Three Dimensional Modelling

of

Scottish Early Medieval Sculpted Stones

Stuart Jeffrey

Submitted to the Department of Archaeology,

University of Glasgow for the degree of Ph.D.

March 2003

Abstract

In the past all records of Scottish Early Medieval sculpted stones have been presented to a mass audience via text, drawings and photographs. A range of technologies have now become available that allow digital three dimensional records of archaeological material to be generated which capture the size, shape and texture of the target object. From these records digital three dimensional models can be created. The development of this new type of record offers many advantages to both the archaeological community and to wider audiences. This study evaluates the available technologies and considers how to best utilise the new opportunities for interactive exploration, reconstruction and recontextualisation of Early Medieval sculpted stones.

It is a century since the last comprehensive corpus of all Early Medieval sculpted stone in Scotland was written. In this thesis three dimensional recording and modelling techniques are investigated in the context of a proposed new corpus that is specifically designed to embrace information and communication technology. A new corpus would comprise an on-line multi-media database, one component of which would be three dimensional models of the most significant sculpted stones. These new technological approaches are examined in the context of existing recording techniques as well as being examined with specific reference to the practical difficulties likely to arise given the varied nature of the source material in terms of size, location and access.

The potential audiences for three dimensional models of Early Medieval sculpted stones, the modes of delivery of those models and the potential impact that those models might have on the perceptions of the material being modelled are all investigated. Special attention is paid to the relationship between the intended audience, the means of presentation and the data capture methodologies required to satisfy the demands of the various audiences. Likely future developments in the fields of data capture and presentation are investigated. The impact of Virtual Reality as a mode of presenting archaeological information on Early Medieval

sculpted stone is examined in detail and the potentially detrimental affect of its uncritical use on our understanding of the monuments and the people who created them is examined as well as the positive outcomes envisaged by its proponents. New approaches to the use of Virtual Reality are suggested and its utility in presenting information on Early Medieval sculpted stone is situated within the wider archaeological applications of new recording technologies.

Annotation

Items in the text that are marked with an asterisk (*) have a domain name entry in the Uniform Resource Locator (URL) listings section.
Captioned items in the text, such as Animations or QTVR object movies that are indicated by a CD symbol (see below) are available on the compact disc accompanying this thesis. They may require stand-alone or browser plug-in applications for viewing.

 CD ROM Symbol.

Acknowledgements

The author would like to acknowledge the help and assistance of the following people and organisations. For abundant encouragement and guidance I would like to thank Dr Jeremy Huggett and Dr Ewan Campbell (University of Glasgow) as well as the University of Glasgow Faculty of Arts who generously awarded me the scholarship that enabled this research to be carried out in the first place. Dr Steve Driscoll's advice and encouragement has been very much appreciated and the patience and understanding of Dr Carol Swanson (West of Scotland Archaeology Service) has been crucial to the completion of this thesis. Ingrid Shearer's (GUARD) assistance in proof reading and general support has been invaluable. I would also like to thank: Meggen Gondek for innumerable stimulating conversations, Barry Grove for his helpful insights into the world of the stone carver and artist, Dr Sián Jones (University of Manchester) for a wider perspective on how 21st century people feel about medieval sculpture, and Dr Sally Foster (Historic Scotland) for her encouragement and enthusiasm for the project. I would also extend my thanks to Dr Alan Chalmers (University of Bristol) who introduced me to many of the concepts of 3D data capture as well as to the ACM SIGGRAPH, Rev. Tom Davidson-Kelly for access to Govan Old Parish Church and its monuments, I.G.Scott (RCAHMS) for advice and a glimpse of the artistry required in recording sculpted stone, Jim Devine (Hunterian Museum) for advice on on-line exhibitions, Andrew Mardon and Kirsi Sutherland whose research at the University of Glasgow informed sections of this thesis. I also received technical assistance from many companies and organisations and I would especially like to thank; Theatron, John Clark (Babcock Rosyth Engineering), Alistair Carty (Archaeoptics), Jenoptik, Kodak UK, Douglas Hinds Associates, Measurement Devices Limited and Kaidan

Table of contents

List of Figures

Table of CD contents

1 The future catches up with the past.

For many hundreds of years the rich legacy of sculpted stone from the Early Medieval period in Scotland has fascinated scholar and layman alike. Many of the sculpted forms and much of the iconography draws inspiration from a wider European body of Early Christian sculpture (Henderson 1967; 1998; 2000; James 1998), but there are also forms that are unique to Scotland. Most notable amongst these are the tantalisingly enigmatic Pictish symbol stones predominantly found in North East Scotland (for example, Aberlemno (Angus) (Allen and Anderson 1903, Pt.3 209; NO55NW 26)), see Figure 1.1). These carvings, on monoliths, outcrops, and elsewhere, carry a set of symbols found nowhere else in the world. Stylised and abstract, they hint at a way of thinking about and representing the world that has defied conclusive academic exposition for generations. Serpents, eagles, centaurs and sea beasts share the stones with forms meaningless to us, such as the Z-rod, V-rod, double disc and crescent symbols. The combinations of these symbols are myriad and they so clearly carry significant meaning that their incomprehensibility seems all the more unfortunate given that the once similarly incomprehensible pictographs of the Maya and the hieroglyphs of Egypt have yielded some way to interpretation. This is not to suggest that there has not been innumerable attempts to interpret this symbology ranging from the plausible (e.g. Thomas 1984; Jackson 1984; Samson 1992) to the absurd (Peterson 1996).

Interest amongst the public in Scotland's Early Medieval sculptured stones has been more or less fashionable over the years, the peak of interest probably being the period in the 19th century when public excitement over the whole notion of the Picts, or 'pictomania', resulted in much wild romantic speculation being accepted as fact by the public (see Ritchie 1994b). One of the lasting legacies of this early interest in the Picts is that a people with only a handful of classical references, a small number of early historical references and only one secondary documentary source of their own (Foster 1996, 18) occupy a special place in the public imagination. The classical references are appropriately colourful in reference to the warlike, polygamous ‘Picti’, the name itself possibly meaning ‘painted people’ from their supposed habit of tattooing or painting their bodies (Figure 1.2), although it is uncertain whether this was a name they used themselves. The apparent mystery and romance of the Picts and their arcane symbology mean they have a tendency to overshadow the other Early Medieval groupings in Scotland: Dál Riata (Gaels), Britons, Angles, and Vikings, at least in the public mind.

Figure 1.1 Aberlemno I, Class I Symbol Stone, Angus. (NMRS no. NO 55 NW 8). Image NMRS.

With the advent of the 21st century it seems that public interest in pre-history, history and archaeology has again risen, with the Early Medieval period benefiting from this heightened interest, as witnessed by the formalisation of tourist routes such as the Pictish Trail*. Academic interest in the Early Medieval sculptured stones of Scotland has remained constantly high with historical and art-historical approaches predominating. The more recently evolved archaeological interests in landscape: people's varied relationships to it, and the relationship of monuments and sites to each other and the landscape, have provided new avenues for exploring this rich source material.

Figure 1.2 A fantastical antiquarian illustration of a tattooed Pict holding a severed head by John White (16^{th} century).

Underpinning all investigations, whether by the public, historians, or archaeologists, are the records we keep of the stones. These records, predominantly paper publications, represent the most frequently visited resource in examining the stones: probably more frequently visited than the stones themselves. It is the nature of this record, its range and reliability as well as the choice of information and media, that is the largest conditioning factor in how we perceive individual artefacts when not in their physical presence and how we perceive the body of sculpture as a whole.

The current state of the record is in fact a cause for concern for many in the field, as the major reference work, the *Early Christian Monuments of Scotland* (ECMS), will be one hundred years old in 2003. This work, commissioned by the Society of Antiquaries of Scotland in the 1890s, was compiled by a Welsh engineer, J Romilly Allen, and the Keeper of the National Museum of Antiquities of Scotland, Joseph Anderson. It was intended to be a complete register of every monument and fragment known (RCAHMS 1999, 8). A century later, these volumes are incomplete and outdated and there is no other body of work that encompasses all Early Medieval sculptured stones in Scotland. The Royal Commission on Ancient and Historic Monuments in Scotland notes the efforts of many to update the Allen and Anderson ECMS list (1999, 8), such as: the Ordnance Survey (1939,1966); Isabel Henderson (1958); Charles Thomas (1963) and more recently Anthony Jackson (1984) and Elizabeth Alcock in 1989. However these corrections and additions appear in several different volumes or as appendices to papers. This means that the most frequently used resources in researching the stones are piecemeal, widely distributed amongst different publications and of varying quality. Almost all of them are text and image based, the major exception being the collection of three dimensional casts held by the National Museums of Scotland.

Despite the numerous benefits of the paper record one detrimental influence of the recording techniques used in the ECMS and later additions to the corpus has been to reduce the monuments from three dimensional landscape features to two dimensional media for the symbols that they carry. This has facilitated a widening gap between different perspectives of the stones. Art historical analysis of a form of interlace and its precedents, for example, are not often considered together with archaeological context and landscape relationships. Similarly discussion on the meaning of the symbols can take place without reference to the stone as a material with intrinsic meaning. The most prominent missing factor in the record, and the hardest to convey is the ‘physical presence’ of these objects. The scale of the object, the relationship of one carved segment to another, the depth of the carving, the roughness of the stone's surface, the way the object's shape appears to change as we walk towards and around it, how light and shadow constantly change the character of the carving; in short, all the aspects of the artefact that we appreciate fully when we are actually approaching it, touching it and examining it, but which are hard or impossible to adequately represent on paper. What is therefore required is a means by which this information can be captured and presented.

Information and Communication Technology (ICT) has provided fast and convenient ways for text and image records to be digitally archived and delivered via a variety of computer based techniques. It has also opened up the possibility of novel forms of presentation that allow for a new kind of record. It is possible to capture a digital record of the three dimensional shape of a sculpted stone, and to present that model to a wide audience in meaningful way. Instead of being a list of dimensions, height, width, breadth, and so on, the digital record can be presented in the form of a three dimensional computer model allowing the viewer the opportunity to examine the model from various angles and under different conditions by interacting with the model via the computer. Interaction is key to the appreciation of all three dimensions.

Given that the current state of the record regarding Early Medieval sculptured stones in Scotland could be legitimately be described as variable, that it has little or no three dimensional component, and that there are emerging technologies that may offer a new form of three dimensional digital record, the notion of creating a cohesive single record with a three dimensional component seems attractive.

These factors underpin the research presented here and in part, seek to lay the ground work for the Scotland's Early Medieval Sculptured Stones (SEMSS) project. This project has as its aims:

> “to conduct a broad ranging programme of research which will document all of the sculptured stones of Early Medieval Scotland to a new standard of excellence at a time when they are under increasing threat from atmospheric factors and are being removed from their local communities. The project will contribute to the preservation of these monuments by establishing a new standard of high definition 3D recording, developing monitoring procedures, and forming an electronic database of graphical and textual material. The results will contribute to a greater understanding and public accessibility through conventional and electronic publishing aimed at a variety of levels, including academic, schools and the general public” (Campbell et al 1998) .

The objective of the research presented here is to examine currently available and nascent technologies for digitally modelling the Early Medieval sculpted stones of Scotland in three dimensions. It examines the need for, and suitability of, these technologies and perhaps more importantly, it aims to investigate the cascade of changes that such technologies could potentially cause in both archaeological practice and theory.

As this research evolved it became clear that the originally envisioned structure: an explanation of the technologies, their capabilities and implications together with examples of application to Scottish sculpted stones, would miss many of the important and wider points arising from their adoption by the archaeological community. Indeed, it became apparent that although the Early Medieval sculpted stones of Scotland are a rich and exciting archaeological resource, many general points could be made relating to how three dimensional modelling will affect all areas of archaeology, beyond this specific place, time and material. As a result, although the focus is on Early Medieval sculptured stones, many observations, methods, and conclusions apply to other artefacts and monuments from around the world.

In fact, the concentration on discussing modelling technology in relation to Early Medieval sculpted stones needs some special justification. One of the critical points that emerged from this research is the need for close examination of the appropriateness of three dimensional recording for each chosen type of archaeological material. A clear set of objectives is needed to narrow the range of technologies and delivery techniques down to the one most suited for the task. This means that a general objective such as “generate a three dimensional model of the Govan sarcophagus” raises questions ranging from “how accurate?” to “who is it for?”. The most important question it raises, however, is why do it at all?

Fortunately, the Early Medieval sculpture of Scotland encompasses such a broad range of material that it is well suited to exemplify where three dimensional modelling may be useful and appropriate and indeed where it might be wholly inappropriate.

The starting point of the research was therefore whether or not digital three dimensional models would help archaeologists, historians or the public appreciate Early Medieval sculpted stones any better than, or in a different way from, traditional recording and presentation techniques. The conclusions will show that the answers to these questions are in no way black and white, but are contingent on a series of technical, practical and theoretical arguments which, taken together, rarely provide a single conclusive answer that covers all situations and circumstances.

Overriding all the technical questions in this thesis is the practicality of digital three dimensional recording and modelling. This research does not represent a “proof of concept” exercise for an imagined project with unlimited funds. Inevitably, many issues raised concerning various hardware and software solutions could be easily countered by the argument that the technology exists to remedy any such technical quibbles. In fact, large scale, large budget three dimensional recording projects have taken place in areas as diverse as medicine, landscape survey and filmmaking (e.g. Imaging Faraday Partnership*, Lidar Services*, Cyra*) There has even been highly sophisticated one-off scanning projects of museum based sculpture, most notably computer scientist Mark Levoy's Digital Michaelangelo project where Michaelangelo's David was scanned and generated a 2 billion polygon model collection comprising 250 Gigabytes of data (Levoy et al. 2000). It is important to emphasise, that without pushing back the boundaries of sciences such as physics or electronics, a micron level definition model of every sculpted stone, rendered accurately with multi million colour palettes and presented in a fully immersive virtual reality realm with haptic capabilities, is perfectly feasible. It is only the engineering and ultimately money that would be the limiting factors in this respect. Research into the purely technical aspects of three dimensional recording, even of existing commercial technologies, would have required a research budget to allow for the hire or purchase of some very expensive items of software and hardware. The fact that this budget was not available, did not stop the investigation of technologies at 'demonstration level'. This approach did allow specific pros and cons for various technologies to be identified, but it did not offer the opportunity to fully explore appropriate technical solutions. The exploration of those solutions remains, rightly, the domain of engineers and computer scientists.

In this research the focus has been on what is practical, what can be feasibly done in Scottish archaeology, and how these new technologies will fit into the worlds of academic and public archaeology, given the actual prevailing conditions in which they operate today.

2 The people, the stones and the record.

2.1 The sculptors.

The Early Medieval sculptured stones of Scotland comprises a body of artefacts dating from the 4th century to the 12th century and ranging from graffiti symbols carved on natural outcrops to elaborate sarcophagi and high crosses. They are a particularly rich and potent archaeological and cultural resource and amongst the most important collections of carved archaeological artefacts from any period. Some elements, such as the enigmatic ‘abstract’ Pictish iconography, are unique and occur nowhere else in Europe and have no parallels in other time periods. The Early Medieval period of Scotland’s past is particularly fascinating as it represents a time of flux from proto-historic to historic as well as from pre-Christian to Christian cosmologies (Henderson 1967, 68). This time period also represents the genesis of the Scottish state and straddles the centuries from tribal groupings to thanages and ultimately, in the 9th century, to a state which is still geographically recognisable today (Driscoll 1991). As such it stimulates an academic discourse in which archaeology and history both complement and challenge each other. Although there are a handful of ambiguous proto-historic references by classical writers such as Ptolemy and Tacitus, the main early historical sources, beginning in the 7th century are the Irish Annals describing the events in Scotland perceived to be important by their Irish monastic writers. They detail battles, the lives and deaths of Bishops and various incidents amongst the social elite. Other sources, such as Bede’s *Ecclesiastical History* and hagiographic works like Adomnán's *Life of Columba*, also concentrate on significant events for the social elites of the time as well as episodes of conversion to Christianity. The Picts themselves leave us only one historical record in their own language, the so called ‘King-Lists’ (Foster 1996, 18). There is also a range of archaeological evidence from this period: duns, brochs, settlements, chapels, workshops and artefacts, for example, which can help flesh out our picture of life during this period. However it is the monumental sculpted stones that to many remain the defining artefacts of the period. A number of these monuments are still standing where they were originally erected; many, especially those with Christian symbolism, have been moved into churches and churchyards, and many more have been removed to shelters or museums. Occasionally a stone is turned up by the plough or rediscovered incorporated in to a field wall or barn, such as the stone found in a wall at Ballachly, near Chapel Hill, Caithness in 1996 (Banks and Hooper 1998). Stones have also been uncovered by archaeological excavation such as Portmahomack (Carver 2001; Carver et al 1997;1998) and by Historic Scotland/GUARD at Hilton of Cadboll in Rosshire (Murray and Ewart 2001; Murray 2001; James 2001(a)).

The five different cultural groupings: Picts, Britons, Angles, Dál Riata (or Gaels, or Scotti) and Vikings, that dominated in the Early Medieval period all created sculpted stones of some kind. The earlier Neolithic and Bronze Age traditions of megalithic architecture and monumentality in Scotland appear to decline, although the monuments remain prominent in the landscape, and it is not until the late Iron Age and the beginning of the Early Medieval period that standing stones (this time bearing symbols) are again erected in the landscape. Similarly the prehistoric practice of the ornamentation of outcrops with meaningful symbols is revived with the carving of animals, crosses and footprints such as those at Dunadd (Argyll) (RCAHMS 1999, 23; NR89SW 1) and Columba's Chapel (Kintyre)(Fisher 2001, 118; NR60NE 1). It is not possible to argue that the intention or effect of Early Medieval monumentality - the symbol stones and the high crosses, or the outcrop and cave carvings - is in any way similar to that of prehistoric megaliths or cup and ring markings. There is however a very important similarity, in that the location of all these artefacts was crucial to their meaning. How they have been understood throughout history has been dependent on where they are. Aside from the dependence on context, the practice of each of the Early Medieval cultural groupings with regard to sculpted stone appears to have as many differences as similarities.

Figure 2.1 Hogback stone, Govan Old Parish Church (Lang 1994, 124). Image J.Lang.

Some stones like the Norse influenced hogback stones (Figure 2.1) appear to be primarily grave markers, others stones like the Shandwick (Allen and Anderson 1903, 68-73; NH87SW 4) and Nigg (Allen and Anderson 1903, 75-83; NH87SW 1) crosses may mark holy places or points on a holy route as well as carrying images detailing people and incidents from biblical and secular tales. Others such as Sueno’s stone (Moray)(Allen and Anderson 1903, Pt.3 149-51; NJ05NW 1) and Aberlemno II (Angus)(Allen and Anderson 1903, Pt.3; NO55NW 26) apparently tell the story of battles (Figure 2.2). Others, such as the footprint carvings at Dunadd (Argyll) (Figure 2.2) and St Columba's chapel (Kintyre), have been strongly linked with inauguration ritual (FitzPatrick 1997) whilst the location of still others hint at attempts to dominate the landscape by a social or political elite (Driscoll 1998).

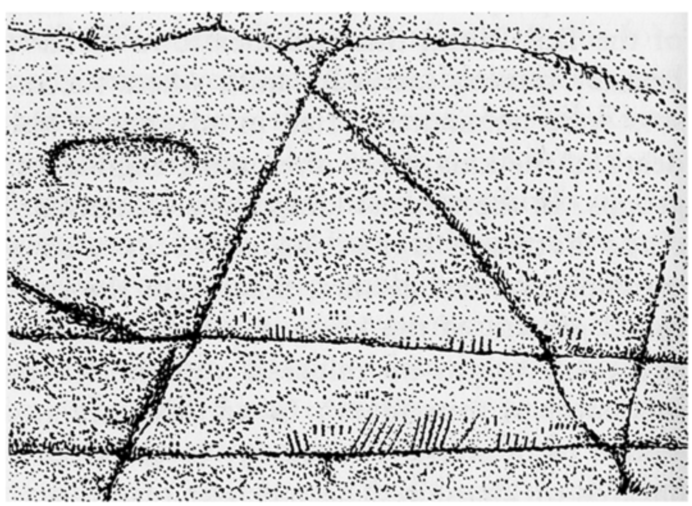


Figure 2.2 . Top. Aberlemno II, (NO55NW 26) Aberlemno Churchyard. Showing the prominent battle scene. Bottom. One of the carved footprints on the summit of Dunadd, Argyll, as well as an ogham inscription. Images, both RCAHMS

Sometimes the Picts appear to reference the earlier prehistoric traditions of megalithic monumentality by the reuse of Bronze Age monuments as symbol stones (e.g. Edderton, (Highland) (RCAHMS 1999, 28; NH78NW 2)) whilst other monuments, such as the much later high crosses of the Gaels on Iona, occupy space in an unambiguously Christian world.

Because of the detailed carving on some of the stones, the historical and archaeological significance of this type of material is difficult to exaggerate. It allows glimpses of clothing styles, social practice, religious practice and social hierarchy. It also allows art historians to suggest chronologies and identify artistic links between these monuments and others elsewhere in the Britain and the wider world (e.g. James 1998, 240-251). It is also hard to over-stress the varied nature of the location, monument type, sculpting style and subject matter encompassed by the catch-all term of Early Medieval sculptured stones. Early Medieval sculpture has been found in every corner of Scotland, from Dumfries and Galloway to Shetland and from the Western Isles to the Lothians. However, it is apparent that certain forms predominate in certain areas of Scotland. A cursory examination of, for example, the distribution of Pictish Symbol stones shows that they are concentrated in the North East of Scotland, in the area sometimes described as “Pictland”, although this distribution bias could be in part due to archaeological survival. Academic arguments have been constructed using the geographical distribution of various forms of sculpted symbols or monument types to imply the presence of political or social groupings, for example Pictish, Scottish or Northumbrian (although Henderson states that the sculptures use as ethnic identifiers cannot be sustained (2000, 46)). Whatever the validity of this type of argument, it is true to say that it is essentially predicated on having a comprehensive corpus of the material available to be mapped. If the argument is constructed on the basis of an incomplete record of what is known to exist it is necessarily open to the criticism that it is fundamentally flawed. Even if an attempt is made to factor in differential survival and recovery, with no complete corpus of known monuments it becomes hard to construct arguments that encompass different regions of Scotland. In fact it is hard to discuss differential survival and recovery without such a corpus. The starting point for any research that wishes to consider sculpted stones and generate hypotheses that cover geographical areas wider than the local must be a comprehensive corpus of the material.

Figure 2.3 Top. A side panel from the St.Andrews Sarcophagus, drawn by I.G.Scott for the RCAHMS in 1997. Bottom. Drawings of the symbols, including a Double Disc (a) in Jonathan’s Cave, East Wemyss. Fife. (RCAHMS).

Despite the high degree of variation in the form and location of the sculpted stones from this period, it still seems archaeologically and historically valid to think of the Early Medieval sculpted stones of Scotland as being suitable for categorisation into a single group. This is true even if the originators of these monuments and artefacts did not always consider this to be so. For example, the carver/s of the intricate and ornate panels that comprise the St. Andrews sarcophagus may not have considered that they were producing an object that would be later categorised in the same general group as the Double Disc symbol in Jonathan’s Cave, Fife (Figure 2.3).

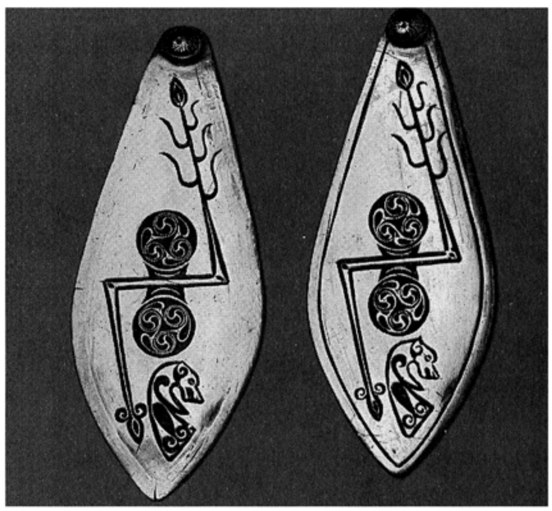


Figure 2.4 Two silver plaques, part of the Norries Law hoard, with Double Disc and Z-rod symbols in red enamel. Image, National Museums of Scotland

The differences in sculpting style, medium, subject matter, intent, geographical and temporal location suggest that these two examples sit at opposite ends of the continuum of material that can be categorised in a single group. It is important to consider that much of the imagery that appears on the stones, such as Pictish symbols, or Saints performing miracles do occur on other media, such as jewellery (Figure 2.4), bone, wood and manuscript. It would be possible to construct a case for a corpus of symbol types irrespective of media and, in the future, electronic publishing may allow us to be less arbitrary in our categorisation of archaeological material.

2.2 Three Dimensions into two.

Any new form of record of Early Medieval sculptured stones should be situated in its context as part of a continually evolving sequence of recording techniques. It is useful to look back to the beginning of archaeological recording of this material as it emerged from the antiquarian tradition in order to sum up the various stages in the sequence that lead us to the present day.

The first permanent records of sculpted stones came in the form of simple written descriptions, by antiquarians. For example:

> "DYCE - A stone with an equal armed cross enclosed in a circle, and with small round holes in the hollows between the arms (as on the pectoral cross of St. Cuthbert at Durham). The circle enclosing the cross is intersected by four smaller circles, altogether a most unusual design. (Rubbing and information supplied by Mr F.C.Eeles.)" (Allen and Anderson 1903 (vol. III), 196)

Despite the best efforts of even the most elegant of writers, textual descriptions of complex three dimensional objects do not always make it easy for the reader to visualise the object being described. A simple geometric shape can often be described by a series of measurements, but more complex shapes and sculpted forms do not fare so well. Written descriptions are still very much in use today; for example, the following refers to a sculpted stone from Dòid Mhàiri, (Port Ellen, Islay) (Fisher 2001, 136; NR34NE 18):

> "Cross-slab found about 1838, about 150m from the shore. It is 1.02m by 0.37m, bearing in low relief a ringed Latin cross with round armpits and splayed arms. The angles of the cross and ring are bead-moulded, and at the centre is a small boss. Above are two discs with sunken centres, probably sun and moon. The foot passes through an irregular double beaded plait which flanks the shaft and splits into lobed terminals, characteristic of the Scandinavian 'Ringerike' style. The slab may be attributed to the second half of the 11th century." (Fisher 2001, 136)

Despite being factually accurate and using specialist terminology and analogy, it would be very fortunate if the image conjured by this description in the reader's mind was identical to the genuine article. Although the entries in Fisher's book are necessarily brief, it is by no means certain that further description would bring the reader closer to a better imagining of the object or simply cause confusion by over complication. Thankfully there is an accompanying photograph of the sculpted face of this cross, taken with oblique lighting (Figure 2.5).

The difficulty in imagining complex monuments from textual description is especially true if the object being described is of undressed or fractured stone. Not unnaturally textual descriptions of sculpted stones tend to concentrate on the nature of the image, its style and its form. There are no strict rules for written description and convention appears to allow fairly general dimensions to be given in some cases (e.g. only maximum dimensions are given for complex shapes). Similarly text descriptions of sculpted detail can either be given in general or subjective language or adhere to recognised descriptions of sculpted forms (as with Fisher's description above). For example, the text description of the two items in Figure 2.6 would both include 'double disc' as a generic descriptor despite the obvious differences in size, technique and quality.

Figure 2.5 Cross-slab from Dòid Mhàiri, Port Ellen, Islay (NMRS no. NR 34 NE 18). (RCAHMS).

Figure 2.6 L: The Hilton of Cadboll stone (Allen and Anderson 1903, Pt.2 61-63; NH87NE 7). (NMS). R: A sculpted Rousay flagstone reused as a paving stone in a pre-Norse structure, Pool, Sanday, Orkney (HY 63 NW 17). (J. Hunter/Historic Scotland).

The most obvious way to augment a textual description is by using pictures. The earliest images of Scotland's Early Medieval sculpted stones from the antiquarian tradition are more in the nature of artistic fantasies than records of the stone. Despite being highly inaccurate and often misleading, favouring the aesthetics of the day rather than accuracy, they are arguably able to transmit more information than plain text (e.g. Figure 2.7).

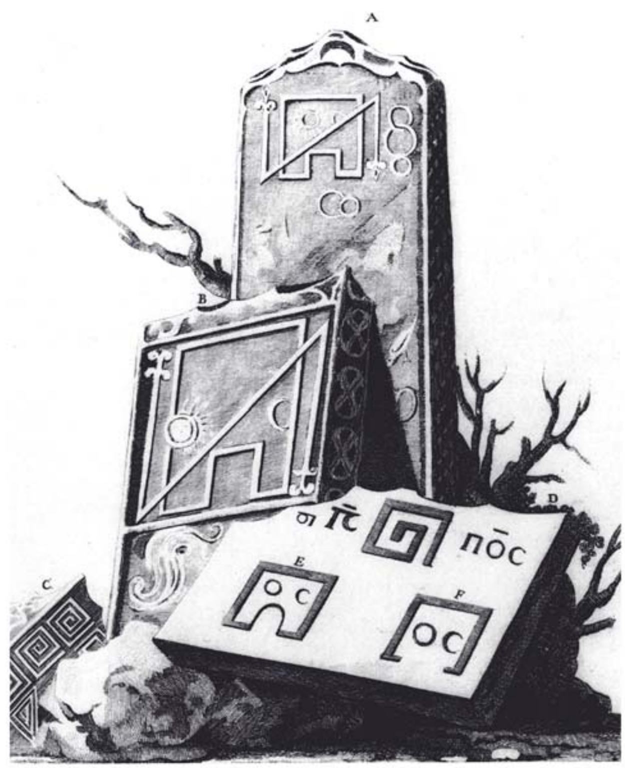


Figure 2.7 An antiquarian image of several stones drawn together in a romantic vista. (Cordiner 1795)

As antiquarianism developed in the nineteenth century the sketches began to take on a more measured air as they began to be presented as records of the monuments as opposed to impressionistic illustrations (Figures 2.8 and 9). Despite the greater attention to detail, many of these sketches are still lacking in the accuracy that modern archaeology and art history expects from a record. It is not until the likes of Captain T.P.White, whose two volumes of *Archaeological Sketches* were produced in 1873 that accuracy improves and for the first time the sketches are presented to a uniform scale (Fisher 2001, 5).

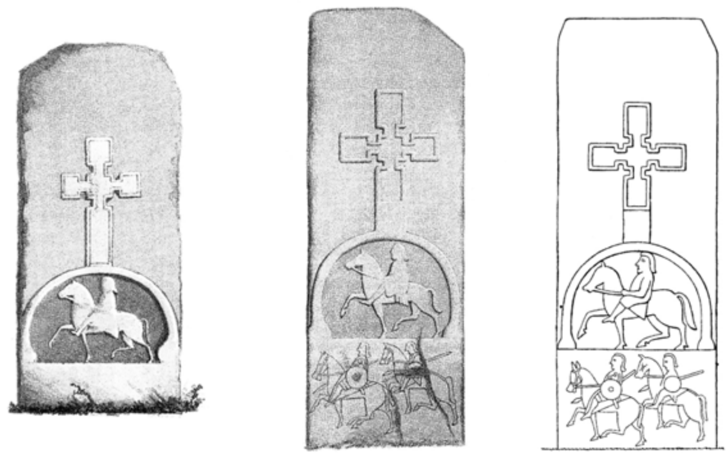


Figure 2.8 A sequence of antiquarian images, all of the same stone, showing considerable differences in style and content. Concentration on the sculpture rather than the stone as a coherent monument is apparent from the treatment of the top edge which appears quite different in each sketch. (G. Ritchie, Groam House).

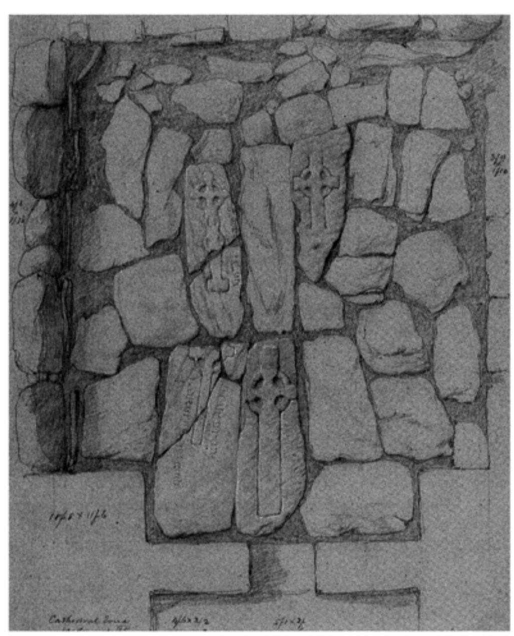


Figure 2.9 An example of Drummond's accomplished drawings of stones from Iona.

As archaeology evolved in the 20th century the nature of illustration moved away from sketches to what we would now call ‘dimensional’ or ‘metric’ drawings. These are very sophisticated, accurate drawings that are meticulously measured so that all dimensions in the drawing are as accurate as possible (see Scott 1997). They also adhere to agreed conventions, such as the use of stippling for shading adopted by the RCAHMS for its inventory illustrations rather than the “misleadingly sharp line-drawings” (Fisher 2001, 6) previously used. Unlike artefacts drawings where, by convention, the direction of light is constrained in all drawings so that it always appears to be from the top left of the illustration (Adkins and Adkins 1994, 43), Ian Scott’s drawings for the RCAHMS (e.g. Figure 2.10) use a more pragmatic approach in order to reveal maximum detail and his approach is the basis of the current RCAHMS style. It is still thought by many that this form of illustration offers advantages over the technically more sophisticated chemical photography which is most often used today, because it allows impossible lighting conditions, but also because the close visual examination by the artist discovers and accentuates detail that is invisible or hard to see on photographs that capture the whole monument as opposed to detailed sections of it (Ian Scott, pers.comm.)

Photography was applied to the subject matter of sculpted stone at a relatively early date. Stones on Iona, for example, were photographed in the late 1860’s and a structured photographic survey that included many sculpted stones was undertaken as part of the National Art Survey around 1900 (Fisher 2001, 6) (Figure 2.11). These early photographs were black and white and generated without the aid of sophisticated electrical lighting rigs (although some photographs were taken of casts in studio conditions). Where scales are used in photographs, this creates a more metrically accurate image than sketches or even metric drawings. However the difficulty of lighting badly worn or highly complex surfaces means that

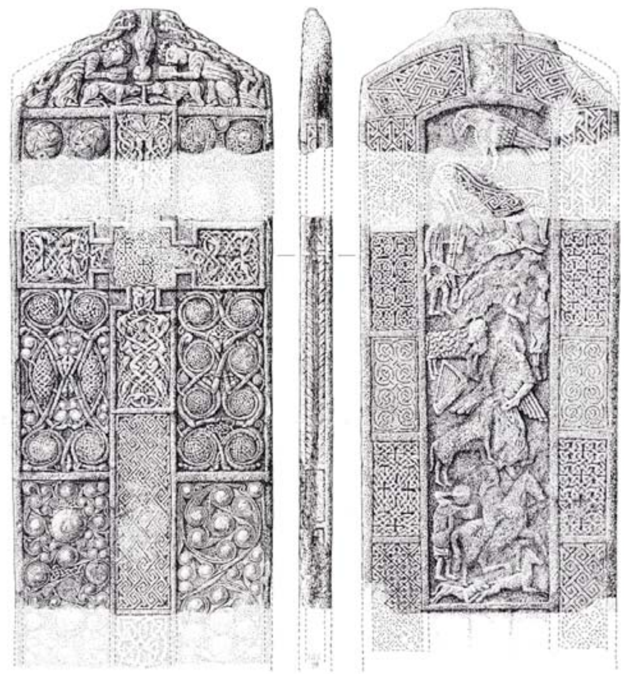


Figure 2.10 The cross slab from Nigg, Highland (NMRS no. NH87SW1) as drawn by I.G.Scott for RCAHMS in 1998.

photographers have to make informed, yet subjective, decisions as to which is the most useful lighting condition under which to photograph any particular side or surface of an object. This is not an unimportant decision, as it would normally be made in order to bring out the most detail, necessarily at the expense of other information which would be obscured by shadow. The decision about what detail was and was not important is bound to be both subjective and contingent on the intended purpose of the photograph. Historically it has been impractical to photograph an object under more than a handful of lighting conditions and then to publish all the resulting images. The advent of colour photography added much to the record, since, as will be discussed in more depth later, the colour of the stone may be of archaeological significance and in black and white photography it is harder to judge the nature of the stone being used. The main argument against the use of colour photographs for images intended to act as a long term record (apart from the additional cost of publishing colour images) is the unstable nature of the chemicals used in both the negative and the print. This means that even if the original film quality was good enough to capture the colour of a stone under natural light then there is no guarantee that the colours would not change as the chemicals involved changed with time. A further issue is that different types of electric light affect the colour scheme as recorded, for example both tungsten and halogen based lights give a very different colour to natural sunlight (which is itself variable) (Gray and Ferguson 1997, 10). To a certain extent digital photography can bypass the issue of colour stability as it is obviously not chemically based; it does, however, have the same problems with the nature of the light source. With digital photography it is possible to electronically compensate for various chemical lighting effects by altering pixel values to emulate "natural light". This produces an image that is fundamentally altered from the original. It may look better, but the electronic enhancement (alteration) of images post-capture in this way can produce an image that is itself more artefact than record.

The most sophisticated from of photography used for recording Early Medieval sculpted stones can be exemplified by the work of Tom Gray (see Gray and Ferguson 1997) (for an example see 2.12). Highly sophisticated lighting rigs and careful attention to technical detail generate excellent records. Given the difficulties in photographing these objects in terms of lighting and access it has become a specialism that non-professional photographers find difficult to emulate. These photographs can be seen as the pinnacle of machine generated visual records currently available for Early Medieval sculpted stone.

Figure 2.11 A National Art Survey photographer at work in 1900.

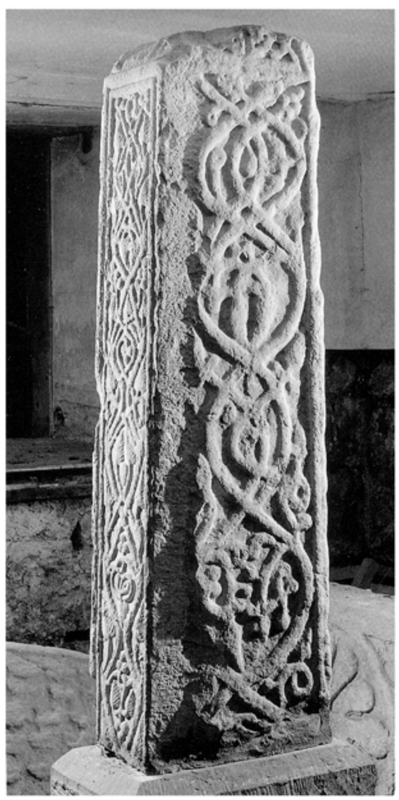


Figure 2.12 One of Tom Grey’s carefully lit and composed photographs of a sculpted stone (Abercorn I).

Moving images, cine film and analogue video, have never made it into the mainstream of records, presumably because of the expense and impracticality of generating the films/videos and then of distributing them widely. Another factor that mitigates against the use of tape based records (including film) is the difficulty in navigating such a record. This problem will be familiar to anyone who made the transition from analogue vinyl disc recordings to magnetic cassette tape for their personal music collection in the 1970's. It was not until the appearance of a digital disc medium, Compact Disc in the 1980's, that access to a specific part of a record became both easy and fast, compared with Digital Audio Tape (DAT) which was easy but slow. Digital Video Cassette (DVC) suffers with the same problem as DAT, with the Digital Versatile Disc (DVD) offering the solution. All forms of moving image and audio recording have also suffered from competing media, (e.g. VHS, Betamax, 8mm, 16mm, Eight track cassette, Laserdisc and so on), which has serious implications for the permanency of access to such records.

There are examples of non-digital three dimensional records, such as casts, models and facsimile sculptures. The National Museum of Scotland has an extensive collection of these casts made in the first half of the century. Although casting is no longer allowed under most circumstances by Historic Scotland and the National Museums of Scotland as a matter of policy due to the detrimental effect of casting on the surface of the stone (Maxwell 1992). Reconstructed sculptures, carved in stone by modern sculptors, are less frequent. A recent example is the reconstruction of the Hilton of Cadboll stone in Easter Ross. This new sculpted stone took more than a year for a single person to sculpt, from design to finished item. (At present only the back (non-cross) side of the monument has been sculpted as the design of the cross side is under discussion in the light of the recently discovered fragments and basal section.) Isabel Henderson is producing an in-depth art-historical analysis of the sculpture for Historic Scotland (see Henderson 2002 for a preliminary assessment). The process of creating the reconstruction itself has provided new insight into time scales and techniques that have allowed interpretation of the socioeconomic implications of creating large highly ornate sculpted stone monuments (see Figure 2.13) (Gondek 2003).

Figure 2.13 Barry Grove's reconstruction of the Hilton of Cadboll Cross.

The intention of Barry Grove's reconstruction is not to act as an academic record, but to ameliorate the concerns of the local community who feel disturbed that the original stone is on display in the National Museums of Scotland and not at Hilton of Cadboll. The issues raised by the Hilton of Cadboll case are discussed more fully in Chapter 7.

Lieutenant-General Pitt-Rivers, the eminent 19th century archaeologist, generated a form of three dimensional models that were created in plaster from measurements, drawings and rubbings. This technique was used to create models of at least forty two Early Medieval monuments and two prehistoric stone circles to a uniform scale of two inches to one foot (1 inch to 5 feet in the case of the stone circles) (Pitt-

Rivers 1889). His motivation for doing this was related to the impracticality (and undesirability) of gathering all of Scotland's sculpted stones together in one place, and the potential benefits of having a "large series of monuments under the eye at one time for the sake of study" (Pitt-Rivers 1889, 176). However this technique has not been widely adopted and represents a curious cul-de-sac in the story of recording and representing sculpted stone, although 20 of the models still survive in Salisbury and South Wiltshire Museum (Foster 2001).

Physical models of the types described above represent a very tiny fraction of all records. There is normally only one cast per stone in the National Museums of Scotland and clearly these have limitations in terms of dissemination. The other forms of record are paper based and therefore suitable for distribution in book form. Physical models, such as casts, cannot be copied and distributed with the same ease.

2.3 The Record as it is now.

As the *Early Christian Monuments of Scotland* (ECMS) was published exactly one hundred years ago (Allen and Anderson 1903), it is no surprise that this corpus does not include all the sculpted pieces now known to exist. A number of the monuments mentioned in the ECMS are no longer at the locations indicated and some have even gone missing. Furthermore, the antiquarian nature of ECMS means that, despite the rich descriptive detail, it does not match more modern corpuses such as *the Corpus of Anglo-Saxon Stone Sculpture* (CASSS*) where changes in the nature of archaeological discourse have provided a more rigorous format for description. There does exist a series of gazetteers published by Royal Commission for Ancient and Historic Monuments of Scotland (RCAHMS), such as the illustrated gazetteer of Pictish Symbol Stones (RCAHMS 1999), and also the RCAHMS regional inventories which contain details of known sculpted stones for each region along with details of all other archaeological material, arranged in volume by period as well as geography. Another excellent source is the previously mentioned RCAHMS and Society of Antiquaries monograph volume by Ian Fisher, *Early Medieval*

Sculpture in the West Highlands and Islands published in 2001, considered by Borland to be the Commission's most significant contribution to the study of carved stones (2002). This volume contains an extensive gazetteer for the West Highlands and Islands. None of the gazetteers have the same level of analysis and synthesis apparent in the ECMS with its rich historical background and discussion of various forms, nor do they have the extensive geographical coverage. Essentially there is no single viable corpus for the Early Medieval sculpted stones throughout Scotland; the additions and updates to the ECMS list by Thomas, Henderson, Jackson and others are themselves distributed amongst various papers and publications as noted in Chapter 1. Estimates of the number of individual monuments and artefacts that would be included in a new complete corpus range as high as 3000 (The SEMSS project already has around 2000 known monuments in its database), making even a simple, but complete, gazetteer a large volume. Furthermore a corpus drawing together a complete illustrated gazetteer, a regional and national synthesis with analysis of art-historical forms and processes and the historical background of each item up to the present, would be an huge undertaking. Publication of such a corpus in traditional formats i.e. a multi-volume hard back book with black and white illustrations, photographs and colour plates would be an enormous expense and would therefore need a large price tag (up to £130 per volume for the six volume Anglo-Saxon corpus), especially with such a small number of institutions and individuals being likely to purchase a work in this format.

It was this perceived gap between the need for a viable corpus and the impracticality of producing a traditional multi-volume paper publication that has led some researchers, notably at the University of Glasgow, to rethink how the collections of information and analysis that comprise the corpus could be presented in a way that takes advantage of digital media and dissemination techniques. Once the material is gathered together and edited then publication on Digital Versatile Disc (DVD) could be an option, another option being direct delivery over the internet. The future dissemination processes of corpora (and many other types of academic work) can be seen as shifting away from traditional forms of publication towards digital media and their associated document forms, such as hypertext. This is partly because corpora can be logically seen as multi-media databases and partly because of the cost of traditional publication. Examples of corpora available as searchable databases include a subset of the Anglo-Saxon corpus mentioned above known as the CASSS Database* (Corpus of Anglo-Saxon Stone Sculpture), the Corpus of Romanesque Sculpture in Britain and Ireland* (CRSBI), and the Celtic Inscribed Stones Project* (CISP), all of which are available, in some form, online. In terms of simply searching a corpus, looking for particular monuments or types of monuments, a database obviously offers advantages over paper data, at least for the computer literate. It also holds out the possibility of more sophisticated analysis via more elaborate interfaces, such as interactive maps or through the use of searches based on sculpted patterns and symbols. While trying to re-imagine how a definitive corpus in multi-media database form might be structured it also becomes apparent that a much greater volume of data could be stored and delivered digitally, in comparison to traditional publication formats. Similarly, display of the data via a computer screen allows for the use of less traditional presentation methods such as audio, video, and complex interactive interfaces. The combination of increased data volume capacity and digital display also gives the opportunity to incorporate novel forms of data within the corpus. For example, three dimensional digital models which accurately represent the size, shape, texture and colour of sculpted stones are an obvious candidate for a new and constructive form of record that could be incorporated into the corpus. This raises a question that is crucial to this thesis: if the money was available would current recording, presentation and dissemination techniques allow for the production of a meaningful and useful three dimensional record ?

2.4 Digital records of sculpted stones with three dimensions

Could three dimensional records improve on the traditional recording techniques ? If we temporarily ignore the paradox of three dimensional digital records generally being presented via a two dimensional computer screen and try and think of a digital model as something that could occupy real space, what would be the additional benefits from such a record ? This is similar to asking the question: what information does traditional recording techniques miss ?

All the previously mentioned forms of record are capable of including the information that is likely to be required by the academic user such as location, orientation, dimensions, material, sculpture form and style. More detailed information such as tool marking can also be both described, sketched and photographed. So the benefit of a three dimensional model that incorporates these types of information could be that it simply improves on the delivery of the types of information already recorded. This would be true unless it provided some other, novel form of information. However, even if this were not the case, the whole is greater than the sum of its parts, all the items of information normally recorded can be presented together in a three dimensional model, and the fact that they are presented together produces a more easily understandable record. A note of caution should be raised here, as delivery and presentation of the record(s) are crucial to whether the underlying information is in fact usable as well as understandable. It might be more accurate to say that presentation of the complete range of physically descriptive information via a three dimensional digital model has the potential to produce a more easily understandable and useable record.

