may help bridge these gaps.

18.4 Agent-Based Modelling and Complex Systems Science

Traditional academic approaches to heritage studies have largely been based on hypothesis testing although postmodern approaches to the past have increasingly emphasised the experiential role of the individual (Tilley 1994). The latter approach has largely rejected numeric analysis but the change to complexity modelling (see Chap. 12—Ch′ng and Gaffney; Ch′ng et al. 2011; Ch′ng 2013b) provides an entirely novel approach to analysing the captured data which should not be confused with the processualist analyses of the past (Costopoulos and Lake 2010). Instead analysis is shifting towards new paradigms of investigation. Rather than concentrate research on traditional hypothesis testing, or a method grounded on theoretical approaches, researchers are now able to model scenarios with increasing complexity using agent-based modelling as a notion for investigating ‘what if’ scenarios. Hundreds of simulations of a model with different parameters can be conducted using agent-based modelling thereby discarding null hypotheses by looking at the general macro states of trends in the output of models. Similar to a map of a city, or an abstract map of the routes of a subway, a model is a useful map of the physical world, past or present which our research may investigate. A computational model distills reality into a few key features, leaving out unnecessary details so as to let us see our world in a new light. A model maps connections and its intertwined relationships between agents of change, between agents and the environments, and between the different hierarchical levels of collective groups of agents forming a community, society or population. Such models have the potential to investigate the macro–micro link, and the mechanisms that influences the link (Buskens et al. 2011; Schillo et al. 2001; Squazzoni 2008). Agent-based modelling can help heritage practitioners map a clear picture of ancient, and contemporary, societies or behaviour. The interaction of agents with each other and with their environment within a multi-agent simulation can exhibit phenomena such as emergence (Holland 1998) and self-organisation (De Wolf and Holvoet 2005) at the macro level, such as the flow and diffusion of information across society, the distribution of wealth, the formation of cohesive groups, the co-discovery and interaction of communities, population movements in climate change, the development of culture, the evolution of landscape over time and also interaction with museum displays or tourist behaviour at larger scales. The capacity to construct and simulate models in order to see general developmental trends can provide us with new knowledge that is impossible to achieve through traditional approaches. Since agents can be modelled as homogenous or heterogeneous individuals, with different characteristics such as personality, gender, age and size or preferences such as habitat, climate and food. The implications of introducing such approaches into arts and humanities where, as the introduction emphasised, the proper study of mankind is (wo)man, are clearly profound.

Complex systems science will also play an important role in contemporary views of society with regards to the value of heritage. The capacity of computational algorithms to capture large volumes, velocity and variety of information associated with social media and social networks on topics that interest heritage academics is again significant, and the quantitative approaches of statistics and social network analysis (Scott 2012) will mean that significant trends within society which may affect heritage perception or practice can be quickly identified and analysed. For example, the 61,000 viral YouTube views and comments (Fig. 18.2), generated over a short time by the public on IBM VISTA's research on pits possibly related to the summer solstice provided very intriquing comments and links to other sites which could be used for further understanding of how the public reacts to such information. Public interest (Fig. 18.3) in an agent-based modelling simulation on the survivability of Mesolithic agents in the inundation of Doggerland, prior to VISTA's participation at the Royal Society's Summer Science Exhibition (Carlton House Terrace from 1 to 7 July 2012) provided us with valuable information which led us to engineer the simulation in a slightly different direction.