That a unified presentation of available information may provide a more understandable record is especially true with regard to the morphology of the monument. Two dimensional photographs or drawings can be presented showing a monument from several different angles, and by considering them together it is possible for the viewer to gain an impression of the overall shape of the object. A three dimensional model is a single item that necessarily encapsulates the shape of the monument. If the user can interact with the model, to manipulate it and thereby change their viewpoint, then the natural process of discerning shape by changing our viewpoint is emulated. In the real world changing of position does not only enable the whole object to be seen, it also augments the process of stereoscopic depth perception. Binocular vision allows distance to be judged, because it naturally supplies two points of view from which the brain can interpolate a single image that is perceived as having depth. However, for certain surfaces, visual effects such as foreshortening can mislead the brain; the way this is compensated for naturally is to change our viewing position by tilting our head or moving about. Photographs and drawings do not allow this to be done, the brain stubbornly tells us that we are looking at a flat object, which indeed we are, requiring depth to be inferred almost consciously from the captured lines of perspective in the image.

A three dimensional model could be viewable from any angle giving a theoretically infinite number of viewpoints, rather than the limited number offered by a series of photographs. Furthermore the decisions made in the field by the photographer or artist in creating the two dimensional record limits the viewer to the viewing angle(s) selected by the creator of the record. The viewing angles may be selected to make it as easy as possible for the viewer to recreate the three dimensional shape in their minds eye. It is not necessarily the case that all people do this in the same way (Kosslyn 1980; Smyth et al 1994), nor will all have the same approach to reconstructing three dimensional shapes from two dimensional images. Giving the viewer the freedom to interact with the model in a more natural way might mitigate against the photographers or artists bias. In reality most images of sculpted stones are intended to capture sculpted areas and as such are usually captured normal to the base plane of the sculpture, ironically the least helpful angle for gaining an impression of depth and three dimensionality.

Clearly interactivity is vital to the notion of three dimensional models, since without interaction the only way of giving any impression of the three dimensionality of the model would be via two dimensional images. As noted above, the varying degrees and types of interactivity are key to understanding the nature of three dimensional models and their impact.

In addition to the gross shape of a monument, the spatial relationship of various elements of sculpture are better understood when they can be viewed together in a single model as opposed to separate images. Elements of sculpture are sometimes visually exclusive, i.e. they cannot be seen together at the same time (such as the front and back panels of a cross slab). We compensate for this naturally in a similar way to the way we understand shape: moving between views of a monument at will, we better understand how various elements relate to each other. Sculpted stones were *intended* to be experienced in three dimensions. They are not simply a media for the images they carry, the spatial relationship of various carved elements has significance. The size and shape of the monuments also carries its own significance, just as the material used, the location, and the sculpted images employed are significant. This is clearly demonstrated by a comparison of the two sculpted stones in Figure 2.6 above, where the significance of those objects does not lie simply in the fact that they both carry an image of a double disc. The experience of any individual relating to these objects in the real world would be very different: the difference between a large and imposing Hilton of Cadboll Cross and a small coarse sculpted flagstone. The Hilton of Cadboll Cross also offers an example where the spatial relationship of sculpted elements on visually exclusive surfaces is significant. The area of dressing on either side of the monuments stops at different distances from the bottom of the stone, which has allowed a hypothesis about the story of the stones creation to be formulated and has given an insight into the various stages in the carving process (Grove, B. pers. comm.). Similarly the Kildonnan cross slab (Eigg) (Fisher 2001, 92; NM48NE 24) (Figure 2.14) shows similar anomalies in the length of carved surface on either side suggesting a previous episode in the history of the stone when it may have been used as a shrine slab (Gondek and Jeffrey, 2003).

Figure 2.14 Sculpted stone from Glamisdale (originally from Kildonnan), Eigg (NM48NE 24).

So the relationship between carved elements on objects that cannot be seen from the same location may be significant, as may the orientation of the carving in space. With cross slabs the general orientation of the cross side towards the west is deemed significant, similarly the fact that carved cross slabs occur both as upright monuments as well as recumbent grave markers (grave slabs) means that the presentation of a single image may be misleading. Figure 2.15 shows a typically presented image of a cross slab, it is impossible to tell from these images alone whether it is an upright or recumbent monument let alone what direction the cross side might face. The text and/or further images are needed to make it clear that this stone was intended to be upright (by, in this case, reference to the decorated sides and back). A three dimensional model with the correct orientation could convey this without reference to text, as well as showing the relationships between each carved surface and demonstrating that, in this instance, there is a cross sculpted on both sides of the monument. Three dimensional models offer a more intuitive route into exploring these relationships. Again, the level at which the interactivity offered by the mode of presenting the model constrains just how intuitive the exploration can be.

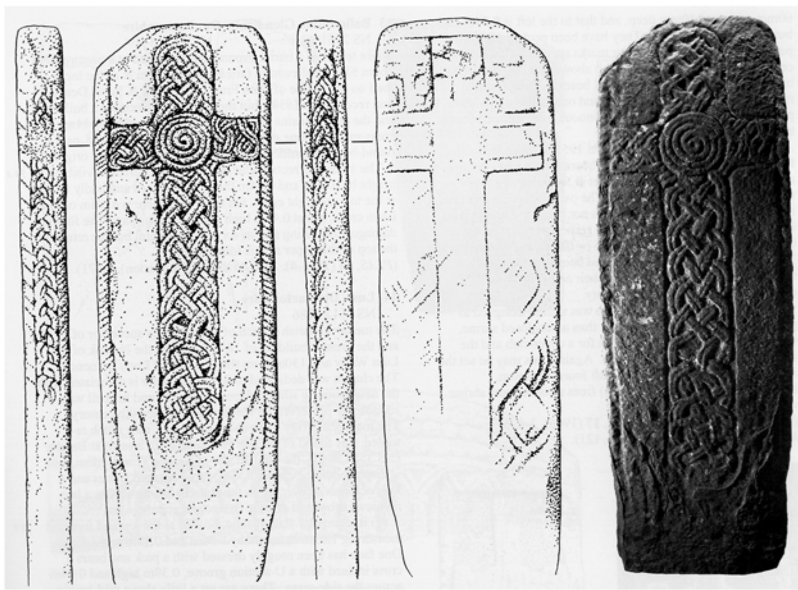


Figure 2.15 St Modan's Stone, Rosneath, Dunbartonshire. NS28SE 3 (RCAHMS).

Both the shape of a monument or artefact and the spatial relationship of sculpted surfaces and elements can be more clearly comprehended when presented via a three dimensional model but what are the unique forms of information that the model can carry? The most clearly distinctive information that a digital three dimensional model can carry is a record of the actual surface (micro) topology of the stone itself (although we shall see not all three dimensional records actually record the surface topology of an object). This information opens the way to new forms of presentation and analysis. In Chapter 3 the basic principles of three dimensional recording are explored and techniques that use an underlying surface model and those which give a visual impression of three dimensionality without actually recording information in three dimensions, are compared. It is important to note that if there is no valid use for an underlying surface model, records that do not contain them, i.e. those that will only ever be presented visually, can be used instead. In fact, the potential actual uses of an underlying surface model are numerous. If an accurate record of a stone’s surface can be taken digitally it can be used to monitor changes to the surface, supplying more extensive and objective metrics for this process than current measurement techniques which rely on either subjective assessment or measurement of small surface areas (Historic Scotland 1999). A digital surface model could also potentially replace casting, with its attendant risk of surface damage, as a way of generating physical facsimiles of monuments and artefacts. Once a surface record and model have been generated it can be used to monitor the surface and to create a copy of the surface; it can also be used to allow us to experience the surface through haptic technology (see Chapters 6 and 8). In addition a surface model offers the opportunity to examine the surface in very fine detail, beyond the level of visual acuity. This facility is entirely dependant on the resolution and reliability of the original data but has been demonstrated in principle through work on the marble sculptures of Michelangelo (Levoy et al. 2000). Finally, just as digital photographs can be enhanced algorithmically to compensate for unnatural light sources or to accentuate some detail, a digital surface model is in a form that would allow analogous enhancements, for example using filters to exaggerate specific surface features to “bring out” worn or eroded detail.

In comparison to traditional recording techniques it appears that three dimensional models do in fact offer the potential of better records of artefacts such as sculptured stones. By ‘better’ here it is meant that the model would give a clearer impression of what the object or monument is actually like in comparison to text, drawings or photographs. Inevitably there is a conviction that the only way of getting a true, personal impression of what a sculpted stone is like is to actually visit and experience it for oneself. This point is inarguable, but it applies to all forms of record.

2.5 The bias of the record

To see further potential benefits of three dimensional records it is first necessary to understand how the traditional methods of recording sculptured stone have contributed to the current approaches to the material. For example the classification of Pictish monuments is an example of an art-historical bias in the classification of what would otherwise be considered as archaeological material. It was J.Romilly Allen himself who, at the turn of the 19th century, grouped the monuments into three classes:

Class I; "Roughly dressed stones or boulders with the characteristic (Pictish) symbols incised on them".
Class II; "Carefully dressed stone slabs …. On these an interlace cross occupies the whole of one face…. In nearly every case the symbols appear on the opposite side to the cross".
Class III; "… sculptures obviously related in manner to Class II but omitting altogether the symbols".
(Henderson 1967, 106-108).

This classification system still enjoys some currency to this day. It implies a chronological sequence that has little other evidence to support it and which may yet prove to be overly simplistic (chronologies based primarily on art-historical approaches are still being developed e.g. Laing 2000; 2001). The roughly dressed non-Christian monuments are earliest, the finely dressed monuments are later, after the arrival of Christianity, and the monuments that are Christian and no longer have Pictish symbols are the latest. The assumptions inherent within this scheme are myriad, ranging from the pagan nature of Pictish symbols to the chronological exclusiveness of each form. Archaeologists would like to rely on scientific dating techniques or definitely dated typologies to construct a sequence, but none are suitable to date the stones with enough accuracy. Alternatively dating by association with archaeological context would be appropriate, but unfortunately symbol stones recovered from sealed, dateable contexts are very rare. Two notable exceptions are the flagstone with a double disc symbol found during excavation on Sanday, Orkney and dated to the 4th century (RCAHMS 1999, 37; HY63NW 17), and the Hilton of Cadboll stone which may potentially be dated using the nascent technique of Optically Stimulated Thermoluminesence (OSL) on its surrounding contexts although the post-excavation program is ongoing at this time and results are not yet available (both Figure 2.6).

There are two factors that have played a significant role in how Pictish sculpted stone are studied. First is the fact that they normally turn up as isolated finds or appear in the landscape as isolated monuments, most frequently having been moved from their original context. Archaeologically speaking, an isolated find, with no archaeological context tells us little about the archaeology of the period; similarly a monument that has been removed from its archaeological context offers us less archaeological information than one that has not. Of course, even if the monument is in a secondary or tertiary setting then archaeologists should be able to derive information about the archaeology of the time when it was moved and reset. This remains true even if the time in question is relatively recent. However, if the weight of interest lies with the people who originally generated the monument and the communities in which they lived, the monument without any archaeological association tells us less than we might like to know.

Secondly, the sculpted subject matter is often both complex and enigmatic which has the effect of focusing academic attention overwhelmingly on the iconography. A brief comparison between the treatment of Bronze Age monoliths and Pictish symbol stones reveals an interesting bias in our thinking about this class of monument.

The Bronze Age monument is produced by a pre-literate, pre-Christian society which chose to erect undressed (or coarsely dressed) monoliths in a landscape with an already existing and prominent tradition of monolith use over millennia. The Class I Pictish symbol stone is generated by a pre-literate, pre or early Christian society, which chose to erect undressed monoliths with symbols sculpted on them in a landscape with a prominent tradition of monument use over millennia.

What approaches do we use to try and understand the significance and meaning of monumentality in the Bronze Age? The following might be actively considered in addition to excavation of Bronze Age monuments and settlements :

- Materiality. The significance and meaning of the type of stone used, its colour its texture, its original quarrying location.
- Landscape Context. The motivation for situating the monument where it was, the significance of its associations with earlier monuments. Also the significance of the wider landscape in the Bronze Age for example associations with settlement, routes through the landscape and phenomenological impact of the monument and landscape in combination.
- Social Meaning. Who were the motivational forces behind the creation of the monument? How many people were involved and what were the social processes that facilitated its creation? What is the relative significance of the monument itself versus the processes that created it?

In contrast to the majority of illustrative material of Early Medieval sculpted stone, photographs and illustrations of prehistoric stone monuments tend to include landscape context. This is partly because the monuments have not been so frequently moved, there is more confidence that the monolith or stone circle being recorded is in fact is in its original position. It is also due to the fact that close up full frame photographs of undressed stones would give a misleading impression of their presence and impact in the landscape. Early Medieval sculpted stones suffer from exactly the opposite problems, there is often no knowledge of its original landscape positioning and close up full frame photographs are actually required to capture the sculpted detail. The result is that the academic approaches to understanding the significance of each form of monument are both constrained and directed by the nature of the record.

2.6 Uses of a new corpus

One of the primary beneficiaries of an improved record of Early Medieval sculptured stones, specifically a three dimensional record, could be the general public. As stated in the introduction, archaeology and history are currently relatively high on the public's list of interesting subjects and the Early Medieval period is included in that general interest. This is witnessed by the use of specifically archaeological tourist routes and the strong public interest in visiting excavations such at Portmahomack* and the nearby Hilton of Cadboll*. In addition to the interest of tourists and visitors, many members of the public have an interest in their own local archaeology and Early Medieval field monuments can raise strong proprietorial feelings in those who feel connected to them (Jones forthcoming). Indeed, the Early Medieval period, especially in 'Pictland' can have some interesting socio-political connotations for many people, being seen by some as the true 'Scottish Nation' prior to the invasion of the non-indigenous Scots from Ireland and the basis for a modern "Pictish Free State"*. From an academic archaeological point of view, most feel that this type of notion contains so many misconceptions (or actual fallacies) that it can be ignored. However, the role of archaeologists and historians in informing the public should require that such claims are challenged. Not least because archaeologists and historians may themselves become complicit through inaction in the kind of political uses of the past that have led to social division and worse in Eastern Europe and elsewhere in the last decade. The twin imperatives of increasing public interest and professional archeo-historical responsibility alone provide a legitimate motive for improving public information.

The majority of popular literature on Early Medieval monuments for example, Sutherland 1997, Mack 1997) is synthetic and selective in its approach. This is perhaps unsurprising given both what has been noted about the disjointed nature of the record and the intended audience for the books. There is also a sizeable body of literature that can fall into the catch-all category of 'fringe archaeology', which usually only means that it is different from the current academic consensus. Examples of this might be publications such as *The Message of Scotland's Symbol Stones* (Peterson 1996), where the message centres around domestic cats, or *The symbolism of the Pictish stones in Scotland* : *a study of origins* (Gilbert 1995) which traces the roots of Pictish iconography directly to Sumeria. Both books have little regard for more conventional archaeological, historical or art-historical approaches.

Would a new corpus be advantageous to the public? The usefulness of a new corpus would be dependant on the ease of access to that corpus and its accessibility in terms of tone. A new corpus that consists of several large paper volumes and a limited print run with an expensive price tag would not necessarily improve public awareness of the stones or their access to information about them. A hypothetical corpus which was solely written in dry, pseudo-objective academic or scientific language, would also not necessarily improve public access. What is suitable for the academic community is not always fully appreciated by a more general audience. In addition to general tone, a more synthetic approach is likely to appeal to a lay audience. Rather than simply listing and describing items, the presentation of current interpretations that provide historical and archaeological context would be more appealing. Clearly a new corpus project that had public access as an objective would need to consider both the means of dissemination and the nature of the text.

If a corpus would be advantageous then could three dimensional modelling fit into this context? If three dimensional models were included in a new corpus as part of the record of the stones, but the corpus did not take into account the twin issues of delivery and tone then clearly the models would be of no particular benefit. This is because the access to the models is conditioned by their presentation context. Our willingness to engage with any body of information may depend on whether or not we feel included in the target audience. This means that people who could benefit or enjoy access to a body of information might consciously exclude themselves from the group accessing it simply because they do not feel it was intended for them. This process operates irrespective of the stated aims of any body of work. It is perfectly possible to have a situation where the author or authors of a particular work state that it is hoped to be accessible to a general audience, but initial impressions of the work have the effect of excluding that audience.

It would be unfortunate if this were to happen, because three dimensional models represent a far more “readable” record to the public than any of the more traditional forms discussed above. Especially for a younger audience, more used to media rich in computer generated imagery. Gaming environments, World Wide Web, cinema and television representations of the past, from *Tomb Raider* (Figure 2.16) to the Virtual Avebury (Figure 2.17) to *The Mummy* (Figure 2.16), all use computer generated imagery (CGI) extensively.

It has become a norm and is likely to become more and more frequent in our everyday lives, moving from pure entertainment or illustrative functions into more complex applications such as being elements in graphical user interfaces (GUIs). Objects that are three dimensional are increasingly being represented via various forms of three dimensional presentation techniques, rather than as still two dimensional images. This has the effect of rendering three dimensional models and the interactive interfaces that can accompany them as a highly acceptable method of information delivery. The obvious caveats regarding differential access and usage of ICT in respect of age, gender, financial status and geographical locus apply here, and are explored further in Chapter 6.

Figure 2.16 Top: Still from The Mummy (Steven Sommers 1999). Bottom: Screenshot of the Tomb Raider game (Eidos Interactive 1996) EOS entertainment.

Figure 2.17 Screenshot of the Virtual Avebury, created by Jennifer Garofalini, University of Southhampton*.

As no database/corpus containing three dimensional models of Scottish Early Medieval sculptured stones exists as yet, it is hard to say definitively that it would be more accessible and understandable to the public than an academic text based record. However a pattern that we might expect to be replicated is that of the Hunterian Museums ‘Online exhibition’ of the Neolithic carved stone ball collection. The Hunterian Museum* was the first in the UK to produce a web site and has embraced ICT as a technique for expanding public access with vigour. This exhibition uses QTVR Object Movies (see Chapter 4) to great effect. There is no exhibition space in the museum for the full collection to be displayed to those who actually visit the museum. The collection is available to examine interactively on-line as three dimensional models. Both still images and Object Movies of the carved stone balls are presented, with ancillary textual description and analysis, however, it is the Object Movies that demand the users attention. Of course some of this may still be the “novelty” of the presentation medium, although with the passage of time the novelty lessens whilst usage statistics for the models remains high (Jim Devine pers. comm.). The Hunterian is not alone in using this approach and a number of museums around the world are currently engaged in generating three dimensional models, using various techniques, of their artefact collections, both as an archive record and for public access (Pieraccini et al 2001). Another interesting example is the Artefact* project for the Victoria and Albert Museum where the ability to interactively investigate a subset of the museum's artefact collection on-line in the form of three dimensional models is contrasted with the traditional static display of artefacts within protective cases. However the recording of small artefacts, in studio conditions does not raise the same technical issues as recording large immovable objects in the field and the presentation of portable artefacts does not raise the same visualisation issues as models of field monuments.

2.6.1 Cultural ownership.

Closely related to the issue of where the public would benefit from three dimensional models of Early Medieval sculpted stones, is the issue of how they might impact on some of the more actively interested groups in society. As hinted at earlier in this Chapter Early Medieval sculpted stones in general and occasionally a particular stone can raise some cultural and political issues that have consequences in the 21st century. For the public at large who actually owns a particular stone is not always the most critical thing about it, but there are at least two circumstances in which it can become very important. Firstly, where the monument or artefact is held on private land and access is forbidden or restricted by the land owner, and secondly, where the local community perceive a monument to be important to them, for any number of reasons, but the stone is owned by or in the care of a body that has the power to remove it from its location at some point in the future.

If an individual is physically prohibited from visiting a monument then the record of that monument can become very important (although never as important as the monument itself). This can be seen as an argument for prioritising new record generation techniques, such as three dimensional digital modelling, on stones where other means of access are restricted. However, a situation where restricted access is spuriously justified on the grounds that an adequate record of the monument is publicly available should be rigorously avoided.

2.6.2 Special Needs

One area where enhanced public access to three dimensional models has undeniable potential is in mitigating the access restrictions imposed by physical disability. The fact that many Early Medieval sculpted stones remain field monuments, often on rough ground or far from a metalled surface, means that those who experience difficulty with mobility can find it hard if not impossible to visit these monuments. The notion of improving access by creating wheelchair access, has resonance with the arguments surrounding the provision of wheelchair access to listed buildings. Providing paths to some of these monuments would change the character of the landscape and therefore the monument. This is in addition to the obvious cost implications of any such proposals. Although Historic Scotland are committed to improving access wherever possible, they also have to be sensitive to the changes in setting that such access might require and as a result it may not always be appropriate. For the most part, then, those who are not physically able to reach field monuments have to use the record to gain an impression of what they are like. The current record is entirely two dimensional which means that the complexity, imposing scale and landscape ‘presence’ of the monuments may be hard to convey. Three dimensional models can go some way to improve the delivery of these factors and certain types of presentation (such as immersive VR) may provide the only means by which those with impaired mobility can interact with monuments in a manner similar to that of the able bodied sections of the community.

As well as providing a more accessible record (e.g. allowing ‘blow-up images, large type and/or audio commentary), there is the potential for three dimensional surface models to benefit the visually impaired via the emerging field of haptics, where virtual objects can be ‘touched’. This technology is dealt with in more depth in Chapters 6 and 8. It is fair to say that three dimensional records would improve the ability of those with special needs to access the record and therefore appreciate the monuments, as much as it would for the rest of the population, and probably more so.

2.6.3 Heritage management uses

Chemical and normal weathering results in degradation of the stones, removal to a stable environment (i.e. a museum) is the safest option, but there is no entirely quantitative methodology for justifying a move. These decisions are most often taken on the basis of visual inspection, photographic and textual descriptions - such as those created by the pro forma recording sheets available from HS (Yates et al 1999) - and comparison of the current condition of a monument with photographs, earlier sketches and even antiquarian drawings. This means that the criteria for moving a stone are essentially qualitative, for example an Inspector of Ancient Monuments might look at a stone and decide that it is considerably more eroded than on the last inspection and that remedial action should be taken. Accurate three dimensional measurement may offer a way of quantifying erosional or other damage more accurately and therefore feed more data into the management process. Essentially high resolution scan data can be used to create a ‘base-line’ record against which subsequent scans can be compared. A large scale recording project could in theory generate this base-line data for all the Early Medieval sculpture in Scotland allowing curators to target national resources more effectively. The success of this approach would be entirely contingent on the level of detail at which the record was created. A vast database of three dimensional records would only be of use in this respect if the level of detail was equal or greater than the level of detail perceivable by eye or recordable photographically.

3 Capturing the third dimension digitally

3.1 Three dimensional world, three dimensional record.

Since the earliest prehistoric cave paintings the three dimensional world has usually been represented in just two dimensions. As a result the concept of representing a three dimensional world in two dimensions has become almost as natural to us as language. However, just we are able to use language without necessarily considering the formal rules of semantics, the underlying rules we use to interpret two dimensional representations are not always obvious to us.

Early efforts to intimate the intricacies of describing higher dimensional worlds in lower dimensional media include *Flatland: A Romance in Many Dimensions*, the 19th century social satire and geometric treatise by the English clergyman Edwin A. Abbott (Abbott 1884). In this short work Abbott imagined a world in which there were only two dimensions. Leaving aside the elements of satire on the rigid strictures of Victorian society and theological analogy, the novel invites the reader to envisage life in a land where there is no third dimension. Perhaps inspired by Plato's *Allegory of the Cave* and the works of Gustave Fechner (Banchoff 1990, 365), the book elegantly describes beings in the form of two dimensional geometric shapes and the complicated rules of interaction required to live life in such a world.

More than an amusement, it accurately describes how three dimensional objects would appear to the inhabitants of a two dimensional world, most notably in an episode when a being in the form of a sphere visits the two dimensional realm. It appears first as a dot then as an lengthening line before shortening, until finally it is a dot once more as it passes through the plane that comprises Flatland (Figure 3.1).

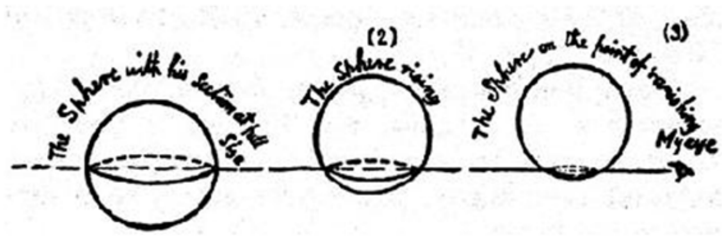


Figure 3.1 An original Illustration from Flatland showing how the sphere appears to its inhabitants.

Higher physics not withstanding, we live in a world that is generally thought of as having three spatial dimensions. Our senses describe the world in three dimensions. Binocular vision gives us the ability to perceive depth visually (Vince 1995, 53) whilst two ears allow us to do the same aurally and we have similar abilities with touch and smell. Only taste appears to have no spatial component. Flatland momentarily jolts us into a realisation of how rich our world is and how complex our interactions with it are. However, it points to a deeper truth. We most often record our world in two dimensions, and so, for clear historical reasons relating to practicality and technology, the vast majority of our records of the world are flat. Where a record is made that is stored and presented on paper then it is necessarily two dimensional (discounting the physical depth of the paper!). We have had to find ways of describing three dimensional objects or worlds using a two dimensional medium. Interestingly the above illustration from Flatland is sometimes difficult for us to understand because despite being a two dimensional image of a two dimensional world we are so used to thinking of illustrations and photographs as representations of the three dimensional world that we have to consciously remind ourselves that this is not the case with these illustrations. Flatland serves as a useful primer for starting to think about how higher dimensional objects can be presented in two dimensions. Thomas Banchoff, the mathematician and biographer of Abbot, positions Flatland and its use of dimensional analogy as amongst the first hypothetical stepping stones to the world of modern computer graphics (Banchoff 1990, 370)

Despite the fact that we are considering three dimensional recording we must address the fact that we are almost always limited to two dimensional presentation media. The computer screen itself is only capable of presenting two dimensional information (i.e. the screen is flat, it has no depth); it is the way that we are allowed to interact with these two dimensional images that generates an impression of three dimensionality. In Chapter 8 presentation techniques that occupy a space somewhere between two and three dimensions such as immersive virtual reality and volumetric displays are discussed. It should be noted that, unless stated otherwise, when three dimensions are referred to what is meant are the three spatial dimensions, as other non-spatial factors relating to the stone, such as colour, reflectance values or even time, can sometimes be referred to as ‘dimensions’.

Another important point to note in thinking about recording three dimensions to create a digital model of a real world object is the fundamental limitation of all recording processes. A model is by definition a simplification of that which it models, otherwise it would be an exact replica not a model. In fact the digital model is a simplification and a translation of the real world object into a semi-permanent media for later representation of the model at a lower order of dimensionality, whether that representation is designed to give the impression of three dimensions or not. Even where the model is used to try and create a physical three dimensional replica, ultimately at some scale the replica will not be exact. This is one of the reasons why a definition of the purpose of the model is so important in making choices about what level of simplification is acceptable.

3.2 Sampling an analogue world

Most music that we now listen to is recorded, edited, stored and transmitted in digital format rather than the analogue formats of yesteryear such as vinyl discs. This fact is interesting only when we consider that most music is originally generated in analogue form. The music is sampled digitally at a fast enough rate that we are unable to tell the difference from the analogue form when the sampled, digital recording is played back to us. Thus a long continuous note on a violin has its tonal values and volume recorded as numbers at discrete time intervals. As long as the time intervals are short enough when the tone and volume are recreated as analogue sound waves via a speaker we think we can hear the violin. In the same way the surfaces of carved objects are continuous, they rise and fall, they change texture and colour as they form the shapes and patterns intended by the sculptor. To create an analogue recording of a carved stone surface is possible; for example, a plaster cast would capture every nuance of the surface. However such records (casts) are time consuming, difficult to make and bulky to store. More importantly, casts are potentially damaging to the surface of the object and as a matter of policy Historic Scotland discourages their use (Maxwell 1992). Casting and other non-digital three dimensional recording techniques are discussed in the Chapter 4. What would seem a more practical approach would be to digitally capture and store information on the surface of carved stones; this means that we have to ‘sample’ the surface of the stone at discrete intervals. Hopefully the measuring intervals on the stone will be small enough that we still recognise the stone in the same way that small time intervals allow us to recognise the tune on the violin.

The notion of sampling intervals is crucial to how we generate digital models of the real world. It could be said we live in an ‘analogue’ world; everything around us can be examined at a finer and finer scale, from colours to sounds to smell to solid objects; As long as we have the tools we can always measure them more accurately. Digital representations of real world phenomena do not allow us to do this. When a sampling interval has been decided on and the data captured the resulting model cannot be examined a scale finer than the original sampling interval. For music on CD the sampling rate is about 40,000 samples a second (40 kHz) or a sampling interval of 1/40000 of a second (to fulfil the “Nyquist criterion” that requires sampling at twice the maximum analogue frequency, which is most usually practically constrained at about 20 kHz for audio (Watkinson 1994, 104)). This rate provides good enough reproduction such that the unassisted human ear cannot detect whether the sound wave is generated from a digital or an analogue recording. Similarly for vision, thirty two samples of a moving scene per second (effectively a sampling rate of 32 Hz) taken as photographic images, can be played back on a cinema screen and are enough to convince the human brain that it is seeing continuous movement. Surfaces however are a little different. We perceive surfaces through both touch and sight, there is no time component in our perception of surfaces as there is with music and motion. Our brains will not fill in the blanks for us. How do we convince the brain that what we are presenting is a good representation of a surface rather than a jumble of digital data? Firstly we must explore how the surface measurements are taken, that is, how the sampling is done.

3.3 Co-ordinate systems and interpolated surfaces.

To measure a point on a surface in three dimensions we must first have a fixed point to which we can relate it and all other measurements, just as in maps co-ordinates are given relative to an origin (zero degrees latitude, zero degrees longitude) and heights are measured relative to mean sea level. This allows us to represent a point on the surface of a stone in three dimensions relative to the point of origin. The origin can be real, i.e. it can relate to a real world co-ordinate, it could be notional but separate from the object, or it could be any one point on the surface of the object, perhaps the first one measured. Often it is a fixed point on the measuring device.

The position of any or all points on the surface of the object can now be expressed as X, Y and Z (Cartesian) co-ordinates relative to the origin (although they could also be expressed as distance (range) and angle from the origin or as Octree values which describe volumes). Now it is possible to imagine travelling over the surface of the carved stone and at specific intervals measuring the Cartesian co-ordinates of points on the surface. The ‘sampling interval’ here is a distance, not a time as it is with audio signals, so the term ‘sampling rate’ does not apply since the sampling interval cannot be expressed in cycles per second (Hertz). However, the speed at which the value of each point separated by the sampling interval is measured can be thought of as a sampling rate, expressed as say 100 points per second, or 3000 points per second, this does not affect the sampling interval. There are several ways of deciding how to define the distance between each point and the different hardware and software systems described in Chapter 4 use different techniques. For example, a decision could be made that the sampling interval is to be 1cm; this is sometimes referred to as a ‘resolution’ of 1cm. Imagine projecting a regular, one centimetre grid onto a flat surface , where the lines cross would represent a sampling point using this strategy. Now imagine the same grid projected onto a convoluted surface, such as a carved stone. If you were standing close to the point of projection then the grid would appear regular, with every intersection one centimetre apart, however on the surface the points of intersection could be much further than one centimetre apart if you travelled over the actual surface (Figure 3.2).

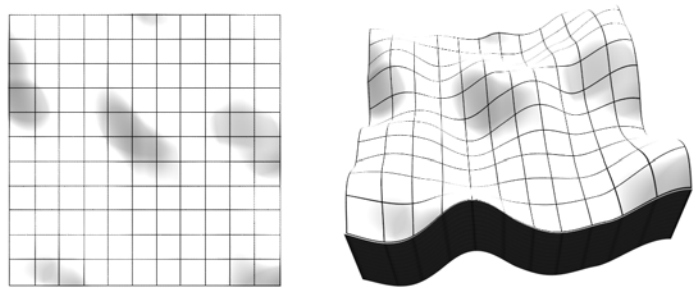


Figure 3.2 L. Looking at the surface from the point of projection of the grid. R. Looking at the surface obliquely, the projected lines are of irregular lengths.

Another way to imagine this is to think about the grid lines on a map. Despite the fact they are all the same distance from each other on the map, how far you will walk between two grid points is dictated by the rise and fall of the land. Experience soon teaches hill walkers to calculate distance using contours as well as gridlines.

An alternative way of separating sampling points by one centimetre might be to say that the next point to be measured is one centimetre of travel over the surface of the stone in a straight line from the previous one, and that each line of travel is to be separated by one centimetre. This avoids the potential for large unrecorded gaps on convoluted surfaces, however it would require an ability to measure a centimetre of travel over the surface.

These issues are very closely related to how the sampled data is used to construct a surface. The sampled data most often delivers what is called a ‘point cloud’. When this is represented on screen using visualisation software it looks like a cloud or a mist of points floating in space, each point representing a location on the surface and each being correctly positioned in relation to the others. Neither mathematically nor in real life does a set of points make a surface: the surface lies between the points themselves. It is necessary to reconstruct the surface in software. This is where the reference to our brain not filling in the blanks between samples may make more sense. In the musical analogy given above, the brain does not register any time between the sampled pieces of music and it sounds continuous, with a point cloud the blanks are very apparent (Figure 3.3).

Figure 3.3 A point cloud, here irregularly generated using soft photogrammetry. Each point lies on the surface of the object (the Govan Sarcophagus (Allen and Anderson 1903, Pt.3 462-71; Spearman 1994; NS56NE 17)) but we cannot mentally extrapolate the surface from the points.

The simplest way to reconstruct the surface and one used in several of the modelling solutions referred to later, is to generate a triangulated surface. This is similar to generating a Triangulated Irregular Network (TIN), a technique borrowed from topographic science. Triangular polygons are generated so that each polygon has a sampled point as each of its vertices. When only the edges of the polygons are shown this forms a wireframe model (Figure 3.4).

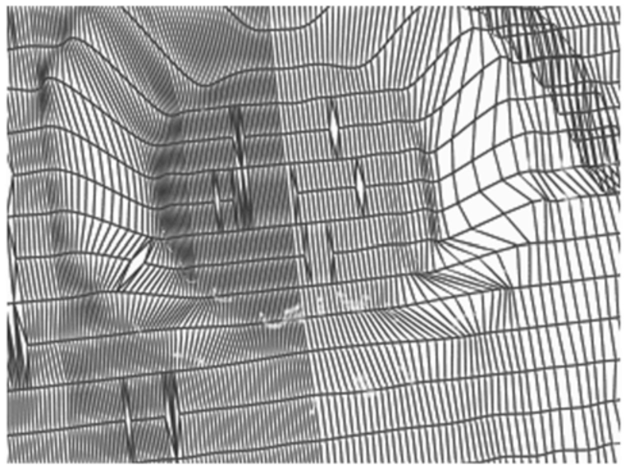


Figure 3.4 A wireframe model from a point cloud generated from a Time of Flight laser scan of Aberlemno II (detail).

Here a complex surface is being represented by a series of many planar polygons. A surface has been generated and can be rendered, lit and edited in software. It is important to note that no point on the surface other than the vertices of the polygons actually represents a measurement from the surface of the object. A TIN is frequently used in map making or GIS work as a stepping stone to generating contours or a raster image which are both approximations of the surface (see Figure 3.5). In recording terms the record consists only of the measured points: everything else, the TIN, the contours and shaded images is interpolated from the original measured points.

A common practice where more than one scan of a surface area is generated is to combine them into one point cloud and then into one polygon surface. Frequently either the point cloud or the polygon surface are 'decimated' at this stage in order to reduce file size. This process is designed to discard unnecessary points, since flat surfaces and straight lines need less points to define. This is 'lossy' compression (as opposed to loss-less) and data is sacrificed for file usability. Decimated or undecimated surfaces can be rationalised by converting an irregular polygon surface into a regular one by re-sampling so that each polygon edge is the same and the points are evenly distributed over the surface (this is similar to the process of converting a polygon mesh to a NURBS model described later in this section). In this case the original measured points are discarded and the points that appear in the wireframe model or point cloud are there to define the interpolated surface rather than as representatives of the measured points. This can mean that regions of the surface where there are many measured points may be represented in the model by fewer points whilst regions with only a few measured points may be represented by more, thus allowing for smoother and more uniform rendering. This rationalisation process allows a whole surface resolution to be decided upon at this stage by making the arbitrary decision that the edge length will be set at the maximum length of edge derived from the recorded point cloud. Several scans with a resolution of say 1cm when taken from offset recording positions can be combined and decimated to give a regular polygon surface with a standard edge of 0.1mm. When discussing the resolution of this model the longest edge of the polygon surface before decimation is what matters, this being the maximum distance between recorded points, while a decimated/rationalised surface may have a standard edge length of 0.1mm the real, resolution may be much lower.

A more sophisticated way of generating a surface from a series of points or polygons is to generate a NURBS surface. This technique does not exist in drafting or topographic science and was created specifically for modelling using computers (Kinetix 1997, 10-14). NURBS means Non-Uniform Rational B-Spline (B for Bias) (Vince 1995, 119) and is a system of mathematically modelling surfaces using ‘control vertices’ (CVs) that lie outside the surface but exercise an ‘influence’ on it. Although visible and editable by the modeller, CVs are invisible on rendering. This technique gives a more curvilinear surface than the angular polygon surface as well as being efficient in terms of data volume. One of the most important properties of NURBS surfaces is that the curves of the surface are mathematically defined in a way that gives them *continuity*. This impacts on both how they behave under perspective projection and how they appear at different scales. They can be drawn to screen as what appears to be a continuous curve at various scales, whereas a polygon surface will only look curved at certain scales and will become clearly angular on closer inspection. In fact when a NURBS surface is rendered it is actually approximated by polygons but the approximation can be very fine grained (Kinetix 1997, 10-1). Only the locations on the NURBS surface that coincide with original measured points can be considered truly representative and these are unlocateable, just as with the polygon surface all other points are assumed to be in that location by software. Interpolation techniques for surfaces, although based on complex algorithms and mathematical formulae cannot be considered as providing anything other than a hypothesis of what the shape of the surface between the points might be like. However as we experience the world as surfaces not as points, it is hard to remember when looking at a three dimensional model, or a contour map, that only infinitesimal areas of what we are seeing are derived from a measurement of a real world object, the rest is essentially conjecture.

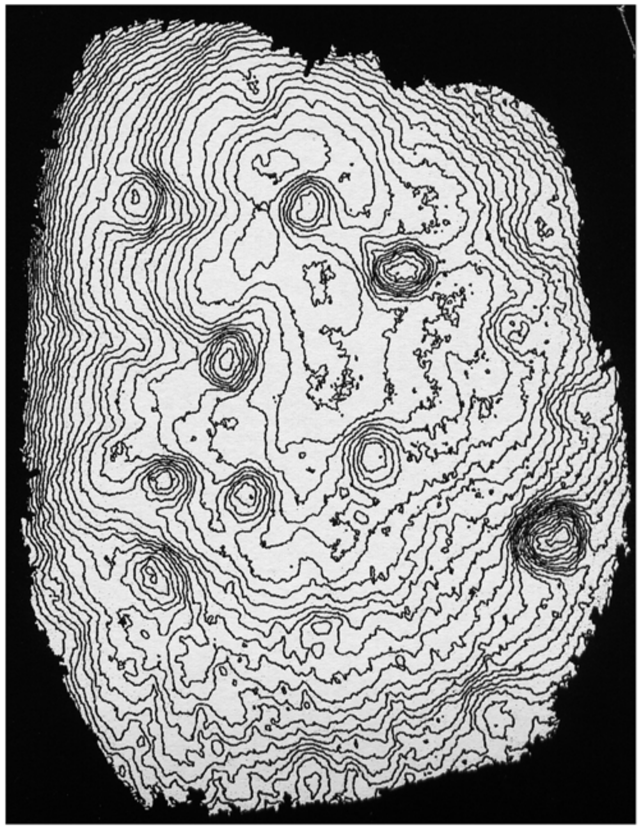


Figure 3.5 A contour image of a prehistoric cup-marked rock, contours at 2mm intervals. Generated from a laser triangulation scan for the Rock–Art Pilot Project (RAPP 2000, panel 8000). Although unrepresentative of the true visual properties of the surface the contours allow the depth of various features to be approximately gauged from the image.

Given we are likely to be handling sampled data as polygonal or NURBS surfaces, how does this affect what we might consider a suitable sampling interval? In an ideal world this means that the sampling interval should be small enough that the multi-planar nature of a polygonal surface would only become apparent at a scale that would represent magnification. When we look closely with the human eye at a real surface it appears continuous and complex, when we use magnification this continues to be the case. The sampling interval should be small enough that the polygonal surface generated from it only becomes apparent when the surface is examined more closely than is possible with the naked eye. In the case of a NURBS surface the transition from apparently continuous surface to clearly generated surface would be less apparent to the observer, but equally important. The desirability of this sampling interval is based on the notion that Early Medieval carved stones were not examined at any magnification by their original audience. Ideally a sampling rate higher than the visual threshold would be desirable as the potential for recovering microscopic traces of tool marks or wear patterns exists and may offer information that is archaeologically significant.

An important factor in deciding on sampling intervals is how accuracy in the measuring process interacts with sampling intervals. Some of the methodologies for measuring three dimensional co-ordinates of points on a surface claim accuracy below 0.1mm. To explain what this figure might actually mean it is necessary to look a little more closely at what ‘accuracy’ means in this context. The first distinction to make is between precision and accuracy. Precision is a function of the ability of the recording system to measure accurately whereas accuracy itself relates to how close a measured point is to its ‘true’ position. Precision is dependant on random errors in measurement. If the same point was measured twice and two different values were given but they were both exactly 1mm out in the same direction, this error is systematic; if they were 2mm and 0.5mm out in differing directions the error is random and if one result was out by 5cm this is a gross error. The random errors effect the precision of the measuring technique and the precision, systematic and gross errors all affect the *accuracy* of the system. Accuracy is not to be confused with repeatability, precision or resolution.

Accuracy statements should always be accompanied by statements of probability. This relates to the probability that the measurement falls within ‘n’ standard deviations of a normal (Gaussian) distribution curve. Where no probability is given it is common to assume a 95% probability, i.e. the true value lies within the stated error range with a 95% probability, this probability is the ISO standard for stating accuracy. This value can also be expressed as +/- X at two standard deviations, where X is a distance. Obviously measurements can be made to appear more accurate if probable error (50%) or mean error (68%) are used, see Figure 3.6.

Probability level actually used but not stated	Stated Error	Actual Error at 95% probability.
50%, Probable error	0.1mm	0.3mm
68%, Mean error	0.1mm	0.2mm
95%,Standard error	0.1mm	0.1mm

Figure 3.6 Table of actual errors at various probabilities (after Eos Systems Inc. 1997, 355).

The vast majority of measuring techniques discussed in Chapter 4 state accuracy either as a single figure, e.g. "accurate to within 0.1mm" or as a range, e.g. +/- 0.1mm. None explicitly state probability. It is worth noting, as a general comment on all commercial devices, that it is almost impossible to get reliable figures for accuracy independent of those given by the manufacturer, whether they state probability or not. Essentially we have to rely on the accuracy figures given to us because the equipment and process required to verify them is likely to be as expensive as the equipment itself.

3.4 Constraints on data capture methodologies

A key aspect of sampling is to establish the constraints under which a sampling technique would have to operate. In order to provide a framework in which to assess the various data capture solutions explored in Chapter 4 sections 3.4 and 3.5 discuss the various constraints within which any system would be required to work and also a series of idealised requirements indicating the expected needs of any project engaged in recording sculptured stones in three dimensions. The importance of some of the requirements and constraints are particularly salient to a large scale recording project, such as SEMSS, where the opportunity to engage in a similar project might not re-occur for decades.

The first series of constraints to be discussed include cost. They relate to cost in general terms as there is currently no project engaged in a large scale programme of 3D recording so no acceptably accurate cost range for a recording methodology can be proposed. There is an assumption that any archaeological project would be cost sensitive and if dedicated hardware were required that ran into millions of pounds then such a project is less likely to find funding. In light of this, cost is a serious consideration and the general issues and trends are highlighted.

3.4.1 Hardware

Historically computer related hardware costs are on a downward trend. That said, many of the recording methodologies investigated are dependant on emergent technologies and/or require top end computing platforms for those technologies. As a result, retail costs for cutting edge equipment are still likely to reflect initial research and development budgets. In the case of some of the most expensive equipment such as the Cyra scanners, buy back/upgrade deals are in place. The reason why this is a significant factor, is that a large scale long term project should be more inclined to opt for equipment and technology that is as ‘state of the art’ as possible in order to avoid the need for major capital expenditure late in the life span of the project in order to keep up with new developments.

The other side of the coin to buying ‘state of the art’ are the twin issues of rapidly developing technologies and divergent technologies. These raise the spectre of investment in cul-de-sac technologies or hardware redundancy caused by rival commercial development and/or adoption of technology that lies outside an eventual industry standard.

3.4.2 Software

All the factors that might affect choices in hardware selection also apply to software selection. Software is also a rapidly changing field and the possibility of getting locked into an ultimately inappropriate regime is as likely with software as it is with hardware. There are also several other factors that relate specifically to software. The most important is the distinction between data formats (file formats) and applications that actually manipulate the data.

Many applications use file formats that are exclusive to them i.e. a file formatted for use with application ‘A’ may not necessarily be readable by application ‘B’. Therefore the ‘best’ file format, the one that uses the best compression or is fastest to open, may not be the one that will be used because the ‘best’ application for the job uses its own, less suitable, format. Of course, there are always options that allow conversion between formats and normally this is possible even where commercial pressures have meant that application developers have tried to defend their applications and formats by making conversion a non-trivial task. More and more developers are realising that data portability is seen as desirable in the market place and as a result conversion tools and portability between a wide range of file formats is being sold as an application feature. An example of this is the clumsy but widely used AutoDesk DXF (Drawing Exchange Format). Since many graphics packages grew specifically to service the engineering and architecture industries, it was realised that it would be very difficult to sell software into these markets if the applications could not handle the DXF file format that was (and is) extremely common due to the domination of AutoDesk’s AutoCAD software. Thus a commercial, proprietary format emerges as one of the most widely supported vector graphics formats in the world today. AutoDesk made the details of the format available to the CAD community and as result competitors could write the code converting those files to formats of their own. This does not always happen. DXF represents a de facto standard, a standard that has become such due to its popularity. Often such standards are created by consortia of commercial organisations and are never actually submitted to standards organisations such as the International Standards Organisation* (ISO) or the Association of Computing Machinery*

(ACM). Where the formats are submitted to standards organisations they essentially become ‘open’ standards. This allows anybody with an interest to have access to the specification of the standard and therefore the potential for developing applications that utilise it. Some standards such as JPEG are ‘open’, specified and curated by the Joint Photographic Expert Group whilst others such as TIFF, which is a de facto standard, is in fact copyrighted to Adobe Systems Inc. Unfortunately there is no one standards body and the result is a degree of confusion surrounding file formats.

Three dimensional modelling packages, the applications that would be used to manipulate captured surface data from a sculpted stone, occupy what is one of the fastest growing and most competitive areas in the software market. As a result file formats are a big concern, as unlike text processing or flat and moving image processing there is, as yet, no obvious leading candidate for industry standardisation.

It is almost inevitable that a series of different data formats would have to be utilised as the formats themselves are designed to optimise differing functions of the data. For example the format that is best suited to archiving is unlikely to be the most suitable for transmission or presentation.

It is known that physical data storage formats such as magnetic disc, tape or optical formats may not have the durability of traditional archive media such as paper both in physical terms and in terms of accessibility. However the pros and cons of particular physical media and the issues concerning them are a highly specialised area that does not directly impact on the choice of data format suitable for archiving. The archiving of digital information has long been problematic in the commercial and industrial sectors and the Archaeological Data Service (ADS) has brought to the attention of the archaeological community that the life span of a data format is normally contingent on the commercial life of the application that generates it. In essence, if data is stored in a proprietary format or even in an open format, it could be a matter of a few years before an application that can access that data is no longer available or else is available but unsupported. Open formats have the advantage of allowing software engineers to access the format specification and therefore write code that could extract/convert information from an outmoded format. This may not be possible with proprietary formats. ADS experience of trying to recover data from orphaned databases, created as recently as the early eighties (Brown et al 1999), has been such that they have occasionally been unable to identify the application from the file extension and even where they can identify the application they have been unable to locate a copy with which to extract the data. So before considering the best formats for storage using factors such as compression and extraction, longevity and 'degree of standardisation' of the format must be considered.

It is fairly safe to say that plain text is the least problematic material to archive digitally. The ASCII (American Standard for Communication and Information Interchange) coding has its roots in early telegraphy and is the current de facto standard for text encoding in digital form, the only challenger is the recently developed Unicode* which encapsulates ASCII as a subset of itself in order to maintain the longevity of ASCII. Most word processing formats base their encoding of text on ASCII , with only the formatting information being particular to the application/format. As a result the text itself is unlikely to become lost, although formatting information may. Unfortunately a problem exits with the compression of files for archiving purposes. Until very recently mass storage devices with a capacity of a gigabyte were considered huge and as a result a lot of effort was spent in designing ways of compressing digital text in order to reduce file size and therefore the physical space occupied in the mass storage device. There is a large array of compression algorithms for text all of which maintain the integrity of the data (i.e. they are 'loss-less') such as Gzip or Sun's Tape Archive format. The issues relating to longevity of proprietary formats apply here to the compression methods it is impossible to know how long the software to decompress compressed files (where they are not self-extracting) will remain available and supported. Algorithms designed specifically to compress text can be very efficient and will of course also compress the code representing formatting data. However if images are embedded in the text, as nearly all word processing packages will now allow, then these algorithms can become highly inefficient. Compression of text and images clearly requires different approaches. The most popular image compression techniques today are those designed to give high compression specifically for internet delivery such as JPEG and GIF (also TIFF as mentioned earlier). Of course JPEG and GIF operate in different ways and graphics specialists can construct arguments for the use of either of these or others depending on the nature of the original image for example, colour palette, resolution and so on. The ‘lossy’ nature of algorithms like JPEG mean that although they are suitable for transmission purposes (Internet delivery) they are not suitable for long term storage of original images. A new generation of compressed formats typified by Kodak’s Flashpix (FPX) and Photo CD (PCD) have recently emerged offering loss-less highly compressed files with, in case of PCD, a hierarchical extraction protocol allowing extraction at various levels of resolution. These formats are not currently open formats and in the case of PCD require proprietary software to generate. Whether these formats emerge as ‘standards’ in the ways discussed above remains to be seen.

Three dimensional data presents extreme forms of all the issues mentioned regarding file formats for archiving, transmission and presentation. The main reason for this is the relative newness of three dimensional models. The models themselves may have been around since the seventies but only in very limited and specialised forms and in small enough numbers and with so few applications that sharing, transmission and so on was not a serious issue. The explosion in use of models in the last five to ten years has meant that there is both a far larger number of models around and a far larger number of applications generating them. As yet there is no de facto standard application nor a de facto file format standard. There is still a confusing number of ways to generate models and many stages in the process, from point cloud to fully rendered. Each of these stages requires its own format; for reasons of space efficiency it would not make sense to design a file format that could handle surfaces and bitmaps if all that was to be stored was a point cloud, (although some applications do in fact do this, sacrificing file efficiency for ease of use, e.g. PhotoModeler project files)

The result of the explosion in three dimensional modelling is many formats, almost all proprietary and exclusive. The two proprietary formats that are currently in most frequent use by modelling professionals are Wavefront Object files (.obj) and 3D Studio Mesh files (.3ds), however the semi-open format 3D DXF is still frequently used for vector data and the fully open (but now unsupported) VRML format is still used for models built for internet delivery (although it can handle much larger models e.g. Terras 1999). A newer format, Qsplat* which has a highly efficient incrementally loading file structure that requires its own viewer has the potential to become very popular as a delivery format for models of discrete objects (see 6.2). VRML's successor is the three dimensional subset of the potentially vast extensible mark-up language model (XML), this is known as X3D*, and is currently being specified by the web3D Consortium*. The consortium's objective is to express the geometry and behaviour capabilities of VRML 97 in XML. This development holds out the potential for a definitive standard that is unlikely to become outmoded, as it is explicitly designed to be extensible, at least for the distribution and presentation of digital three dimensional models. The fact that it is the Web3D consortium that is developing X3D also means that its specifications will be subject to oversight by the ISO as well as being completely open to the development community.

The reason that VRML is still often used is that it gets around the tricky problem of how three dimensional data is actually presented to its intended audience. The nature of the potential audience for models of Early Medieval sculpted stones is discussed in Chapter 6 but it is safe to assume that they are unlikely to have access to the three dimensional model generation software in which the model was constructed. The implications of this are more apparent when three dimensional models are compared to still 2D digital images. A two dimensional image can be captured, altered and edited using, for example, a digital camera and Adobe Photoshop. If it is in an open format such as JPEG this image can be viewed by any number of viewer programs or as an embedded image in many document formats from MS Word to Adobe PDF or via a Web Browser referenced from a HTML document. Unfortunately the viewers for three dimensional models are not so common. There are a few such as 3DWinOGL* that will handle models in (or converted to) Open Graphics Language format that are standalone viewers which a user can install and run locally. QSplat, mentioned above, also has a standalone viewer. The reason VRML was very popular was that it allowed the model to be accessed via a Web Browser with just the addition of a downloadable viewer plug-in. There are a large number of VRML client plug-ins, some excellent and some less so. The main advantage of this type of delivery is that allows it a huge audience to access the models with the minimum of additional software (most VRML plug-ins are free). Unfortunately all VRML plug-ins present the user with a 'learning opportunity'. If we return to the comparison with 2D images, the number of functions required to examine a 2D image are minimal: basically zoom and pan. This makes for a simple interface. 3D models presented in VRML , or any other format for that matter, generally allow much more interaction: pan , zoom, dolly, walk, rotate, light, gravity etc. The result of this is that the user is generally presented with an interface that is far less intuitive than that of text or image handling interfaces and has to learn how to operate the plug-in to get maximum benefit. This may appear to be a trivial point, but to a large extent the issue of interface complexity and the time required to master an interface will apply whenever a model is presented in a format allowing user interactivity. Chapter 7 discusses some of the potential for tailoring presentation methodologies for an audience's skill levels.

3.4.3 Training and labour

When considering any large scale project, labour costs are a major factor in deciding on methodologies. Apart from wage costs the next most important consideration is likely to be training. A recording methodology that requires expensive and specialist hardware is also likely to require specialist training. How difficult is the hardware and software to use? How much time is required to train the user? Is the technique dependant on a user's experience and ability to produce a adequate data set or, once trained, would all users produce exactly the same data set? The second question is a crucial one, it refers to the relationship between training and the end product. Some techniques may produce identical results irrespective of the operator providing all operators are trained to the same level of proficiency. In fact most techniques will not give exactly reproducible results and the quality of the recording is dependant on both training and experience (e.g. RAPP 2000, 7.4.1.6). Experience can never be short-circuited and attempts to do this may mean presenting sub-standard products. It should be acknowledged that unless fully trained and experienced operators are employed initially then any three dimensional recording project would take time to generate consistently satisfactory products.

In some cases the training required to operate hardware and software systems is so specialist and expensive that if that system were to be adopted consideration should be given to hiring in/contracting out to the necessary specialists. When taken together with the potential dangers of cul-de-sac technologies then the benefits of not buying expensive equipment and expensively training operators may outweigh the benefits of having such equipment and personnel 'in-house'.

A further pertinent question is, how long does the methodology take to generate an acceptable product ? Irrespective of training levels the time required for data capture will impact on labour costs. For example the cost implications of a recording technique that could record a monument in three hours versus one that would take three days are obvious. Similarly the time for 'post-processing' should be factored in. The hypothetical technique that records a monument in three hours might not be so attractive if the data requires two days worth of further software work to generate a suitable model.

A final and most pragmatic point relates to the dangers of employing and training operators in specialist and commercially “hot” technologies. Traditionally most academic, and especially archaeological, projects do not operate at the same level of funding as commercial operations and this includes rates of pay. It may become difficult to retain expensively trained staff if there is the lure of more lucrative, but essentially similar positions in the commercial world. This is balanced to some extent by the notion that anyone embarking on a specifically archaeological recording project is essentially interested in archaeology and will derive the job satisfaction required to compensate.

3.4.4 Portability

As discussed in Chapters 1 and 2, Early Medieval sculptured stone in Scotland comprises a wide range of material, of which many items are indoors, but a large number of the monuments that need recording are located in the field. Often they are literally in fields, or they are on rough ground away from metalled roads (Figure 3.7). There are a number of practical considerations for any proposed recording methodology

Figure 3.7 The Dupplin Cross, isolated in a rural landscape, where it originally stood, it is now housed in St. Serf’s Church, Dunning.

The general portability of any system would have to be considered. How heavy is the equipment? A system that could not be conveniently carried reasonable distances over rough ground by one or two people may have to be excluded as impractical. It is worth bearing in mind that all of the systems described in the next Chapter require a power source, so batteries or generators would have to be considered. In addition to this, many of the systems require a laptop PC to store and/or process information in the field. The term “conveniently carried” should also cover any potential health and safety implications, for example if the equipment was dropped on an operators foot would it cause injury? If so, protective footwear may have to be supplied. Similarly, lifting training might have to be given if the weight of the equipment was such that it might cause injury during a lift or through long term frequent lifting. Even where one person is capable of operating the recording device, weight and size, as well as security, may mean two or three person recording teams are appropriate.

The system must also be robust enough to survive a large number of carries with the inevitable knocks and scrapes that this would entail. It is not be enough to say that the system can be moved, it should in fact be designed to be moved. Calibration after a move, if required, should not make the system impractical. Reliability and repair issues have concomitant cost implications, for example can replacement of damaged parts be carried out by the operator or does the device require shipping to the manufacturer for repair and recalibration? Maintenance and repair contacts may counter these difficulties, but undoubtedly with additional costs.

3.4.5 Environmental Robustness

In addition to the ability of a hardware and/or software package being able to survive repeated, and possibly careless, handling by the operators the package should also be able to operate without performance degradation within a reasonable range of environmental conditions. There are, especially in Scotland, a number of environmental threats to all mechanical and electronic devices including the following:

3.4.5.1 Humidity.

Atmospheric humidity and rain, hail, snow, and even sea spray may have a significant impact on the workings of mechanical, electronic and optical devices. Apart from the decay of mechanical equipment via corrosion effects like rusting, unprotected electronic equipment easily malfunctions in high humidity due to its effects on conductivity. Optics are especially prone to the effects of humidity and condensation effects on glass surfaces can render them optically useless. Less likely, but possible, are the detrimental effects of lack of humidity.

3.4.5.2 Temperature.

Almost all electronic equipment has an operating temperature range. How do the extreme ends of normally occurring temperature ranges affect the system ? This is only likely to be an issue on cold winter days, however the possible impact of cold on stored power systems such as batteries should be borne in mind.

3.4.5.3 Wind and weather.

Wind is an environmental constant in many parts of Scotland irrespective of season. It is unlikely to effect the internal electronic or mechanical workings of any device, however if the device is not adequately stable it may move enough to affect the accuracy of any measurement. It would be unreasonable to expect any device to be able to operate in any weather conditions, extreme weather is likely to discourage the human operators for reasons of comfort. It would be desirable for any package to be able to operate up to the comfort threshold that would normally be expected by archaeological workers in the field. Where this threshold lies is a highly subjective, and often contentious, matter.

3.4.5.4 Light levels.

Does the system require the object to be well lit (better than direct sunlight) or, conversely, will excessive light interfere with the quality of the resulting product? This applies especially to laser or camera based systems. Even where it is clear that light levels do not interfere with the recording of surface topography it may interfere with the recording of non-topographic surface information (NTSI), that is information about the surface of the stone that does not relate to its topographic geometry (see section 3.5.3)

3.4.5.5 Power Requirements.

The primary consideration here is how much power the system draws. Will it run on batteries? How large and heavy are the batteries? How long will the batteries last? Will the system run off a generator, if so how will it handle power spikes? This is probably one of the most important practical issues to contend with, working in field conditions with equipment requiring power supply in excess of standard disposable batteries could impact greatly on any systems practicality. This especially true for a system that requires a portable computer as well as a powered recording device.

3.4.6 Access.

Besides those monuments in the field many other objects are stored or presented in very cramped indoor locations. This raises the issue of how much space is required to perform the data capture, i.e. how close or far from the object the hardware is required to be. There are examples, such as the Nigg cross slab, where it would be impossible for the device to be further away than a metre or so as the stone is displayed in a confined interior space. Similarly the space around the artefact to be recorded may be so constricted that it is not be possible to get a recording device to it (Figure 3.8). The frequent inaccessibility of interesting surfaces for viewing, let alone recording is problematic and any recording regime would inevitably require some objects to be physically moved if it were to generate a complete record.

Figure 3.8 Stones on display in Iona, not all surfaces of these stones are accessible for recording purposes as they are currently displayed.

The sections that will be least affected by weathering will be the buried sections of monuments intended to be set upright in a setting of some kind such as cross slabs and high crosses. These are the sections most likely to carry unworn tool marks and in some cases such as the Hilton of Cadboll stone, pristine carved sections. It is unrealistic to anticipate the disturbance of field monuments specifically to allow for the recording of buried or obscured sections either for the 'completeness' of the model or because there is the possibility of tool markings or previously unseen sections of sculpture. Some monuments, such as the cross slab at Shandwick (Highland, NMRS NH87SE 4) have settings that clearly obscure further sculpture. However the range of conservation and heritage management issues that mitigate moving the monument, including the possibility of damaging it, suggest that obscured sections will remain unrecorded. The Shandwick cross is also an example of how a modern protective glass structure seriously limits the access to the stone by recording equipment requiring space to set up and operate (Figure 3.9).

Figure 3.9 The Shandwick cross slab as it is currently displayed, housed in a protective glass structure.

A further access issue is the problem of size. We have seen that the type of objects under discussion can range from small fragments all the way up to the 6m tall

Sueno's stone. It is important to consider how the top of such a stone can be captured. This constraint obviously relates to the matters of portability, size and weight discussed above. If lifting equipment is required for the hardware is this a manually operated pole, a cherry picker or a scaffold? Obviously all these options again have further cost implications.

3.4.7 Surface contact

Because of the nature of some of the stones specifically friability and risk of cracking the data capture method should be non-contact. Undoubtedly many of the stones could survive a recording method that involved contact without any damage, but it is a general principle of conservation and curation that objects such as these should be handled as little as possible and therefore a contact recording technique, which would definitely not be applicable to all stones, would not be considered suitable even for stones that would not be damaged, simply because non contact methods are known to be available.

3.4.8 Invisible Damage.

Even non contact techniques may have implications for future archaeological work. Thermoluminesence and the still developing Optically Stimulated Luminescence (OSL) techniques can be used to date quartz crystals, especially in sediments and metamorphic stones derived from sediments, such as sandstone. It has been suggested that OSL technique could be used to date the first exposure of dressed or carved stone surfaces to sunlight (Habermann et al, 2000) This might give a date for the creation of the monument or artefact. The archaeological benefits for such a technique are potentially numerous. The technique itself is predicated on various physical phenomenon but is especially reliant on the sample being tested not having been exposed to light levels that would interfere with the dating curves based on exposure to natural sunlight. Techniques that use powerful light sources such as lasers may in fact ‘reset’ the dating clock that OSL uses. However, even ‘eye-safe’ lasers may effectively render the surface undateable. OSL would be most useful on segments of stone that were not exposed to direct sunlight for any length of time, which would mainly apply to sections of monuments that were deliberately buried such as cross bases and associated structure. On excavation these would have to be immediately covered to avoid light exposure until OSL dating has been performed. Only a small area of the surface is required for the dating technique and it should be feasible to protect a small section of any monument from light exposure even if it is not practical to do this with the whole object. While the OSL dating of dressed or carved stone surfaces is a technique under development in the Scottish Universities Research and Reactor Centre (SURRC)* care should be taken that any object on which a reliable OSL dating technique could potentially be used is carefully recorded as having been swept with a laser of a specific rating, and if possible a small area of the object left unaffected by the laser and its position recorded. It would be unfortunate if a large scale recording project inadvertently removed the opportunity for the collection of scientific dates at some point in the future.

3.4.9 Surface Cover and physical environment.

Moss and lichen cover many of the stones, especially those out of doors. Current practice tends to leave this in place as removal can further damage the surface of the stone. How will a recording methodology be affected by these soft, complex materials? All the recording techniques discussed in Chapter 4 are in some way or other impacted by surface cover, such as moss and lichen. This means that, as with very restricted access, some other way may have to be found to deal with this problem. For example, it may be necessary for carefully controlled cleaning to take place in order to get the required record. Other physical environmental factors that are known to affect recording are things like metal fences, braces and brackets on the stones themselves. Metal fences are clearly not easy to move, nor for that matter are wooden ones, but it is fair to say that railings (for example at St Orland’s stone Cossans (Allen and Anderson 1903, Pt.3 216-18; NO45SW 4) (Figure 3.10)) are for practical purposes immovable objects. Similarly some stones have metal braces or staples holding them together. The simplest solution here is simply to record the braces. However both metal fences and braces may have an effect on those recording techniques which rely on radio signals or magnetic signals for positional information, since it is known that the proximity of dense metallic objects will degrade or invalidate their performance.

Figure 3.10 A metal fence round St Orland’s stone, restricting lines of sight and access..

In a similar vein, the monuments are carved from many different stone types, some of which have higher reflectance values than others due, for example, to the concentration of quartz or mica crystals in the stone. The non-topographic surface qualities of the stone can have a bearing on the accuracy of some recording techniques which rely on reflectance qualities in order to measure the distance from the object to equipment. In this case laser light is especially prone to diffusion or interference due to reflectance qualities of the surface.

3.4.10 Flexibility.

The last constraint that needs investigation is that of the form of the surfaces themselves. Many Early Medieval sculpted stones have convoluted and complex surfaces. In addition, the three dimensional shape of the object itself can be complex. An excellent example of this is the high cross at Kildalton (Islay) where the object to be recorded has several holes running right through it, curvilinear edges and straight edges as well as finely sculpted high relief panels (Figure 3.11).

All the constraints mentioned above could apply to any stone object. However in this instance it is the uniquely ornate nature of both the sculpture and the object that poses a problem. Where all the other constraints have been met by a technical solution it may well still be a problem to gain access to all the remote corners of a sculpture. Any recording device would have to be flexible enough to gain access to difficult to reach areas in the carving. It seems self evident that in order to record an Early Medieval sculptured stone in three dimensions it is necessary to be able, at the very least, to record any possible point on its surface.

Figure 3.11 The Kildalton Cross on Islay, (NR45SE 3) the cross is a highly complex three dimensional shape as well as having sculpted surfaces. RCAHMS.

3.5 Idealised requirements.

Section 3.4 above dealt with the constraints within which any three dimensional recording solution would have to operate, ranging from portability to weather resistance and flexibility of use. In this section the ideal requirements for a solution are detailed, i.e. what exactly the perfect solution would be expected to do. It was always extremely unlikely that any technology existed that could in fact fully meet all the requirements but it is necessary to consider the ideal so that various systems can be compared. Where one system meets one set of requirements but not others it can be hard to make a comparison with systems that meet a similar number of, but different, requirements. One way round this would be to rank the requirements in some kind of scale of desirability. However the varied nature of the requirements and the varied nature of the target objects, from small stone fragments to 6m high in-situ monuments means that varied technological solutions are likely to be required. Thus any ranking of requirements is not going to be universally applicable over the entire range of targets and desired products.

There is a fuller discussion in Chapter 7 on how the issues of intended audience, presentation method, and levels of interpretation all impact on the desirability of particular sets of requirements over others. For example a model intended for two dimensional, non-interactive presentation in a youth oriented museum context is unlikely to require a 0.1mm surface sampling interval, but is more likely to benefit from good quality recording of surface colour. The academic scholar interested in tool marks may be less interested in colour than the level of detail used to describe the surface. However the following set of idealised requirements is predicated on the notion that the best possible model is always desirable and that lesser quality models or images of models can be generated or 're-tasked' from the original.

3.5.1 Resolution.

As already mentioned real world surfaces are to all intents and purposes continuous. Clearly the 'best possible' record of the surface would have to be a continuum. Since we are recording the surface digitally, this is not possible, therefore what we are looking for is the minimum possible interval between measured points, referred to as the resolution of the model.

A good starting point for thinking about resolution is to consider what the human eye is capable of resolving as a discrete object. This is referred to as the visual acuity of the eye and is not normally given as a sampling interval. The normal way of expressing the normal visual acuity of the human eye is the ability to resolve a spatial pattern separated by a visual angle of one minute of arc at a particular viewing distance (information from Center for Non-destructive Examination (CNDE*)) Expressed as a linear measurement this equates to a visual acuity of 0.00349 inch (0.0886mm) at 12 inches (30.48cm). Put another way, if the eye is about 30 cm from an object, a comfortable viewing distance, and the object had alternating black and white lines that were 0.0886mm wide, it would appear to most of the population as an undifferentiated grey mass. Rounding up this level of acuity to 0.1mm seems reasonable as in the case of Scottish Early Medieval sculptured stones the original intended viewing distance seems unlikely to be closer than 30cm. For our purposes then, points measured at regular intervals of 0.1mm allow a surface to be generated in which each polygon plane had no dimension longer than 0.1mm which when viewed at a simulated distance of 30cm would appear as a continuous surface. This also means that when viewed closer than this the angular nature of the discrete surface polygons would become apparent. If the three dimensional model was expected to reveal detail that was not visible to the human eye then the resolution would have to be less than 0.1mm.

To put this into context, a regular sampling interval of 0.1mm applied over 1 square meter would capture 1,000,000 points; over the same area an interval of 0.05mm would result in 40,000,000 points. In other words as the resolution becomes finer the number of points per standard area increases exponentially. The idealised requirements for data mass are discussed 3.5.3 below.

Some devices (e.g. Co-ordinate Measuring Machines, see Chapter 4) are capable of measuring at a sub micron level and Mark Levoy's Digital Michelangelo project* succeeded in measuring the surface of Michelangelo Bounarotti's 'David' at an interval of 0.25mm with a laser triangulation device. This however was achieved via specially funded, purpose built, static equipment with a team of around twenty people working indoors and over a time period of several weeks (Levoy 2000, and http://graphics.stanford.edu/projects/mich/). Given the constraints indicated in section 3.4, what is the best possible level of resolution that is obtainable practically? Marc Levoy's scanning work of Michelangelo's sculptures needed a resolution of 0.25mm in order to capture the characteristics of Michelangelo's tool marks on hard Carerra marble. The resulting models had up to 2 billion polygons defined, the database eventually rose to 10 billion polygons and thousands of images requiring 250 Gigabytes of storage. Given that the majority of Early Medieval carved stones in Scotland are sandstone (Maxwell 1992), which is much softer than marble, and that they are likely to have been exposed to the elements for many centuries, the discovery of tool marks will probably be limited to exceptional finds such as the Hilton of Cadboll cross base whose excellent condition indicates that it was buried not long after it was carved, or very coarse tool marks such as on the stone at Inchinnan (Renfrewshire)(NS46NE 7.01).

The ideal requirement for resolution is at the level of visual acuity for worn surfaces, i.e. where no detail of tool marking would remain due to weathering, and something less than 0.1mm for surfaces that have valuable detail that is not visible to the human eye. Furthermore the regularity of the recording interval should be guaranteed, it should be selectable in advance of recording and there should be no point on the surface that has a recording interval less than the one selected. In other words, if the recording interval is selected as being 0.1mm and the resulting data has one million points per square meter it should not be the case that some areas have a resolution of 0.05mm and others 1cm. The points must be recorded at regular intervals over the surface of the target. To guarantee a minimum recording interval it may be necessary to combine the results of more than one scanning episode. It would also be highly desirable to be able to select different resolutions for different sections of a monument. By way of example if we look at the Sounding stone (Figure 3.12) then we can see that the vast majority of the object has an undressed surface and the actual sculpted detail occupies a discrete area of the monument. In this, and similar, cases it could be advantageous to be able to record the undressed and sculpted areas at different resolutions, depending on whether there was any archaeological value from having a high resolution model of undressed stone surfaces.

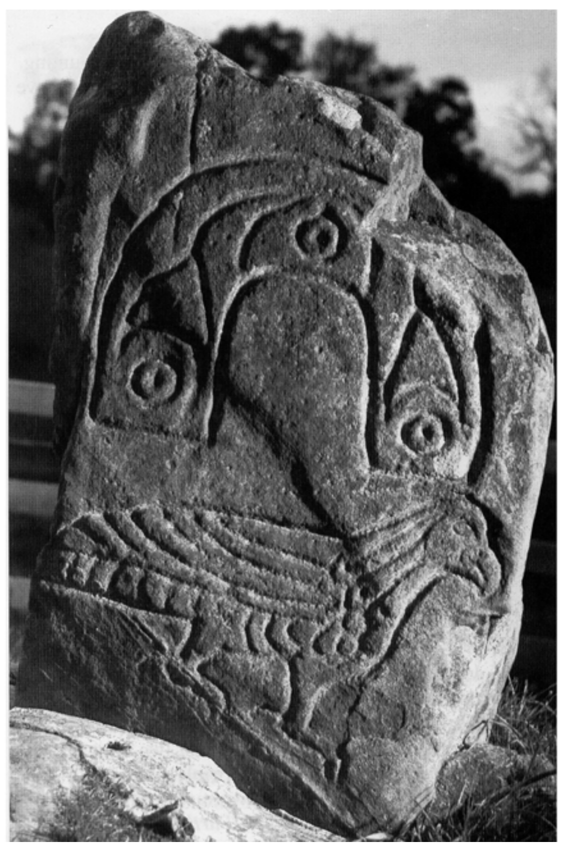


Figure 3.12 The Sounding Stone (Strathpeffer, Highland)(NH45NE 6) A combination of very roughly dressed surfaces and sculpted elements. RCAHMS.

In practice, based on Levoy's experience, tool marks can be recorded at an interval of 0.25mm. This means that insisting on an interval of 0.1mm because that would be the size of detail which could be visually resolved at 30cm from the surface of a sculpted stone may be unreasonable. This is especially true when balanced against other factors such as data mass, stone wear, whether the original audience would have examined a stone from 30cms away and whether any bitmaps captured to render a models surface would be able to match that level of detail or whether it would in fact obscure it.

3.5.2 Coverage and accuracy.

Where possible the complete object should be recorded (a complete fragment where the object is itself not in its original complete form). This requirement is particularly sensitive to the constraints of access and flexibility. Either the target can be recorded in its entirety in one complete operation or the results of several recording operations can be linked together, without affecting accuracy, to produce a single record. In the former either the target object or the recording device will have to move, in the latter only the recording device will need to move. This is because it is physically impossible to access all parts of a three dimensional object from a single location.

The process by which a number of records generated from separate recording events can be linked together should have the minimum amount of user intervention. A technique that requires the user to fit the various surface models together until ‘they look right’ would negate any claims to either resolution or accuracy over the entire model, even if individual sections are satisfactory. This function can be performed in software or using a combination of hardware and software, but it should be an automated process.

For accuracy the ideal requirement would be for zero error in the measurement of the point. Obviously this is impossible to achieve for any form of measurement. If an object was recorded at a resolution of 1cm and an absolute accuracy figure was given as +/- 1mm then the whole point surface should be within 1mm of its measured position relative to some origin. This may be acceptable for a resolution of 1cm, since, provided all the points have the same error in the same direction then the whole model can be considered accurate to within +/-1mm of the recording origin. It is hard to envisage a situation where it would be unacceptable to be able to relate an object to some other item, building or landscape feature with more accuracy than this. However precision is far more significant. If we consider two points both located in three dimensional space to an accuracy of 1mm, if one point is 1mm out in one direction and the other is 1mm out in the opposite direction then clearly they are 2mm further apart from each other than they should be. Low precision here doubles the effect of the inaccuracy of one point relative to another. If however they are both 1mm out in the same direction then the relative accuracy is high, because the errors are systematic, and although the points may be inaccurately placed in space they are in the correct position in relation to each other. The ideal here is high relative accuracy (low random and gross errors). Unfortunately our target objects, Scottish Early Medieval sculptured stones, have surfaces that change in more than a topographical sense. The crystalinity of the stone’s surface, its colour and its condition, all change frequently from one place to another on the surface of a single stone. In addition, large monuments such as Sueno's stone present different ranges for a measuring device to operate over and accuracy can alter with range to the measuring device. In the above examples an accuracy figure of +/- 1mm is used and the distinction between whether we can rely on recording errors to be systematic or not is made. To reinforce that concept the ideal resolution suggested in section 3.5 was 0.1mm, but clearly +/- 0.1mm accuracy would render this resolution a nonsense. Therefore achievable resolution will be heavily reliant on the accuracy of the measuring device.

3.5.3 Data mass

The amount of data produced by a recording process can be expected to have a reasonable relationship to the size of the target object and to the resolution of the recording. A hardware and software combination that was highly accurate but generated hundreds of gigabytes of data would have implications in terms of data handling, storage and dissemination. There will always be a balance to strike between the resolution of the record and the amount of data that is needed to store it. For small objects this may not be an issue but for a large high-cross the amount of data could be substantial. Looking again at Marc Levoy's Digital Michaelangelo project we see that his database comprised 250 Gigabytes of digital data (Levoy 2000). This represents the high resolution scanning of a handful of large statues. With around 3000 potential recording targets in a new corpus of Early Medieval sculpted stone it is clear that data mass and data management would not be trivial issues. Large data volumes and large individual files have implications for both hardware and software requirements for the curators of the record as well as processes for the distribution of data to its intended audiences. Clearly a 10Gb record is not going to be easily delivered over the internet on the current global infrastructure. The majority of archaeological three dimensional models of non geometric (architectural) real world objects are of portable artefacts: the larger the object the lower the resolution at which it is captured. As an example of why this might be, a hypothetical upper limit in data handling terms might be a model of 1 million polygons. This number of polygons could be applied to a small complex artefact giving a high resolution model; if the same upper limit was reached on a model of a large building, it would be a low resolution model. There are few real world objects that are as large and consistently complex as sculpted monuments. For example, the Cuneiform.net project* is a daughter project of the Cuneiform Digital Library Initiative* (UCLA) based at The University of Birmingham in 2001. This project intended to produce high resolution scans of Cuneiform tablets for distribution to scholars over the internet. This project needed a resolution of

0.005mm generating 100mb files for a single tablet (normally around 10cm by 10cm by 3cm). The project found these files challenging to manipulate in real time locally and completely unsuitable for remote access. Available compression was lossy and the project is currently working on scaleable 3D compression techniques that might allow internet delivery. Even with small objects, scans that capture the necessary detail can be too large to allow the required manipulation and distribution.

3.5.4 Non-topographic surface information

It is necessary at this point to think of the other types of data, other than three dimensional shape that might be captured in order to enhance a model (e.g. RAPP 2000, 7.5, Rushmeier and Bernardini 2000, 42) This can be referred to as non topographic surface information or NTSI. For our purposes the two most important items that can be recorded about a surface other than its shape are its colour and its reflectance value. There are many other qualities that could be recorded such as hardness, density, chemical composition and so on. The surface of all stone will display variability in all these qualities and they could be rendered to the surface of a model so that instead of a three dimensional model being rendered with the colour of the surface it is rendered in such a way as to indicate the relative hardness of various points on the surface. This kind of information would have very specialised uses, such as helping to identify the original quarrying location of the stone (if it was quarried) or possibly to help design conservation strategies. Irrespective of the glimmer of potential archaeological uses for such information none of the techniques investigated in this thesis measure NTSI other than colour or reflectance. It would seem unreasonable to include such NTSI other than this in a set of requirements, even idealised requirements. To settle on an ideal for measuring colour and reflectance we again have to bear in mind the constraints on a data gathering technique outlined in the sections above. What would be an ideal requirement would be the ability to capture the surface colour under natural light at each recorded surface point and even in-between. Because nearly all models are polygon surfaces when presented to a computer screen, we actually want the colours that should be represented on the surface of the polygon. What usually happens in practice is that photographs are used to generate a bitmap with which to render the polygon surface in software at a far lower resolution than the surface could be recorded at. Imagine a recording device is situated 3m away from an object and its surface is being recorded at a resolution of 1mm and at the same time colour images are being captured that can be associated with the polygon surface being generated. When on screen at a virtual viewing location 3m from the object the surface colour may look convincing, as we move closer pixelation will occur whereby we can see the individual captured pixels representing colour but the underlying surface still appears to be a continuum (Figure 3.13). If the resolution is set at the level of visual acuity then the pixel density and palette of the image should match this. In practice this is likely to be very difficult to achieve.

The difficulties in capturing surface colour are not limited to image resolution and associating colour with surface polygons. The lighting conditions under which the colour image is recorded will have a significant impact on the actual record. For this reason reflectance values rather than actual colour would be a more desirable recording product. Reflectance values would allow the surface to be rendered under simulated lighting conditions.

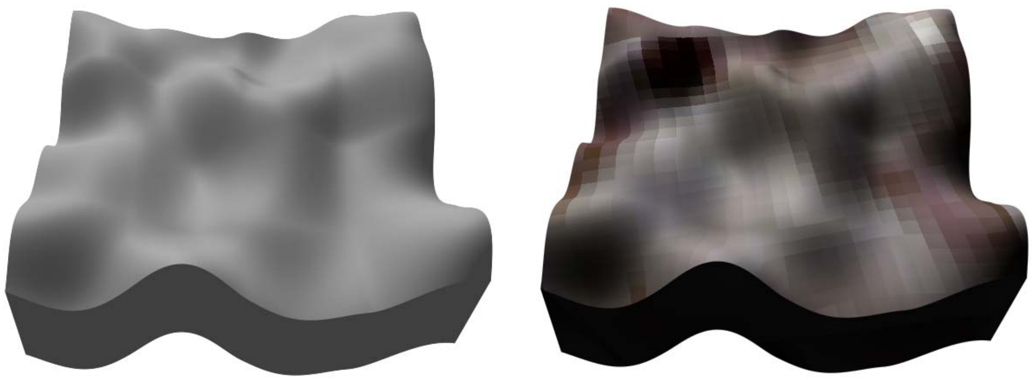


Figure 3.13 L. A greyscale complex surface, where the polygons are not apparent. R. The same surface rendered with a bit map generated from a photograph. A higher resolution or differentially rendered image could avoid this problem (see section 5.1.2).

3.5.5 Summary

In summary, the ideal requirements of a three dimensional recording system would be that in all weather and lighting conditions a single operator could quickly and easily capture high resolution (<0.1mm) surface geometry whilst simultaneously capturing photographs and reflectance values at the same resolution. The system would be flexible enough to be accessible to monuments in constricted areas and with complex shapes and would be equally suitable for small fragments and large monuments. Finally the resulting data could be manipulated with standard software and on standard hardware producing models for internet delivery with no loss of detail. Unsurprisingly no such system is commercially available. The following Chapter examines general techniques and some available systems to see how close to the ideal they come.

4 Data capture techniques, some examples and critiques.

The previous Chapter clarified the potential requirements of a three dimensional recording system specifically for use on Early Medieval sculptured stones, as well as the constraints that any system would have to operate under. This chapter deals with the recording technologies that are currently available, or are soon to become available. There is little point conducting a point by point comparison of commercially available products; instead, an overview of the varied technological approaches that might be appropriately applied to three dimensional recording of Early Medieval sculpted stones will be undertaken together with an examination of reasons why some recording technologies are not suitable.

4.1 Ruled out methodologies

This section briefly outlines approaches to three dimensional recording that are currently available or have been used in the past, and that are in some way capable of recording three dimensional objects such as Early Medieval sculptured stones. However, they have been discounted either because they require contact with the surface of the target object or because they fail to meet some of the other criteria detailed in Chapter 3. Special attention is given to photogrammetry and soft photogrammetry as these techniques are initially very appealing, and their shortcomings are related to the way three dimensional points are generated rather than to any of the practical considerations detailed in sections 3.4 and 3.5.

4.1.1 Casts

As previously mentioned the simplest traditional method of accurately recording a stone monument in three dimensions is to create a plaster cast (e.g. Figure 4.1). This technique has been employed for decades and allows the production of very accurate 1:1 physical facsimiles. However the potentially damaging impact on fragile stone surfaces is now considered too great for monuments in the care of curatorial organisations for them to allow it (Maxwell 1992, 8). In the past casting using improper materials has caused staining, discoloration, deposition of residual material and removal of the stone surface. In addition some casting materials chemically contaminate the surface making them unsuitable for some dating techniques (RAPP 2000, 7.4.3.5). Casts, although accurate physical records, do not allow any of the benefits that are offered by digital records in terms of mass distribution and access. There are other problems of a technical nature associated with casting as a way of capturing an accurate record, such as shrinkage of the casting material and the replication of complex surface textures. However, the fact remains that the National Museums of Scotland has a large collection of casts created during the last century, either on display or in storage. Even if no more casts are created because of the potential damage to stones, the existing casts represent a significant resource of material that could be digitally recorded. Where contact with the original stone is inappropriate, the recording of the cast (if one exists) would be an excellent alternative where the model is intended for electronic distribution. Because the casts are relatively light weight and portable, this approach could also offer the opportunity to create digital models of stones (from casts) where the necessary access is not possible for the original monument, for example because of space restrictions. Some of the techniques outlined in section 4.2 which offer good recording possibilities but need controlled lighting, such as Structured Light techniques and QTVR could also benefit from the flexibility that recording a pre-existing cast offers, allowing them to be applied in controlling lighting conditions.

Figure 4.1 The National Museums of Scotland plaster cast of the cross slab from Eigg.

4.1.2 Coordinate Measuring Machines

Co-ordinate Measuring Machines (CMMs) are a much used technology in engineering and manufacturing. Theses devices generate extremely accurate digital models of complex surfaces, and are capable of producing models accurate to the sub-micron level (Eos systems 1997, 328). The technique involves the use of a measuring point attached to three perpendicular moving carriages or a robot arm. As the pointer is drawn across the surface of the target object, the relative position of the measuring point to the carriages or the arm provide the co-ordinate measurements in the X,Y and Z axis. Unfortunately this technique requires the pointer to be in contact with the surface of the object. Some of the same considerations that make casting unsuitable also apply here i.e. the surfaces of many Early Medieval sculptured stones are considered too fragile to be recorded by any technique requiring physical contact. In addition the device requires accurate calibration between the tip of the pointer (or wand) and the fixed point against which its position is measured. This means that portability would inevitably be an issue since recalibration would be required after every move, which may be a more or less complex process depending on the specific model of CMM device. Even in cases where recalibration might be straightforward, there is no version of this device that is designed for use in any environment other than an engineering or production plant; outdoor use may present further problems as these devices are sensitive to vibration and heat. Finally cost is a very serious issue with these devices as a model capable of recording an object in the size range 3m x 4m x 2m, the range in which the largest stone crosses fall, would be in excess of $300,000 (Eos 1997, 329),(For examples see the Mitutoyo*). Despite the disadvantages of CMMs they have been used in an archaeological context. The Mechanical Engineering Department at the University of Callabria, Bologna, Italy is currently engaged in a project to semi-automate the recognition and classification of archaeological artefacts. In this project three dimensional computer models of various archaeological ceramic types, such as Kraters or Skyphoi, are generated using Constructive Solid Geometry (see 5.2.3) and recorded models of ceramic sherds recovered from excavation are automatically matched to the shapes of the complete models. This project uses a type of CMM (Microscribe 3DX*) to capture the geometry of the ceramic sherd (Figure 4.2 L.) (De Napoli et al. 2001), although it is not clear why it is considered appropriate to use a contact recording method in this project. It is also of note that although each measured point is claimed to be accurate to within +/- 0.23, the coverage of points on the surface of the object is far from consistent (Figure 4.2 R.). In the case of ceramic sherds this approach may allow a digital surface to be generated that matches the curves of the sherd, however far more points would be required in order to handle more complex shapes.

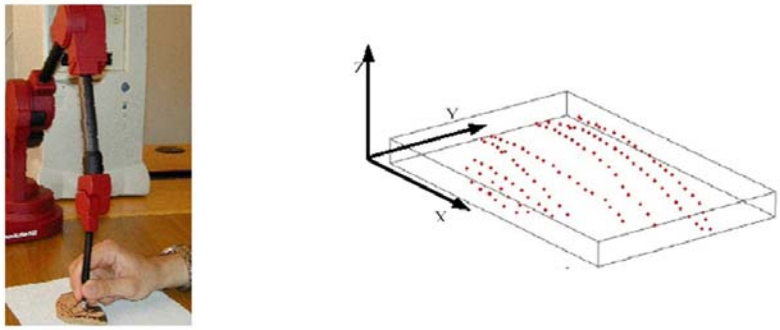


Figure 4.2 L. The Microscribe 3DX in action at the University of Callabria, image from De Napoli et al. 2001. R. Illustration showing the distribution of measured points over the surface of single shard, image from De Napoli et al. 2001.

4.1.3 Sonic and Light triangulating digitisers

An alternative approach is to use sound or light sources to triangulate the exact location of a point. Sonic triangulation devices use multiple microphones and at least one sound source. The known relative locations of the microphones in combination with triangulation algorithms allow the exact location of the sound source to be resolved in three dimensional space. A wand (that contains the sound source(s)) is brought into contact with the surface to be measured and the co-ordinates of its tip is triangulated using the microphone array, after compensating for the orientation and length of the wand. Essentially this is very similar to the CMM device except the measuring point, or wand, is not attached to moving carriages or an arm but can move freely in space. An example of a recent sonic digitiser is The Freepoint 3D Sonic Digitizer, which has a relatively large working volume of 2.4x2.4x4.8m and a claimed accuracy of 0.01mm. It could potentially be used to create models of casts as described in 4.1.1. The device is “self-calibrating”, portable, and is claimed to work in almost any environment. However, it is clear that this does not include out-door environments, where inability to control the levels of background noise could be a serious impairment to the efficiency of the system. Again this technology is ruled out because of the need for contact with the target object . However if this were not the case their unsuitability for measuring large objects and the slowness with which the points are generated mean their use might still be unfeasible.

Light triangulation technology works in a similar way. Instead of a sound source and microphone array, a light source and camera array are used to generate the co-ordinate. Two or more LEDs (the favoured light source on the wand) indicates the orientation of the wand and the exact position of the tip can be calculated (see Figure 4.3). Unlike sonic digitisers light digitisers require a line of sight between the wand and the cameras.

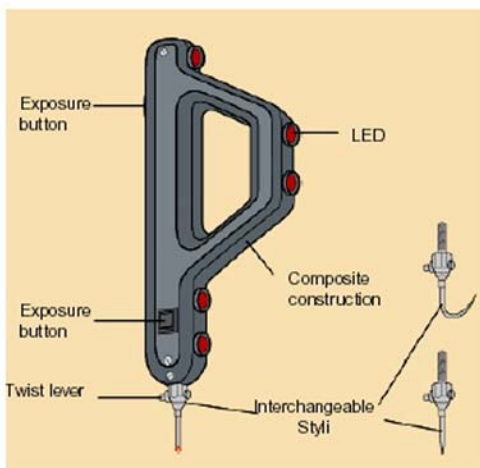


Figure 4.3 Diagram of Metronor's* 'Light pen' digitising wand (Metronor).

Even if fixed co-ordinate measuring machines, light and sonic digitisers were not ruled out because of the need for surface contact, they would still be problematic.

All these techniques are intended for use in single locations and in controlled environments. They would only be appropriate for portable sculpted fragments or stones that could be brought to the measuring device rather than vice versa, although this could include casts. Furthermore, each point on the surface of the target object has to be measured individually. For Early Medieval sculpted stones many thousands, hundreds of thousand, or even millions of points would have to be generated for a reasonably high resolution. Consequently these techniques would mean that the necessary time allocation for recording a large monument would rapidly become impractical, and this is before the knock on effects for labour costs and other time dependant factors are taken into account.

4.1.4 Soft photogrammetry

The basic concept behind soft photogrammetry is relatively straightforward and represents an elaboration of stereoscopic photogrammetry. In standard stereoscopic photogrammetry the fact that the physical relationship between the two lenses is known and constant allows for the position of objects in the resulting pair of images to be located in three dimensional space by triangulation. Soft photogrammetry uses additional calibration information and the known properties of a single camera as well as a larger data set (i.e. several images rather than a pair). A series of points that each appear on several images are manually cross referenced in software, and the soft photogrammetry application applies a sophisticated set of algorithms iteratively. The relative camera positions from which the images were captured are derived, and then discrepancies in the position of the cross referenced points between any pair of images are reduced to a level that allows soft photogrammetry to locate the point in an arbitrary three dimensional grid. The calculations involved are more complex than triangulation and the production of an initial three dimensional model is likely to involve re-referencing of badly referenced points before soft photogrammetry will successfully resolve a point cloud (Figure 4.4).

Figure 4.4 A selection of some of the twenty digital images of the Govan sarcophagus that were captured whilst it was undergoing conservation with Historic Scotland in order to generate a photogrammetric model.

The next stage in production of a three dimensional model is to specify the surfaces that the points in the cloud are associated with, this is done by specifying three points representing appropriate vertices (nodes) for a triangular polygon surface. A complete surface coverage can be built up of many triangles in this way. Finally soft photogrammetry can use photo-derived textures to render the three dimensional image giving a convincing representation of the original object, not only in shape but also in texture and colour, Figure 4.5).

In short, soft photogrammetry facilitates the creation of a three dimensional model from a set of two dimensional images taken with a single camera by the cross referencing of known points between the images.

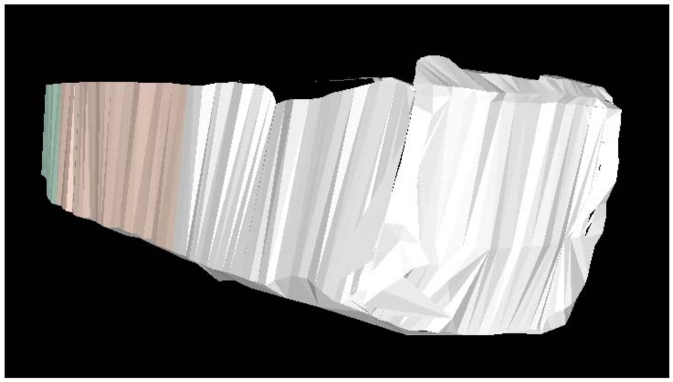


Figure 4.5 Top. The polygonal surface defined by the point cloud of the Govan sarcophagus. Bottom. The surfaces rendered with bitmaps derived from the original photographs.