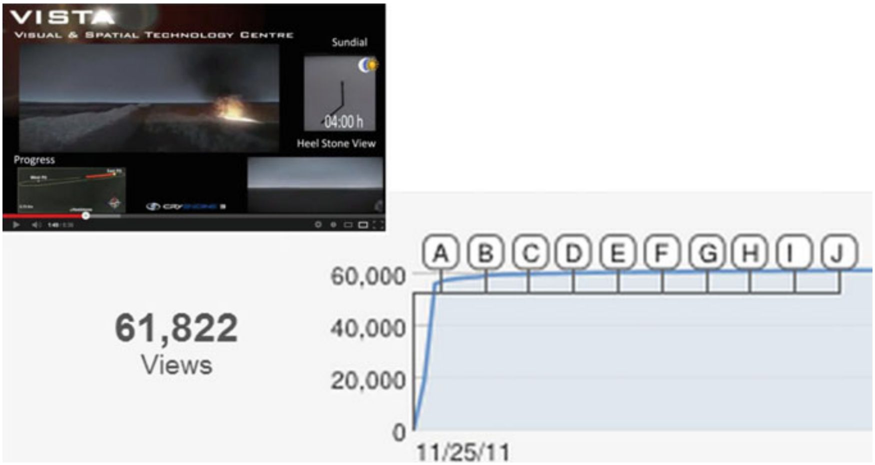


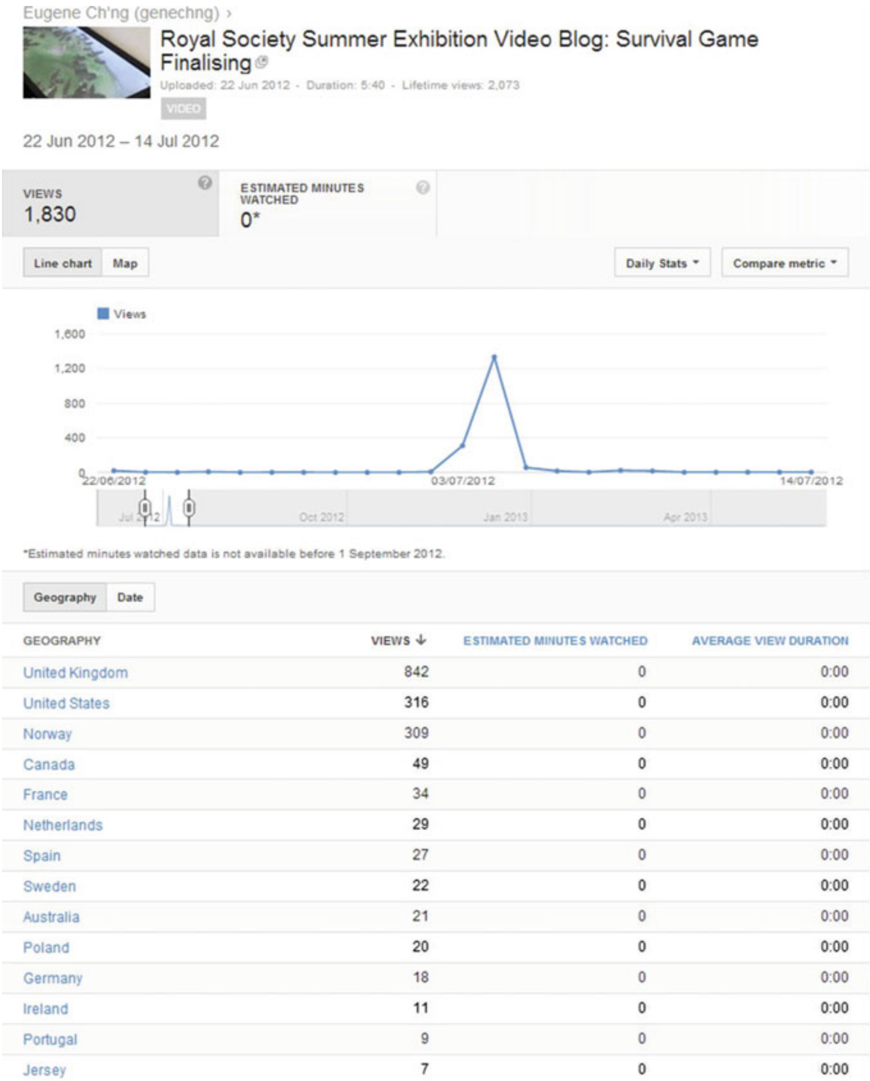
Fig. 18.2 Stonehenge heel stone summer solstice viral video views

18.5 Seeing Better? The Future of Visualisation

Unlike traditional statistical approaches, which depended on reading regression information with graphs and values on tables, Complex systems science using agent-based modelling requires new ways of seeing results both during the process of research and the visualisation associated with the end product of an investigation.

Traditionally, visualisation and reconstruction were used as a final element of a lengthy research. Visualisation demonstrated the summative work of an academic enquiry; it was an end product produced by contracted illustrators at the conclusion of a project. The results of such work are seen in countless publications, such as Tim Taylor's impression of a Mesolithic village (Wymer 1991), the numerous illustrations by archaeological illustrators such as Alan Sorrell (1976) and, more recently, Victor Ambrus (Ambrus and Aston 2009; Ambrus 2006). Set alongside these visual products, of course, are the requirements for technical illustration which may provide relatively realistic reconstruction of artefacts or structures for interpretative purposes and which might lead to physical reconstruction (Barker 1982, pp. 233–247; pp. 254–267).