This approach is initially very appealing: it requires only a standard camera for data capture, is non-contact and offers the potential of relatively accurate three dimensional models ready rendered with photo derived surfaces. Its potential for creating models of Early Medieval sculpted stones was investigated using the Govan sarcophagus which was photographed whilst it was undergoing cleaning and conservation by Historic Scotland. This allowed image capture of the complete object from a number of angles, including its underside, that would otherwise be impossible in its usual position within Govan Old Church. The application used was PhotoModeler Pro written by Eos Systems Inc.

Image capture itself is relatively simple, although good angular separation of camera position is important: as close to 90 degrees as possible is recommended (Eos Systems 1997, 39). For most subjects this should present few problems; however it is worth noting that in order to capture all surfaces on very complicated objects images may have to be taken from positions with far less angular separation than this. Unfortunately the result of low angular separation of camera positions is that, even with accurate referencing, the final point locations resolved by software algorithms may be of reduced accuracy.

The cross referencing of known points on each image is the crux of the soft photogrammetric process. This provides the base information by which soft photogrammetry resolves the 3D location of each point. In soft photogrammetry this is carried out manually: the operator examines each image, locates a point and then locates exactly the same point on another image. It is here that the accuracy of the model is most vulnerable as it is entirely contingent on the operator's judgement which itself may be restricted by the nature of the subject (e.g. lack of detail) or the quality of the image (e.g. blurred or low resolution). Furthermore, complex objects require far more reference points than simple ones which obviously contributes to the length of time required by both the operator and the software to process the project. One point relating to the actual usability of the software here is that soft photogrammetry necessarily reduces the resolution of images dependant on the number displayed on screen. Eos recommends that referencing is carried out using the highest possible resolution, this can mean frequent switching between images which adds to the time needed to create reference points, especially in a project with a large number of images.

Unlike standard photogrammetry where points can be generated independently, a typical soft photogrammetry package will either process the 'project' (i.e. produce a model) or fail to do so. Little indication is given of the overall accuracy of the model, other than a point by point indication of 'tightness' which is a measure of how much a point had to be moved in order to give it a location consistent with its position on each referenced image. Obviously in a project with hundreds or thousands of points this information is difficult to use. Again the accuracy of the surfaces are contingent on the accuracy and location of the points and are therefore even harder to gauge.

A further feature of a typical soft photogrammetry package is its ability to render surfaces from photo derived texture maps. This process gives the appearance of 'draping' or 'projecting' onto the surface of the model. This is done by a process of 'best fit', such that the image relating to that surface which requires the least distortion to fit the surface is the one from which the texture is derived. However, resolution can be significantly affected because of the recommendation that images are taken with high degrees of angular separation from each other and the requirement that each image should overlap with at least one other. The resolution (or detail captured) of the image diminishes with subject distance from the lens. In images with a high degree of perspective this can result in a differential resolution in the texture map. This is why Eos recommends a straight on image be taken of the surface to be mapped so that at least there will be a consistent level of resolution over the texture map. The straight on image will be the best fit and hence be automatically selected, although it is possible to force selection of other images. The potential problem with this is that points referenced across several images may be harder to resolve. The introduction of a third image between two images at, say, 90 degree separation obviously reduces the angle of separation between all three images to 45 degrees. In addition, the accuracy of the point solution will be dependant on good referencing in every case, i.e. a good reference will be degraded by association with a bad reference of the same point.

Soft photogrammetry claims levels of accuracy up to 1 unit in 10,000. What this means is that at the maximum claimed accuracy, a model of a 50m by 50m building facade may be accurate to 0.5cm. This implies that a subject with a maximum dimension of 2m could be accurate to less than 0.2mm. In order for either of these results to be achieved, the original image capture technique must be capable of resolving objects of these sizes; as each project is limited to one camera and lens pairing this may be easier to achieve for larger subjects than for smaller ones. Eos do make clear that a good project would actually expect an accuracy of around 1:2000 with 95% probability of all points being this accurate, *for a man made object* (Eos Systems 1997, 341). Clearly the nature of the target has a significant bearing on expected levels of accuracy, and in this instance, a *man made* object seems most likely to consist of flat planes and straight lines or consistent curves.

An example of soft photogrammetry in use for recording a building is the Theseus Temple in Vienna recorded by the Institute for Prehistory and Early History at the University of Vienna *.This project captured an entire temple with 700 points. This indicates that although the temple itself may be complex in shape, it is made up of simple shapes and those shapes had little or no surface complexity. However, for example, the columns on this temple are fluted but were treated as cylinders and the fluting is only apparent from the photo derived textures. Despite the original photographic images being chemical and scanned (at 1000dpi) the project claims that all points are accurate to within 5-15cm. Obviously for a large building this level of accuracy is quite acceptable for most purposes. The team responsible went on to create fully rendered models and VRML models as well as an anaglyph requiring coloured lenses to be worn for a 3D effect. The actual objective of this project appears to be to have been the teaching of photogrammetric principles to students.

The Waldau Flood Bridge project* was part of a restoration project run by Visuplan* Engineering and Consulting. This project is particularly interesting because it demonstrates the level of complexity that it is actually possible to capture using soft photogrammetry, and, according to Eos, it is their most complex project known.

The bridge itself is a very irregular stone built structure and it required 66 images and 40,000 points to give a model suitable for the processing. In order for this to be done the project was split in to 22 sub-projects and additional standard surveying techniques were used to tie these together. It is not clear from the information supplied that a surface model for this project was ever created, as its objective was simply to accurately locate each block and assess “integrity and consistency” in AutoCAD. The project took 6 weeks to complete, although it is not stated how many people were involved or whether surfaces were modelled. Despite this, “the successful and straight forward completion of the Flood Bridge measurement project proves that with Soft photogrammetry models of virtually unlimited size and complexity can be created”(Arnold 1998).

Mark Gilling’s and Joshua Pollard’s use of PhotoModeler to generate three dimensional models of the stones forming the late Neolithic complex at Avebury as part of the *Negotiating Avebury* project gives us the most useful benchmark to compare with modelling of Early Medieval sculpted stones. The deficiencies in the technique identified by Gillings, such as the difficulty in getting photographic coverage of the tops of stones, the need for extensive photographic coverage and overlap to get well referenced points, and the capturing of dark shadows on the images used for rendering (Gillings 2000, 68) would all apply to monolithic Early Medieval sculpture such as free standing crosses and cross slabs. Although solutions to some of these issues are possible – for instance, Gilling’s and Pollard’s use of tiddlywinks placed on the monuments as reference markers may improve the viability of the technique for the relatively coarsely dressed Neolithic stones - the fact remains that for more complex objects and surfaces the need to manually reference points makes this approach unfeasible. Even for the stones at Avebury there is detail that is three dimensional, such as polished surfaces, that is not reflected in the actual surface record of the stone but only in the photographs from which the surface was derived. Gillings and Pollard explicitly created models of the stones to be used in conjunction with topographic models of the surrounding area and presented via VR. Gillings makes clear that the intended purpose of the models was that they be part of a VR approach that is specifically not trying to perfectly replicate the original, creating a ‘manufactured deficiency’ but rather to create a “manufactured intensity……… a flexible and fluid environment for interpretation and negotiation” (Gillings and Goodrick 1996, 148). In this context, soft photogrammetry, which is cheap and relatively easy, compares well to some of the techniques in section 4.2, especially digital photogrammetry which was used in the Virtual Stonehenge project described in 4.2.5 below. The influence of the intended audience and purpose of the model here allowed a pragmatic approach to the recording phase: no need for extreme detail meant no need to utilise a technology that captured it. An even simpler approach, where no surface detail record is required, is discussed in section 4.2.5 but it is not appropriate for groups of monuments.

While a soft photogrammetry model gives a good representation of a sculptured stone with good enough detail for some presentation purposes it will not provide enough accuracy for detailed work. This means that it is unlikely to be of use in tasks such as conservation work dealing with erosional damage or analysis investigating tool use during manufacture. A further point to note is that the surfaces generated from the wire frame model may in fact be misleading, not simply being inaccurate approximations of the surface, but actually misrepresenting them. This also has a bearing on the reliability of the photoderived texture maps applied to the polygon surface as they are distorted to fit the surface in order to create a seamless texture map.

4.2 Viable methodologies

The methodologies in this section all offer automated approaches to data-capture. They all also capture point data from the surface of the target object (with the exception of QTVR). There are alternative techniques that also offer non-contact three dimensional measurement, such as radar-interferometry; however for the resolution and accuracy required for application to Early Medieval sculpted stones these five approaches represent the current best options for capturing that data. How that data is subsequently manipulated, used to generate surfaces and ultimately models is a function of post-processing and is discussed in Chapter 5. The majority of technical data in the following sections, such as figures for resolution, accuracy, and technical specifications, are derived from information supplied by various commercial organisations. The necessity for a critical approach to this type of information, as discussed in Chapter 3, is accentuated by an inability to benchmark or otherwise independently test manufacturer's claims due to restricted access to the equipment and its software.

4.2.1 Topometry, Structured light techniques

Three dimensional recording using structured light is a non-contact, potentially highly accurate technique for recording the actual surface geometry of large objects at resolutions fine enough that they approach the requirements specified in Chapter 3 i.e. less than 1mm. Like photogrammetry, the measurement principle relies on triangulation, but with this technique patterns of light are projected onto the surface of the target object. The patterns formed by the light as it falls on the surface are captured by a camera and this allows the surface of the object to be measured at discrete intervals generating a point cloud. This projection of various patterns incorporating horizontal and vertical lines (normally called fringe pattern projection) is at the heart of topometry. The science of designing these patterns, combining lines and colour and tilting fringe patterns in relation to each other is highly complex, drawing heavily on the fields of optics and mathematics (Creath and Wyant 2002). Multiple projectors and sensors (normally CCD cameras) can allow objects to be captured in a single operation, although for complex surfaces the number of sensors required to cover an entire object for one recording operation may be impractical.

Topometry has been used extensively for medical applications and has found a niche in paleoanthropology through Kullmar's work at Frankfurt University* where skulls and other hominid remains have been measured. Kullmar's project includes a database of hominid tooth patterns measured to micron level resolution and accuracy (the project is called HOTPAD*) using a ‘Grey Code’ projection technique and an optoTop 3D-System from Breukmann GmbH* (Figure 4.6). The small measured volume and the resolution of the CCDs in this system is what allows such spectacular resolution of three dimensional co-ordinates, each being calculated via trigonometry on a pixel by pixel basis (the ability of the sensor to resolve an image at a particular scale being the limiting factor in point cloud resolution). One significant advantage over laser trigonometry and time of flight recording (see sections 4.2.2 and 4.2.3) is that still images from a fixed location can be captured at the time of recording with some devices, e.g. Inspeck-EM*. This means that texture maps derived from these images can be associated with surfaces interpolated from the initial point cloud automatically via proprietary software.

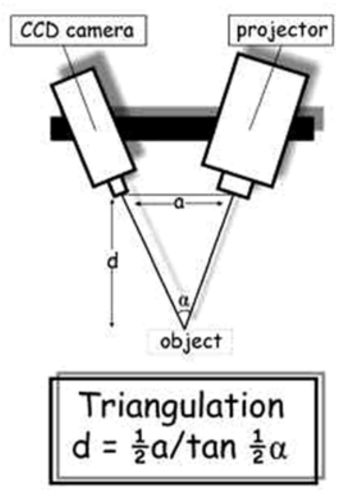


Figure 4.6 A schematic from Breuckman GmbH showing the basic topometry principle of the optoTop device.

Application of topometry to non-portable Early Medieval sculpted stone runs into two basic problems. The first is that because topometric devices rely on absolute distances, such as between the projector(s) and the sensor(s), these need to be known within extremely fine tolerances which requires extensive calibration. This calibration would have to be carried out each time the device is moved, which means that although the actual recording time is extremely fast (as low as 1 second for a complete scan) the mechanical set up is time consuming. The second obstacle is far more serious; the necessity of controlling the lighting conditions under which the recording process takes place. The projection of the fringe patterns must take place in low or very low light levels for them to be effectively detected and utilised by the sensors. For indoor use with portable objects this is not a serious restriction, since even where the darkening of an entire room is undesirable or impossible the use of portable darkrooms allows control of stray light. RSI GmbH* suppliers of the DigiScan-3D family of products also supply a darkroom structure for their devices, the largest of which is shown in Figure 4.7. It is feasible to scan stones in the field in low light conditions (at night), and it would also be possible to use portable darkrooms in the field. However, in practical terms, the time required for transporting and setting up the device in addition to the creation of a darkroom environment makes this a less attractive option for monuments in the field.

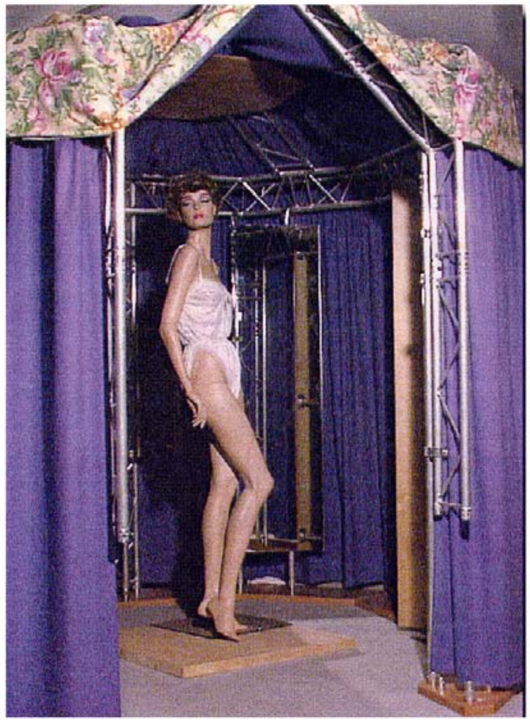


Figure 4.7 A portable dark room to control the ambient light during structured light projection for topometry using a DigiScan-3D device.

4.2.2 Laser trigonometry

Like structured light, laser (or laser stripe) trigonometry is a technique that uses light projected on the surface of the object with sensors to capture the deformation of the projected light as it falls on the surface. The nature of that deformation allows software to resolve the position of points by trigonometry. In this case the structured light being used is generally a single instance laser line. The use of a laser overcomes the major drawback of structured light systems since it is no longer essential to control all the lighting of the target object in order to recover usable information from the structured light. Lasers can be used out of doors and remain visible to the detection systems, although the rating of the laser will obviously affect the levels of ambient light in which this system can operate.

This technique can be applied in two different ways. The first is exemplified by the ModelMaker system manufactured by Nvision Inc.* (Figure 4.8). This type of recording device uses a laser stripe and sensor mounted on a mechanical arm. This gives the advantage of being able to fix the position of the laser/sensor unit in three dimensional space at all times. This is an advantage because it means that multiple scans of an object, for example to increase resolution, are always positioned accurately relative to each other. This is very important with laser trigonometry because of the small data capture area represented by the laser line length. Various sensor options are available but for high resolution recording a line length of around 20cm is normal. This can allow a resolution as fine as 0.025mm, well beyond the level of visual acuity. The fact that the laser/sensor unit has to be swept over the surface of the target object and will only cover a 20cm wide strip means multiple sweeps will be necessary to capture all but the smallest of objects. Being able to align each set of generated points into a single cloud is essential and it is the positioning of the laser and sensor unit via the mechanical arm that allows this to take place. The laser line length will vary with the range from the sensor to the target as will the accuracy of the recorded points, and the resolution between measured lines will be contingent on the speed of the sweep. For the ModelMaker the laser ratings are IIA or IIIA which gives them a peak power in excess of 1Mw, meaning that they are not eye safe devices. In addition to the health and safety and training implications of this it should be remembered that there is the possibility of invisibly damaging the stone as indicated in section 3.4.8. Another benefit of this system is the speed at which data can be captured: up to 14,000 points per second is claimed by the manufacturer.

Figure 4.8 The ModelMaker device in use recording the surface of a sports car (Nvision).

Figure 4.8 shows the device in action and also highlights the type of task for which it was initially designed. ModelMaker is extensively used in the automotive industry to monitor the manufacturing tolerances of pressed car panels. For this function a stand or desk-mounted mains powered device is perfectly acceptable, but for application to Early Medieval sculpture the lack of portability of the device limits its optimal use to recording portable objects indoors. The Conservation Centre at the National Museums and Galleries on Merseyside* have been using the ModelMaker system on range of subjects for reconstruction (see section 5.2), replication and recording, and they have also used the systems out doors, and even recorded architectural features from a scaffold (Nick Alamaris (3D Scanners UK*), pers. comm.). The system can be considered portable, in the sense that it can be moved from building to building and requires minimal set up on each move, but it is not designed for use in the field nor is it designed for environmental robustness. The most significant environmental constraint (apart from rain) is that the sensors would have difficulty detecting the laser strip in conditions of bright light (see RAPP 2000

7.4.2.1.11.6). The speed of recording, the resolution and accuracy would make this an ideal device for the recording of portable sculpted stone. However the question remains as to how feasible it would be to embark on a recording project that would require the movement around the country of hundreds (or even thousands) of archaeological items, many of which are on permanent display. In fact, as discussed in Chapter 2, the vast majority of Early Medieval sculpted stones are not portable in any practical sense. A further note of caution should be sounded concerning the cost of the ModelMaker device. A high resolution version currently ranges from £70,000 to £120,000 depending on configuration, which represents a significant investment for any archaeological project. It can also be hired, with trained staff at around £1400 a day (plus £795 per day post-processing).

The impracticality of using a static system deigned specifically for indoor use for large field monuments means that although this approach is ideal for a minority of objects, a technique that does not rely on a calibrated mechanical arm would be advantageous.

The second application of laser trigonometry that is appropriate for recording Early Medieval sculpted stones are systems that use magnetic or radio trackers to monitor the location of the laser unit in space. The example system used here is the Polhemus Inc.* FastSCAN device. The technical specifications for this device claim an accuracy of just over +/-1mm and resolutions between 0.5 and 1mm, although both accuracy and resolution are contingent on wand-object range and speed of travel, and accuracy is additionally contingent on the range between the radio/magnetic tracker receiver and the object. The data from the scan is downloaded from the device to a laptop and the efficacy of the scan can be monitored in real time. This was initially tested on a small portable incised stone from Ballachly (Caithness) with good results. Several sweeps were taken over the stone, combined and decimated to create a regular 0.5mm resolution grid. In Figure 4.9 the lightly incised lines comprising the decoration can be seen to have been captured.

Because this device is truly portable (it can run from a generator or batteries) it clearly has potential for recording a far wider range of monuments than the ModelMaker type device. Furthermore, as it is handheld many of the issues of access that affect tripod mounted devices, either cameras or laser scanners, are avoided. This device is capable of recording surfaces that would cause major difficulties for other devices, as the user can simply point the device at the surface to be recorded, (Figure 4.10). Polhemus Inc. do point out that as scanning relies on the two sensors (mono DVCs) being able to see the scan line, some surfaces, such as translucent, reflective, dark or deeply convoluted surfaces, may cause it problems and ambient light below 200 lux is required for best results.

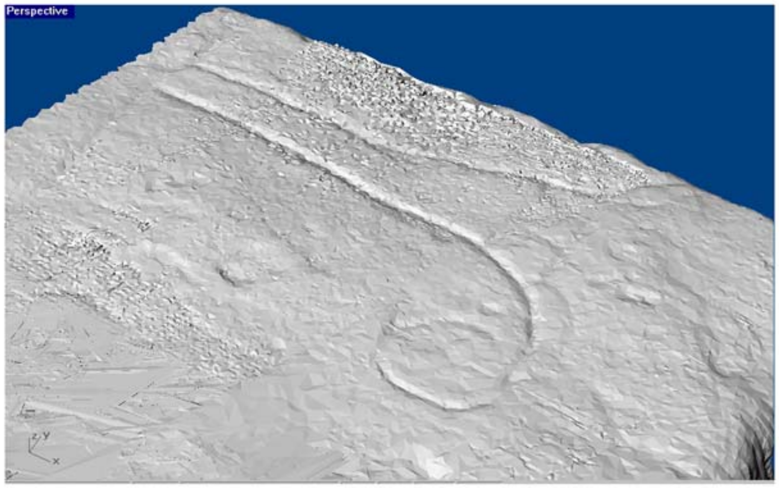


Figure 4.9 Top. The incised stone found in Ballachly, Caithness in 1998. Bottom. a TIN generated from a point cloud captured using a FastSCAN device showing a detail of the cross.

Figure 4.10 L. Archaeoptics performing a FastSCAN scan on the Jordan Hill Cross, Govan Old Parish Church. R. Archaeoptics render of the horseman panel of the cross. Copyright Archaeoptics 2000.

The magnetic tracker used has a range of up to 68cm, i.e. the wand can be 68cm away from the magnetic transmitter and still be located. This range can be extended by relay devices, but unfortunately the presence of metal objects interferes with the trackers performance causing it to degrade. In capturing data from medieval sculpted stones this may not seem like an immediate consideration; however many monuments have metal either attached or in close proximity (such as staples and fences). This is especially true of monuments displayed or stored indoors where the presence of metal is very commonplace.

Archaeoptics*, a Glasgow based company with a commercial interest in scanning archaeological material, have carried out extensive tests and commissions in addition to the demonstration scan of the Jordan Hill cross. The most impressive application of this device on Early Medieval sculpted stones to date is the generation of a 0.5mm resolution ‘watertight’ model comprising 6,800,000 triangles of the Govan sarcophagus. Comparison of this model, (Figure 4.11), with the model of the same monument generated using soft photogrammetry (Figure 4.5), which consisted of under 100 triangles further demonstrates why soft photogrammetry is perceived as unviable for this level of three dimensional recording. The Archaeoptic’s model was later used as the basis for a 1/3 scale physical facsimile of the sarcophagus using sterolithography.

Archaeoptics have also used the device to scan the Kirriemuir I symbol stone in Forfar (NMRS no. NO35SE 20). The purpose of this scan was to try and resolve a question relating to an unidentified feature on the chest of a carved figure on the monument. Figure 4.11 provides a comparative images of the figure. In the end the results proved as inconclusive as examination by eye and examination of photographs. In this instance this is most likely because the feature was so slight that it would elude definitive identification by any technique. It is not clear that scans that are above the level of resolution of normal visual acuity will be able to provide the basis for models that allow clarification of this type of question.

The current cost of the FastSCAN is approximately £27,000 (or £450 per day, plus post-processing), which compares very favourably with devices like the

ModelMaker, although this has to be balanced against the different potential resolutions of each system.

Neither of the laser trigonometry devices capture photographic images at the time of scanning, despite the sensors being CCD cameras. This means that for photorealistic rendering, separate images are required and their application to the model must take place in post-processing. Polhemus Inc. intend to enhance their device to provide this functionality by using an additional camera to capture greyscale values for points on each sweep. This would be a major step forward in the technology and, if photorealism is considered desirable, then this would be the obvious solution for capturing the base images.

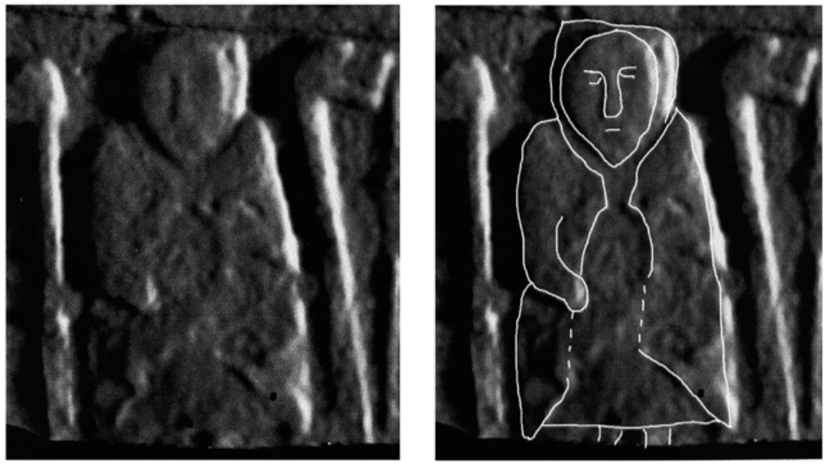


Figure 4.11 Top. A still of the high resolution scan of the Govan Sarcophagus, flat rendering. Bottom. The Kirriemuir figure, the right side version of the figure has had the outline of a cloak superimposed upon it by Archaeoptics. All images copyright Archaeoptics 2000.

4.2.3 Time of Flight Laser Scanning, Lidar

Time of flight laser recording utilises the properties of laser light in a totally different way to that of laser trigonometry. The simplest application of this technology is the Electronic Distance Measurer (EDM) that in combination with a theodolite comprises a Total Station. Here a laser light is directed at a prism and a time of flight measurement is taken allowing the range from the laser source to the prism to be calculated. Measurement Devices Limited (MDL*) produced a target-less version of the EDM, that does not require a prism, but relies on the light being reflected from the target surface. Their device (the Surveyor ALS) has the laser and measuring units mounted on a motorised scanning head that allows hundreds of measurements to be taken without a user having to re-aim the device after each 'shot'. The original purpose of this device was to measure the surface of a quarry face before and after blasting so that the exact quantity of the material removed by the blasting operation could be calculated. The maximums claimed for accuracy and resolution were given as 2cm and 1cm respectively and the scanning rate was given as 3600 points per hour (1 per second). The point co-ordinates are stored on board the device or on an attached data pack and could be downloaded after the recording operation. The resolution and accuracy figures were dependant on the laser unit whilst the rate of measurement was dependant on the efficiency of the motorised head. After a trial, due to the low maximum resolution and accuracy and slow scanning rate the Surveyor ALS was not considered appropriate for recording Early Medieval sculpted stones. Despite this, the technology itself was noted as having enormous potential and has in fact been used in other archaeological contexts (see section 5.12).

In 1999 Babcock Rosyth Defence Ltd, purchased a Cyrax 2400 device from Cyra Inc.* This was the first of these devices to become available in the UK and only the second in Europe. Working on similar principles to the Surveyor ALS, the Cyrax 2400 used a mirror to target the laser and a laser unit calibrated for more accurate measurement (at the cost of a shorter range). These and other differences meant that the Cyrax 2400 was capable of measuring 800 points per second at a maximum resolution of 2mm. Although this resolution was still a long way from the ideal, as with laser trigonometry it is possible to combine several offset scans, massively increasing the actual resolution. Whilst this may not be practical if the scanning rate is in the region of 1 point per second, the Cyrax 2400 rate of 800 points per second makes this feasible.

A demonstration of the Cyra machine was carried out on the Aberlemno II stone and later on an Iron Age structure at Minehowe, Deerness, (Orkney) as it was undergoing excavation. Unlike the handheld FastSCAN device, the Cyrax 2400 is a tripod mounted device which means that multiple scans are necessary to capture the shape of an object with the device and tripod being moved between scans to ensure appropriate coverage. The size and shape of the device also raised questions regarding whether this configuration would be able to scan objects with very convoluted or complex features or that were located in spaces with restricted access. To a certain extent the scanning of the interior of the Iron Age structure at Minehowe alleviated the concerns regarding areas with restricted access. As demonstrated by Animation 4.1 the structure is a very confined space. It was effectively scanned in one day, simply by detaching the device from its tripod head and resting it on the ground at various locations within the structure. The ruggedness, portability and flexibility of system were all demonstrated simultaneously. The end result, a VR model and animation was ultimately used on Channel Four's Time Team documentary on the excavation.

The scanning of the Aberlemno II stone was the first time that this technology had been applied to Early Medieval sculpture and also the first time that BRE's Cyrax 2400 had been required to perform a scan with a resolution as low as 2mm (Figure 4.12). The system uses proprietary software loaded on a ruggedised laptop in the field that accepted measured points in real-time. As with the FastSCAN system this allows scans to be monitored as they are generated. The ability to monitor the scan in real time is particularly important for devices like the Cyra 2400 because, unlike laser trigonometry devices, there is no line indicating that the required surface coverage of the target object is achieved. This means that in order to achieve full coverage of complex and convoluted shapes in the field it is highly desirable to be able to see an indication of the cover on screen as it happens. In order to register the necessary multiple scans the Cyra systems use geometric shapes as targets that should appear in each scan. At Aberlemno spheres were used. The reason for this is that the software is able to detect the area of the point cloud that represents the scanned spherical target. Once it is detected the software can resolve both scale and a centre point for the target, and with more than one target in each scan, the centre points can be used as common reference points allowing the scans to be accurately registered.

The initial attempts to generate a surface from the captured point cloud in the field highlighted a significant problem with the system as it was configured at the time. At a 2mm resolution the Cyrax scanners accuracy was low enough that the resulting polygon surface was extremely rough. This was a result of unsystematic errors in the accuracy of the point scan i.e. the direction and amount of the error on each point was not consistent. The resulting rough surface was therefore entirely an artefact of the scanning process. This problem could be tackled in two ways, the first is via post-processing in software which is discussed in section 5.1.2 and the second is by recalibration of the laser and sensor for higher accuracy and lower range. This recalibration would require the entire system being shipped back to Cyra's headquarters in California and would also mean that other functions of the device would be disrupted due to its reduced range. This means the device would have to be dedicated to close range work, drastically reducing the flexibility of a device which costs in excess of $100,000 and would be a more attractive investment if it could be applied to a range of material including buildings.

In comparison to topometric systems and even the trigonometry systems discussed in the previous two sections, the ruggedness and environmental robustness of the system is impressive. Even light rain and humidity are not considered problems, although the device should ideally be kept under cover with an umbrella or similar. The Laser Mapping team who operated the machine had learned to use packets of silica gel inside the device (which is not a sealed unit) to stop the inside glass surfaces from misting.

An important further application of the Cyrax range of devices is topographic survey. Used as an ultra fast target-less EDM with a range as long as 100m fine scale (e.g. 10-25cm) DTMs can be generated with ease. In this was fairly large areas of landscape can be recorded with impressive accuracy. The actual necessity or otherwise of this type of DTM is discussed in section 5.3.

Figure 4.12 The Cyrax 2400 scan in progress in Aberlemno Churchyard. The orange spheres are registration targets for multiple scans.

Animation 4.1 An animation taken from the BRE Cyrax 2400 scan based VR model of the enigmatic ‘well’ structure at Minehowe, Orkney.

A second commercially available device was also tested on the Early Medieval sculpture of Govan Old Parish Church. This was because, as mentioned above, the Cyra device was not in fact calibrated for resolutions below 2mm. This device, similar in principle to the Cyra scanner, was manufactured by Callidus* and uses prisms to reference multiple scans. The prisms themselves can be independently and accurately located in 3D space giving the entire point cloud real world co-ordinates if required. Because the Callidus is designed for ‘as built’ survey, its selling point is a rotating head that can scan an entire room in a single operation, (for an example of this see Figure 4.13). This may not have immediate benefits for the capture of Early Medieval sculpted stones, but like the Cyra system it can also be used to conduct micro-topographical survey, such as the recording of immediate landscape or display context of a monument.

As with the Cyrax 2400 the referencing of multiple scans is a far more serious issue than it is with laser trigonometry, relying as it does on software functions to orient and join individual point clouds after the data capture phase. This is not usually done by ‘best fit’ algorithms but by using the reference targets which have been included in each scan, spheres in the case of Cyra and prisms in the case of Callidus.

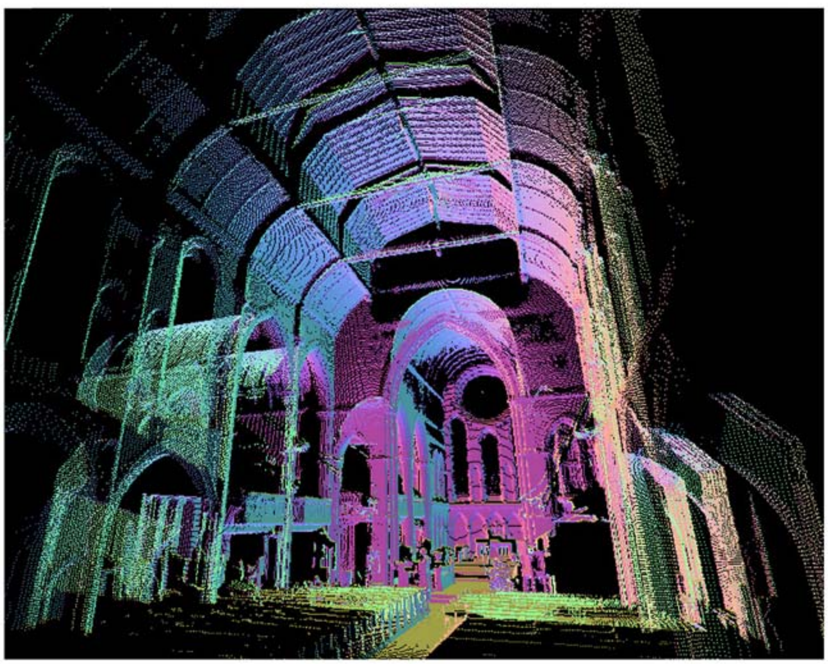


Figure 4.13 This is a range image of the interior of Govan Old Parish Church generated by a single Callidus scan.

Time of flight laser scanning technology is developing at a very fast rate, even in comparison to other digital technologies, and as a result accuracy, resolution and flexibility will all improve in the near future. Most devices as they stand at the moment are designed for survey work, and their primary use in archaeology will be standing building and site survey as well as micro-topographic survey.

4.2.4 Digital Photogrammetry

A useful photogrammetry project to examine in order to gauge the appropriateness of this technique for recording Early Medieval sculpture is the work undertaken by the Photogrammetric Unit of English Heritage* from 1993-1996 to record Stonehenge by semi-automated photogrammetry. The project had two main objectives: first, to create an accurate high resolution photographic record of each stone in the monument complex, and secondly to create a full set of three dimensional survey data of the stone's surfaces such that each stone could be tied accurately to its neighbours and to the surrounding landscape. The anticipated use of the data was by conservators and researchers and an aim of the project was to make the data available on standard PC's and using a 'standard' application such as AutoCAD. Close range photogrammetry was at the time seen as the most efficient approach because it not only supplied the photographic record, in the form of stereo pairs, but also allowed the three dimensional model to be generated from those images by photogrammetry. Balancing file size against resolution, the EH team established a recording interval of 2cm (i.e. points were located in three dimensional space at 2cm intervals over the surface of the stones), estimating 60,000 points for a typical stone and 6mb per file (a relatively small file size by today's standards). Photogrammetry relies on the fact that the distance between the lenses of the camera taking the stereopairs is known exactly, and the location of target observations (which have been resolved in 3D space, using a Total Station) are visible in each stereo pair. The captured data set consisted of 671 images (stereo pairs) and 1482 target observations. The generation of the surface models, referred to as Digital Elevation Models (DEMs) by EH, took place on a specially configured digital photogrammetric workstation after the images had been scanned by a high resolution scanner. This eventually allowed the creation of 350 models of 70 stones (Bryan and Clowes 1996).

The end result is extremely impressive, especially those images with photographs ‘draped’ to effectively render the surface. These models were used as the base for the ‘Virtual Stonehenge’* project funded by the Intel Corporation and EH, which combined the models of the stones with digital terrain models (DTMs) of the surrounding landscape in a VR model of the whole complex and its surrounding area. Models of monuments in context are discussed more fully in Chapter 5; however it is important to note that the original data set had to be drastically reduced in complexity by filtering out points from the DEMs of the stones in order for them to be presented in this way.

This approach would seem to offer excellent potential for the recording of Early Medieval sculpted stones, but there are drawbacks that make it less attractive. First, the process was extremely time consuming. The project itself took over three years, despite fieldwork and desk based model production being sub-contracted to specialist companies. Second, the resolution of a 2cm regular grid is undoubtedly suitable for large roughly dressed monoliths but, as discussed elsewhere, Early Medieval sculpted stone would ideally require a much finer resolution due to the complexity of the surfaces to be recorded. There is in fact some carved detail on the Stonehenge monoliths, such as incised ‘daggers’ and later graffiti, which would not be adequately recorded with a 2cm resolution. Very fine resolutions are possible using photogrammetry but in this project up to 10% of points generated by this system need manual intervention, which means that the datasets generated are both time consuming and subjective.

The Rock Art Pilot Project commissioned in 2000 by English Heritage to investigate a number of aspects of prehistoric rock art in England also examined the use of close range photogrammetry on three rock art panels. This project created a Digital Elevation Model (DEM) with a resolution of 0.5mm and an accuracy of 0.3mm (plan) and 0.8mm (height). This resolution and accuracy was obtained using basic camera equipment and automated data processing (RAPP 2000 7.4.2.1.9.4). This is in contrast to the complex multi-camera systems favoured for close-range photogrammetry in museum and art gallery contexts (e.g. Pedersini et al 2000). The increased availability of high end processing power on PCs as well as the development of ever more sophisticated image matching software may result in the previously expensive and complex world of digital photogrammetry being more and more accessible to the non-specialist (Jacobsen 2001).

Photogrammetry remains a much favoured method of recording standing buildings, organisations such as the International Committee for Architectural Photogrammetry (CIPA)* (part of the International Council on Monuments and Sites (ICOMOS) and funded by UNESCO), have actively encouraged and even funded a number of international projects where monuments are in need of precision recording (Desmond 1994). This is a well understood technology and its applications to standing buildings or even complexes of buildings such as at Yucatan (Mexico) (Desmond 1994) and Petra (Jordan) by Brown University's ambitious SHAPE* project, continue to create exciting products. However for smaller, more complex objects requiring fast scan times and large numbers of captured points it is being increasingly superseded by other techniques.

A number of projects to record standing buildings with complex architectural features are adopting pragmatic hybrid approaches using both photogrammetry and, for example, laser scanning. The SHAPE project in Petra is one such project and another is the Malta Centre for Restoration recording of Pre-historic Maltese temples the hybrid approach is dubbed 'Thealasermetry' (Borg and Cannataci 2002). Another hybrid approach uses time of flight laser scans, but aligns them to a global co-ordinate systems using close range photogrammetry (for an example using Donatello's Maddalena see Beraldin et al. 2002).

4.2.5 QuickTime Virtual Reality

The inclusion of Quick Time Virtual Reality (QTVR) may seem surprising as the technique does not generate any topographical information for the surface of a target object at all. Instead this technique uses a series of strategically captured photographs which are presented to the user in such a way that the illusion of three dimensionality is created. On the face of it this may seem to be little more than an elaboration of the decades old tradition of archaeological photography. However, most three dimensional models are actually presented to the user as animations; as interactives or as still images, in other words these models are themselves being presented as a series of two dimensional images that give the illusion of three dimensionality. With QTVR the modelling stage is omitted, the still images are captured from the real world object and the result is a presented as single interactive digital file. Although the resulting ‘object movie’ is not a true three dimensional model, for many archaeological applications the ability to convincingly imply three dimensionality of an object is all that is required. Furthermore, the technique is fast, cheap and simple for small objects (for an example see Object Movie 4.1).

Object Movie 4.1 A planar object movie of a bone tool fragment from Minehowe (Orkney), (OAT/Northstar).

Quick Time Virtual Reality (QTVR) is most familiar as a technique for presenting panoramic landscape images and objects over the internet and is a technology designed by Apple specifically for the internet. For environments, a series of images taken from a single location are stitched together to form a 360 degree panorama. This panoramic image is then conceptually projected onto the inside of a cylinder, and the user is able to view the image through a window situated at the centre of the cylinder, referred to as a node, panning round the cylinder and also zooming in an out. This is known as pseudo-immersive virtual reality and the use of the technique has exploded in the last few years and is also found on archaeological web sites where landscape context and visualisation are important (e.g. McElearney 1999; Krasniewicz 2000) (for an example of a QTVR panorama see Panorama 4.1).

QTVR treats objects in a different manner, effectively the opposite of the environmental panoramas described above. Here the object sits in the centre of an imaginary globe and a series of images is taken of the object from around the inside surface of the globe. The images are then presented in an interactively defined sequence that has the affect of animating the movement from image to image making the object appear to rotate in the viewing window (for an example of an object movie of a small artefact see Object Movie 4.1). In order for this rotation to appear smooth, the horizontal and vertical angular separation of the original images must be carefully controlled. This is ordinarily done using a turntable or a specifically manufactured “object rig” (Figure 4.14). These cannot be used with large immovable objects, for example a cross slab *in situ*. In such cases other methods for controlling the camera positions must be used, such as using an EDM to accurately position the camera

Figure 4.14 An object rig in operation. The camera is attached to the moveable curved arm and can photograph the object (in this case an iMac), from any angle with high precision. This object rig is manufactured by Kaidan*.

Panorama 4.1 A linked sequence of QTVR panoramas of Dunadd Hillfort (Argyll). The user can navigate from the plain surrounding Dunadd hill via a series of panoramas to the summit, using hotlinks embedded in the panoramas.

Because Object Movie models have no underlying three dimensional surface record the techniques of digital modelling and QTVR are not fully interchangeable, although it is possible to present animations generated in three dimensional modelling packages using the Quick Time Player media plug-in (e.g. Object Movie 5.3). For QTVR panoramas the reverse is also true, panoramic landscape images can be used to contextualise true three dimensional models (Jeffrey 2001). Using this approach the resulting combined model can be presented either via standard VR packages, as an animation or via the QTVR plug-in (Animation 5.5 and Object Movie 5.3). One of the most obvious benefits of applying QTVR Object technology to monuments in the landscape is that in order to present the monument in its landscape context no additional recording is required the original photographic sequence will have captured the surrounding landscape as well as the monument (see Object Movies 4.2 and 4.4)

The full range of difficulties that arise in applying Object Movie technology to large and immobile objects situated in the field can be demonstrated by the example of the St.Orland’s stone at Cossans (Aberdeenshire) (Figure 4.15). The most obvious problem is that the vertical frames that would be required to allow the user to change their viewing position to examine the top of the monument would need some kind of aerial access platform or scaffold to capture, this was deemed impractical and was not attempted for this monument. An attempt was made to capture an Object Movie of this stone by using an EDM and a laser level in order to position the camera at precise locations around the monument, even though the ground surface was uneven and fell away dramatically at one side of the monument. This was not wholly successful and the initial object movie had considerable ‘jitter’ creating the unwanted impression that the monument was jerking around in space (Object Movie 4.2). This is a very serious problem and one that is unlikely to be countered by any but the most elaborate hardware solution that may involve such expense that full digital recording by one of the previously discussed techniques might actually be cheaper, negating one of the major advantages of QTVR. The other possibility for countering the very serious difficulties in positioning the camera for good quality Object Movies is to post-process the images in order to correct their misalignment. This post-processing, along with the associated problem of frame rates, is discussed in depth in section 5.1.3 and it can in fact produce acceptably smooth Object Movies (see Object Movie 5.1).

Figure 4.15 St Orland’s stone

Object Movie 4.2 A QTVR object movie of St Orland’s stone showing serious misalignment, too few frames, deep shadows and poor resolution.

Just as serious as the ‘jitter ‘ caused by misalignment of the images are the problems of clear access, natural shadows and resolution. Object Movie 4.2 demonstrates all these problems. Access is a problem for all the techniques discussed this section, however whereas most of the techniques do not have to ‘see’ the entire object in one go, they can scan small sections and then stitch the scans together, for Object Movies the entire object must be seen in each shot. If only a part of the target object is photographed in a sequence, there is no easy way of stitching more than one sequence together to make them appear as if they were taken as a single sequence (although it is hypothetically possible). The fact that the entire object has to be seen in each frame also means that access must be clear all the way around the monument allowing the camera to be placed at the same distance from the monument for each frame. With a standard 35mm lens it may be necessary to place the camera quite some distance from a large object in order to get it all in the frame. As well as requiring a large clear area around the monument this also has implications for the level of detail that will be seen in the final model. The further from the target the less detail will be recorded. This can mean that for highly detailed carving the photograph needs to be taken using a large format digital camera in order to capture the appropriate level of detail. For Object Movies tasked for internet delivery this may not be important because the delivered file is likely to be highly compressed in any case, however if the Object Movie model is intended as a record then the resolution at which the initial images are captured is of major significance. Object Movie 4.2 also shows the permanent metal fence that surrounds the St. Orland’s stone, it was not possible to take the images from inside the fence because it was impossible to frame the entire monument at such close range. Being forced to capture the sequence from outside resulted in the fence appearing in the finished model.

The fence also cast shadows onto the monument obscuring detail. This would have been considered problematic if it was not made unimportant by the fact that natural shadow obscures one entire face of the monument. This draws attention to the other major problem with this technique when applied to objects in the field. Ideally all the frames in a QTVR sequence should be captured under identical lighting conditions, this means that frame transitions are not made more noticeable each frame having a different colour/brightness balance caused by changes in aperture. There is no easy solution to this problem. If one side of the monument is captured in sunlight, say in the morning, and the reverse is captured in the afternoon when it is illuminated by sunlight, not only might lots of other factors have changed in the frame (e.g. clouds move, or it has started to rain), but shadows will fall in two directions in the same model.

There are a number of possibilities for gaining more control over the lighting conditions under which the images are captured. These are quite dissimilar to the way that an object can be well lit for a single still image. To avoid poor frame transitions each base image for the QTVR sequence would have to taken under the same lighting conditions, direction as well as colour and intensity. This can never happen under natural lighting conditions, and even using lamps the entire object would have to be lit prior to the sequence being taken. In order for the natural lighting conditions not to interfere with the artificial set up, the sequence would have to be taken at night, preferably a moonless night (or less feasibly, under cover with a mobile dark room such as that illustrated in Figure 4.7, 4.2.2).

If it is accepted that the object movie is intended as an illustration rather than a three dimensional record and that the level of detail needed for the illustration does not require the sophisticated control of lighting that a high quality photographic record might offer then natural light may be acceptable. In this case dull, shadowless days would be best. Low light levels can be compensated for during photography, but again to avoid poor transitions the lighting conditions between frames must be as similar as possible.

In the case of finely carved or inscribed stones changing the angle of the lighting under which the surface is viewed may be the primary objective. A three dimensional surface model can be flat rendered and ‘virtual’ lighting applied to the surface. This process would require the capture of a high resolution point cloud, the generation of an appropriate surface and then a presentation technique that allows the user to interact with the virtual lighting. In many circumstances this may be an elaborate, time consuming and expensive procedure when compared to an Object Movie where as an alternative to moving the object or camera between frames the position or intensity of the light source is changed. This technique was applied to a finely incised medieval slate slab uncovered during excavation at Tintagel castle* (Figure 4.16). Although this was a portable object the technique could equally be applied to incised panels on larger monuments as the camera position is static for each frame and only the light source has to be moved.

Figure 4.16 The incised slate from Tintagel (Cornwall), bearing the inscription “Artognou”.

The artefact was photographed from the same position 18 times, but the light source was moved around the object roughly twenty degrees between each shot. The Oblique angle at which the light struck the surface of the slate was kept constant at around 30 degrees. The resulting object movie allowed the user to view the complex series of inscriptions from 18 different lighting angles from within a single package.

This compares well to traditional photography and publishing where, as described in Chapter 2 (2.3), only a very few photographs tend to be presented and in each it is the photographer, not the viewer who makes the decision on which angle of lighting is most appropriate. The example of the Tintagel slate used here also highlights another drawback with traditional photographic presentation, when one interesting section of the slate is well lit, other sections are in shadow and vice versa. A technique that would allow multiple lighting angles to be explored would mitigate against the potentially spurious impression that those areas in shadow are not as archaeologically significant as those well illuminated, by allowing the user to select the most appropriate angle of lighting for their purposes.

With 18 frames the transition between each frame was quite apparent, in order to counter this a further 18 frames were ‘interpolated’, one interpolated frame between each original frame. This was done manually in an Adobe Photoshop by overlying the two original images at 50% transparency to create the new image. In the resulting model (Object Movie 4.3), not only has much smoother transition, it is almost impossible to tell which are the original and which are the interpolated frames. Interpolation in QTVR is examined in the next Chapter (5.1.3.2), however for a genuine record it would be unacceptable to have interpolated frames unacknowledged visually in the final product.

A useful enhancement of this technique would be to use the ‘spare’ vertical frames in the object movie to take further sequences of images but with the angle at which the light falls on the stone being altered. This would allow the user to interactively select both the horizontal and vertical angle of the light in the model. Altering the light colour or intensity is also possible using this technique. A simple example of where this was done experimentally can be seen in Object Movie 4.4 where one of the prehistoric standing stones on Machrie Moor (Arran) has been captured as an Object Movie, but instead of the vertical frames being used to change the viewpoint to a higher position, when the user draws the cursor upwards it changes the scene from daytime to night time (note: these are touched-up images to give the appearance of images taken just after dusk.

Object Movie 4.3 The Tintagel slate Object Movie. The user can use the grabber tool to change the position of the light source in order to better illuminate various segments of the slate.

Object Movie 4.4 One of the prehistoric monoliths from the Machrie Moor complex in an environment where daytime or night time lighting can be selected.

For small objects it is even possible to semi-automate the image capture process. The use of a computer controlled ‘flash dome’ (Matzbender et al 2001) (Figure 4.17) has been used to rapidly capture complete sets of images of small fossils. The Geological Museum of Oslo* uses 50 computer-controlled flashes mounted on an acrylic dome (hemisphere of diameter 40cm) A digital camera was mounted at the top of the dome, pointing directly down onto the target fossil. The flashes are synchronised with the camera exposures and bespoke software controls the flashes, the camera, and the transfer of images to the computer in an automated sequence.

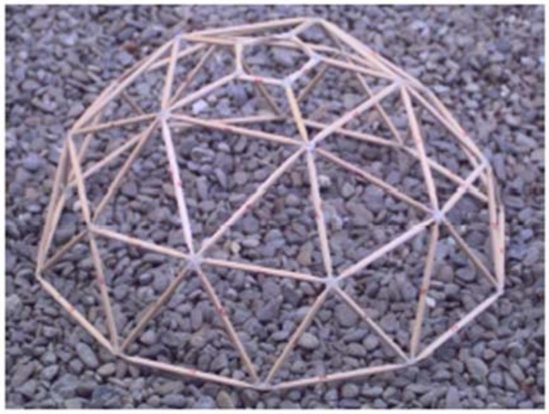


Figure 4.17 The Oslo light dome.

Although this is a novel and useful tool for generating Object Movies of small artefacts with interactively controllable lighting positions, the actual purpose of the geological experiments in Oslo and elsewhere was in a fact to capture base data for polynomial texture maps (PTM) for increased photorealism and to assist in bringing out low surface relief. The capturing of reflectance values using multiple camera and lighting positions for techniques similar to PTM is discussed in section 8.1.2

Finally, it should be noted that although QTVR object movies have no underlying three dimensional model and their main benefit (apart from cost and simplicity) is that they can capture the landscape context of a monument as well as the monument itself, this does not mean that they cannot be used for recontextualising monuments that are located away from their original context. It is possible to extract the part of an image that relates to the monument only and replace the background of each frame with a panorama captured from an other location or even a completely manufactured background. This process is being assisted by the addition of 'masking' tools in the latest versions of Apple's QTVR development tools, however it should be pointed out that the process still operates on a frame by frame basis, is not fully automated, and as a result can be complex and time consuming. This means, that for the time being at least, presentations that require a monument to be represented in a different location from where it actually is at the moment may still be more conveniently generated from three dimensional surface models.

5 Records of sculpture and models of conjecture.

As with many archaeological processes, from excavation to field survey, gathering the data is just the start of the story. In the case of three dimensional models of Early Medieval sculpted stone the data are likely to be a series of digital images, a point cloud or a surface derived from a point cloud. This Chapter discusses some of the processes that take place after the data capture phase for some of the modelling techniques, with special reference to the levels of user intervention required (in this instance the ‘user’ is the user of the modelling application rather than the end-user of the model). This is sometimes referred to as ‘post-processing’ and is often a time consuming and non-trivial task, requiring knowledge of the appropriate modelling concepts and the software applications used to generate the model. More importantly it requires an understanding of the archaeological significance of various elements of the target objects and of the audience for whom the model is ultimately intended. It is these attributes that inform the sequence of judgements and subjective decisions that transforms a collection of apparently ‘hard data’ into a useable archaeological model.

Beyond the collected data lies the realm of archaeological and artistic reconstruction. This can be the joining together of separated fragments that were unarguably intended to be part of the same object, or the hypothetical reconstruction of missing fragments, or both. If three dimensional models are being generated from records of the extant material it can seem logical to represent rejoined and reconstructed sections in a similar fashion. In this way computer models can be used to represent the complete object and not just the fragments that remain. This Chapter looks at some of the techniques for doing this and discusses some of the archaeological issues that are raised by going one step beyond recording what has been found by recreating what has been lost.

5.1 User Intervention in the modelling process.

There is as yet no set of complementary hardware and software that would allow a user to point the hardware at an object and without further intervention generate a suitable model. In fact the host of post-processing stages can be more time consuming than the initial data capture phase. And it will often involve high levels of user intervention. To investigate the levels of user intervention required, three examples will be explored here:

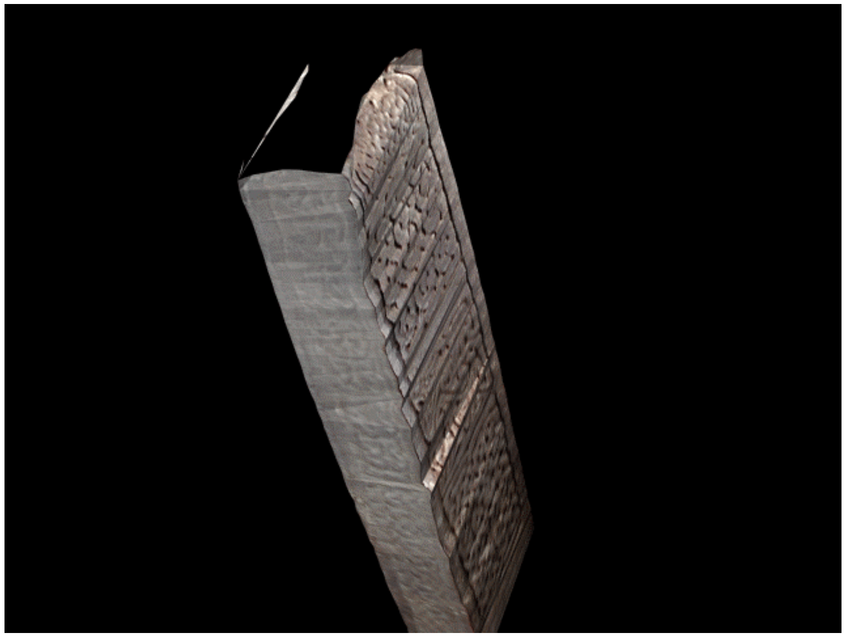
- the creation of a model of the Jordanhill Cross, currently on display in Govan Old parish Church (Glasgow, NS56NE 17). It is a free standing cross tentatively dated to the 10th or 11th (Fisher 1994, 47) currently missing both its cross head and its basal section. In the case of the Jordanhill Cross, the data capture technique was photography and the point model was generated using soft photogrammetry as described in Chapter 4. Although this technique for model generation was later ruled out as a viable methodology for a SEMSS project, the post processing steps described below would apply to many models irrespective of the data capture technique.
- A partial model of the Aberlemno II stone standing in Aberlemno Churchyard (Angus, NO55NW 26) dated to the 8th century. The difficulties associated with rendering a model with a suitable surface is explored using the partial model of the Aberlemno II stone, generated from a Time of Flight Laser (or Lidar) scan using a Cyrax 2400 device.
- The creation of a QTVR object movie of St.Orland's stone, Cossans (Angus, NO45SW 4), of a similar or earlier date to Aberlemno II. The Cossans stone's initial data capture technique was also photography, again as described in Chapter 4, and the post-processing techniques described relate to both QTVR object generation and a prototype but potentially useful enhancement that has been investigated at Glasgow University but is not commercially available. (Figure 5.1).

Figure 5.1 L. Aberlemno II cross face, M. The Jordanhill Cross, R. St Orland's Stone and its surrounding landscape.

5.1.1 The Jordanhill Cross

With the use of soft photogrammetry the initial data capture phase is photographic and the point cloud is actually generated in software. Here the post-processing is the creation of a model for presentation, beyond simply defining the surface polygons and rendering them from bit-maps. There was no polygon surface of the top of the monument, there being no photographs from which to derive this surface. Similarly the monument was initially modelled (Mardon 1998) complete with the modern base in which it is displayed in Govan Old Parish Church. The first decision taken was that the model should not include the modern base. In order to manipulate the PhotoModeler model it was imported (via VRML) as a mesh into 3D Studio Max, a three dimensional modelling and animation package that is one of the most successful in the commercial market. This application allows the manipulation of any wireframe mesh down to individual vertex level and provides a host of tools for preparing the model for presentation. The first step was to delete the base from the model, which was achieved by simply selecting and deleting the relevant mesh nodes which automatically deleted (or culled) the polygons that were associated with it. The resulting mesh model was now essentially a tube, with a roughly rectangular section. In this state the model actually represented the recorded surface; any further manipulation of the mesh would create a model containing elements that were not recorded. However, to present the model as a tube, without top or base, would give a spurious impression of what the actual monument was like, i.e. a solid stone object. Consequently ‘false’ surfaces were used to patch the holes in the top and bottom of the monument in order to create the impression of a solid object. This process was again relatively simple in 3D Studio Max: mesh surfaces were generated and their nodes ‘welded’ to the nodes in the original mesh. Without rendering the polygon surface with the photo-derived bitmaps it would be impossible to tell that these sections were not part of the original model. In fact samples of bitmaps from other sections of the stone were used to create an appropriate, not realistic, final rendering. The generated surface used to fill in the base of the tube was actually perfectly flat, as it followed the plane through the monument where it met the modern base. The top section had to be created with more nodes and more carefully shaped to follow the slightly curving top surface of the cross. In this instance it was not necessary to move any of the nodes in the ‘recorded’ surface.

In this phase and with a relatively uncomplicated object such as the Jordanhill Cross the creation of patches to give the impression of solidity was relatively straightforward using modelling software. However it should be noted that these patches do not represent records of real world surfaces in any way. In this respect they could almost be considered as reconstruction, although their function is not to represent the surfaces that we know are there or to represent a hypothesis of what the surfaces might have looked like at some other time. Instead, the only function of these patches is to mitigate against the undesirable and fallacious impression given by the surface model alone that the cross shaft is tubular (Figure 5.2).



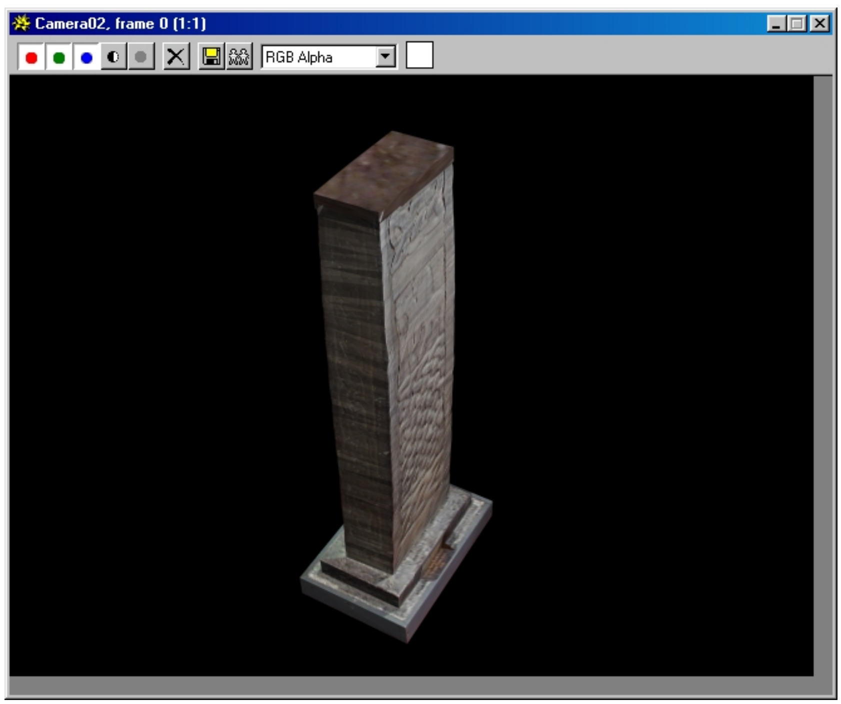


Figure 5.2 Top. A screen shot of the ‘tubular model’ (ex. 3D Studio Max). Bottom. A screen shot of the patched model (ex. 3D Studio Max).

Since the model was photogrammetrically derived, it is fairly coarse, comprising less than 500 polygons, although it does represent the gross three dimensional shape of the cross shaft well. There is no possibility of enhancing the surface geometry of the model as there is no more underlying data to work with (this would have to be generated in PhotoModeler). However the model is ideal for presentation on-line via VRML (VRML Model 5.1), as its lack of complexity generates little data mass.

VRML Model 5.1 A VRML model of the Jordanhill cross with its modern base.

As mentioned above, this monument is a cross shaft only, and the head of the cross and its base are lost. The three dimensional reconstruction of representations of what these elements may have hypothetically looked like is discussed later in this Chapter (section 5.3).

5.1.2 Aberlemno II

The base data for this model was originally captured as a 2mm resolution point cloud using the Cyra 2400 Lidar scanner. The team at Babcock were initially employing the scanner to survey the internal geometry of warships. The survey of ‘as-built’ plant was one of the original design functions of the hardware and software package. The initial problems with the creation of spurious surfaces in the Cyra-supplied software are discussed in Chapter 4 (4.2.3). However, the solution to the problem highlights the ‘reconstructed’ nature of extrapolated surfaces. The various algorithms used to generate either polygonal or NURBS surfaces do not all act on the point cloud in the same way and so will generate different surfaces. This is an important point to consider when the objective of the three dimensional modelling exercise is to generate a ‘record’. Figures 5.4 and 5.5 show two modelled surfaces: one a NURBS surface generated directly from the point cloud using Rhinoceros* software, the other is generated using CNC Rapid Prototyping software and is a standard polygon surface generated from the same point cloud. Comparison between them clearly shows that they are not the same surface. Deciding which extrapolated surface is actually the best representation of the real surface is not as straightforward as might be assumed. They both share the same point cloud, and that point cloud represents the most accurate record of the surface, yet different surfaces result. The problems associated with gauging the accuracy of the measured point has been discussed previously, but the fact that accuracy is affected by such things as the reflectance properties of the stone surface and the humidity levels in the atmosphere only serves to compound the problems of evaluating the accuracy of a surface generated from that point cloud. The most obvious way of trying to distinguish the relative accuracy of interpolated surfaces would be to compare sections of the modelled surface (i.e. not from locations on the surface that represent points in the point cloud) to measurements taken directly from the surface of the stone by some other technique, provided that the measurement directly from the surface are accurate enough to make the comparison valid (Bernardini and Rushmeier 2000). Even this approach does not allow a decision to be made with absolute confidence since levels of accuracy may vary from place to place over the area of the modelled surface. Comparisons with measurements taken directly from the surface of the stone would have to be made over the whole recorded area rather than just one or two places in order to adequately make a judgement about the accuracy of the extrapolated surface. In practice this type of measuring process is only likely to be engaged in once to settle on the most suitable method of surface generation (see Figure 5.3,5.4 and 5.5 for the results of different software generated surfaces). A finer resolution in the initial point cloud will always allow more confidence in the interpolated surface, simply because there will be less physical distance for radical changes in surface topography to go unrecorded. Having said that, the only safe measurement from the data would be one taken from one point to another in the point cloud. As there is no way of ensuring that point data will be captured at every location on the surface of a stone that a user might wish to measure from, the density of the point cloud (i.e. resolution), is paramount to the value of the record for research needing very accurate measurements. A clear distinction between what actually represents the record and what is generated in software allows judgements about surface generation methodologies to be made on the grounds of what actually looks the best on aesthetic and presentational grounds. Again the intended use of the model dictates the processes that are appropriate in its generation.

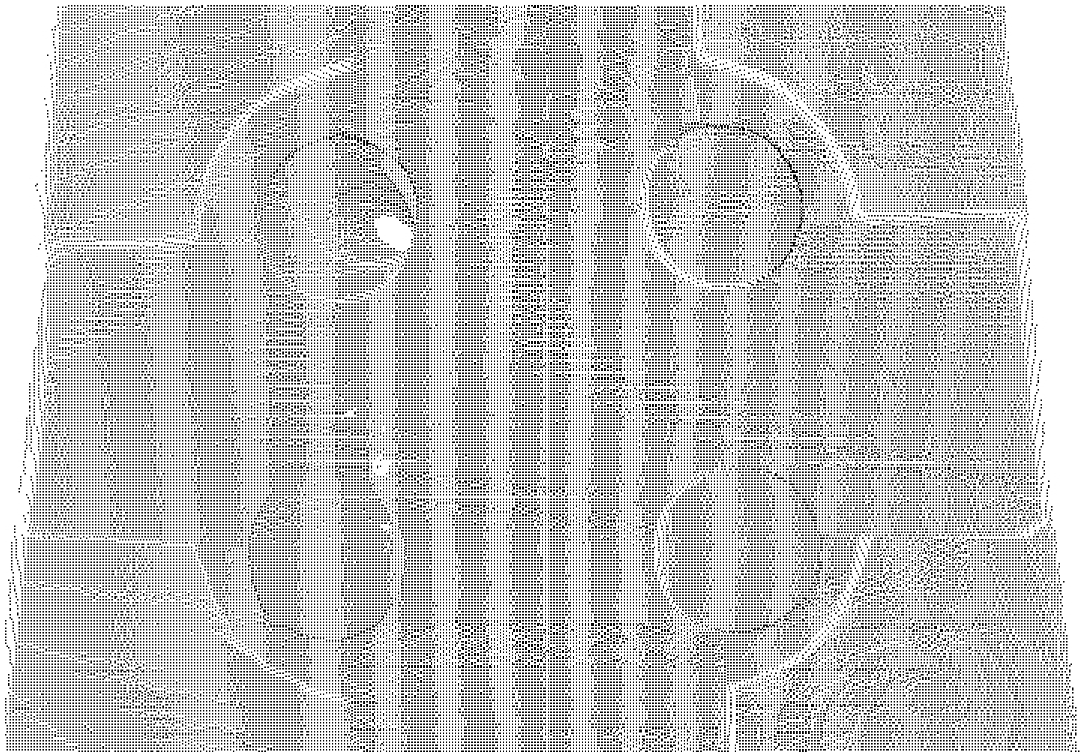


Figure 5.3 A section of a point cloud of the cross side of Aberlemno II (ex. Cyra 2400). A spiral detail can just be discerned in the lower left of the image below the cross arm (see Figure 5.4).

Animation 5.1 A detail of the Aberlemno II stone as a NURBS surface under virtual lighting conditions, low resolution results in an unwanted ‘gusseting’ effect, sharp edges are blurred as points have not been recorded exactly where the surface changes angle, therefore the generated surface ‘cut the corners’. (Quick Time format).

Figure 5.4 A NURBS surface generated from the small spiral section of the Aberlemno II point cloud (Figure 5.3) (see also Animation 5.1).

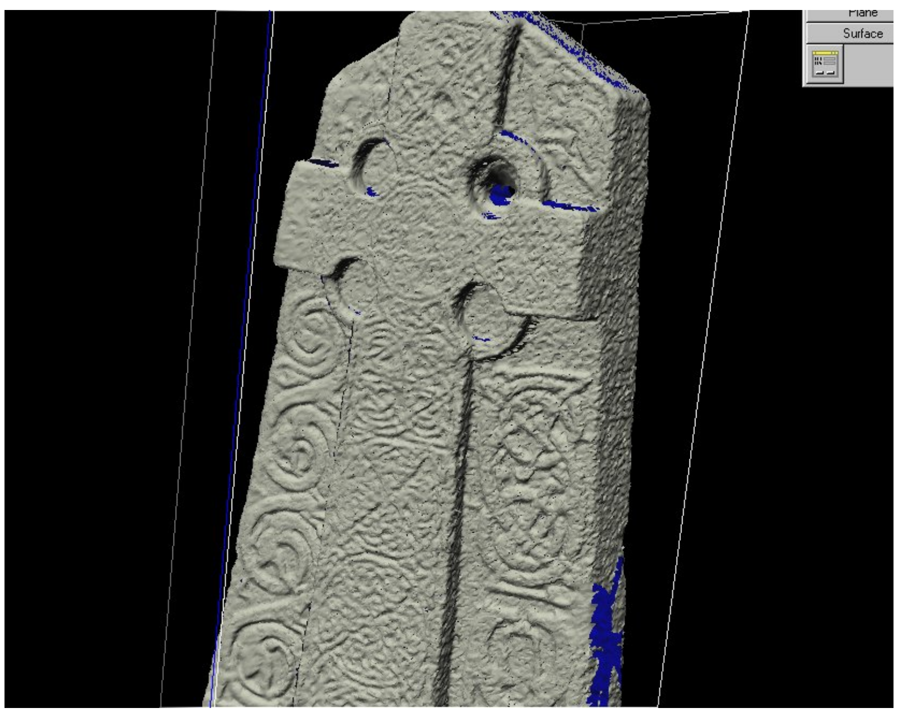


Figure 5.5 The reworked surface from BRE generated in CNC software, note the sharper edges. The surface generation software compensates for the low resolution.

This highlights one major advantage of techniques based on images, such as soft photogrammetry. There is no post-processing involved in associating photo derived bitmaps with surfaces for rendering purposes. As discussed in Chapter 4 (4.1.4) the initial process of generating the point cloud model in photogrammetry requires the use of referenced points on photographs. When triangular surfaces are specified to generate the wire frame model, bitmaps derived from the original photographs are associated with the surface polygon (triangle). However, with most other point cloud generation techniques this association is not made – in most cases, surface images are not captured at the same time as the point cloud is captured. This means that rendering the surfaces of a model using photographs has to be done in post-processing. New devices are now coming on stream that do in fact capture digital photographic images at the time of scanning (for example, forthcoming enhancements to the Cyra and Callidus scanners). This is a very new development and will undoubtedly reduce the burden on post-processing described below.

So far the assumption has been made that the best rendering for a modelled surface will be derived from photographs of the surface itself (image-based rendering). In order to produce a model that looks realistic it would be inappropriate to render it with unnatural surface patterns, or even a plain surface. The problems associated with getting good photographic images of Early Medieval sculpted stones are well known. Technical issues such as low light and shadow casting by high relief or deep incision mean that photography of these monuments is a highly specialised photographic skill, often requiring specialist equipment as described in Chapter 1. The results can be quite spectacular with photographs dramatically lit to bring out features of interest. Although photographers such as Tom Grey favour black and white film, for the purposes of rendering a model realistically colour images would be more suitable. The ability of a good photograph to disguise the simplicity of the surface it is rendered upon is demonstrated by comparison of the two images in Figure 4.5. Here, the unrendered surface of the soft photogrammetry model of the Govan sarcophagus is clearly composed of quite large polygons, but when rendered incorporating the photographs the model appears to have a much more realistic surface. However, there are good reasons why it might not be useful to use photographs to derive the bitmaps for rendering surfaces.

Captured shadows have been previously discussed and represent the biggest drawback with image-based rendering techniques that derive bitmaps from photographs of the object. The shadows themselves are actually very useful in analysing fine detail on the surface (see Object Movie 4.3). In the case of Aberlemno II, Lloyd Laing recently used two T.E. Gray photographs of the battle scene on the back of the stone under different lighting conditions to highlight the morphology of lightly incised swords. Identifying the swords (and helmets) has allowed him to suggest that the date of carving is later than previously thought (Laing 2001). However, if a model was presented rendered with only one version of the photograph, no amount of manipulation of the light source would remove the original shadow, even as new ones were cast. Animation 5.1 shows the NURBS surface of a detail from the cross side of the Aberlemno II stone under varying lighting conditions. In this case the surface is rendered with a “stone effect” material available from 3D Studio Max’s material library. The stone effect may be unconvincing but it has no intrinsic information about the surface it is rendered to, whereas shadows from a photograph represent surface information. Thus the shadow seen in the animation accurately represent those that would fall on the real object under the same lighting conditions (subject to the degree of accuracy of the modelled surface).

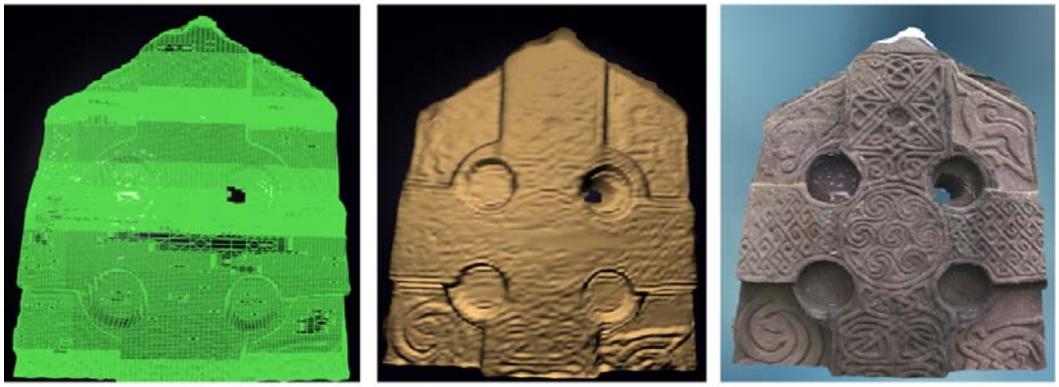


Figure 5.6 All images are taken from Animation 5.2, created from the BRE Aberlemno II scan. L. The wireframe. M. The flat rendered polygon surface. R The polygon surface rendered with a planar projection of a photo-derived bitmap.

Animation 5.2 shows a transition from mesh model to unrendered surface to a surface rendered by a project photograph, representing various stages in the rendering process. (Quick Time format).

It is worth noting here that modelling and animation packages do not render surfaces as if they were simply being ‘painted’ with the selected rendering pattern. The interaction between light and real world objects is highly complex and some of the most sophisticated mathematics employed in 3D modelling packages is designed to mimic this. The reflectance of a surface, the angle of incidence between the surface and the light source, ambient light and so on all affect what is rendered. In addition ‘Shading types’ allow polygon surfaces to be rendered with more realism. Flat shading simply projects the material onto the surface, while Phong, Blinn and Gouraud shading all interpolate intensities across a polygon face and smooth the edges between faces. This is the visual equivalent of smoothing the polygon mesh discussed section 3.3. In the case of Phong shading the interpolation acts on every pixel of the surface and thus generates computational overheads (Kinetix 1997, 20-

11). This is may be appropriate for ‘render-once’ animations, but Phong rendering does not operate well in real-time rendering environments without appropriate graphics hardware. In addition to the potential for complex rendering offered by shading types, most rendering ‘materials’ are in themselves complex. For example, the stone effect material used in Animation 5.1 is highly patterned, the intention being that these materials imitate real-world materials which rarely have perfect colour or pattern consistency. Decisions taken by the modeller about how to render a surface will be influenced by a number of factors, the most important of which is the intended audience for the model. The most realistic render, and the one that is most forgiving of low resolution surfaces, would be photo-derived (see Figure 5.6, above). The most ‘honest’ rendering would be a flat shaded basic material which would show the model as it really is (rather than enhanced by rendering) and perhaps give the best impression of the surface topography under oblique virtual lighting. Between these two options there is a range of possibilities that can either produce a realistic looking model or a stark representation of the model as a record. In Chapter 7 the potential for using rendering variables to carry information about the model itself rather than about the modelled object are discussed.

Although the use of photo-derived bitmaps in an image-based rendering scheme can be problematic it is important to bear in mind that the colour of a stone, and how that colour changes, may be important in understanding either the iconography or the significance of the monument itself. Figure 5.7 is a close up of the Govan Sarcophagus and banding in the sandstone is clearly visible. Since the source of the stone may be significant either because it tells us something about trade and communication in the past or because the source location may have had special significance in the past, the banding may provide information to those looking for clues. If a model of the cross is presented without photographic evidence then the colour and nature of the banding is lost. Animation 5.1 shows that it is possible to present a model with more than one type of rendering; the users may interact with the model to view it in the way best suited to their needs. Obviously several renderings will increase file size and decrease ease of delivery.

Figure 5.7 Close up digital photograph of one of the side panels of the Govan Sarcophagus. This was taken immediately after cleaning and conservation by Historic Scotland.

An important new advancement in capturing and rendering surfaces is the capturing of luminosity values of various types of flame for Very Realistic Rendering. Until recently no attempt had been made to capture physically accurate values for ancient light sources and surface reflectance (Chalmers 2000, 7). In Chapter 8 the capturing of reflectance values from the surface of objects will be touched upon. However how these surfaces are rendered remains an issue. Capturing the reflectance values of a surface provides the opportunity to realistically model how it will behave under various lighting conditions. However, knowing what an Early Medieval sculpted stone looks like under neon lighting may be useful for the museologist but not necessarily for the archaeologist, whereas seeing them under ancient lighting conditions may.

Figure 5.8 The horse frieze from Cap Blanc, a 55,000 point scan using a MDL scanner. Image courtesy of Alan Chalmers.

Alan Chalmers (University of Bristol) has been working on capturing the luminaire values of various light sources using a spectroradiometer. These values are then used to generate virtual light sources, which can emulate the colour flux associated with flame sources such as tallow candles and oil lamps. This produces what Chalmers has called ‘validated flame lighting’ (Chalmers 2002). The nature of the models that Chalmers has so far applied this technique to range from Palaeolithic cave friezes (relief, captured with the MDL Surveyor ALS) to Pompeiian frescoes (Devlin and Chalmers 2001). In the case of the cave frieze, of horses from Cap Blanc in the Dordogne, (Figure 5.8) the surface was rendered using photographs that had been processed to make then “approximately ‘illumination free’” (Chalmers 2002, 3.1). This was done by extracting spectral values on a pixel by pixel basis based on the known values of a rock art colour chart included in the photographs. The most exciting result in this instance is the apparent movement of the horse when the flickering virtual light source was moved. Although it is most likely that Early Medieval sculpted stones were generally viewed under natural lighting conditions, there is clearly potential to investigate large high relief Early Medieval monuments under controlled and malleable artificial lighting conditions (Chapter 8).

5.1.3 St.Orland's Stone

The simplicity and lack of expense in generating QTVR object movies means that it is a popular technique for creating three dimensional models of small objects for web delivery. There is little or no post-processing: object movies of small objects the images are taken using an object rig or similar and the model is then generated in a single software process, although there are a number of variables that the user can assign. However if the technique is to be applied to larger monuments which are immovable or cannot feasibly be moved, then post-processing is inevitably required.

The issue of rendering surfaces in post-processing does not arise with this technique because, as discussed in Chapter 4 (4.2.5), there is no underlying surface model to render. Any alterations required to make the surface clearer in terms of colour or contrast have to be done by retouching the sequence of images from which the object movie is generated. Whilst possible this is not an enticing prospect: not only would each image have to be retouched (and there may be tens of them), but alterations affecting colour would have to be replicated exactly across each image in order that there would not be incongruous changes from frame to frame, which would interfere with the desired smooth transitions as the model is interacted with. Batch processing may be a solution, but even with shortcuts like this it would seem best that the original captured images do not require enhancing if at all possible.

The most significant disadvantage to using photographs of complex surfaces is the one already discussed above regarding 'captured shadows' and rendering surface models. This is an equally serious problem for QTVR object movie models, especially given the difficulties in retouching highlighted earlier. Potential methods for controlling lighting were outlined in Chapter 3 and the sample model of St

Orland’s stone (Object Movie 5.1), with its dark shadows over one side of the monument, clearly illustrates the drawbacks of not being able to control lighting.

This example also serves to illustrate two other factors that impinge on object movie construction that can, to some extent at least, be mitigated by post-processing the base image sequence. The first problem is controlling camera position and angle on uneven ground. Angles that are easily controlled by an object rig are extremely difficult to control in the field when trying to capture a sequence of images of a large object. The second problem is that larger objects require more frames in order to generate both smooth rotation and natural rotation speeds.

5.1.3.1 Aligning images.

A comparison of the two Object Movies 4.2 and 5.1 shows that initial movie (4.2) was generated from images that are seriously misaligned. This is despite the care and effort that was put into the data capture process as described in 4.2.4. The image alignment tools available in the QTVR authoring package used (The VR Worx*) are designed to rectify small discrepancies in panoramic head mounting rather than object movie frames. The tools will allow ‘keystone’ adjustments to be made manually. These occur when the film plane of the camera is not perpendicular to the base plane of the panoramic head (see Figure 5.9) (Proni and Weisman 1999, 39). In the case of an object movie the same problem occurs when the film plane is not at the same perpendicular angle to a notional model base plane for each frame. It does not allow correction of rotational error (also see 5.9) and offers no way of compensating if a series of images are not all centred exactly on one point giving a stable point of rotation for the model.

Figure 5.9 L. The film plane is not perpendicular to the model base plane (keystoning). M. The frame is rotated. R. The frames are not centred on the same point.

Without all these angles being consistent the image in the object movie (5.3) can be clearly seen to 'jitter'. Using Adobe Photoshop, each frame was centred, rotated and 'keystoned' until their alignment was acceptable and the movie was regenerated giving (Object Movie 5.1). The aligned movie is smaller than the original because frames had to be cropped to compensate for 'blank space' generated as rectilinear images are rotated

If object movies are to be applied to large immovable monuments in the field at all then clearly this problem will need a better solution than manual reorientation and alignment of frames. The development of an automated alignment process could greatly enhance the usefulness of this technique.

Object Movie 5.1 The St.Orland's stone Object Movie model after manual re-alignment of the frames.

There is more than one way in which this automation process could be achieved. For example specialist self centring and levelling equipment could be developed that would reduce misalignment. Alternatively the alignment could be carried out in software. One method would be to use markers in the original images that were used to align those images in software. With this approach, two brightly and unnaturally coloured physical markers would be placed vertically, one over the other, on the axis of rotation. Given the colour value of the markers and their desired orientation, an adjustment program could batch process any number of images, aligning them all such that the markers were in the desired location and the images therefore correctly aligned. This would require keystoning where the markers were too close together (vertical foreshortening), rotation where the markers were not vertically aligned, and the centring of each image to ensure that they shared a point of rotation. Finally the markers would be removed from each image and replaced with the averaged values of surrounding pixels and the images cropped to compensate for blank space. Fortunately the algorithms for manipulating the pixel arrays of images in these ways are well understood; however the interfaces and process control elements of such a program would require significant development. In the light of this, a proof of concept application was undertaken (Sutherland 2000), and the resulting program, ‘Align Pictures’, does indeed demonstrate that this is a viable approach.

The Align Pictures interface allows the user to select a ‘starting frame’which is considered to have the correct orientation and forms the template to which all other images are aligned. The user selects the colour that indicates the marker colour by clicking a cursor on the marker in the ‘starting frame’. Unnatural colours were most appropriate for the markers, since it is desirable (but not essential) that the colour of the markers occurs nowhere else in the image. The application examines surrounding pixels and derives the centre of the marker based on the adjacent colour values. The next stage is to examine the rest of the image to find the second marker (the same colour) and again discern the array co-ordinate of its centre. Once the co-ordinates that represent the correct location of the markers in the image are known the application steps through each image in turn finding the location of its two marker points and aligning them to the correct co-ordinates using the transforms described above. Finally the marker colour is removed from the image and replaced by the colour of adjacent pixels. Special test images were used to test the application (Figure 5.10) and the initial results were encouraging.

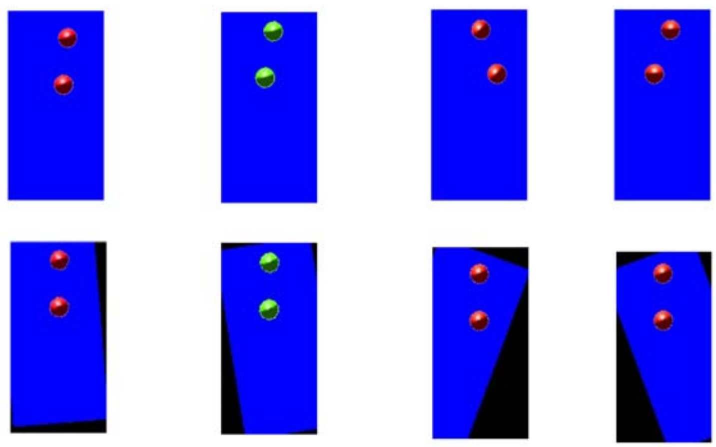


Figure 5.10 Test images for the Align Images Software (Kirsi Sutherland). The top row are the original images and the bottom row are the images after automatic alignment.

Further tests were carried out using photographs rather than test images. The markers used for these tests were two luminous pink tennis balls mounted on the vertical support of a camera tripod. Figure 5.11 L. shows the initial test in bright outdoor light. Figure 5.11 R. and Object Movie5.2 shows a test under realistic conditions. This test comprised taking a series of deliberately misaligned images in poor lighting conditions of the Jordanhill cross. Unfortunately during testing the application became unstable resulting in no usable aligned images. In order to try and track down where the problem lay it was decided to enhance the markers in the original images manually by applying single colour circles to the marker locations in Adobe Photoshop. Under these conditions the application correctly identified the markers, resolved their co-ordinates and aligned the remaining images correctly. The resulting images were then used to generate an object movie (Object Movie 5.2). While the movie is still obviously of poor quality it does demonstrate that once the markers are identified by the program alignment can be successful.

Figure 5.11 L. The tripod and tennis balls being tested on a modern sculpture. R. A further test in deliberately poor conditions, this resulted in the partial Object Movie 5.2

Object Movie 5.2 The automatically aligned (but otherwise poor quality) partial object movie of the Jordanhill Cross generated during testing of the Align Images software.

It would be advantageous to allow for handling of horizontal markers to allow keystoning of horizontally foreshortened images, but this was left out of the original design both for the sake of simplicity and also because in practical terms it is the easiest angular error to avoid using framing indicators on a camera lens. Other potential enhancements noted by Sutherland herself include handling larger image sizes, more sophisticated colour selection, compensating for colour variation on the markers caused by shadows (this resulted in the alignment failures described above), and a number of interface enhancements (Sutherland 2000, 46-7).

It is also useful to note that this approach to aligning images was never intended to handle gross errors in the original image alignment. Due care would still have to be taken in the original data capture phase to ensure the best possible alignment, minimising the inevitable distortion that results in images that are manipulated by the process employed here. It is again important to consider the point at which a ‘touched-up’ or manipulated photograph ceases to be a record and transforms into an image derived from the record.

5.1.3.2 Frame rates and rotation.

The second problem highlighted by the St. Orland’s Stone object movie is the number of frames required to give the appearance of smooth rotation around the object (or in the case of small objects, smooth rotation of the object itself). In creating animations or interactive models such as VRML models from a genuine three dimensional surface model the user can theoretically specify or view an infinite number of frames. With QTVR, the model is based on a finite number of frames. For example, given a notional minimum of 15 frames per second (15fps) for smooth motion, then 15-30 frames for a small object that can be rotated 180° by hand in around a second would generate a model that produces a natural looking rotation. With this number of frames the model would have to be rotated very slowly for the transitions to become apparent, since, as discussed in Chapter 3, the brain is interpolating between the frames. In contrast, an object like the St.Orland’s stone would take much longer to walk around – say 15-20 seconds. At 15fps this means that around 225 frames would be necessary to allow a 360° ‘walk-around’ of the monument, and up to 500 frames to allow for slower rotation. A smaller number of frames would only allow the monument to be rotated at unnatural speed and the transitions between frames would become increasingly discordant. Given camera positioning and other issues taking a series of 225 photographs in the field is non-trivial. The model of St. Orland’s stone, Object Movie 4.2, was generated with 18 photographs.

An alternative to actually capturing the images in the field is to use frame interpolation. Frame interpolation, like interpolation of surfaces, is the process by which software makes a best estimate at what lies between two known points. With interpolated polygon surfaces, software examines the available point data and generates new points on a surface between the known points by estimating their position with reference to the known points. With frame interpolation, two separate frames are compared and transitional frames are generated that would incrementally ‘morph’ the image from the first to the second. This technique is frequently used to compress video for transmission or ‘streaming’ over satellite links or across the internet. Only key frames (or sections of frames) are actually transmitted and the intervening frames are interpolated at the receiving end. This works particularly well with frames with little change between them such as ‘talking head’ shots. Just as interpolated surfaces are a sophisticated model of reality, so it is with interpolated frames: the more points on the original surface, the more successful the interpolation will be, and the more key frames there are in relation to interpolated frames (I-Frames) the more likely it is that the I-Frames will be acceptable. The use of interpolation again raises the question of whether the model is being tasked as a record or as an illustration. Interpolated frames record nothing other than the sophistication of the algorithms that generated them whilst the original frames (key frames) can be considered a genuine record. However this is a possible technique for generating the required number of frames for object movies of large objects. Another alternative, the use of digital video to capture the number of frames required by videoing a walk around the monument in real-time, is likely to be more problematic because of the alignment issues discussed in the section above. It is possible that software alignment of the frames could be developed to the point that video footage could be used.

The Tintagel slate under various oblique lighting conditions (Object Movie 4.3) is in fact an example of manual frame interpolation as the original 18 frames were expanded to 32 frames to allow smooth transition of the light source. As described in Chapter 4, the intervening frames are generated by combining the characteristics of the neighbouring real frames. This may be feasible for 18 frames where light intensity is all that is changing but the manual process would not scale well to say 100 frames where the target object is moving.

With a combination of image alignment software and frame interpolation it would be theoretically possible to use a hand held digital or DVC camera to walk round a standing monument in the field, capture 20 or 30 images and after post-processing have a smooth, steady object movie that allows a 'walk-round' of the object at a natural pace. Because image alignment software is undeveloped and frame interpolation is currently designed for video framing rather than embedded in the QTVR design scheme the development of this idea is something that would require substantial further work. Ultimately the development of image-based rendering techniques such as light field capture in combination with interpolation, discussed in Chapter 4, may render the current concept of object movies redundant.

5.2 Reconstruction

The above sections detail the high level of user intervention required to generate even the simplest of computer models. It should be apparent that all surfaces and shapes displayed in computer models are in fact 'reconstructed', either by an automated process such as surface interpolation or by user intervention, or by a combination of both. In the following discussion 'reconstruction' is used in a broader sense: it refers to sections of models (or complete models) that represent no real world object. The use of reconstruction in archaeology is not an uncontentious issue (for a discussion on the appropriateness or otherwise of creating 3D digital reconstructions at all see Chapter 7). Despite this, it is common practice in artefact analysis fields such as ceramics and in the representation historical buildings. It is also common in relation to Early Medieval sculpted stone where the fragmentary survival of much of the material makes the reconstruction of missing segments, by whatever technique, almost essential in trying to understand how the original artefact looked.

5.2.1 Traditional techniques for reconstruction.

There are a number of approaches that have been used in the past to reconstruct lost sections of sculpted stones. The most frequently used form of reconstruction for Early Medieval sculpted stone is drawn reconstruction. The reconstruction can take many forms, ranging from simple extrapolated lines (Figure 5.12, Right), metric drawings and artistic impressions (Figure 5.13).

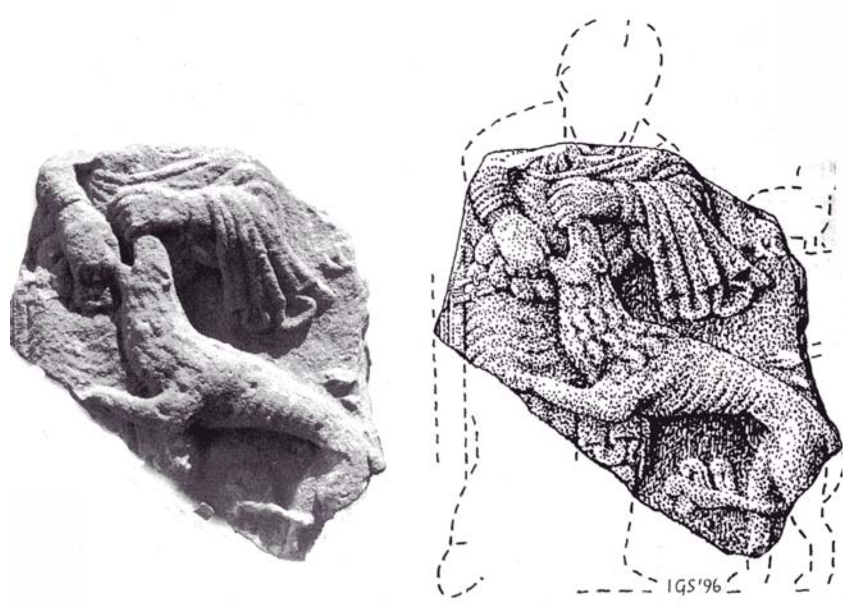


Figure 5.12 David killing the lion from a fragment of a shrine panel at Drainie, Kinneddar (Moray). With an outline reconstruction by Ian G. Scott (Henderson 1998, 130). Note: this is a reconstruction of the figure rather than the entire panel.

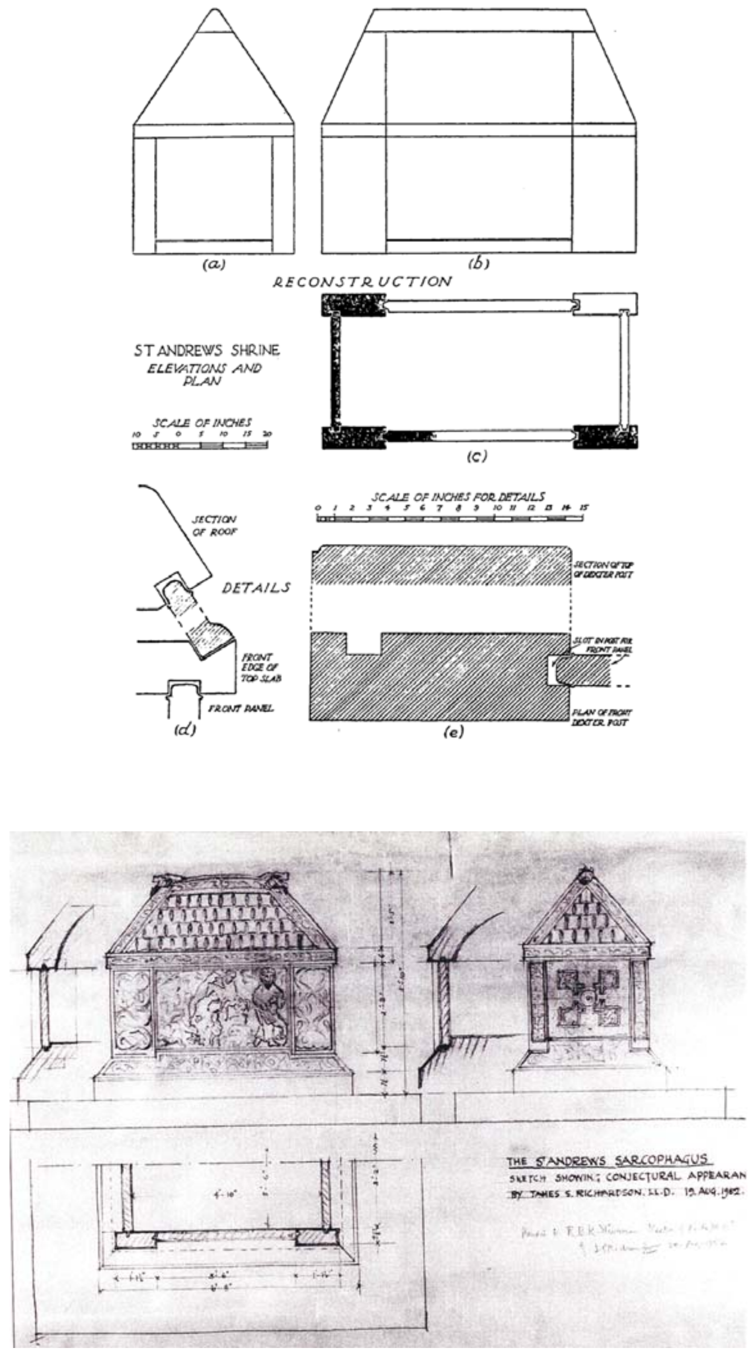


Figure 5.13 Top. A reconstruction of the St. Andrews Sarcophagus and its lid, by Ralegh Radford 1955. Bottom. Another reconstruction, this is by J.S.Richardson in 1952. Both are clearly marked as reconstruction or conjectural appearance.