The growth of digital technologies has changed this irrevocably as exponential growth in computing power not only allows us to collect and store large amounts of data, it has also provided us with the capacity to process these data into structured information that can be meaningfully visualised in a form that facilitates interpretation within the research framework. As a result, visualisation has become a fundamental part of the research itself, it has a new place within the research process. Figure 18.1 is a research roadmap for an archaeological project using visualisation as an integral part of research. For example, the Stonehenge



GEOGRAPHY	VIEWS ↓	ESTIMATED MINUTES WATCHED	AVERAGE VIEW DURATION
United Kingdom	842	0	0:00
United States	316	0	0:00
Norway	309	0	0:00
Canada	49	0	0:00
France	34	0	0:00
Netherlands	29	0	0:00
Spain	27	0	0:00
Sweden	22	0	0:00
Australia	21	0	0:00
Poland	20	0	0:00
Germany	18	0	0:00
Ireland	11	0	0:00
Portugal	9	0	0:00
Jersey	7	0	0:00

Fig. 18.3 Agent-based model of mesolithic survival trending youtube video views. The Royal Society Summer Science Exhibition, Carlton House Terrace, 1–7 July 2012

landscapes and the north sea visualisation project depends on large-scale visualisation of the integration of remote sensing with GIS maps for identifying geological and landscape features that ancient inhabitants depended on for living (Gaffney et al. 2007; Ch′ng et al. 2011). The use of agent-based modelling for growing vegetation in order to populate a submerged landscape (Ch′ng and Stone 2006a, b; Ch′ng 2009), for the most part, depends on visualisation in order to interpret the emerging results of an on-going simulation. Similarly, the route ways of human journeys and the ecological niche of flora and fauna depend not only on graphs of statistical analysis, but on the visual cues represented as heat maps of population concentration and 'trodden' areas of a forest landscape. Hypothesis testing using interactive reconstruction of the original arrangement of the cargo prior to the Kyrenia shipwreck, for example, uses heavy computer graphics simulation and rendering that integrates Newtonian physics and real-time rendering technology (Bentkowska-Kafel et al. 2012, pp. 48–51). Other aspects of the beneficial use of visualisation are in the phenomenological interpretation of landscapes (Ch′ng 2007) using computer games technology.

Heritage visualisation is likely to become increasingly complex as a reflection of developments driven by the entertainment industry's need for high-end computer graphics. As software and hardware that were once accessible only to specialists due to their large costs and specialised skills become widely available, automated and user-friendly, we will witness an explosion of research driven visualisation from within the academic community.

18.6 Digital Democracy

Although access to digital technology may empower people there has, for some time, been a concern with the democratic nature of technology (Pickles 1995). The ethical landscape has, however, changed and the ubiquity of digital technologies, the new ways in which information can be accessed and the accessibility of freely available 2D and 3D software packages has had a direct impact on the world of heritage (see Kokalj et al. this volume). These developments have meant that digital technologies are much more widely accessible and are increasingly being used by non-digital specialists and the increasing issues about who owns what digitally now permeate the creative sector and implicate governments as they seek to control the Net (Goldsmith et al. 2007).

However, it remains true that although specialist skills remain invaluable the outputs from their work are now made available to even wider audiences in a manner never anticipated until very recently. Moreover, the development of social media has also revolutionised the ways in which people communicate, network and engage with one another and this affects academics. The availability of data and new analytical tools is fundamentally changing the manner in which academics work and their disciplines develop. It may also be true that many academics may not be aware of this process but that these trends will only deepen and spread as networks expand and Metcalfe's law kicks in, in relation to the increasing value of network to communication, social or dissemination terms according to the numbers of nodes (Metcalfe 1995).

Finally, some 50 years after McLuhan (1964) it remains true that the medium is still the message and, perhaps, more so in that increasing immersion of technologies and their ubiquity also mean that the boundaries of digital and non-digital have been blurred. Although we may not have exactly reached Baudrillard's position on the hyperreal (Baudrillard 1983) it is true that digital heritage and the wider humanities are now in an unfamiliar position. Many resources only exist as a digital presence prior to any physical existence. Consequently, it must be true that we are creating entirely new spaces for heritage debate, analysis and representation. Some of these issues are touched upon by papers within this book but it is doubtful whether any publication can adequately infer a future that has no obvious correlate. Digital heritage is in a state of perpetual revolution but this reflects the potentially unfettered nature of technology and this raises serious challenges in respect of who owns content or controls interpretation, who and how many may access heritage resources, and wider social issues concerning globalisation and governmental control. Despite this, it has never been a better time to engage with digital heritage. Heritage is a living and dynamic study which touches everyone and helps them to understand their place not in the past but the present, and, in this sense heritage practitioners are creating a future for present and future generations. This is and will be a great responsibility and a wonderful challenge in the many years to come.

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