This simple technique of representing missing sections has the major advantage of being easily done. This means that several possible versions of the conjectural appearance can be created and presented, by different scholars at different times with ease.

Another technique used to represent missing sections three dimensionally is to physically reconstruct the missing section in another material, such as concrete. For example, the Pictish Cross slab from Eigg in the Western isles (Figure 5.14) consists of two fragments held together with a concrete section formed in the approximate shape of the missing section. No attempt has been made to recreate the carving that the missing section would have carried and the concrete section acts as a kind of three dimensional space holder to allow the two fragments be displayed in the correct three dimensional relationship to each other. This is an effective technique and preferable to the two fragments being presented separately or without their relationship to each other otherwise being made clear. A cast of this monument created in the 1930s uses the same device, this time in blank plaster, to present the fragments in their correct spatial relationship. However recent work has suggested that the cross slab is in fact a re-used shrine slab, with a further section missing from it (Gondek and Jeffrey 2003). This presents a dilemma for its presentation. It is not clear whether or not it is appropriate to add a reconstruction of the further missing section, and perhaps change the orientation of the stone as it is displayed from vertical to horizontal in order to bring it closer to its original intended orientation and shape.

Figure 5.14 L. The reused shrine slab on Eigg, with its missing section shaped in concrete. R. The cast of the Eigg shrine slab.

One further level in the reconstruction of missing sections is to actually create a hypothetical version of the actual carving based on interpretation of the existing fragments. This is the approach that has been used with the missing base section of the Hilton of Cadboll stone, a monument which has also had the entire cross face side of the sculpture removed prior to its re-use as a funerary monument in the 17th century (James 2001). The monument, on prominent display in the National Museum of Scotland, has its missing basal section hypothetically reconstructed in bronze, with the carving on the stone section being continued and completed on the bronze basal section. A reconstruction carved in stone was commissioned by the villagers of Hilton and this also has a reconstruction of the missing basal section. However, early in 2001 the missing basal section was discovered during excavation. (Figure 2.13 and 7.1) Fortunately both reconstructions chimed well with the actual carving on the cross base. In the case of Hilton of Cadboll the reconstructions served two purposes: to complete the object in terms of size and shape and also to complete the missing sections of carving. In the case of the National Museum example, the difference between the stone and its bronze base is quite apparent, whereas in the carved reconstruction it is impossible to tell what is copied from the original and what is conjecture without reference to another record of the monument. In neither case has there been an attempt to recreate the cross face of the monument. During the excavation of the cross base large sculpted fragments of the cross face were recovered and it is the intention of the NMS to piece together as much as possible of the cross face. The time and effort involved in creating physical reconstructions, whether hypothetical or not, means that this approach is quite rare. One other major example where two competing hypotheses are represented by separate physical reconstructions is the lid of the St Andrews sarcophagus (Allen and Anderson 1903, Pt.3351-63; NO51NW 23) where one favoured hypothesis was replaced by another (Figure 5.15).

Less frequent are photographic reconstructions. Manipulation of photographic images, especially digital versions, has become commonplace. ‘Touching-up’ photographs in order to produce a better image has been carried out for many years. This is relatively uncontroversial where the alteration is confined to altering colour balance or contrast as the intention is to produce a more useable image. However when substantive changes are made then the image moves from being a photographic record to being an illustrative image based on the photographic record. Where the line is drawn between ‘touching-up’ a photograph and producing an illustrative image is exceedingly hard to pin down. Simple lines can be added to photographs using an image manipulation package in the photographic equivalent of the technique used in Figure 5.12 above (e.g. Orton 1998, 75). Modern photo manipulation packages such as Adobe Photoshop* offer a vast range of tools for altering every aspect of a photographic image. The process of image manipulation can involve many steps each with many user specified variables; however, keeping track of the manipulation and presenting the history of the process as a data set associated with the image is rarely done.

Figure 5.15 Top. The St Andrews sarcophagus as displayed c. 1954-89. Bottom. The sarcophagus as displayed c. 1989-96. (from Foster 1998). Since 1997 the sarcophagus has been displayed without a reconstructed lid.

Quite basic photo manipulation techniques can allow for “photo-realistic” reconstructions of missing sections of Early Medieval stones. An example of this is shown in Figure (5.16) where half a collar stone, used for the setting for the Early Medieval cross slab at Hilton of Cadboll was recovered. It was a simple process to reconstruct the whole item using photographic image manipulation. The effect is such that, unlike an artistic reconstruction, it is difficult to tell without close examination that the image has been doctored. Obviously it is the responsibility of the creator of the image to ensure it is never presented as an image of a real world object.

Figure 5.16 Top. The section of a cross “collar” stone under excavation in Hilton of Cadboll. Bottom. A digital photographic reconstruction of what it might have looked like when complete.

5.2.2 Combining Models

Combining three dimensional models of monuments or artefacts that were originally intended to be seen as a single piece but are now fragmentary is relatively trivial. Individual models of fragments can be presented together in the same virtual space in their correct spatial relationships. The crucial decision that has to be taken by the modeller is whether to join the fragments into a single model by welding vertices as described in 5.1.1 or simply present them together. This is essentially a practical decision, since unless the end-user can manipulate individual elements of the model in relationship to each other, whether or not they comprise a single model or several presented together will not be apparent. A potentially significant development in this form of reconstruction is automated refitting. Just as the 'best-fit' algorithms described in Chapter 4 can fit together overlapping point clouds, it is possible to imagine an algorithmic solution to fitting together fragments based on their surface geometry. This is perhaps of less use with a shrine panel that has split into two or three pieces, where with such a low number of pieces to refit, the process hardly needs automation. However in the case of the Hilton of Cadboll stone the assemblage of fragments, representing an entire carved surface which was deliberately dressed off, runs into thousands of individual pieces. Ian G. Scott and Isabel Henderson are currently working on this reconstruction manually, using large sand boxes at the National Museums of Scotland in Edinburgh (see the Hilton of Cadboll web site*) However, hypothetically each fragment could be modelled in three dimensions and the refitting process at least partly automated. Although this may seem like a far fetched scenario, given the likely cost of such a project, there are archaeological examples of this kind of approach in progress. For example, The Forma Urbis Romae or Severan Marble Plan of Rome is an enormous map, measuring approximately 18.10 x 13 meters. It was carved between 203-211 AD and covered an entire wall inside the Templum Pacis in Rome. It depicted the ground plan of every architectural feature in the ancient city, from large public monuments to small shops, rooms, and even staircases (Levoy 2003). Only around 15% of the map survives and this was broken into 1,186 fragments in antiquity. This highly ambitious project, which is still ongoing, intends to refit the giant stone three dimensional map, thus 'solving' what has been described as a "great puzzle" (Digital Forma Urbis Romae Project 2003). The project has created three dimensional models of each of the fragments and is designing the software to automate the refitting process with as little human intervention as possible. Major technical issues have been encountered beyond those relating to the scale of the project. The most significant of these is that the surfaces of the fragments have become abraded or otherwise altered since they were originally split apart. This means that the algorithms designed to refit them must be able to cope with a certain amount of 'fuzziness' in the process. which is notoriously difficult to program. However, if successful the development of the algorithms for surface fitting the Forma Urbis Romae if successful could be transferred to similar problems in the field of Early Medieval sculpture in Scotland (as well as other areas of archaeology such as lithics and ceramics). In the context of a corpus of Early Medieval sculpted stones incorporating three dimensional models of the numerous fragments that are located at numerous sites around the country, from museum store rooms to church porches, this technique holds out the possibility of investigating which fragments actually belong together without having to physically move the fragments from place to place.

5.2.3 Reconstruction of lost material in three dimenions.

The building blocks for constructing three dimensional models of objects for which there is no digital record are known as primitives. In three dimensional modelling applications the modeller can create a complex shape by combining primitives such as cubes, spheres, cones, cylinders, and so on, using boolean operations such as union and intersection. Additional modifiers such as distort, extrude and scale can be applied to individual shapes and combinations of shapes. This process can be facilitated by both constructive solid geometry (CSG) or boundary representation (B-rep) paradigms and can allow the modeller to come close to achieving the kind of three dimensional complexity we see in real world objects. In section 5.1.1 the post-processing of the Jordanhill cross model was discussed, in relation to the creation of the model of the cross as it currently is. However, as already noted, the cross is actually a cross shaft with both its head and base missing. It was decided that in order to facilitate an understanding of how the monument may have originally looked that the cross head and base could be reconstructed using CSG.

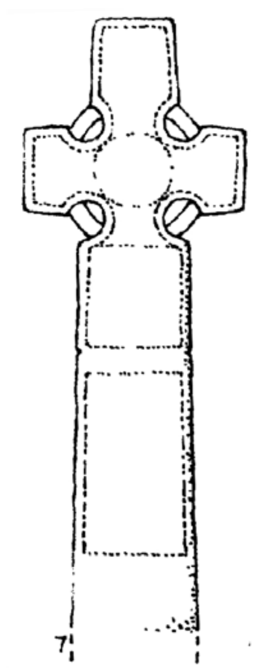


Figure 5.17 The Barochan Cross, sketch by Ian G. Scott (from Ritchie 1994(a), 91)

The first stage in this process is deciding what the cross and base were likely to have looked like. Whether traditional or CSG reconstruction, this must remain an archaeological decision, founded on an in-depth archaeological (or art historical) understanding of the material and potential analogies with similar artefacts. In this case the size and shape of the shaft as well as the dimensions suggested that it may have been similar in form to the Barochan cross (Allen and Anderson 1903, Pt.3 456-7; NS46NW 1) which is also likely to have been of a similar date, in addition to belonging to the assemblage of crosses in South West Scotland (Figure 5.17).

Figure 5.18 R., a flat rendered close-up of the reconstructed head, shows clearly that it is constructed of various primitive shapes in combination: the central boss is part of a sphere, the ring a torus, and the arms of the cross are assorted cuboids (Figure 5.18 L.). The primitive shapes have been distorted: for example, the cross arms are tapered in two directions, before being combined into a single complex shape. The whole reconstruction was then scaled to match the size of the polygonal surface model of the original shaft. In this example the reconstructed section is not in fact ‘welded’ to the polygon surface but simply locked in position. Although time consuming, the reconstructed head is a good approximation of the intended shape. The major difference between the recorded polygon surface and the purely modelled head is the apparent surface texture. Because the head is modelled using geometric shapes, the lines are clean and all the surfaces smooth. In reality, carved stone has an undulating texture at some scale, even where it is intended to be smooth. The crispness of the reconstructed section could be reduced by the addition of ‘noise’ to the surface, introducing a randomness into one or more dimensions in the model. The randomness can be constrained within bounds to give the impression of natural surface. This entire process increases the complexity of the model and therefore its data mass. For example, a cuboid may be defined by a mesh with eight points, eight edges and six faces, each face being defined by four points. In order for the noise to be apparent the face must be defined by a larger number of polygons (and therefore points). In Figure 5.18 no surface noise has been applied, as rendering with a complex pattern breaks the surface visually giving the impression that it has more texture than it actually has. The colour differential between the rendering of the reconstructed section and the polygon surface rendered with the photo-derived bitmaps is quite deliberate and is in keeping with the general tradition of distinguishing reconstruction from record in archaeological contexts. The importance of this with regard to digital reconstruction is explored in Chapter 7.

The problem of modelling rough and complex surfaces with CSG, leads to another limitation with the technique. If the area to be reconstructed actually carried complex carving then the process by which it is modelled in CSG becomes similarly complex. Similar levels of skill and artistry to those of the carver who created the sculpture in the first place would be required to create a digital version using CSG.

The limits to the sophistication of this type of reconstruction do not lie with the applications: even living creatures can be digitally modelled quite convincingly, as a number of recent films and documentaries have demonstrated. The limitations lie with the skill of the modeller and the time and cost restraints imposed on him or her.

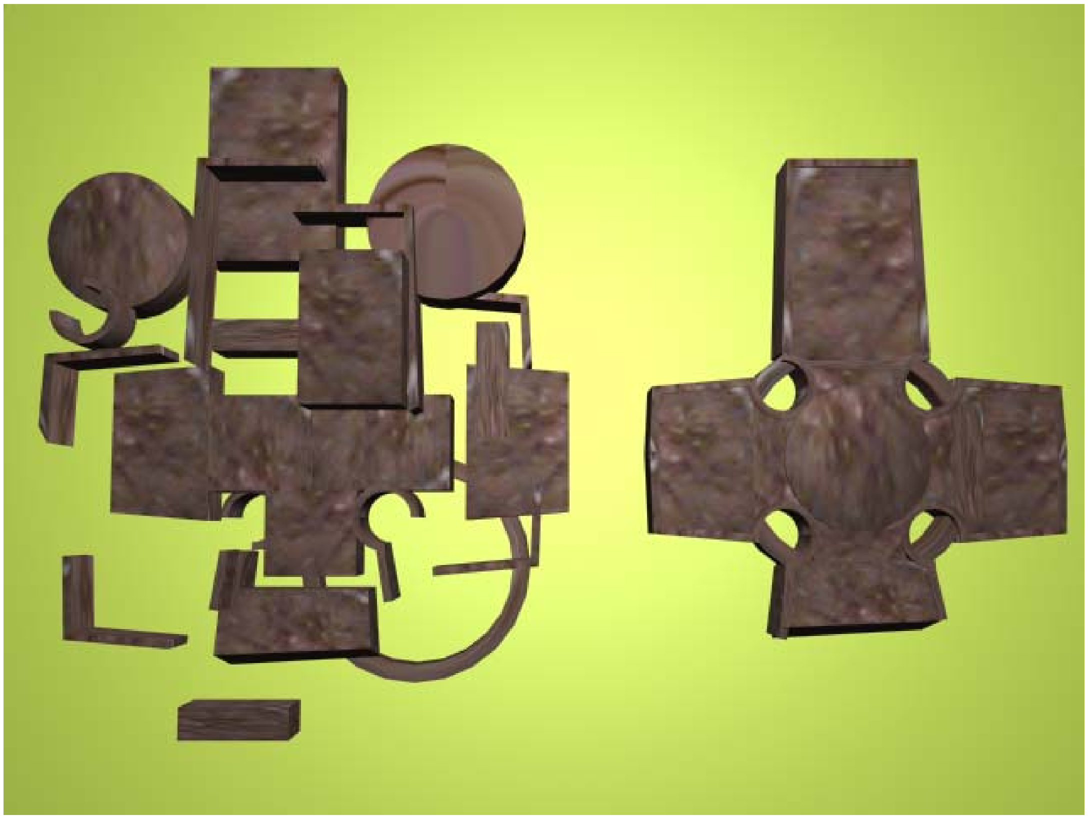


Figure 5.18 L. The various elements of the reconstructed head. R. The combined complex shape.

Animation 5.3 An animation taking the viewer round the reconstructed version of the Jordanhill cross.

Object Movie 5.3 An object movie using transparency to 'dissolve' between the model of the Jordanhill cross shaft with modern base and the reconstruction of the cross with head and base.

The complexities of creating a realistic rather than impressionistic digital reconstruction mean that it is more closely comparable with physical reconstruction than with sketched or drawn reconstructions. This includes the likelihood that fewer different versions of a reconstruction for a particular monument will be produced in digital format. It is possible that in the future as modelling software interfaces evolve and as a larger and larger number of archaeologists engage with digital modelling, this may not prove to be the case. That fewer versions of reconstructions may be done using digital technology than using some traditional techniques may have implications as electronic publishing and digital modelling start to dominate archaeological information dissemination in the next few years. The impact that such a change may have on our perception of reconstructions is more closely analysed in Chapter 7.

5.3 Recontextualisation: reconstructing context.

Sections 5.1 and 5.2 have dealt with post-processing, re-joining and reconstruction of the stones themselves, but it is not necessary for the reconstruction process to stop here. For historical reasons, sculpted stones have frequently been studied as artefacts divorced from their archaeological and landscape context: the three dimensional, physical landscape which they originally occupied. As previously noted, there has been a centuries-long process by which these monuments have been removed from the landscape and deposited in church buildings, museums and other structures. One result of this process is that there is a lack of focus on the stones themselves and a strong focus on the iconography they carry. We often see illustrations, not of the stone, but simply of the image carved on the stone. Archaeologically speaking this approach concentrates on a small part of a much wider picture, the materiality of the stone, its position in the landscape, its relation to other features or monuments in the landscape and the relationship between people in the past and the monuments and landscape in combination.

If these stones had no carvings on them at all they would be approached in a very different way. The earliest of them could be characterised as being created by pre-literate, pre-Christian people living in a landscape that has pre-existing megalithic monumentality representing thousands of years of tradition. Yet we still most often think of the stones as art historical objects, artefacts rather than landscape elements. There is an abundance of theories regarding the relationship of Neolithic and Bronze Age monuments to the landscape, built and natural environment (e.g. Bradley 1997; 1998; Tilley 1994). This is not true to the same extent for Early Medieval sculpture. Any technique that encouraged researchers and other audiences to think of the stones as part of a wider social and political landscape could be considered a useful tool. Recontextualisation is an attempt to facilitate this by placing models of stones, or digital reconstructions of them, into digitally generated landscapes, with the objective of encouraging and enabling us to think about wider landscape issues as well as the minutiae of carved detail. Investigation of intervisibility, lines of approach and associations with earlier monuments and other landscape features has so far required a trip to the location of the monument in question (or one of its previous locations). It is fair to say that there is no substitute for this approach; however not all members of potential audience groups are able to make these journeys for a variety of reasons.

5.3.1 Landscape capture and rendering

There are a number of techniques for capturing three dimensional data from real world landscapes. The Ordnance Survey* has traditionally used levels and theodolites, more recently photogrammetry, radar and lidar and very recently GPS and satellite based remote sensing. These techniques generate spot heights distributed across the landscape that when digitised can be used to create digital elevation models (DEMs) and digital terrain models (DTMs) in geographical information systems (GIS). These three dimensional landscape models can in turn be exported into 3D modelling or VR packages that allow the viewpoint of the user to approximate that of an individual on the ground rather than the standard 21st century landscape representation, where the viewpoint is directly above the landscape and it is seen in plan view, as with maps. Of prime importance for the usefulness of three dimensional representations is the resolution of the spot heights, this is true of GIS applications such as viewshed analysis and it is also true for representative landscape models in three dimensions. A grid of spot heights at 100m spacing may not come close to representing the complexity of the land surface in anything other than a plain. Hilly or mountainous terrains can undulate dramatically in the space of 100m. A coarse resolution translated into the extrapolated surface of a DTM will have the effect of smoothing out the landscape, turning craggy rough ground into something much less dramatic. The OS can currently supply DTM data that has a resolution of 50-100m in rural areas (Land-form Panorama, heights extrapolated from contour data). Contour data from paper maps can also be digitised by hand and will give a Z (height) resolution of 10m, the resulting polygons can then be extruded and smoothed in a 3D modelling package to give an approximate surface as in VRML Model 5.2. For smaller areas (micro-topography), say up to 1km^2 an EDM (Total Station) (Rick 1996) or GPS survey (e.g. Chapman and Fenwick 2002) may allow much finer resolution and therefore a much more accurate DTM. For even smaller areas the Cyrax 2400 and the MDL disto mentioned in section 4.2.3 can semi-automate the process by automatically capturing topography at dense resolutions, with the Cyra having a range up to 100m and the MDL device up to 1km, with these techniques resolutions of 1m or even 0.5m can be achieved. This approach, using a Cyra scanner, has been proposed for entire sections of the Kilmartin Valley (Argyll), by Kilmartin House Museum* (Clough and Long 2000)

There are problems with three dimensional modelling as an approach to landscape representation, not least of which is the difficulty in rendering surfaces with sufficient detail and texture to give the impression of a real landscape. The most common approach is to use generic landscape rendering. This, depending on user defined levels of complexity, can give a very realistic impression of vegetation, rocks and so on (see Figure 5.19). The types of vegetation or the occurrence of outcrops are often generated in relation to the height given by the DEM, in this way the user can define at what height the tree level might be or at what steepness grass gives way to cliff. However the problem is that this realistic impression is only loosely related to what the landscape actually looks like. If there is a rock outcrop at a particular location and this requires rendering with a different texture map to make it apparent in the model then this has to be done explicitly by the user. What this means is that for a surface rendering that is not just photorealistic but actually a representative of the real landscape a great deal of time and effort is required.

Figure 5.19 A still from a highly realistic looking QTVR model of Monterosa generated using World Construction Set* software (Marco Gualdrini, 1999).

Animation 5.4 The Dunadd hill and its surrounding landscape rendered with a generic landscape rendering package. Note the incongurence of the background image in this model, this was an attempt to illustrate the surrounding mountainous countryside. (This DTM was generated from manually digitised contours). (Theatron).

VRML Model 5.2 Unrendered VRML model of Dunadd showing the extruded digitised contours, smoothed in areas, and the extent of the model, later used in Animations 5.4 and 7.1.

As already indicated above, decisions have to be taken by the user at various stages in model construction regarding the number of points that will satisfactorily represent a landscape. Visually, good results can be generated with fairly poor levels of surface detail provided the rendering is complex enough and effectively breaks up the blocky, geometric impression given by a fairly coarse polygon structure. However, poor levels of surface detail, i.e. widely spaced points or contours will obviously result in a less accurate result, no matter how realistic the rendering package makes it look. This problem in combination with the difficulties of landscape rendering mentioned in the previous paragraph often means that in all but the most sophisticated models the landscape is neither highly accurate nor does it have the "look and feel" of a real landscape.

An even more difficult problem for three dimensional modelling packages that are intended to represent an archaeological landscape is the problem of the horizon. If the horizon or far distance is significant to the understanding of the landscape, for example, which hill or mountain tops can be seen, or whether the sea can be seen from a particular location, then a DTM/DEM may have to be very large indeed to cover the entire geographical area that is visible from the area of interest. The fact that the horizon is either completely false or impressionistic in many models used for civil engineering or architectural purposes has little relevance to their usefulness (for an example of an impressionistic background see Animation 5.4). However the significance of the horizon for defining a place in anthropological terms and the importance of the visibility of distant places in the historical past (Ingold 1997 29-32, Lemaire 1997 5-22) means that the inclusion of an accurate horizon could be as crucial in the creation of a virtual world as it is in the social construction of the real world.

An experimental approach to combining a three dimensional model of an Early Medieval sculpted stone with a micro-topographical surface and a panoramic image capturing the horizon was developed in order to solve this problem (Jeffrey 2001). In this instance the reconstructed model of the Jordanhill Cross (see section 5.1.1) and a QTVR panorama of a location where the cross may have originated (in this case the location was hypothetical and it was used for demonstration purposes only).

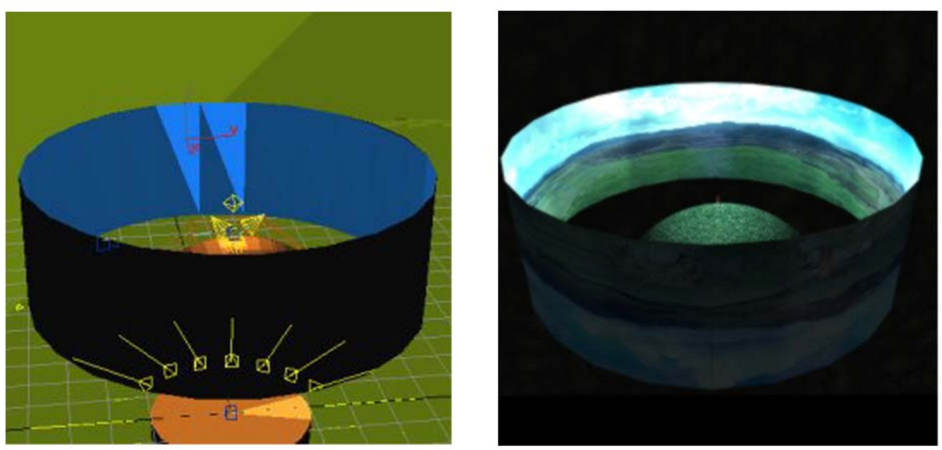


Figure 5.20 L. A screen shot showing the cylinder and projected image inside 3D Studio Max with the photogrammetrically generated model (barely visible) and a fragment of landscape at its centre. R. A lit and rendered version.

This new technique involves using a 3D modelling package to create a cylinder and then taking a stitched and blended QTVR panoramic tile, which has been distorted to allow for parallax effect, and projecting it (i.e. selecting it as the rendering image) onto the inside surface of the cylinder (Figure 5.20). The panoramic tile is best generated using QTVR authoring tools, but a potentially acceptable tile could be created by generating the panorama in an image handling application like Photoshop. The proportions of the cylinder must be calculated carefully to ensure that the full 360 degree span of the panoramic tile is projected onto the inside of the cylinder. In order to do this the width of the panoramic tile is used as the inside circumference of the cylinder. It is then possible to place 3D models either of individual monuments and/or parts of their associated landscape at the centre of the cylinder. Virtual cameras, used by modelling packages to give viewpoints, are then positioned inside the cylinder and so long as their field of view is normal to the inside surface of the cylinder this gives the appearance of the model being in the landscape represented by the panorama. The vertical position of the cylinder relative to the model can be manipulated to gain the desired effect. For example, if there is a fairly large landscape surface model inside the cylinder a combination of camera position, model position and cylinder height can be used align the model with the landscape projected on the cylinder. A small landscape model, say, one that just gives only the immediate ground around a monument (as in Figure 5.20) could utilise almost the full vertical extent of the panoramic tile. Care must also be taken to ensure that the model and cylinder are in the correct orientation relative to each other and to the internal orientation of the modelling package if ‘time of day’ natural lighting effects are to be used.

This approach presents two obvious possibilities for archaeological landscape reconstruction. Firstly, QTVR object movies and panoramas can be generated using the three dimensional model with the reconstructed monument back in context, without the problems of camera angle control mentioned earlier (section 4.2.5). Secondly, 3D guided animations can be created using detailed DTM/DEMs for the local area (Animation 5.5), but with the far distance represented by the photorealistic panorama, although in this case, care would still have to be taken with the angle of the camera. The fact that QTVR object movies can now be generated (with a genuine photographic landscape panorama) from a series of images generated by the 3D modelling package allows for a fairly high degree of interactivity. The user is able to zoom in and out of any part of the image, to slide the image in the window when zoomed in. Most significantly, the user is able to “walk round” the monument by rotating it whilst at the same time observing the surrounding landscape to the horizon (Object Movie 5.4)

Object Movie 5.4 An example of the results of the described technique. Here the reconstructed model of the Jordanhill Cross is apparently placed in a photo realistic rural landscape environment, allowing full rotation and zooming on both the model and the cross. (see also Animation 5.5)

Animation 5.5 An animation derived from the same model as Object Movie 5.4.

Despite the limited success of this approach the problems of integrating real horizons into large landscape models in which Early Medieval sculpted stones might be placed remains. For models presented via interfaces that allow greater freedom of movement around the environment this is an especial problem as the user approaches the edge of the model (see VRML Model 5.2). However, even though the modelling of real landscapes in three dimensions is not without difficulty it is the only way of visualising three dimensional models of Early Medieval sculpted stones in a landscape context that still allows the stone to be appreciated in three dimensions.

6 Audience, delivery and tasking models.

Chapter 4 examined techniques for capturing three dimensional data from Early Medieval sculpted stones, Chapter 5 explored the processes required to prepare them and their landscapes for presentation. This chapter examines modes of presentation and the impact that the choice of presentation medium has on all the issues discussed in preceding chapters. The crux of this chapter is that the audience dictates the mode of presentation and the mode of presentation dictates the nature of the model, and the nature of the model dictates the method of data capture. To a certain extent the 'audience' and the 'reason' for the model can be thought of as interchangeable, although published material can find itself with an audience that was never expected or intended. It is therefore likely that models generated with a particular intention or with a particular audience in mind may actually be accessed by people for whom they were not originally intended.

The SEMSS project has as a central aim, to "…contribute to a greater understanding and public accessibility through conventional and electronic publishing aimed at a variety of levels, including academic, schools and the general public" (Campbell et al 1998). It is unlikely that a single set of models would meet the requirements of such a diverse range of audiences. Even within the three groups mentioned above there will be differing expectations and needs.

Academics would include specialists in, for example, tool markings or deciphering worn inscriptions, they would require very high resolution surface models presented via media where lighting conditions can be manipulated and accurate measurements taken. Academics would also include those with an interest in the landscape setting and archaeological context of field monuments, they might require models presented embedded in larger topographic models that can be navigated over relatively large distances. A further academic field would include art-history where monuments reconstructed in various ways as well as in context would be desirable. There are also specialists in ancient pigments who would benefit from the ability to interactively colour and light monuments as they might have appeared in the past. Curatorial bodies may prefer access to the original point clouds so that they can monitor changes in the stones surfaces as they occur due to erosion. This is not an exhaustive list of specialisms that may take advantage of three dimensional models, and new applications for the models are likely to appear as this type of record becomes more common, but it is already clear each task and each audience requires their model to be presented in a different way. The simplest approach would be to supply only the original record (point cloud or polygon surface) as a resource for academics, if they require recontextualisation, reconstruction or virtual lighting then the record is source material for them to use in the creation of their desired product or in the exploration of the archaeological process. This would severely limit the number of individuals for whom this data is useful. To supply only the original record implies that those to whom it is delivered have the hardware, software and expertise to transform it into a useful product. This has the effect of piling one specialism on top of another, limiting the corpus not only to those who have an interest in, or a specialism, in Early Medieval sculpted stones, but to those who have the ability to meaningfully manipulate raw digital data.

If the nature of the supplied record and/or model is problematic for an academic audience the problems are magnified for schools and the general public. It is not realistic to expect either of these groups to be able to take advantage of unmediated electronic data. Within these groups there will be sub groups whose needs and expectations for the available resources may be quite radically different. It is critical to the presentation mode of the model that the intention of the model is clear. The model may be designed to illustrate a specific point, it may allow unguided interactive exploration of the monument and its context, it may simply be to show what the monument looks like, it may be to offer an interpretation of what a reconstructed or complete monument looked like. The range of questions that can be answered using three dimensional models as illustrative material is immense, as is the degree to which they can be used as a tool for individual unguided investigation. It is important to note that the unguided exploration of a model does not imply that there is no mediation, in fact, as Chapter 5 highlighted, there are numerous layers of interpretation and mediation in the production of even the most basic model or record. What it does mean is that the user is allowed to explore the model and environment without being nudged or directed to particular conclusions by the models generator. Given what has just been stated about the levels of interpretation, intervention and mediation in any model it is fair to say that ‘unguided’ implies nothing more than freedom to examine the model interactively. The user may be able to navigate to a point in the model or a particular view of a monument, what they see when they get there is normally very much under the control of the model builder. The potential for users being able to construct their own models and interpretations is discussed more fully in Chapter 7.

6.1 Virtual Reality

There is no denying that the presentation of three dimensional models via still images, without movement or interaction, or via animations with no interaction, fails to exploit the full potential of the data set. Still images and animation may allow the creator absolute control over what is seen, if that is what is desired, but it reduces three dimensional models to the format of more traditional forms of record. As discussed in Chapter 2 interaction with our environment is at the core of how we appreciate its three dimensionality, similarly the full appreciation of three dimensional models is contingent on an ability to interact with them via their mode of presentation. For this reason Virtual Reality offers the most appropriate mode of dissemination. Virtual Reality, however comes in many forms and means different things to different people. The term Virtual Reality (VR) can give the impression that “virtual” is being used in the sense of ‘near’ (as in ‘virtually’ and ‘nearly’) or one of a range of meanings used in the hard sciences. In this case ‘Virtual’ is being used as term specific to computing science meaning : “not physically existing as such but made by software to appear to do so from the point of view of the program or the user” (Oxford English Dictionary (OED)), as in ‘virtual memory’ or ‘virtual machine’. This is not the most common English usage of the term. In addition

‘Reality’ is just shorthand for navigable three dimensional space. The earliest examples of VR, part funded by the CIA in the mid nineteen sixties (Myers 1998), did not represent anything real in any sense, but did give the illusion of space. More appropriate terms would be the military term ‘synthetic environments’(Fernie and Richards 2002, 2.1), ‘Software Space’ (Softspace), or indeed, ‘Cyberspace’. Unfortunately the novelist William Gibson’s original intended usage for Cyberspace in *Neuromancer* (1984) as: “space perceived as such by an observer but generated by a computer system and having no real existence”(OED), has been usurped by another meaning, which is now more common i.e. “the notional environment within which electronic communication occurs, esp. when represented as the inside of a computer system” (OED). Unless some other term catches on, which is unlikely, we are left with ‘Virtual Reality’ with all the misleading impressions that this term can bring with it to the non-computer scientist. According to some strict definitions ‘Virtual Reality’ or VR, refers only to ‘immersive’ environments, i.e. those involving head mounted displays (HMDs), body suits or similar (e.g. Webopedia*). However it can be used as a catch-all term, to quote Gillings, “ for the diverse set of visualisation, rendering and solid-modelling applications currently finding a growing place within archaeological research”(2000). Attempts to specifically define the term may be best avoided in favour of a concentration of what each technology can actually do (Fernie and Richards 2002, 2.1).

Chapter 5 discussed the recontextualisation of monuments and in Chapter 7 the advantages of doing this are more fully explored. The impact of this on the mode of presentation can be quite significant. The following sections deal with a few of the most widely used VR presentation technologies, some of which are appropriate for ‘worlds’ that is landscapes, or building interiors (frequently referred to in VR short hand as a ‘realm’), but some of which are specifically for three dimensional objects rather than the larger spaces that the objects occupy.

6.2 Pseudo-immersive VR

As described above VR comes in many different forms and as result applications for delivering VR also come in many forms. For the vast majority of us VR is not enjoyed as a fully immersive experience but rather by what is known as pseudo-immersive VR. This phrase either means that the user is experiencing a potentially immersive VR realm via a two dimensional viewing window, or it means that it appears as if that is what the user is doing, but there is no actual VR model. The most accessible technologies for delivering pseudo-immersive VR are VRML, X3D, Qsplat* and QTVR.

All these technologies are designed to be standalone viewers and web-enabled (most operating as browser plug-ins or ‘helper’ applications). Only VRML and X3D are actually capable of presenting both models of objects and models of virtual environments simultaneously. QTVR, as discussed in Chapter 4, can present either object movies or panoramas, and is an image based rendering technique that does not use an underlying three dimensional surface model. Qsplat has the great advantage of incrementally loading large 3D files, this means that an object can be easily rotated in a crudely detailed form, when rotation (or other interaction) stops the detail is loaded incrementally until the full resolution of the model is reached (Figure 6.1). This may seem like a small technical detail, but in fact this system is specifically designed to handle large models and is capable of incrementally loading streaming data (i.e. streaming over the internet) (Rusinkiewicz and Levoy 2000). The implications of this are that, where QTVR and VRML both rely on hardware support to maintain user interaction and will grind to a halt under large loadings, Qsplat will continue to allow user interaction whilst it is accepting streaming data and whilst it is rendering the model. This is a significant advantage for large models intended for internet delivery. Qsplat is a proprietary format that is only openly available to the academic community for research purposes, although QSplat has inspired others to write streaming point-based display systems for 3D models. For example Archaeoptics has produced a version called Octopus which is available commercially

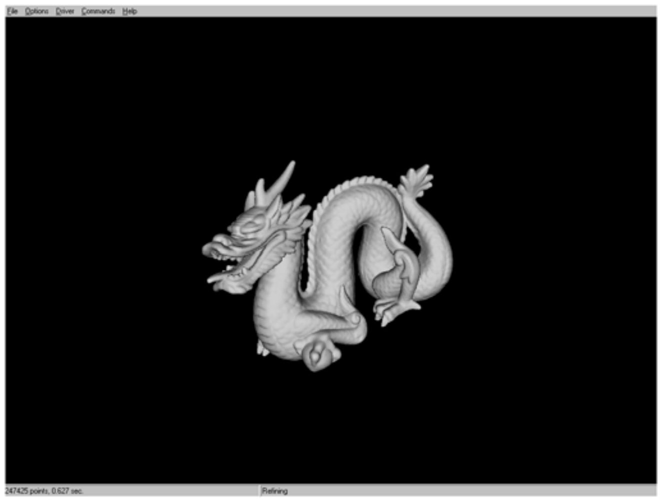


Figure 6.1 A screenshot of the Qsplat interface showing it in the process of rendering.

Qsplat is not capable of delivering models of landscapes and currently has not been developed to include the suite of interface tools that are familiar to users of VRML such as pan and zoom, the interface is currently limited to simple rotation of the object.

X3D is under development as a replacement for VRML (see section 3.4.2) and is likely to be the favoured format for web delivery of VR models which include landscapes in the medium term. VRML and X3D are in fact open source mark-up languages which means that their ultimate delivery is dependant on a range of browser plug-ins that each have their own interface design. VRML Models 4.1 and 5.1 demonstrate how the design paradigm of the language allows users to examine discrete objects (VRML Model 5.1) and navigate VR realms (VRML Model 5.2) via the same basic interface. The language includes support for a huge range of user defined variables that are simply not available to image or point based rendering systems such as QTVR and Qsplat. These include: texturing; viewpoint setting; global lighting parameters; and most importantly proximity and collision detection that stops users from moving through solid objects in the environment and constrains the types of motion that the user is allowed (see section 7.3). However, the variety of implementations of VRML across the numerous plug-ins results in there being no standardisation in colouring and lighting, meaning that unlike QTVR, Qsplat and Animations, VRML models may well look very different from one user's machine to another (Fernie and Richards 2002. 3.7.4). For internet delivery of pseudo-immersive VR realms VRML/X3Ds only major competitor is Java3D*. This is an subset of Sun's interpreted Java language, requiring both a Java enabled browser and a Java 3D extension. It has not become as popular as VRML/X3D because, unusually for a Java package, it is not fully supported across all platforms (it cannot run on Apple systems). In addition Java limits memory and will not load large models, and its interpretation at runtime means that it can be very slow in comparison to compiled applications (Fernie and Richards 2002, 3.8.5).

6.3 Semi-immersive VR

Semi-immersive reality is essentially a technique for surrounding the user with enough screens or screen space that they feel immersed in the environment. The apparent three dimensionality of the projected images is created by wireless LCD 'shutter glasses' which alternatively block and pass images. The computer system running the projection generates left and right eye images sequentially. An infra-red signal synchronises the glasses to the computer generated images, so that the right image is shown when the right lens is transparent and the left image is shown when the left image is transparent (Abdelguerfi 2001, 29). Previously referred to generically as Responsive Workbenches, this type of system is typified by Immersadesk* (Figure 6.2)

Because of cost this type of technology, like fully immersive VR, is going to remain the province of well funded institutions or commercial operators rather than private individuals, for the time being at least (for example British Petroleum use this technology to visualise geological survey data (Kemp 2001). Its primary use in an archaeological context is for VR presentations in museum environments. The Foundation of the Hellenic World* based in Greece has created a number of cultural heritage experiences for presentation via the Immersadesk and ReaCTor* systems, including the Temple of Zeus at Olympia (Roussou 2001; Gaitatzes et al 2001). For museum and educational purposes the fact that up to ten people at a time can share the experience means that throughput of visitors is much higher than with single user systems. Even in a museum or exhibition space Roussou notes considerable practical problems with the technology notably: the fact that the systems are hard for children to use, some systems only track one user (causing perspective errors for other viewers), and there is a lack of developed content (2001). The most telling problem she noted with the system was the issue of cost in terms of both the hardware and concomitant staff training.

Figure 6.2 The Immersadesk system (single curved screen version). (Immersadesk).

Semi-immersive systems such as Immersadesk were actually preceded by ‘fully-immersive’ projected systems such as the CAVE (or Automatic Virtual Environment). Working on the same principle as Responsive Workbenches, CAVEs can be considered fully immersive because, instead of a single large curved screen the physical environment of the user is actually surrounded on all sides by a number of back-projected screens. This systems also uses tracking to monitor the users head and hand orientation, as the user moves inside the CAVE the correct stereoscopic projections are calculated based on the viewer’s position (Abdelguerfi 2001, 29). This systems suffers from the same drawbacks as the Immersadesk, being even more expensive, and with the additional disadvantage that the number of users are restricted to the number that can be comfortably fitted into the enclosed CAVE environment.

Immersive VR is generally thought of as relying on HMDs rather than large screen projected images (occasionally a Binocular Omni-Orientation Monitor, or BOOM, is used as a hand held alternative to head mounting (Dai 1998, 47)). With HMDs two small screens, one for each eye, display slightly different images to create the illusion of three dimensionality. Each user occupies their own VR environment rather than sharing a projected environment with multiple users, this circumvents the problem of which user in a shared environment to track in order to generate the correct projection. Multiple users using HMDs can, in fact, share the same *virtual* environment, these are known as collaborative or distributed virtual environments and are discussed in section 8.2.6.

6.4 Augmented Reality

A further manifestation of VR is a hybrid form known as Augmented Reality (AR). What separates AR other types of VR is that part of the image the viewer accesses is drawn directly from the real world, or actually is a view of the real world, in combination with a digital model (Vince 1995, 15). This technique is used extensively in cinema and television special effects where three dimensional models of objects or buildings or even creatures and people are inserted into footage of real environments. The resulting film or video gives the impression of an entirely real scene. The use of AR in real-time in an archaeological context is being extensively explored by a number of projects such as SimVis* (University of Hull) and Archaeoguide *. Archaeoguide has a very ambitious program for developing an AR system in which users wearing HMDs and a portable computer (see Figures 6.3 and 6.4) can physically traverse an archaeological site and at strategic points have three dimensional reconstructions of buildings superimposed on their view of the real world via their HMDs. As the user moves their head around, or changes location, the AR projections redraws in real-time to maintain the correct visual perspective. This application of AR obviously has great potential (Ryan 2000), but has significant technical hurdles to overcome, not least being the tracking of the location and orientation of the user's HMD to allow the correct perspective image to be projected.

Figure 6.3 Archaeoguide's HMD and portable PC system in action (Archaeoguide).

This approach could be adopted as a means of recontextualising Early Medieval sculpted stone, the advantage being that there is no requirement to model the landscape as it can either be seen directly by the user (with the monument superimposed) or it can be recorded by traditional means such as film or video (as in Figure 6.5). Given that not all modes of delivery for three dimensional models can also present landscape environments, AR can be seen as offering a hybrid approach.

Delivery via HMDs in real-time might be the most technically impressive means of delivery, but once the spatial relationship between the model and the real world environment has been captured animations or QTVR movies could be generated, allowing access to the AR experience via pseudo-immersive media. AR can also be seen as an alternative to fully immersive VR as the user need never lose contact with the real world. AR has been proposed as a model interface for distributed virtual museums (Century 2001) and as a delivery method for adaptive hypermedia displays in real museums (Sinclair and Martinez 2001).

Figure 6.4 A 3D model of a Roman temple superimposed on a real world view of its original location in real-time (Archaeoguide).

Figure 6.5 Impression of what an AR model of the Jordanhill cross might look like.

6.5 Education and diverse needs.

Sections 6.1– 4 discuss the various modes of presentation for three dimensional models and virtual reality environments. Irrespective of presentation via augmented reality, or some other form of virtual reality (fully immersive to pseudo-immersive) the nature of the delivered product will itself need to be varied. As Roussou noted, for museum uses, there is a lack of developed computer based content (2001) and the same is true for higher education in the UK, with 58% of educators feeling the need to further develop computer based learning, including the use of VR technology (Reynier 2002). An analysis of the efficacy of interactive VR based learning tools is beyond the scope of this thesis, but what is clear is that simply creating a series of records (point clouds or image sequences), modelling them - or even recontextualising them in modelled versions of their supposed landscapes locations – will not provide ultimately useful products for all possible applications. For example Bouras argues for web delivered virtual reality environments as a tool for distance learning (a DVE see section 8.2.6) (Bouras and Filopoulos 2000),whilst Champion suggests that in order to enhance engagement with a virtual heritage environment elements of gaming and game theory should be incorporated within it (2002). Although these approaches are not entirely mutually exclusive, they both imply a substantial level of development beyond simply delivering a digital file containing a record of the surface geometry of a sculpted stone. The diverse requirements of curators and educators catering to a range of age groups and differing levels of ability means that ultimate delivery of the records will either have to be negotiated by specialists in these fields or specifically catered for by the SEMSS project by the development of teaching tools and the re-tasking of models in addition to its function as an archive of the original digital records.

6.6 An on-line multi-media database

The sections in this Chapter above all relate to how three dimensional models might be presented, but each is a mode of presenting a single model. The SEMSS project envisages a new corpus and the number of Early Medieval sculpted stones that might be recorded in such a corpus is estimated as being in the thousands. It is worth stepping back from the means of delivering a single model and considering how a collection of thousands of models (and associated text and other media) might be presented.

In practical terms this problem needs to be split into two separate issues. First, how the data is to be organised with individual elements being accessible, and secondly, how the collection is to be distributed to its intended audience.

6.6.1 Local storage and access

It is now standard practice amongst many archaeologists to utilise database technology to store and manage large and complex data sets (e.g. see Hodder 1999). Normally these data sets consist of numeric or short textual records, but increasingly other media are being included in multi-media databases. These databases allow for the storage, manipulation, investigation and retrieval of media such as still images, sound clips, video clips and also embedded objects that cannot be handled by the database itself but that can be accessed by the database invoking a helper application. This means that text containing formatting information, for example a PDF document, can be referenced by a database but read by an external application invoked by the database. Traditionally PC based databases have stored their data internally, within the file structure of the database file, but it is now becoming more common for large database elements to be archived outwith the database but linked to them by some form of internal database record. Object Linking and Embedding (OLE, a Microsoft paradigm that is well, but not universally, supported) is one such technology for doing this, although it can be achieved by simple Hyperlink. This offers the ability for a multi-media database to act as a gateway to large digital objects without having to handle the data internally. For a large collection of three dimensional models (and their precursor point clouds or images) this means that top level metadata, describing the objects for resource discovery, can be stored in the database whilst the large volumes of data representing the objects themselves are stored externally. In simple data management terms this may be a more complicated approach than a discrete database, as links have to be maintained and distributed data is harder to keep track of, but it allows access to the whole range of media required by an archaeological corpus to be accessed by the user via a single coherent interface.

6.6.2 External access

The issues surrounding the distribution of a large multi-media database are numerous. The data may constitute hundreds of gigabytes, how do the users access this? The most obvious technological solution is access via the world wide web. It is very common and relatively easy to mount databases for web access. The penetration of the internet throughout western society is already so high that it can be considered a mass media, even though its penetration is strongly skewed towards particular social groupings. Much depends on the development of the communications infrastructure in the UK and around the world. If access times were to remain static then the delivery of large volumes of data might still be most efficiently achieved by sending a DVD via the post. If broadband technology is successfully rolled out in the next decade by the various commercial interests involved then bandwidth and throughput figures might allow the bottleneck in handling data to be moved back to the PC.

Currently a two tier strategy is often adopted for supplying high volumes of data in varied formats over the internet (e.g. Scottish Cultural Resource Access Network (SCRAN*), Hunterian Art Gallery*). The first stage would consist of an on-line multimedia database that would allow users to search for resources, perhaps manipulate and query records, but would only actually deliver multimedia data that has been specifically 'tasked' for internet delivery. This basically means low file size which in turn means low resolution and/or high compression (e.g. Object Movies 4.3 and 5.4 are low quality internet deliverable versions of Object Movies 6.1 and 6.2, respectively, on the CD). It also means that the selection of file types should be appropriate for internet delivery, i.e. they can at least be accessed by a plug-in application extension if not actually edited by one. The second stage would be master resource delivery, perhaps via a dedicated FTP server for those with high speed internet access or by physical delivery of mass storage media, i.e. a DVD through the post. This two tier approach also allows re-tasking of data at the 'supply-side'. As previous sections in this chapter have noted, there are many different ways in which three dimensional models can be viewed by the user, each involving different hardware and software. A two stage approach to delivery allows for data to be tasked specifically for the end users application in terms of both file format and data mass prior to distribution. A further benefit is that sites which require payment for their resources (or for application specific tasking of it) to effectively advertise what they have available via the web, but deliver and charge for the resources in the traditional way.

Object Movie 6.1 A higher quality version of Object Movie 4.3 (The Tintagel slate) featuring higher resolution base images unsuitable for internet delivery via standard speed modems.

Object Movie 6.2 A higher quality version of Object Movie 5.4. Not only is this model unsuitable for delivery to most recipients, but for most users the large file size causes the transitions to appear jerky although the images in each frame can be examined in much greater detail (via zooming) before pixelation.

The internet and especially the world wide web may hold out the promise of complete and universal access to resources. That promise has not yet been fulfilled, access to a web enabled PC at home is still heavily dependant on social, economic and geographical factors. It is fair to say that elder members of society or those with limited financial resources are least likely to engage with internet technology. It is also fair to say that the vast majority of the worlds population that does not live in the technically dominant rich nations are also very less likely to have unrestricted access to the internet. Even where there is the possibility of access, say amongst wealthy communities in the UK, other biases may come into play such as suspicion of, or distaste for, the technology. If an intended audience is purely academic and national, rather than international, then the differential access for society at large may not be a factor. It should be borne in mind that electronic publication and dissemination can exclude some groups in society as well as enhancing access for those who are able to take advantage of it.

A further factor to be considered if the adoption of an on-line multimedia database is the intended delivery strategy is that this mode of deliveries efficacy is entirely dependant on the usability of the interface. This is a non-trivial issue. The changes in paradigm that have convulsed the field of Human Computer Interaction (HCI)

(Myers 1998) in the last ten years are hard to overstate. We have moved from command line interfaces to accessing complex online databases via interactive virtual environment front ends. An interesting example of this approach is the new English Heritage visual thesaurus project PastScape* (designed by Mike Pringle, only test pages are available on-line at the moment (Pringle 2000)). This very ambitious project is intending to use VRML models of the English National Monuments Records Centre (NMRC*) and various historical and archaeological artefacts and buildings to provide the interface to the NMR on-line. Intended as a 'four-dimensional' (i.e. time (time periods) being the fourth dimension) for the general public (Pringle 2000) this interface allows the user to navigate the NMR record set by navigating an analogous VR realm. This is an increasingly common approach to the visualisation and access for large and complex data sets. Initially it is hard to see a problem with HCI paradigms that make it easier for all users to access information. There are, however, two important points that should be borne in mind. The first is that simplification of access inevitably means complication of the underlying delivery mechanism. Making a database easier to access by, for example the VR interface in PastScape, necessarily makes the programming of the interface more complex. This issue will have little impact on most users, but it does mean that further layers of indirection are being placed between the data and the user. For some a command line interface is a more comfortable means of accessing data, the feeling of engaging with data directly rather than through the filter of a highly designed interface gives some users more confidence that they are actually getting what they are looking for rather than a mediated, incomplete or biased version of the original dataset. It should be stressed that good HCI and interface design may in fact allow all the functionality of directly accessing the database via a language like SQL, however the perception can remain that without command line control of the data, full control is lost.

The second issue raised by interface design is the impact of the longevity of the interface design paradigm on the longevity of the data set. This point runs a little counter to the point made in the paragraph above about direct access to the data, but it is also true. If database interface design had stopped at the command line then who would now be accessing the data in the database? Many people today who are perfectly computer literate and competent would find it quite difficult to operate DOS without a graphical user interface (GUI). If they were presented with a database that required SQL to access the data, without training, they might never get at the data at all. Commercial databases such as MS Access* use sophisticated GUIs to distance the user from the underlying code operations. The future of database access is likely to lie in pseudo-immersive VR interfaces, which are themselves likely to evolve continuously. Taking these two points together, means that a database cannot be created and then abandoned (orphaned). If the interface to the data is not in step with the current paradigm then the data becomes less and less accessible, simply because the users are not able to access the data either because they have not been provided with the technical skills or they are simply unfamiliar with the access design paradigm.

The implications of this are, that unlike traditional publication in book form, where a corpus is created and distributed and the job can then be considered done, a corpus that is published electronically would need curation for it to continue to be useful. Put more simply, Allen and Anderson's *Early Christian Monuments of Scotland* has lasted in a usable format for 100 years with virtually no intervention, it is inconceivable that an electronic SEMSS corpus would remain usable for 25 years without some level of intervention.

A final point to be noted on the topic of audiences and delivery is that the mode of delivery impacts on the perception of resources being delivered. This happens in at least two significant ways. The first is that, in the words of Marshall McLuhan "the medium is the message" (McLuhan 1964, 7), the impact that ICT has as medium on the perceptions of the information it delivers can be profound, this point is discussed more fully in the next chapter. The second point is more pragmatic, because it appears electronic access to information is becoming the norm and that the will and/or ability to access paper records is diminishing the process of migrating paper resources to electronic formats has begun in a vast range of academic and commercial fields. Initially it is only newly generated material that is available electronic means and later archived material slowly begins to be adopted into the new electronic corpus. The process by which this happens is generally that *the most significant* material is migrated first and, slowly, *less significant* material is migrated to the new medium. The italics are to emphasise that significance in this context is entirely subjective. Unless all material is available immediately in the new format, there will inevitably be an assumption that what is available is more *significant* than what is not. This effect can give completely spurious impressions to an uncritical audience. Worse, material can become genuinely significant simply because it is available whilst other material is not.

The second effect is that due to deficits in the available finances or motivation, some material is unlikely ever to be migrated to electronic formats. This will also happen because the volume of material that already exists on paper is so large and the rate at which new material is being generated in electronic formats is so rapid. It is almost a philosophical question, whether it would ever be possible to abandon physical media in favour of electronic media entirely, let alone whether it is desirable. Practically this means that some, if not most, material will remain unconverted to electronic format. This issue bears comparison to the issue of foreign language publications. Not all archaeological material exists in the English language, unless a paper or book is considered *very significant* it may never be translated from say, Hungarian into English. This means that for the majority of English monoglots the majority of Hungarian publications have no impact on their understanding on archaeology, indeed they may as well not exist. For material that is never destined to be migrated into electronic formats, for many of us, it may cease to exist. The assigning of this type of manufactured significance rests almost entirely on the decisions of financially powerful organisations, the funding for migration of data is controlled by them and control of funding ultimately means control of information. As a result positions of archaeological authority can be entrenched and re-enforced as the opportunity arises to retrospectively edit the complete archaeological record by selective migration. Therefore it is possible to see the eventual dominance of a new form of publication as presenting serious difficulties as well as significant advantages.

6.7 Faith in the record.

The possibility that paper media will wither away and be entirely replaced by electronic media in the medium term is unlikely. The CBA's* *Publication of Archaeological Projects: a user needs survey* (Jones et al. 2001) highlighted the fact that a sizeable proportion of the wider archaeological community, even those that had internet access, preferred to read paper publications. Just as the invention of radio did not spell the end for newspapers, but became a parallel medium, all forms of electronic media are likely to co-exist with traditional forms, with each form of information dissemination having something unique to offer the user. The issue of trust is bound to be a factor in whether or not three dimensional models of Early Medieval sculpted stone begin to replace traditional records. In the light of Chapters 4 and 5 it is apparent that there are layers of user intervention and interpretation in the production of even the simplest three dimensional model, so will the end user trust the veracity of the final model? For example, a NURBS surface can be examined in closer and closer detail with each re-rendering giving the impression of a continuous surface rather than a polygon mesh. If the user zooms into the model, close enough to the surface that what they are seeing on the screen represents magnification, yet the surface still appears smooth and continuous, if the user does not know that the original data capture was at a resolution above visual acuity they will not be aware that the surface they are seeing on the screen is entirely interpolated.

It is also true that data stored on electronic media are far more easily manipulated. This is normally considered a major benefit of electronic media, however, constancy can be seen as an advantage. For example, the text in a book never alters (between editions), printed photographs stay constant, they can both be referred to again and again and they will remain unchanged. The potential for fluid editing and continuous updating of electronic data may undermine a users faith in the authority of what they are seeing. If three dimensional models are constantly being remodelled and re-presented those who are engaged in the search for a ‘definitive record’ may be disconcerted by the fact that there is not one on offer. This is actually a question of time scale. Books and other paper records do change, either appearing as new editions or being superseded by new publications. It is primarily the pace at which change can take place with electronic publishing that marks the difference.

The long time scales (years or decades) for substantive changes in the record allow more space for assimilation and contemplation, although, it would be difficult to use this argument persuasively against electronic publishing, given its numerous other advantages.

7 Virtual interpretation.

7.1 Interpreting Digital Representations

In the last quarter of the 20th century and the start of the 21st there has been no more influential area of technological advancement than that of information and communication technology (ICT). It has had an impact on almost every area of life in the western world, from business and politics to the nature of social interaction. Through computer technology the character of what can be presented to us on cinema screens, television screens and computer screens has blurred our ability to distinguish between what is a special effect and what is a record of an actual event or object. In the same time period the digital recording and presentation technologies described in Chapters 4, 5 and 6 have moved from prototype to specialist equipment to commonplace, at least in some industries. At first sight there is indeed a huge potential for harnessing these converging trends to create a new form of archaeological record. There are obvious benefits for those with special needs, such as individuals with impaired mobility or vision. This is because, as discussed in Chapter 6, three dimensional models can be presented using a number of interesting presentation media such as immersive "Virtual Reality", pseudo-immersive VR, with or without haptic interfaces that allow three dimensional digital surfaces to be 'felt' by the user. Looking beyond the technicalities of three dimensional modelling the most significant question for archaeologists studying a corpus of Early Medieval sculpted stone is how three dimensional digital records presented via VR interfaces might influence our understanding of these monuments.

Discussions on the ways that three dimensional models alter and bias our understanding of the modelled object should not be seen as criticisms of the approach in general, but rather as embracing the opportunity to construct a critical framework within which to interpret three dimensional records once generated. This would appear to be a timely moment in the development of three dimensional modelling and its adoption as an archaeological tool to consider how, paraphrasing

McLuhan again, the *medium* affects our understanding of the *message* (1964, 7). To date, the majority of three dimensional models created for the archaeological community have been experimental, developmental and “proof of concept” works (Ryan 2002). They are investigations into the suitability of technologies for the presentation of archaeological material. It is not yet a widely adopted approach which is fully embedded in the canon of acceptable archaeological practices, although trends suggest that these technologies will increasingly become part of standard archaeological practice within the next few years. Future practitioners of three dimensional modelling are less likely to be computer scientists, or indeed, specialists in computer technology of any kind. Instead they are much more likely to be archaeologists who have developed the skills needed to handle the appropriate hardware and software (although practitioners on the cutting edge will always be specialists). This change is being facilitated by the constantly improving usability and hence accessibility of all the relevant technologies. Consequently, now is the time for archaeologists to be thinking about the impact of this new form of record and presentation media and how it will affect our perceptions.

One of the ultimate goals of archaeologists is to gain an insight into how the world was perceived in the past. The debate continues about to what extent this can be done (for example, Uzzell 2002), but nevertheless, simply recording the remains of the past would be a sterile pursuit if there was no attempt to appreciate some of the significance of those remains and therefore how they were thought about in the past. To what extent, if any, does three dimensional recording help or hinder this process?

7.2 Real objects and digital models

7.2.1 Authenticity

> "People want to see the real past, not some virtual reality model. It would be vandalism to found a cultural centre on the remains of a treasure of national and international importance like this without making the effort to save it." - Francis Pryor, President, Council for British Archaeology, August 2002, discussing the discovery of a medieval ship at Newport, Wales.(Pryor 2002)

In the context of the recent discovery of the medieval ship in Newport it is clear that it is the object itself that is important; no matter how it is recorded or presented via images or as "some virtual reality model" people in general still want to engage with the original object. In much the same way, a facsimile or reconstruction will never replace what is considered to be the 'real' experience of interacting with a medieval sculpted stone or its landscape. The authenticity of monument or context are not socially or politically neutral issues: indeed even the conception of 'authenticity' has itself become contentious, especially with regard to the reconstruction of monuments or the re-instatement of sites. The Venice Charter of 1964 and the Operational Guidelines of the World Heritage Organisation both stress authenticity as a crucial factor in the presentation of monuments (McBryde 1997, 94). However, there is no unanimous notion of what constitutes an authentic vision of the past, and therefore no way to represent it. As Isabel McBryde points out, authenticity is an elusive entity to put into operation in heritage practice (McBryde 1997). In the case of Early Medieval sculpted stone, many of these artefacts have long histories of movement around the landscape, or around the country, of being reworked or re-oriented. Each change reflects a change in the meaning of the monuments; these sequences of change can begin as soon as the monument is created and continue through the centuries to the present day. Even static monuments that have been neither moved or substantially altered can still have lengthy biographies (Gillings and Pollard 1999, 179). Which period of change or which set of meanings represents the authentic context of the monument is clearly problematic. Is the original meaning and context intended by the sculptor the authentic one, the one that we should strive to represent? In fact McBryde points out that the usefulness of the word "authenticity" itself has been called into question and favours the more ambiguous 'integrity' (1997, 95). Even so, people's engagement with artefacts, monuments, and their context is coloured by whether they feel they are actually engaging with a 'real' monument or a representation of a 'real' context. Interacting with an authentic representation or viewing a reconstruction with archaeological 'integrity' will not wholly mitigate against the fact that they are not engaging with the actual physical item itself. It remains a representation mediated by heritage practitioners.

For example, a carved stone reconstruction of the Hilton of Cadboll monument, by sculptor Barry Grove, was erected just yards from where the carved base section was subsequently found. The reason that a reconstruction was commissioned was because a local campaign to return the cross to Hilton of Cadboll from Edinburgh was not successful, and the reconstruction was therefore, to some extent, a surrogate for the authentic object. Currently an intense debate amongst national bodies and local groups is taking place on where the sections of the object will be exhibited. Despite there being no quantitative survey it is clear that local feeling is almost unanimous in desiring that both sections of the monument be exhibited in Hilton of Cadboll (Siân Jones, pers. comm.). There are a large number of issues, (archaeological, conservatorial, historical, and especially social and political) that fuel this debate and a resolution satisfactory to all parties is unlikely. The fact remains that even where the best possible replacement can be provided, the authenticity of the original and its original context carry a social significance that cannot be adequately reproduced by any means.

Figure 7.1 Top: Barry Grove's modern reconstruction, detail. Bottom: the Hilton of Cadboll cross base during excavation.

The desire for the authentic may be genuine, but it is hard to define or fully explain. Art historians, historians and even archaeologists do not need to be in constant attendance at the original monument in order to conduct research on it; they can and do rely on the record, and the record alone often allows them to fulfil their objectives. For example, J. Romilly Allen comments that Sir John Stirling-Maxwell's monograph *The Sculpted Stones at Govan* meant that:

> "… the antiquary sitting comfortably in an armchair can learn more about the Govan stones in a few hours than he could previously have done in as many weeks , if not months, of hard work sketching out of doors". (1900)

Academia is to a certain extent built on the quality control of such records in order that they may be used with confidence by other scholars. Scholarly engagement with the past is different in nature to the forms of engagement that many other people may be seeking. There may be a mistaken notion that those who are not actively researching an object but who nevertheless want in some way to experience or appreciate it, will be satisfied with the record, whether as a book, a three dimensional model, or a physical surrogate.

The stone reconstruction at Hilton of Cadboll is a highly accomplished piece of craftsmanship and artistry; consequently it was an expensive item to commission. By comparison, a three dimensional computer model generated from a digital record is relatively inexpensive. In addition to being delivered via electronic media a model can be used to produce an accurate physical facsimile of a monument, relatively cheaply. This is particularly important in relation to Early Medieval sculpted stone, as this body of material is, as already noted, particularly subject to collection and dislocation. A current driving force for moving these objects and monuments is degradation due to environmental factors (Campbell et al 1998), and this is certainly the case with the Hilton of Cadboll cross base. The most cost effective way of preserving the artefact from damage is to add it to a museum collection maintained in controlled conditions. The fact that an affordable technique now exists to generate facsimiles which can be used to represent an authentic object in its original location should be seen as major development, but only where there is no other option but to move the monument. It should not be seen as adding weight to any argument for relocating a monument in the first place. The arguments for or against relocating monuments should be conducted without reference to the availability of records, facsimiles or reconstructed objects.

One result of the dissemination of records and representations of an object or place by electronic means, is that far from lessening the urge to see the authentic object, it has the opposite effect. For instance, reading about, or seeing photographs of, for example, the carved footprint on the summit of Dunadd whets the appetite to see the real thing. There is no reason to think that a good digital model of the footprint, realistically rendered and presented in a modelled virtual landscape would not have the same effect. The actual experience of putting your foot in the carved footprint, to physically interact with it, becomes the goal. This experience would be diluted if more people knew that the footprint seen at the summit is actually a facsimile and the real footprint is lying beneath it, protected from wear and the weather (RCAHMS 1999, p23). Digital records, despite being so different in nature and impact to traditional records, will undoubtedly have a very similar effect, encouraging visits to the original monuments rather than replacing those visits with a ‘virtual experience’, except for those who physically cannot get to them.

7.2.2 Objectification

Objectification of the stones - the process by which they are transformed from field monuments embedded in their own social, cultural and physical landscape into archaeological artefacts or art objects - is an inevitable result of relocation. Stones have frequently been relocated to museums, but also into shelters, churches or other protective buildings, often grouped with other objects. Even when the monuments have not been moved any significant distance, they have been removed from their original archaeological context though they may still be in an historical context, if they were first moved in antiquity. The separation of the monument from its original context can, in one sense, be seen as part of an ongoing process, as it is known that many of the monuments have been moved more than once at various times during their existence. In many cases it can be hard to define what the original context might have been, all knowledge of it having been lost. Even in this case, the monument loses almost all sense of archaeological or historical context it might have had when it is moved into a museum environment. In addition, the social and cultural biographies that such monuments accrue can be irrevocably changed by relocation; their aura of permanence in the landscape cannot be regained once they have been moved. Over the years the apparent quasi-portability of this type of monument has contributed massively to their objectification. In addition to the implications this has for the local communities and heritage management bodies, it also facilitates the divorce of images on the stone from the significance of the stone itself and its location. The rich iconography used on Early Medieval sculpted stones and the ornate pattern forms are often considered in abstract, as images that could be carried on any medium, and need not necessarily be intimately bound up with the symbolism of megalithic monumentality and, later, the Christian cross, as landscape features.

Three dimensional computer models cannot completely counter the process of objectification, but they may mitigate against it in several ways. One way is by allowing the relationship between various carved sections of a stone, which may be visually exclusive or cannot be captured in a single photograph, to be seen together as part of a single record. These relationships can be described in text and illustrated in scaled photographs, but benefit enormously from presentation in VR, where a single interactive record can present all sections of a three dimensional object in such a way that these relationships are accurately represented. In this way individual sculpted elements are more clearly seen as part of a single three dimensional object, presented in a single record rather than a series of records such as photographs or drawings.

Probably the most important contribution VR representation can make to lessening the objectification of Early Medieval sculpted stones is to allow for them to be placed in a representation of a landscape context, either at a precise location, if known, or in a hypothetical one. This process of recontextualisation involves embedding a three dimensional model of a monument inside a three dimensional model of a landscape. This can be achieved relatively easily, or can involve very complex and elaborate models of landscapes (Jeffrey 2001). Either way, there is an immediate shift in the perception of the monument from an object in isolation to an object as one element in a larger, more complex landscape.

Recontextualisation can facilitate the understanding of relationships between the monument and other elements of the landscape such as other archaeological sites, other Early Medieval sculptured stones, religious buildings and settlements. The relationships that the monument has to other earlier elements of the landscape are not accidental (Driscoll 1998); the monument's position and outlook would have been carefully considered by their original creators and would have been seen as integral to the function and symbolism of the monument, as can be seen from Dunadd (Campbell 2003). This has been acknowledged and debated by archaeologists and art historians in the past, but the tools for investigating these relationships remotely have not previously been available, even though they are still relatively undeveloped now. The process of recontextualisation can be seen as moving the monuments from the 'artificial' environment of the museum or shelter, into a representation of their 'real' environment. The 'real' environment in this case, is in fact a virtual reality model. As such, the user must be aware that it is itself a construct, developed by other archaeologists, technicians and programmers. At each stage of its construction, decisions are made regarding the accuracy and the 'look and feel' of the model as well as the more obvious interpretational decisions on where to actually locate the monument in the reconstructed landscape. This process of interpretation and decision making which occurs at every stage in the production of the model is often hidden from the end user. This fact is what currently distinguishes VR models from other forms of archaeological record. It seems acceptable to present impressive reconstructions and recontextualisations without details of the technical and archaeological interpretative processes used to create them being made explicit at the point of delivery and assessed by peer review (Miller and Richards 1994). This would not be acceptable in any other form of record. This failing will have different impacts on different audiences. Research audiences may be well equipped to critically appraise the model; public audiences may not be so well equipped.

Recontextualisation is obviously a form of reconstruction and as such needs to be approached with the same cautious sensibilities that all forms of reconstruction do. Nonetheless the re-embedding of models of archaeological sites, monuments, buildings and artefacts in Virtual Reality models of landscapes occurs frequently in the popular media without any apparent due care. Just as frequently the virtual worlds being represented are in fact transposed in time, what is being presented is not a reconstruction of a building in a reconstructed modern environment, but an attempt to recreate how that building and landscape would have looked like in the past.

7.2.3 Past realities.

There is an active debate concerning the representation of landscapes using maps and GIS (e.g. Ingold 1997; Gillings and Pollard 1998;2000; Bowden 2000) with one of the main threads of argument being that the world was not thought of in two dimensional plan view before the common usage of maps. In the developed West we grow up with the concept of these maps as a means of representing the world around us. We absorb the cognitive building blocks required to understand maps at an early age. As a result, all of us have a more or less developed ability to relate what is represented on a map or plan to what we see around us, the most proficient being able to accurately imagine a whole landscape from its representation as contours and fields of colour on a map. This contrasts with the ‘mental map’ of the landscape held by those, like most in the Early Medieval period, with no familiarity with two dimensional plan maps. Virtual Reality environments have more in common with two dimensional maps than with mental maps despite being representations of the world in three dimensions. This is because a mental map is not constructed solely from the physical geometry of the world (Tilley 1994) in the way that 2D maps and 3D models are. Before commenting further on the recontextualisation of Early Medieval sculpted stones in ‘virtual landscapes’ using VR technology, it is worth briefly considering our relationship to the real world landscape and the decisions we take about what to include when we model it. What we see as the quantifiable dimensions of the real world - the three spatial dimensions of Euclidean geometry plus colour - may not be the defining features of the world as it was understood and experienced in the past. Such things as gods, spirits, ancestors, the sound of music, the history of places, good hunting grounds, and good water can all be thought of as occupying a space, but one which defies measurement and definition in three dimensions. They are imponderables to us but they may well have been crucial signifiers in the internal landscape of people in the past. We are constructing models of the physical framework in which reality was experienced in the past, but the framework is unavoidably empty of the things that actually constituted that reality.

To further distance the worlds of 21st century Virtual Reality from the experienced realities of the past, the worlds we construct allow us to fly, to travel at impossible speeds and to manipulate enormous objects. They give us abilities beyond normal physical human experience. They allow us to exist, imperfectly and temporarily, in hyperreality.

7.3 Hyperreality in VR

This section explores some of the ways in which interactions with objects and landscapes in VR models, not only differ from real world interactions, but also change our perceptions of the things that are modelled. A very noticeable difference between traditional archaeological records and almost all Virtual Reality models is the lack of standard indicators of either scale or orientation. Photographs, drawings and even written descriptions normally include some form of benchmark to allow the user/reader to discern the size of the object being described as well as its orientation in space or in the landscape. Scale bars, ranging rods and north arrows are used as standard indicators in archaeology, yet they are rarely if ever used in VR. It is hard to know why this might be as the technical challenges in describing and embedding such information are certainly not insurmountable. In VR environments that have no context, i.e. the modelled object is presented in blank 'neutral' space there is nothing to which it is possible to relate the size of the object (see Animation 5.3). Early Medieval sculpted stones vary so much in size, morphology and sculpted detail that it is not possible to guess at the size of an object without reference to an object of known size for comparison. The lack of scale bars makes recognisable context vitally important in gauging the size and orientation of an object.

7.3.1 Solid objects and movement

A by-product of interactivity in VR models is the impression that it gives of the weight and solidity of a modelled object. Assumptions about the weight and solidity of objects based on experience are made from static images such as photographs, whereas interactive models can be actively misleading in this respect. In general, any modelled object that is rotated or examined in VR, whether a small portable object or a large monument (Figure 7.2), requires the same force to move. This is the physical force that is needed to move a mouse around on a mouse mat, or the force needed to press a computer keyboard key (although, as discussed in Chapter 5 there is the potential for representing weight in other ways). These forces have been kept deliberately low by the designers of computer hardware for ease of use and repetition. Although the designer of the environment may want to give the impression that either the small object is rotating, or, in the case of a modelled building, that the viewpoint of the user is moving, in fact in both cases it is the model that as being rotated in its rotation matrix (or in the case of QTVR models in the viewing window). As a rule, the weight of an object is not recorded and three dimensional representations are presented as unnaturally weightless objects. Models are therefore presented in a weightless environment because there is no easy way of replicating the differential force needed to manipulate objects of varying weights with standard computer hardware. Haptic interfaces using force feedback devices to provide information via the sense of touch may offer a solution to this problem. These devices can be used to represent a differential in weight between different objects in a virtual environment.

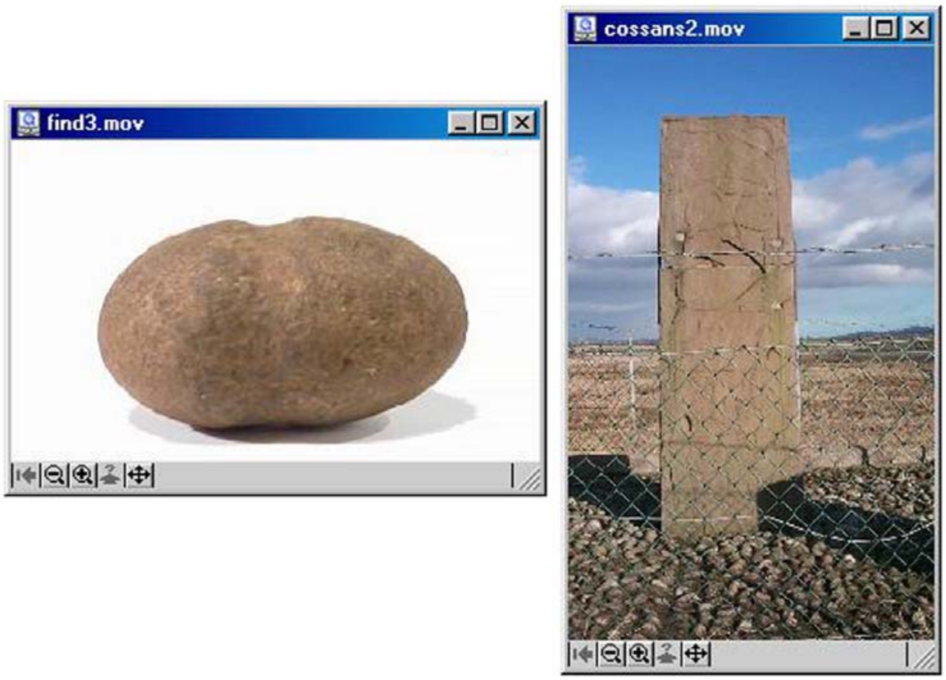


Figure 7.2 Screenshots of object movie interfaces Left: small loom weight (Minehowe, Orkney). Right: St Orland’s Stone, Class II stone (Cossans, Angus) Note the identical interface.

The need find a way to represent the relative weight of objects in VR environments can be circumvented by simply stating the weight of the object, and again relying on the user to critically interpret the model and the relative weight and solidity of the objects being modelled. For portable artefacts this approach may be considered adequate, but for very heavy or immovable objects (i.e. earth-fast), the user should be made aware of the superhuman strength imbued by interaction with the object.

This is a special concern when the object modelled is represented without any context. An example of this is the VRML model of the Jordanhill Cross (VRML Model 5.1). Despite the fact that in the real world this cross is immovable, when it is presented in a neutral or empty environment it is possible to spin and rotate the object in any direction, without context. The idea that it should appear to be the viewpoint that is moving and not the object is lost on the user. In the real world we can walk around the cross, looking at it from many angles and at many ranges, but we cannot lift it up and rotate it to get these angles of sight yet this is exactly the impression given by the model. In fact there is no way of interacting with the model directly that does not give this impression. This reinforces the objectification of the cross by again presenting it in an way that is alien to that intended by its sculptor(s) and indeed in a manner no different to that of any small, portable artefact. Context, of any kind, is essential to our perception of the scale, weight, solidity, and immovability of sculpted stones originally intended to be earth fast. Even when context is included, whether recorded or wholly artificial, there remains the problem of undifferentiated levels of force being required to manipulate objects in virtual reality. A potential solution for portable objects is to link the maximum speed of model rotation to the weight of the object, thus small objects could be rotated quickly and large heavy objects or very dense objects only slowly. This could be used to differentiate the relative weights of portable objects in a VR environment; however where the object is (or should appear to be) immovable this would give the impression of only being able to *move round it* very slowly. If this was strictly adhered to then it would in fact be impossible to interact with immovable objects at all.

However, it is not the case that all hyperreal modes of engaging with virtual reality models are intrinsically bad: a number of monuments are displayed in the real world in ways that do not allow them to be seen as they were originally intended. An example of this is the Nigg (2.10) stone, now on display in a small church annex, but presumably originally intended to be as prominent in the landscape as the nearby stones of Shandwick and Hilton of Cadboll were. Due to the constraints of the room size it is impossible to view either of its broad faces fully looking straight on to the sculpture without crouching. In the circumstances, short of relocation and redisplay, a model of this stone that would allow a more normal, view would be a definite advantage to the researcher. It is also possible to demonstrate that the ability to assume impossible positions in relation to the modelled object has advantages. For example, an impossible ‘birds -eye’ view of Michelangelo’s Florentine Pietà generated from a three dimensional model allowed the art historian Jack Wasserman to confirm a hypothesis concerning the relationship of the figures of the Magdalene and Christ in the statue (Bernardini and Rushmeier 2000, 43).

7.3.2 Time and movement

Although the above section indicates that a potential method of representing weight in VR environments is to use time as a regulated variable of the presentation, this raises the wider issue of how the temporal component in our understanding of landscape and landscape features are dealt with by these models.

Distortion of the temporal component of the real world in VR models has a curious effect on our understanding of landscape monuments. When a digital model of an Early Medieval sculpted stone is presented (by whatever technique) in a digital representation of its surrounding landscape, it is extra-temporal: there is effectively no relationship between time and space. This means that the time taken to move towards or away from the monuments or to walk around it is in no way constrained by how much time it would take to navigate that space in the real world. There is therefore a dissonance between what the landscape looks like and the time taken to navigate it (compare this with the problems of frame rates in QTVR models discussed in section 5.1.3.2). Taking into account the importance of the temporal component in our understanding of landscape, it is legitimate to suggest that models that do not allow for an accurate relationship between time and space can be actively misleading. This phenomenon is especially apparent in animated ‘walk throughs’ or ‘fly-bys’ of VR models, where the objective is often to spectacularly show as much of the model as possible in as little time as possible (see Animation 5.3), where both the viewpoints and the speed of movement are entirely unnatural or even impossible Animations 7.1 and 7.2). The speed of motion through the virtual environment could be very simply relayed to the user by having it indicated on screen as the viewpoint is moving. Essentially this is a very similar issue to that of representing scale: just as the user needs a benchmark to try and gauge the size of an object in a VR environment, so they need to know how fast they are moving in a landscape in order to appreciate its scale. At the very least, the user needs to be provided with the necessary information to appreciate the degree of unreality of motion unfettered by the laws of physics.

Animation 7.1 A wider landscape model of Dunadd, this animation shows an approach to the site along the river Add. Note the speed of movement along the river would not be realistic today and does not represent speed of travel in the past (Theatron).

Animation 7.2 A fly-by of the same model, an unnatural environment with an unnatural viewpoint (Theatron).

An alternative, and superficially attractive, method of embedding temporality in a model, is to constrain the presentation environment in such a way that it is only possible to move through it at an appropriate speed. However, it is not hard to imagine a user’s response to a model containing landscape and monuments that requires twenty-five minutes to navigate from the insertion node (the point at which the user enters the model) to the locus of the monument, simply because that is how long it would take to walk on foot. It also raises the issue of scale yet again. If a monument was a place of pilgrimage or of gathering, then the time taken to travel to it in the past might have been measured in days; what then would be the advantage of insisting that the last section is travelled in real time?

However, an alternative approach to handling movement through virtual environments might be useful: embedding cost surfaces. The notion of a cost surface has been around in Geographical Information Systems analysis (GIS) for some time and offers a way for various environmental factors to be included as variables when performing spatial analyses such as route finding. Steepness, roughness of ground, proximity to specific locations and various other factors are modelled (given numeric values on a scale) and are associated with particular areas of the geographic model. Algorithms can be invoked that would calculate the route between two points, taking into account the environmental factors modelled in each grid square between the two points. Although the technique has its critics, it does appear to be capable of yielding some interesting results when used in predictive modelling (for example Bell and Lock 2000). A full discussion of the usefulness or otherwise of this technique for archaeology is beyond the scope of this research, but there are exciting possibilities for developing both illustrative models and models as tools for interpretation.

An example of an illustrative model using cost surfaces might be one that constrains movement through a landscape depending on purely environmental factors. For example, an important conceptual barrier that has to be overcome when thinking about landscapes in the medieval period is the notion that islands are isolated places. In academic discussion of movement in the pre-industrial age it is always stressed that this is a misconception and that the seas were in fact the “highways of the past” (Campbell 1999, 9). Movement over land, especially of material was in fact slow and difficult in comparison to sea travel, the reverse of present day perceptions. The problem is that the barrier is conceptual, and conditioned by personal experience: simply saying that we have to think about the sea as in a different way does not necessarily produce the desired change in perceptions. To experience an analogue of the difference in a virtual model of the real world might more positively reinforce the new concept in comparison to just thinking about it (see the map in Campbell 1999, 42 for an attempt to do this in two dimensions). A model could therefore constrain movement through the environment dependant on the nature of the surface being traversed. If absolute real world speeds are considered an unrealistic barrier to using the model then at least the relative relationship between the speed of walking over land, up and down hill, rough ground etc. and of sailing in a boat could be maintained. In this way, a user navigating a model representing a broken landscape of islands and large bodies of land would quickly discover that it was much faster to travel by sea. This could be especially revealing in demonstrating why even relatively short land journeys could be faster by sea and could be extended to demonstrate experientially why portage sites were so important in navigating Scotland in the past.

The use of embedded cost surfaces to model cognitive variables is more problematic. Classically, cost surfaces in GIS are used to represent environmental and physical factors; however it is generally accepted that our conception of the world and the landscape we inhabit is also socially constructed (e.g. see Tilley 1994; Ingold 1997). The social component of the landscape can be made up of an almost infinite number of interrelated and reflexive elements such as biography of place, the perceived nearness to holy, polluted or forbidden places, and the visibility of various natural or manufactured features. Attempts have been made to categorise these qualities, resulting in such classes as ‘social-symbolic’, ‘power-hierarchical’ and ‘spatial-temporal’ (Forte 2000; 2002), but these qualities are so inter-related that a universally acceptable categorisation is unlikely. More likely is that each attempt to model the archaeological landscape beyond the physical will have to create its own explanations and justifications. Such notions are particularly hard to model in GIS, let alone in reductive digital models of landscapes. However, if it is acknowledged that these social and personal factors are as significant to perceptions of the landscape in the past as they are now, then it might be useful to try to represent them in some way in model environments in the future. For instance, forms of movement through a landscape and interaction with its various elements might be investigated in VR environments that represent some of the cognitive qualities of the archaeological landscape. This approach could add flesh to the empty framework alluded to earlier in this Chapter, and in certain respects it could produce a more ‘realistic’ environment than one which relied solely on sophisticated visual realism. It is also important to understand what the limitations of such an approach might be. A few years ago it was possible to imagine a VR system in which the landscape was represented in such realistic detail and with such high levels of realism and interactivity that the landscape could be experienced in a phenomenological sense. That is, a user experienced the landscape and the monuments in it in such a way that their unique subjective experience of the landscape allowed insight into perceptions of the landscape in the past. However, what is actually created is a phenomenology of the virtual landscape. Personal experiences in such a landscape would necessarily include the way in which the unreal experience of hovering or moving without real physical effort, the way in which surfaces and objects lose detail and definition on close examination, time does not seem to pass, the sun remains in the same position or else moves quickly and unnaturally. These elements comprise what Forte describes as the virtual-dynamic cognitive quality of this type of landscape representation (Forte 2000) . Essentially no amount of detail and realism in a Virtual landscape can replicate the experience of being in that landscape if the way in which it is being experienced is intrinsically unnatural. Even the most sophisticated fully immersive VR systems can only provide an environment that can be considered realistic because the user is prepared to suspend disbelief in much the same way that cinema audiences can be drawn into a story by wilfully suspending disbelief, consciously or subconsciously ignoring incongruences in the experience.

7.3.3 Timelessness

Probably the least initially noticeable but nevertheless potentially critical aspect of temporality in Virtual Reality realms is the lack of a sense of time passing. A user can interact with a VR environment for hours at a time (if they so wish) but nothing in the landscape will change, the position of clouds, sun, moon or stars remains constant. The position of the sun can be selected in some VR environments, indicating the time of day and casting the appropriate shadows, but it generally does not move in a naturalistic fashion with the passing of time. Shadows do not move, leaves do not rustle in the trees, water does not flow in rivers (see Figure 5, right). These effects are perfectly possible in animations generated from VR models (for a good example see ‘Lone Tree’, Jamie Krutz 2000*) and even some real time environments (Gillings and Goodrick 1996, 3.1.2). These factors are almost exclusively left out of today’s VR environments since the overheads in both constructing suitable algorithms and executing them in real time are large in comparison to the advantages. The result is that VR environments have the ‘look and feel’ of a series of three dimensional photographs, capturing particular moments in time.

To a certain extent the stillness of the environment can be compensated for with the use of sound. The sound of leaves rustling and of water babbling can go some way to giving the desired impression, although using sound in this way runs the risk of drawing attention to the stillness by heightening the difference between what is heard and what is seen. However, a background noise level of sounds appropriate to the environment mitigates against intrusive real world sounds and may encourage some sense of time passing.

7.3.4 The invisibility of the body

One further significant factor to highlight in the peculiar environment of Virtual Worlds is the absence of the body: living creatures and other human beings in virtual environments are commonly absent. This is primarily because fluid complex organic creatures are very hard to model, and it has only been in the very recent past that CGI versions of human beings have become in anyway close to being undetectable, (for example in the Hollywood film *Final Fantasy – The spirits within* (Sony 2001)) in order to produce realistic hair effects 60,000 strands of hair were modelled (not in real time) and a rumoured 100 million dollars went into the technology and processing to create this effect (Meek 2001). Clearly real time versions of such CGI characters are some time away from becoming commonplace. Despite this many archaeological virtual world designers see it as desirable to populate their models with human beings (Millard 2001; Lloyd 2001), This could be seen as a post-processually motivated desire to reintegrate people into the fallaciously empty pseudo-objective representations of archaeological spaces (e.g. Tringham 2000). Although as Bateman observes “Physical space can be seen to be physically populated, but this does not represent a social population of that space, the visualisation of a place in which people are living. The vistas created cannot, by their very nature, represent such places. The people are missing, even when their bodies are shown.”(2000). In fact, more often it is an attempt to present more ‘realistic’ representations of the past by including accurate rendering of body type, clothing and even the behaviour of people in the past (Shirley 2000). Whatever the motivation, there does appear to be a desire to include humans in reconstructions of the past. The levels of interpretation required to create a human population may be challenging: clothes, hairstyles and even language would all have to be hypothesised, but the potential benefits of the inclusion of people, beyond simply adding scale and realism, do exist and are discussed section 8.2.6

7.4 Surreal representations of real objects

The contradiction inherent in this discussion of digital artefacts is that even whilst struggling against objectification in terms of divorcing artefacts from their contexts, we are actually swapping one form of objectification for another. Instead of the object being presented as a museum piece, or an element of iconography being presented as unrelated to the medium that carries it, digital objects are presented in a uniquely 21st century medium, creating an impression just as distant from that intended by their creators.

7.4.1 A potent medium

Virtual reality technologies are not merely extensions of previous recording and presentation technologies; they offer a whole new set of difficulties in maintaining a critical stance. Historically, when a new medium comes along (photography, colour photography, film and video) it is perceived as intrinsically capable of better, clearer representations of the world. Later, a critical language is developed so that the mediation implicit in the medium can be disentangled. Each new medium flourishes and is later deconstructed as an historical source in its own right as opposed to merely an objective record. There is a complex sequence of technical and interpretative decisions involved in generating VR models and presenting them via digital. All media involve these decisions to some extent, but VR is particularly powerful and alluring. The newness of the technology still generates a 'wow factor' and the choice of imagery still tends towards deliberately spectacular, at least in museums and the broadcast media (e.g. Ryan 2000). The computer screen is itself a medium loaded with meanings and messages, its associations with science and technology still lend it a special air of authority in many people's minds. Yet, the computer screen is not a conduit of solely infallible and authoritative information. With Virtual Reality, the combination of powerful imagery delivered via a medium that itself occupies a position of social significance generates a potent product that cannot be taken at face value.

7.4.2 Barriers to reinterpretation

Although it is no longer universally seen as the ultimate goal in virtual archaeology, realism is still seen by many as highly desirable in this type of visualisation (e.g. Shirley 2000; Devlin and Chalmers 200; Chalmers and Rushmeier 2002, 22) In the rush to create virtual environments that look more and more realistic (see Figures 5.19 and 7.3) the impact of the apparent realism of these environments on interpretation should not be ignored. First it is necessary to make the distinction between 'realistic' and 'real'. Digital models that are generated from some underlying record and therefore represent real world objects can in this context be thought of as ‘real’. Hypothesised sections of a model, representing conjectural monuments, fragments or landscapes, are not ‘real’ in the sense that they do not represent real world objects, but they can appear ‘realistic’. Ironically it can be easier to produce a realistic looking model of a hypothetical object than to produce a realistic model of a real object. This is because a model of a real object must conform to very specific criteria (size, shape, texture colour etc.) as these are known, to some extent at least. A non-real world object model, on the other hand, simply has to look ‘realistic’ rather than fully adhering to known criteria.

So in VR environments the distinction between real and realistic is an important one: for the reasons stated above it can be impossible for a user to tell what is based on a real world element and what is conjectural simply by how realistic the object or landscape looks in a VR environment, especially one whose main objective is to create the impression of reality. The acceptability of this in a model purporting to be an archaeological reconstruction is open to question.

Richly detailed and visually impressive models can have an actively detrimental effect on a users ability to reinterpret the source of the model. Graphical information relates more directly to human process of interpretation and communication and this can be unexpectedly potent (Fernie and Richards 2002, 2.6.2). In many audiences there is also an assumption about the provenance of hypothetical components of VR models. Because they are traditionally expensive and technically complex to create, the assumption can be that if the creator is going to the trouble and expense of creating this model in the first place, then the interpretations that are explicit and implicit within it must be to some extent valid and most likely represent some current ‘academic consensus’. The combination of a potent graphical medium with these assumptions could easily give the impression that the model is in some way definitive. This is especially true if the audience is the general public, who may have no access to alternative interpretations, let alone the information from which these interpretations were derived.

Figure 7.3 A landscape model of Dunadd hill fort, Argyll with much less complex landscape modelling than Figure 5.19, but still intending to achieve realism. (Theatron and author).

Another factor inhibits the active reinterpretation of hypotheses presented via VR models. This is the process by which such images seem able to 'trump' the imagination. It is a familiar experience for many of us to read a book and then to see that book interpreted on the cinema screen. The internally imagined world based on the book may be quite different from that imagined by the film's director. The corollary of this is where the film is seen first, after which the faces and images first seen on the cinema screen become hard to re-imagine in a different way when reading the book. The cinema images can be so powerful that famous historical characters are inevitably visualised as the actors who have portrayed them. It is equally likely that powerfully imagined VR representations of one particular archaeological interpretation could make it harder to reinterpret (Eiteljorg 2000). It is not an argument against using VR models as a way of presenting recontextualised monuments, or hypothetical reconstructions of monuments. Rather, it is an argument against attempts at realism in those models and against presenting the model as a *fait accompli*, or, as Gillings (2000, 59) calls them, “ingenious ‘end-products’ ” without any information explaining the process of creating the model and justifying interpretational decisions. This is not just about being explicit regarding levels of interpretation in a model, although that is important, but also recognising that powerfully realised interpretations, what Forte (2000) calls peremptory single interpretations, can dominate more archaeologically valid but less well presented interpretations.

There exists more than one approach to countering this problem and one of the cleverest is to maximise the interaction between the user and the model so that various interpretations can be seen and potentially the user can construct his own interpretation within the model. A good example of this is Jonathan Roberts and Nick Ryan's VR reconstruction of the Roman theatre at Canterbury which allows the user to manipulate various factors such as the number of seats and their dimensions (Roberts and Ryan 1997). However this raises issues of usability and the technical skills that can be reasonably be demanded of your audience. Archaeologists familiar with modelling applications and committed to exploring alternative interpretations are more likely to take advantage of this approach than the general public. A simpler approach is to cast aside the pursuit of realism and to actively create unreal, or surreal, environments.

7.4.3 *The Data rich model.*

The ultimate objective of archaeological computer reconstructions is not to produce a realistic model that is indistinguishable from models of extant structures or monuments. The objective should be to explicate the process of interpretation that led the researcher to believe that this particular reconstruction is the most likely. The first stage in this process is to make distinct what is based on record and what on hypothesis. An example of how this might be done would be a model where reconstructed segments of a model of a real world object are deliberately mis-coloured to draw attention to the fact that they are reconstruction not record (as with the model of the Jordanhill Cross used in Chapter 5) (Eiteljorg 2000). This notion is already well developed in other types of (physical) reconstruction such as ceramic vessels and frescoes where standards exist. As well as indicating which elements are reconstructed, the explanation of the underlying technical and archaeological processes should also be embedded in the model. This means that explanatory text and images are part of the model package, they cannot be separated from it. No matter where the model is delivered, the user will always be able to access an underlying layer of data that describes how the model was produced. This bundling and embedding of information relating to the model is a far more complicated problem and global standards are needed create a benchmark for the process. Such data should include, but go beyond the metadata data sets promoted by the ADS (Fernie and Richards 2002), which are primarily aimed at resource discovery, towards those promoted by the embryonic Cultural Virtual Reality Organisation (CVRO) where assumptions and interpretations are included (Frischer et al. 2000; Ryan 2002). It is possible to shift the notion of an archaeological VR model away from being just the actual three dimensional model itself, often a single file, towards being a package or suite of records bound together which provide the necessary tools to critically assess the model. Such tools would include information such as: the accuracy of the recording technique for recorded segments; the hardware and software used; and what decisions were taken (and who took them) concerning aspects such as surface generation from point clouds or rendering of surfaces. Where an object is recontextualised, the accuracy of the landscape recording technique and the archaeologists confidence in the hypothetical context, can be indicated by different colours, with sections derived from high resolution data being light red, for example, and sections from low resolution being dark red. As systems become more sophisticated other elements of the models such as texture or sound could be used to convey this information. It is possible to imagine looking at an ornately sculpted section of a model and having an explanation of its form and art historical significance relayed by an audio track whilst the accuracy of the recording and landscape positioning is indicated by differential colouring or by texture changes relayed by haptic devices.

In such ways, information relating to the generation processes behind the model can be made explicit in the model itself at the expensive of realism. By using the model as a representation of its own generation processes it is possible to balance out the apparent significance of various elements in the model ‘package’. For example, if the resolution of the data capture technique is crucial to our understanding of a modelled surface then presenting the surface realistically rendered but with information about resolution as a linked HTML document can create an unintentional bias in the perceived relative importance of these two ‘package’ elements. By using colour in the rendering process to indicate data capture resolution the balance can be redressed.

In the near future it is most unlikely that this approach will supersede the use of models that are realistic, but the two approaches are not technically mutually exclusive. It is perfectly feasible to have a artificially coloured, textured and auralized model containing all the information required about its subject and about itself as part of the same ‘package’ as a realistically rendered version. This is probably the most desirable approach of all. The realistic version can appear with the illustrative version, but not without it. This could to some extent counteract the narrowing of interpretational horizons by pre-emptory single interpretations, as the user would have clear indications of the underlying processes of model generation represented to them with a visual intensity as powerful as that of the realistic model. This notion of creating a data rich model which describes itself by layering data in such a way that the user can switch between realistic model, metadata, explanation and interpretation, all presented or accessed via the same VR interface (analogous to selecting themes or layers in GIS/CAD applications), goes far beyond the data integration suggested by either the ADS or the CVRO.

7.4.4 Artistry and the surreal

There is a long tradition of artistry in archaeology. The early antiquarian sketchers and draughtsmen often produced beautiful and attractive works. The photographs of the likes of Flinders Petrie are still enjoyed long after the monuments and sites they capture have been more extensively and accurately recorded. The value of their art does not lie simply with the archaeological utility of their work but in its aesthetic. Photographers and site planners today can still produce material that is as artistically pleasing as it is useful as a record. The symbiosis of art and archaeology expresses itself in many forms today, from the conceptual landscape art of Barbara Bender to the playful abstractions of Philip Barker* both based on archaeological images. Unfortunately the world of pure computer art, whilst gaining ground in the mainstream, has yet to make a significant impact on the world of archaeological computing. This is possibly a side effect of the quest for realism, and possibly because priorities other than aesthetics take precedence in all archaeological projects. However there is an opportunity for the construction of surreal and beautiful images and experiences. Art as a means of expressing human emotion could find very useful tools in three dimensional computer imagery and virtual environments. I have often struggled to express various experiences whilst in the landscape. The written word in the hands of most of us provides a poor tool for modelling the richness of human experience, but the visual arts have been a traditional way of trying to transmit experience that is essentially ineffable. Ruth Tringham has commented on the relationship between photography, art and capitalism and argues that “computer-generated imagery is the ultimate medium for the expression of the visual imagery of late-corporate capitalism” (Tringham 2000, 5) Rather than abandoning the technology to the technocrats who created it and, by implication, are exploiting us through it, she has constructed deliberately surreal and challenging images. Her reconstruction of the Neolithic village of Opovo in Yugoslavia, embedded in a web of linked texts, sounds and images all based on field research is the heart of her ‘Chimera Web’* project. Her intention was to construct multiple realities of Opovo’s past, all illusions, but all “founded empirically in the archaeological, architectural and other data”. This approach draws heavily on strands of philosophy and social criticism that are not often applied to this area of archaeological practice, but if you share her sentiment that abstract, dreamlike and surreal imagery could form the core of our visualisations of past realities then a more challenging and creative application of virtual reality technology may benefit us all.

It bears reiteration that many Early Medieval sculpted stones retain strikingly appealing aesthetic qualities to this day. It is also beyond debate that their original use and appreciation was spiritually and emotionally charged. Tringham's approach may well allow greater insight into the Early Medieval world than even the most perfect representation of reality.

8 For future presentation

It is inevitable that the shelf life of the printed word with regards to three dimensional modelling is short. In the time period in which this research has been undertaken much has already changed, from the appearance of automated time of flight laser recorders to the founding of private companies dedicated to exploiting the growing interest in three dimensional recording in the heritage sector. This chapter is an attempt to look a little further into the future at technologies and approaches that will not be fully developed for a few years yet, but are rich in opportunity and implication. There are two separate but related areas of change in the cultural and heritage sectors. The most tangible is the plethora of new technological approaches to three dimensional visualisation as well as the rapid improvements in technologies designed to capture three dimensional data. Less tangible but equally, if not more, significant is how these technologies impact on the field of archaeology. Some of the changes may be unsubtle, involving technical conferences, consensus standards, large investment and wide acceptance, other changes may operate at a far more subtle level, changing the nature of our relationship with what we see, with other disciplines, and with the past.

8.1 New and improved technology

8.1.1 Data capture

Until very recently portable devices for capturing three dimensional information from object surfaces operated at resolutions that were far coarser than their static counterparts. Although devices that remained on the 'shop floor' could resolve points at sub-micron level, field devices were operating at millimetre resolutions. The Minolta Vivid* portable laser triangulation device now offers a maximum resolution of 0.17mm. Given that the acuity of the human eye is around 0.085mm (section 3.5.1), modern machines are fast approaching levels of resolution that allow effective magnification when examining the surface of the object, potentially field devices will one day match the sub-micron accuracy of static machines. There is no reason to expect that this incremental improvement in the resolution of which these devices are capable will not continue. As recording technologies improve the other issues of data mass, archiving, and delivery will become increasingly significant in the decision making processes relating to what is an appropriate resolution at which to scan a sculpted stone. That being said, parallel improvements in the ability of modern computer systems to handle and deliver large volumes of data can also be expected.

One area of improvement that will deliver immediate benefits specifically to the field of recording Early Medieval sculpted stones will be in size and portability. A useful exemplar for how three dimensional recording devices might look in the future is ‘The Handy’ hand-held digitiser from Electro-optical Information Systems (EOIS*), Figure 8.1. This device is actually a structured light digitiser working on similar principles to the devices described in section 4.2.1. The levels of resolution that ‘The Handy’ offers could soon challenge the tripod mounted lidar/laser trigonometry devices. This device’s resolution is dependant on the CCD resolution in the camera and therefore on the range at which the image is captured and, although a resolution of 0.2mm is claimed in the specification sheet, the device would only approach this level recording very small objects.

The device illustrated in Figure 8.1 would overcome almost all the constraints on data capture devices indicated in section 3.4. The device is handheld, battery operated, lightweight (1.5kg), portable, and small enough to access almost any conceivable location on a sculpted stones surface however it is displayed. It is not unreasonable to expect some of the other technologies which offer better resolution and do not require controlled lighting conditions to aspire to the physical characteristics of ‘The Handy’ in the near future.

Figure 8.1 The EOIS 'The Handy' handheld topometry digitiser.

Future developments in data capture devices are not restricted simply to questions of resolution and portability. Other elements of non-topographic surface information (NTSI) can also now be routinely recorded. The Minolta Vivid device is capable of capturing the RGB value of each point that it resolves in three dimensional space. Similarly Cyra, Callidus and others have either recently deployed Monochrome or RGB capture devices (simple cameras) on their scanning equipment. These developments now allow direct association of RGB (or monochrome) texture maps with polygon surfaces during the post-processing, rendering phase of models derived from point clouds captured with these devices. This now means that techniques such as photogrammetry and topometry (and to a certain extent QTVR) which have the great advantage of deriving texture maps directly from photographs are now being challenged by techniques that do not have their disadvantages (as described in Chapter 4).

Simple RGB data is not the only NTSI that can be captured, Rushmeier and Bernadini (2000) indicate that: Bi-directional Reflectance Distribution Function (BRDF the reflectance of a target as a function of illumination geometry and viewing geometry), UV photography, x-rays and Computed Tomography (CT) volumetric data might all be appropriate datasets for capturing with regards to art works such as Michelangelo's Florentine Pietà. Recent efforts in this field have focused on the simultaneous acquisition and integration of these multiple properties. However, data fusion and presentation issues are currently making it difficult to make this multi-modal information available to the user (Rushmeier and Bernadini 2000, 42). The Rock Art Pilot Project (2000) also investigated NTSI with a view to recording stone strength using a Schmidt Rebound Hammer in order to test stone strength and stability, this was a un-automated process and only 20 measurements were taken from one stone (2000, 7.5.2). It is however conceivable that information on stone strength and stability could in fact be modelled in three dimensions over an entire stone and this information delivered via a three dimensional model. The Schmidt Rebound Hammer is obviously a contact device and the RAPP team noted its destructive nature (2000, 7.5.2.3), so another technique for gathering this data would have to be developed if it were to be applied to Early Medieval sculpted stone. The most likely candidate for appropriate NTSI data in the near future is reflectance values, the most suitable uses of reflectance values are described in 8.1.2 and 3 below.

8.1.2 Image based rendering

As pointed out in section 4.2.5, it is not always necessary to capture three dimensional measurements of the surface of a monument to produce a three dimensional model. Image based rendering is the generic term for three dimensional models based on photographic images rather than on surface models. QTVR object movies represent on of the simplest and best developed examples of this technique (Warniers 1998). Despite the serious difficulties in applying this technique to large field monuments, notably controlling lighting conditions and gaining clear access, the techniques benefits in terms of minimal hardware and ease of production suggest that it will be a useful technique to develop. There are two approaches to its development that offer particular promise and can hopefully be successfully applied in the future. These are Polynomial Texture Mapping (PTM) and Light Fields. Both these approaches depend on the ability to control the lighting conditions under which the recording or data capture phase is undertaken. Previously the practical difficulties of doing this have been indicated to be so serious as to make such techniques unviable except for portable artefacts. However, if PTM and light field technologies come to fruition as robust useable systems then the advantages may be so great that the practical problem of controlling lighting for field monuments may be tackled in earnest.

8.1.2.1 Polynomial Texture Mapping

The semi-automated system developed for capturing multiple lighting angles described in section 4.2.5 to produce QTVR object movies where lighting angles can be interactively controlled (see Object Movie 4.3) has also been used to produce polynomial texture maps. PTMs are an ingenious technology for capturing and manipulating reflectance values from the surface of artefacts. Although the mathematics behind the process are extremely complex the basic principles behind it are relatively simple. Using a light dome, such as the one in Figure 4.17 or the one shown in Figure 8.2 which was developed by Hewlett Packard laboratories*, a series of images are taken of a target object from a large number of varied lighting conditions, but from the same camera position. The images are then combined in such a way that the colour and intensity of reflected light recorded by each pixel is stored together with the same information from the corresponding pixels in each of the original images. In this way a ‘PTM file’ is built up in which the colour and intensity information of each pixel under each lighting position is stored in a single file. This means that in order to render the image from a particular direction, the viewer program accesses the PTM file and extracts the values stored that represent information about the reflectance of each pixel under different lighting conditions. The number, position, and intensity of virtual light sources can then be manipulated.

Figure 8.2 HP Laboratories light dome.

This approach offers two major advantages in addition to the ability to render the image under the numerous lighting positions captured in the original recording event. First, it allows for the interpolation of renderings that represent a lighting position between the original lighting positions, presenting the user with the opportunity to light the model from any direction and light intensity whether or not that particular direction and intensity was used in the light dome. Secondly, it facilitates the manipulation of reflectance values consistently across each pixel of the PMT file. This in turn allows for completely novel lighting conditions and reflectance properties that are not native to the target object. In Figure 8.3 we have a very good example of how this second technique may offer the opportunity to extract information from lightly incised, worn or difficult to see surface that cannot be extracted by any other technique. Figure 8.3 represents 4 different renderings of a Sumerian tablet (the only archaeological example of this technique) created at the HP research laboratories (Malzbender et. al. 2001). Image A is a unaltered digital photograph. Image B is the polynomial texture map that represents lighting conditions identical to those of the photograph (image A). Image C, represents an image where surface normals have been extracted from the PTM and the reflectance has been altered from diffuse to specular (i.e. more light is reflected directly towards the viewpoint, this is what makes surfaces appear shiny, rather than scattered in diffuse directions, which is what makes a surface appear matt). Image D is a combination of images B and C apparently giving the surface of the tablet the reflectance properties of a shiny material such as polished metal. The self shadowing properties of the surface are maintained and as a result surface detail that is hard to discern in the original image becomes much clearer in the manipulated one.

Figure 8.3 The Sumerian tablet rendered using a PTM. TL: Image A, TR: Image B, BL: Image C, BR: Image D. (HP laboratories).

The limitations of this technique as it stands at the moment include the resolution that digital cameras are currently capable of capturing and the small size of the target object. The technique obviously has enormous potential for small detailed objects that can be appropriately captured by the maximum resolution of modern CCD cameras, around 5 megapixels. The same resolution applied to a large object such as an entire side of the Aberlemno II stone (Figure 2.2) would not give anywhere near the same level of detail. Also potentially problematic would be adaptation of light domes to capture much larger objects.

8.1.2.2 Light Fields

Clearly the development of PTM technology would offer an extremely useful tool for the recording and investigation of lightly incised or heavily worn surfaces. However it does not enable the interactive manipulation of the artefact or monument in three dimensions in the way that both three dimensional surface models and QTVR image based models allow. QTVR relies entirely on the viewpoints captured in the initial sequence of photographs. In sections 5.1.3.1 and 2, the problems of aligning images captured in the field are discussed as is the concept of creating interpolated frames between captured frames in order to allow for smoother transitions and an increased number of view points. This approach is rapidly reaching maturity in the form of Light field technology developed by both Mark Levoy and also Paul Debevec. Levoy has already applied the technique in a limited form as part of the Digital Michelangelo project mentioned in Chapter 5 and elsewhere, whilst Debevec's main objectives are in the entertainment sector, such as the development of cinema special effect techniques (Debevec 2002, also Unger et al. 2002), although his work's potential utility to heritage applications is as great as Levoy's. The concept is illustrated in Figure 8.4. The Red dots in this diagram represent camera positions whilst the blue blob in the centre of the camera array represents the target object. The diagram itself represents a *Flatland* view of the system being a single plane seen in plan view. As can be seen from the diagram with enough cameras the light being reflected from the target object can be captured no matter which direction it comes from, this effectively captures what is known as the light field of the object. The yellow dot represents a viewpoint where no physical camera was ever located but which can be constructed by the selective 'borrowing' of pixels from nearby physical camera positions. This technique frees the viewpoint of the user from being tied to the viewpoint of any of the actual camera used in the recording process and allows it to be placed in a theoretically infinite number of locations within the light field of the object.

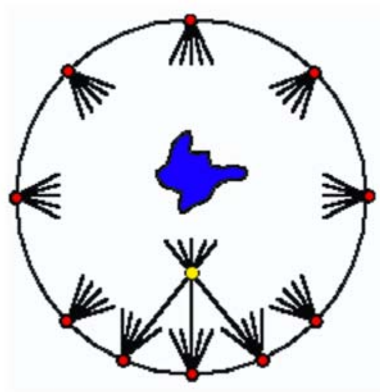


Figure 8.4 A '*Flatland'* view of how a light field is captured (from Levoy 1996).

Early efforts to capture light fields such as those by Levoy (1996) used very sophisticated and expensive rigs such as the Stanford multi-camera array (Figure 8.5) for the initial data capture phase, although, the main thrust of the effort to create effective light field techniques is directed towards the development of effective software because the hardware required is essentially off the shelf i.e. cameras and lights. More recent attempts to incorporate the principles of capturing reflectance values and light fields in combination have used fewer cameras and purpose-built light stages. The current state of development in integrating these two approaches is exemplified by the work if Paul Debevec at the University of California (Berkeley). His project on capturing the reflectance field of the human face (a long time touchstone problem in computer graphics) has produced impressive results (Debevec et al. 2000). The project light stage (Figure 8.6) uses light sources mounted on a dual axis rig that over the space of a minute or so lights the target (a human face) from multiple directions. This process is recorded by multiple digital video cameras and the post-processing phase allows for the extraction of a model of the reflectance values of the target on a pixel by pixel basis allowing it to be lit virtually with complete flexibility as well as allowing for the interpolation of novel camera positions.

For Early Medieval sculpted stones it is possible to envisage a form of model generated by image based rendering techniques that combine and enhance the advantages of three basic forms of model that we have already seen: the ability to model the monument using images only (Object Movie 5.1) allowing the interpolation of novel viewpoints, the ability to interactively light the model from any conceivable direction (Object Movie 4.3), and the utilisation of light values extracted from real world light sources using spectral analysis (section 5.1.2). The combination of these approaches represents the next significant step forward in three dimensional modelling techniques, but it is important to remember that the problem of extracting surface geometry from the base images has not yet been overcome (although if lighting has been effectively controlled during the data capture phase then the use of topometry concurrently with the capture of reflectance field seems appropriate). Without surface geometry to utilise, image based rendering techniques do not allow for the deployment of ancillary techniques such as haptic technology or the recontextualisation of models in landscapes modelled by other methods (see section 5.3).

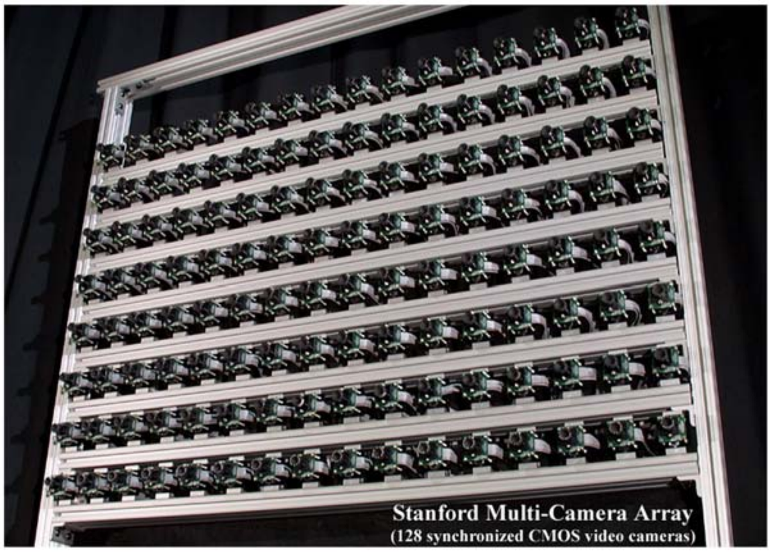


Figure 8.5 The Stanford Multi-camera array (Mark Levoy).

Figure 8.6 A time lapse image of the light stage used to capture the reflectance value (and light field) of the human face. (Debevec 2000).

8.1.3 Display Technologies

Just as the speed and capacity of computer hardware seems to be on a relentless upward path to higher capacity and faster processing, display technology is also improving providing larger screens, higher resolution screens and screens that can display millions of colours with absolute clarity. These advances will undoubtedly continue, but waiting in the wings are other technologies, specifically designed to display three dimensional subject material that could offer an alternative to the fully immersive VR helmet and data glove which may remain beyond the pocket of most users for some years yet, as well as not being convenient or a particularly appealing prospect for many people (see Figure 8.7).

Figure 8.7 A VR4 Head Mounted Display (HMD) for immersive VR environments (Virtual Research*). This type of equipment may not appeal to all potential audiences.

Volumetric displays are a technology that may radically change our interaction with three dimensional models in the future. As previously mentioned, short of immersive VR, all three dimensional models viewed via computer screen are actually two dimensional images projected onto the screen using a Frustum projection. In order to appreciate the three dimensionality of the models in these circumstances it is necessary to interact with the model by moving it in some way. It would be advantageous to be able to project the three dimensional model into three dimensional space. Volumetric displays are actually capable of projecting images into a real three dimensional space. Just as two dimensional displays are constructed of individual picture elements (pixels) volumetric display utilise volume elements (voxels). Actuality System's * Perspecta 3D display is perhaps the most advanced version of this technology commercially available, the display illuminates a 100 million voxels within a transparent dome, enabling users to render high-resolution spatial images that can be viewed from any angle (see Figure 8.8). The great advantage of this system is that it is autostereoscopic (requiring no goggles) and can be viewed by many people simultaneously. Currently the maximum image is 10 inches in diameter and colour at high resolution is limited to 8 channels. If the small size of the display and limited colour rendering are overcome then volumetric displays are a likely candidate for the next big technological move forward in digital displays. Although still an expensive technology (the Perspecta 3D uses 3Gb of RAM and has an embedded 1600 MIPS processor) it could well be appearing in museum and educational contexts within one or two years.

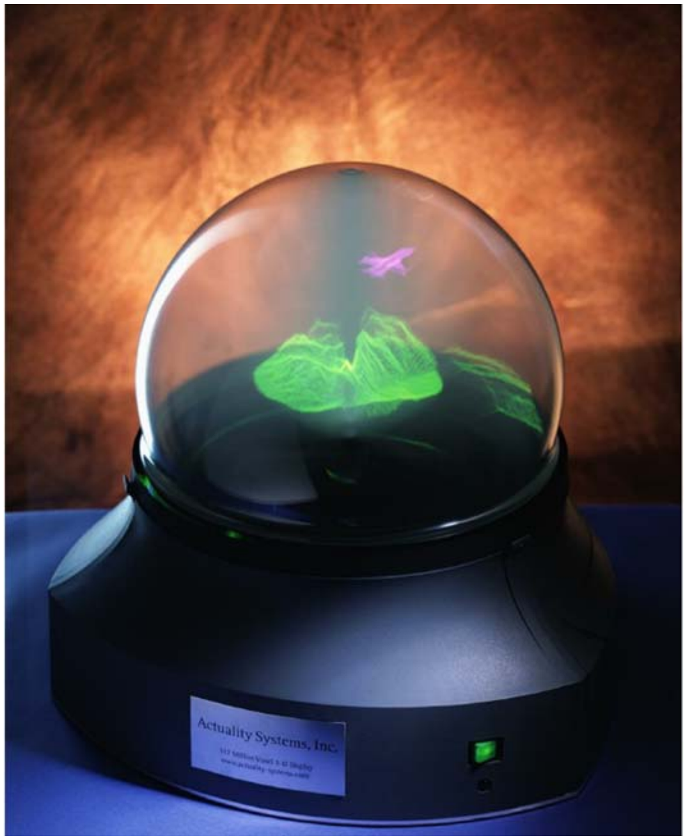


Figure 8.8 Actuality System’s Perspecta 3D volumetric display.

Less well developed than volumetric displays is large scale high resolution holography. Holography is familiar to many of us as the ‘3D photographs’ that appear as security decals on bank credit cards. Photopolymer materials recently developed have allowed for very high resolution holography (3 micrometers resolution). Although primarily aimed at the conservation of artworks, this technique has already been used for capturing and displaying archaeological material, notably at the Laboratory of Bio-physics at the University of Munster*. Here a project, part funded by UNESCO, captures holographic images of Cuneiform tablets at resolutions high enough that they can be studied by scholars, reducing the need to handle the fragile tablets (see Von Bally et al 1997). Fragmentary tablets can even be reconstructed as complete pieces in hologram form. Holography is in fact an analogue form of record and requires the photopolymer for display, at the moment it has more in common with casting than it does with laser scanning. However, for people who prefer to hold and examine a physical object rather than to interact with a projected representation of it on a two dimensional screen (for example, to read from a book rather than from a screen), holography offers this possibility. Potentially three dimensional models captured using other data capture techniques could be presented in photopolymer format.

8.2 The other senses in Virtual Reality

Reflecting the pursuit of realism in non-archaeological VR realms, one of the most apparent trends in three dimensional modelling and virtual reality presentation is the continuing development of hardware and software techniques that are designed to present information to human senses other than sight. Four other senses: hearing, touching, smelling, and even the sense of motion are all being explored as vectors for delivering information within virtual environments. This section deals with each in turn, but it is important to note that in a virtual reality context the affects of several sensory inputs is likely to be cumulative in its impact (McGee et. al 2000, 33). This means that an immersive VR realm that had all the senses covered would be a powerful experience, barring the users access to any sense of the real world by manipulating all their sources of sensory input. The experience of being in a VR realm is often referred to as ‘presence’ (Champion 2002) and it is the intensity of this sense of presence that can be heightened by multi-modal environments. The impact that such a environment might have on the individual is poorly understood as yet since truly convincing systems do not exist. However, where they have been used, for example, in combat simulations they can lead to significantly high levels of stress even though the participants are aware they are in VR (Sterling 1993). The wider social impact of such technologies when applied to entertainment and education remains to be seen. In the context of VR realms carrying representations of Early Medieval sculpted stones the potential for other forms of sensory input is discussed below, however it is very likely that new applications will become apparent as the technology develops.

8.2.1 Sound

Sound is relatively straight forward to integrate in to Virtual Environments. Most modern computers have internal or external speakers and a headphone socket. Stereo presentation has allowed recording artists to simulate three dimensionality for decades. By playing sounds at different volumes through different speaker channels it is possible to create the illusion that the sound source occupies a particular location in three dimensional space. However, headphones alone can only give a very coarse impression of 3D sound, because each ear can actually hear (via the head) the sound going into the other ear, stereo sound often appears to be emanating from within the users own head. More sophisticated VR hardware versions of headphones such as the Convolvotron and Alphatron, which compensate for Head Related Transfer Functions (HRTF's), and allow for the creation of much more convincing 3D sound are already available (Vince 1995, 269:292).

The potential for enhancing the apparent reality of a virtual environment by including natural sounds is discussed in Chapter 7, but does it have a use in helping us understand Early Medieval sculpted stones? The stones themselves are mute, they do not generate noise and may in the past have been experienced in silence. Alternatively, people may have been experienced the stones at times of worship or ritual where music, chanting or sermonising may have been integral to the experience. As an element in a model designed to simulate the experience of interacting with a sculpted stone in the Early Medieval period sound has some potential, although any recreated sound experiences would be based on very little evidence. How sound was used in the past remains such an imponderable that the inclusion of any of these sounds may be seen as an intrusive interpretation by the user and if a sound track is part of a Virtual Environment then it should be user selectable rather than obligatory.

In virtual environments designed to represent fairly large landscape areas, say up to a kilometre, acoustic rendering suggests itself as a technique for integrating sound into an environment. Acoustic rendering is a process whereby sound is associated with space in a virtual environment. It is well understood that sound changes as it interacts with the physical geometry of the world. Acoustic rendering can be used to simulate this in virtual environments (Pope and Chalmers 2000, 105). Investigations have already been carried out into varying acoustic landscapes of real world prehistoric sites, notably Easter Aquorthies recumbent stone circle (Aberdeenshire) (NJ72SW 12)and Camster Round passage grave (Caithness) (ND24SE 16) where the shape and disposition of the stones has a significant impact on how sound is experienced (Watson 1997). At these sites volume and pitch vary depending on the location of the sound source and the location of the listener. Moving amongst the stones or about the tomb can produce some unexpected results, which may have been both deliberate and ritually significant. It is possible to emulate the acoustic changes in various physical locations by associating recorded sound with their modelled equivalent. Thus as the user moves through the Virtual Environment that has some sound being generated in it at a specific location, he or she would experience the changes in sound caused by the acoustic properties of the environment's physical geometry. It is not immediately obvious if similarly interesting results would be generated by investigating the acoustics of single monumental pieces of sculpture, although where stones in a recumbent stone circle have been reused for Pictish sculpture or the sculptured stone is clearly associated with an earlier monument, (e.g. Brandsbutt NJ72SE 23; Broomend of Crichie NJ71NE 8 (RCAHMS 1999, 13)) then it would seem appropriate to investigate this technique. There is also the potential of large cross slabs to act as sounding boards. One can imagine that if a holy person, or secular leader was standing in front of a large slab of stone and addressing a group of people that the stone would act as a sounding board to direct their voice towards his or her audience. This effect may be incidental or deliberate but would be a suitable candidate for inclusion in a three dimensional model of the monument and its locale. As the user walks around the monument the volume of sound heard, either a simple tone, or more appropriately chanting or sermonising, would rise and fall depending on the acoustics in the real world. Clearly the data capture phase of such a project would involve radically different equipment than that used to capture physical geometry and need not necessarily be done at the same time.

8.2.2 Touch

Even as archaeologists we rarely touch Early Medieval sculpted stones. There are conservation arguments for not handling stones in the field and the public are actively discouraged from doing so. This is amplified indoors, especially in a museum environment where physically handling the stones on display is often explicitly forbidden or physically impossible due to display cases. It is possible that as sacred or holy objects it was inappropriate to touch the stones in the past, although many shrines had gaps to allow physical access to the relics within (Thomas 1998, 86) and it is equally possible that the stones were regularly touched during acts of religious devotion.

Our current lack of physical access to the stones is unfortunate for at least two reasons, firstly the stones are undeniably tactile objects, the various textures and curving intricacies of many of the stones almost demand physical contact. This may be especially true for young audiences such as children, who seem to enjoy tactile experiences when they are made available in educational contexts or at special museum displays. Secondly, for the large portion of the community with impaired vision touch is often a vital sense which can allow them a richer experience of objects than they can glean by visual sense alone (Brewster 2001, 1). For these reasons it would seem that any technology that allows a tactile interaction with a three dimensionally modelled surface may have a useful role to play.

In various other sections of this thesis the nascent technology of haptics has been mentioned (sections 2.6.2 and 6.3). Of all the other senses touch, via haptic technology, is the one that might have the both the greatest impact and the greatest benefit as an addition to a visual record. Where there is an underlying surface record (e.g. in a Lidar generated model, but not a QTVR Object Movie model) then hardware devices can simulate the experience of interacting with that surface. This is done by presenting the digitally recorded geometry of the surface to devices that can apply differential force (force-feedback) to the users hands rather than (or as well as) the computer screen (Howe 2001). Currently haptic technology is reliant on fairly crude force-feed back devices such as the PHANToM (SensAble technologies*) stylus and thimble device or the Logitech* Wingman force-feedback mouse. It is in the future as haptic technology improves and realistic sensations of shape and texture can be generated that its impact will become apparent. The first clear benefit would be to the visually impaired or blind, allowing them to physically interact with a model of a sculpted stone. It is probably not appropriate for a sighted person to make assumptions about what would or would not be appropriate for those with impaired vision, but the research currently under way at the University of Glasgow's Department of Computer Science into haptic technology is in part aimed at the visually impaired and the relationship between sound and texture is being investigated to provide enhanced multi-modal experience for the blind (McGee et. al 2000; 2001). The results of this research in the next few years could be that for the visually impaired, and indeed for more general audiences, haptic devices would allow us to not only 'feel' the surface of a sculpted stone, but also to interact with it, perhaps manipulating it in virtual space. The possibility that in order to examine a three dimensional model by 'picking it up and turning it' is a very exciting concept and does much to simplify and make more intuitive our interactions with computer models. However, archaeologists generating models of larger objects should bear in mind the potential for giving misleading impressions of large immovable objects that this technology might have (see section 7.3). Using a glove or wand as a tactile input device (Figure 8.9) for manipulating models of small portable artefacts may be appropriate, doing the same for the larger objects may not.

Figure 8.9 An advanced haptic workstation from Cyberedge* that became commercially available February 2003.

8.2.3 Smell

The smell of the real world may not be foremost in our conscious minds as we go about our everyday business, but its inclusion in a Virtual Environment would enhance the apparent reality of the environment. This is true even if it simply masks the smell of the building in which we are experiencing an outdoor virtual experience. Devices are currently in development that actually use chemical compounds released into the air strategically to simulate the differing smells of the real world. Artificial Reality Corporation is working with a grant from the Defense Advanced Research Projects Agency (USA), which hopes to add ‘telesmell’ or ‘virtual olfaction’ to battlefield telemedicine (DARPA 2002, 5) (Figure 8.10). The main technical difficulty lies in synthesising smells. While the perfume industry has mastered the ability to produce floral and fruit fragrances, less is known about how to concoct many less pleasant odours.

Figure 8.10 Artificial Reality’s prototype ‘Smell-O-Vision’ helmet.

The idea that smells can enhance our experience of simulated environments is not new. The most striking use in an archaeological example is in the physical model of a Viking village at the Jorvik Centre* in York. Visitors to this educational centre move through a physical model in small carriages. As the visitor is carried towards various places in the model village, such as the tannery or the fish processing area, simulations of the appropriate smells are wafted over them. It is certainly an engaging effect, appreciated by children and adults alike and it undeniably enhances the apparent realism of the model. In one sense for those in the audience who are not familiar with certain smells the odours used can be considered as actual vectors of information. In the same vein, it is possible to argue that the smells of the past were very different from the smells of today and that the sense of smell played a more important part in peoples life in the Early Medieval period than it does now. Even if this might feel intuitively correct, as archaeologists we have little or no access to smells in the past. The presence or absence of particular organic materials allows us to hypothesise about the presence or absence of the smells associated with them, but does not allow us to recreate with any certainty the smell of history.

The fact that devices for simulating smells designed for use in virtual environments are in such an early stage of development makes it difficult to comment on the effectiveness or otherwise of them. It is possible to consider what application such technologies might have in virtual environments whose primary purpose is to present models of Early Medieval sculpted stone. Such sculptured stones, undoubtedly had rituals and ceremonies associated with them and almost certainly this means that interaction with them in the past had a particular set of associated smells. The use of incense and scented oils has a long tradition in Christianity and if ceremonies took place at night the smell of torches and lamps may have been apparent. Similarly if a ritual involved feasting (not uncommon, even today) then the smells of cooking and foods may have been associated with the stones, possibly the smell of particular special foods unique to ceremonies associated with the stones.

Unlike sound, humans rarely perceive smell in three dimensions, although we can follow a smell through space if it has a discrete source and is strong enough. The appropriateness of actually trying to produce an actual three dimensional 'smellscape' would depend largely on whether it was thought there was point to be elucidated in doing so. Because smell is harder to control than physical access, lines of sight or even sound, it seems unlikely that the varying levels of smell at different points in three dimensional space had much significance even if the smells themselves were important. Therefore the effort in replicating varying smells in a relatively small virtual environment may not have a huge pay-off in explanatory, educational or interpretative terms even though the basic presence of the smells does.

8.2.4 Motion

A very new and under developed field is that of simulated motion. The development of devices that can fool the inner ear into believing the body is in motion or orientated in a particular way, may be seen as having enormous potential in virtual environments, not least because the discrepancy between what the eyes are seeing and what the inner ear feels is at the root of visually induced motion sickness (VIMS) in immersive environments (Vince 1999, 277) . In Chapter 7 the unreality and incongruences of motion as it is currently replicated in virtual environments are explored, a hardware device that creates the illusion of actual motion would not alter the fact that it is the types of motion that are unreal not just the way that motion is experienced. In a similar way to sound and smell, an improved sense of motion would carry additional recorded information about the modelled object or landscape. It could be used to create a more realistic interaction with the Virtual Environment For example when walking up hill in the virtual environment the user feels as if he is physically moving up hill. Unlike sound and smell it is unlikely to be used as a vector of interpreted information.

One example is the treadportdevice, this is an inertial force feedback system that combines a variable slope treadmill with a mechanical tether. This approach allows the user to walk naturally and turn around in the virtual environment as well as experiencing the feelings of walking up and down hill (Christensen et al. 2000) (Figure 8.11). Such locomotion interfaces may well be become more fully developed in the near future, but again are unlikely to become commonplace due issues of cost. Having said this, they may well appear outside the world of military simulators as an entertainment, allowing gamers an enhanced virtual presence.

Figure 8.11 The ‘treadport’ locomotion interface device (University of Utah*).

Given the discussion in Chapter 7 relating to the desirability or otherwise of realistic virtual realms, the ability to navigate around a virtual environment by walking in a near natural fashion is preferable to the illusion of floating or flying through the realm. However, it is not clear that locomotion interfaces have any special application in terms of aiding the understanding or appreciation of Early Medieval sculpted stone beyond grounding the user within the environment. It is an interesting notion that the user would get genuinely tired walking uphill or over long (virtual) distances whilst using a locomotion interface, but as with the notion that the user should be restricted to walking pace and realistic distances discussed in section 7.3.2 the user may prefer to be selective about which parts of reality they actually want simulated in Virtual Reality.

8.2.5 Taste

The physical sensation of taste, alone of all the senses, appears to be missing from technologies designed to further draw human experience into virtual realms. It is almost inevitable that at some point in the future efforts will be made to simulate flavour via some kind of human/machine interface. It may be many years in the future and may involve changes in our relationships with the inorganic world that many will find abhorrent, but technological change has a logic of its own and somewhere somebody will try and fill this gap in the control of our senses. There is no obvious application of virtual taste to our understanding of Early Medieval sculpted stones beyond increasing the apparent realism of the modes in which they can be presented. It might be possible to argue that the preparation of authentic historic or prehistoric taste sensations would engender empathy with and therefore a better understanding of the original eaters and drinkers of various food stuffs, such as communion host and wine, but authenticity, which is already a contentious notion, could easily be pushed beyond sensible bounds in this debate.

8.3 Shared virtual experience.

It has been frequently stressed throughout this and previous chapters that hardware and software products are far from static and are in a continual state of development. Most changes to either hardware or software systems represent small incremental improvements but occasionally larger shifts in technical capabilities occur that change the field of digital modelling and information dissemination quite radically. The most obvious examples are the development of automated scanning devices, the development of the notion of virtual reality, and the explosion of interconnectivity catalysed by the internet. The influence of these and other developments on archaeological practice, as well as social practice generally, has been extensive (Veltman 1998; Finnemann 1999; Suler 2001; Gidlow 2000). The previous sections in this chapter have concentrated on how a VR experience for an individual in the future might create a heightened sense of presence, in this section I would like to briefly examine future directions in interaction between users, educators and curators in hypothetical VR realms. This is because the next step change in development in information delivery is not just interaction of users with VR environments, but increasingly interaction between users *within* a shared VR environment.

Current examples of VR environments in which users can interact with each other, or collaborative virtual environments (CVEs) (sometimes called distributed virtual environments, or DVEs (Bouras and Filopoulos 2000)), have grown out of the World Wide Web 'chat room' phenomena (e.g. Deepmatrix*) or as tools to allow business conferencing environments where the participants have an increased sense of being in the same environment as each other such as Nottingham University's MASSIVE* system. Put simply, CVEs are networked VR environments that allow numerous geographically dispersed users to come together to in a shared virtual environment. How users appear to each other (their virtual *embodiment*), how they interact with each other and how they react with the virtual environment is a very active field of research globally. The technical problems posed by shared VR environments are non-trivial and include problems that would not occur in static media or exclusive VR environments, such as tracking users positions, creating actions and reactions, and inter-communication via gesture, expression or speech. At the moment most CVEs rely on text for communication between the users. This has the unwanted side affect of distracting users from moving around or visually interacting with users in the CVE (Fernie and Richards 2000, 4.3). However, future developments in CVEs will inevitably integrate the broader sensory experiences of the multi-modal VR environments described in sections 8.2.1-5. This allows us to imagine future CVEs where users can communicate by touch (gesture), expression and speech. The application of CVEs as educational or illustrative environments has obvious potential (Bouras and Filopoulos 2000) for bringing together interested parties or students from remote locations, many subject areas may benefit from abstract data-visualisation in CVEs. The CyberAxis* CVE is an art gallery in which multiple users can browse and discuss works of art and a similar CVE could be imagined featuring models of Early Medieval sculpted stone (Figure 8.12). Ultimately archaeological CVEs could be populated with virtual guides, or avatars (virtual embodiments, see below) that represent the original inhabitants of the spaces be represented in VR. Some of the problems previously discussed (Chapter 7) regarding how to communicate metadata and explanatory material on three dimensional models and reconstructed landscapes could be handled by enabling the user to ask one of the participants in the CVE questions directly, where that participant is essentially a curator of the CVE. This could allow tailored and appropriate explanations of what the CVE and its constituent parts represent and how they might be approached critically. The long term possibility is that a user could arrange to meet the creator of a virtual environment somewhere within it to discuss its finer points, or the creator/s could hold special presentations at specific times within the CVE. In the very long term the participation of the creator/s personally as an element of the CVE could be replaced by an AI ‘sprite’ performing the same function, although this raises a range of additional questions both technical and ethical. More imaginatively yet, the use of gaming and drama within CVEs (Champion 2002) could encourage users to situate the virtual world they are inhabiting in a reconstructed social context, representing medieval power structures and social landscapes.

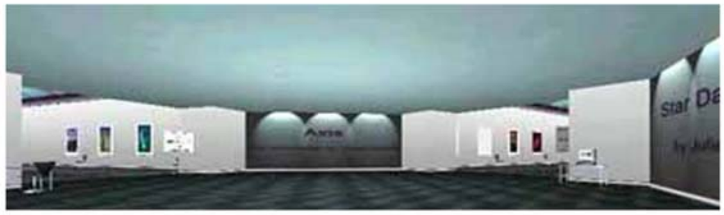


Figure 8.12 One area of the CyberAxis CVE.

Section 7.3.4 pointed out that archaeological VR environments are generally devoid of representation of the human form. CVEs are obviously not, the user normally has the ability to form their own ‘body type’ via the construction of an avatar. An avatar is a three dimensional representation of the user that inhabits the virtual space of the CVE. One of the less well understood aspects of the internet and CVEs in particular is how users choose to manipulate the projection of their persona, frequently selecting or creating avatars that represent animals or imaginary robots or creatures other than the human form. It is perfectly feasible for an avatar to represent the real body and face of the user as closely as, say, a photograph, through scanning and rendering. However, the opportunity for the user to take control of their own bodies representation is seen by many as an active benefit of CVEs, liberating them from the social prejudices adhering to body types, age, race and gender. The affect that factors like this have on group dynamics and the relationships between users in CVEs is an embryonic area of research (see Castells 1996; Suler 2001), however, it is possible to say that such environments have their own emergent social rules and as a result the utilisation of standard approaches to teaching and didactics may not transfer well to such an artificial environment. It might be an awkward experience for the creator of a virtual representation of medieval Scotland to try and explain the significance of a monument or its context to a group of users who are represented by virtual ‘Vikings, ‘tigers’ and ‘robots’, none of with whom the use of such nonverbal cues as posture and eye-contact are possible (see Figure 8.13 for examples of avatars from DeepMatrix).

Figure 8.13 Some avatars from DeepMatrix, these are ready made, but users can construct their own.

8.3.1 Conclusion

The emergence of multi-modal immersive (or pseudo-immersive) CVEs or VR realms which create a heightened sense of presence and therefore a more intense experience for the user actually compounds the dangers of spurious, misleading and pre-emptory interpretation as discussed in Chapter 7, as well as presenting a whole vista of new opportunities for exploration and illustration. There is a fundamental problem with generating auditory, olfactory and haptic experiences, let alone social interactions, in that archaeologists have very little information to base their reconstructions on. The fact that such reconstructed experiences will be based on interpretation and speculation should not in itself mean that they are to be avoided. In recognition of the potential power of the VR experience, it is the context in which it is presented that should be carefully considered. VR experiences presented in museum or educational contexts may carry with them and expectation on the part of the audience that what is being presented is in some sense authentic. VR experiences presented as part of a gaming environment or art gallery might be expected to be more loosely based on archaeological information. It would be possible to circumvent accusations of inauthenticity and irresponsibility if intensive VR presentations were restricted to those contexts in which the audience expects a level of inauthenticity. More challenging, and potentially more beneficial to archaeology, would be to alter the expectations of the audience such that they are empowered to challenge representations of the past in academic and museum contexts (whether VR or not). Ideally the audience, public or academic, should be engaged with the representation, questioning, collaborating and reinterpreting it rather than acting as passive recipients of it.

9 Fitting the pieces together

At the beginning of this thesis it was emphasised that, with unlimited time and unlimited funds, all of the technical challenges involved in recording Early Medieval sculpted stones to the ideal requirements specified in chapter 3 could be overcome. The exploration of technologies in chapters 4 and 8, both those currently in use and future enhancements, suggest that the rate of advance and the multiplicity of approaches being used ensures that good technical solutions to nearly all the problems posed in chapter 3 will be available in the near future. In fact, it could be said that the restraining factors in model creation and dissemination already rest with the ability of internet infrastructure and personal computers to handle very large volumes of data in real time rather than with our ability to generate that data. This problem will diminish rapidly if current trends in personal computer development continue. These advances in both data capture and data handling are not being driven primarily by commercial imperatives generated in the heritage sector, but, as previously discussed, by the manufacturing, construction, architecture, and most notably, the entertainment sectors. Whilst this means that hardware and software combinations specifically tailored to archaeological or heritage applications will remain the preserve of individual, well-funded, projects it also means that more flexible and more accurate systems, whose usefulness to the heritage sector is incidental, will become available commercially as the technologies mature.

Rather than examining the ever changing technical minutiae of available commercial systems this thesis has provided an insight into three dimensional recording and modelling concepts, technical approaches and future trends. Presenting this background together with contextual information on Early Medieval sculpted stones and the potential audiences for three dimensional models has highlighted the four most important factors to be considered in this field:

- The nature of the audience dictates the appropriateness of the various recording methodologies as well as the means of dissemination. For example, people who are interested in what a monument looks like do not necessarily need a rendered polygon mesh generated from a high resolution point cloud. At the other extreme a researcher examining very faint inscriptions may prefer a PTM based rendering of a micrometer resolution surface, rather than a photo-realistic model (Chapter 6 and section 8.1.2).

- The nature of the model and its mode of presentation will have a powerful influence on how Early Medieval sculpture will be perceived in the future (sections 7.1-7.4).

- Time and cost constrain quality at all stages in the processes of data capture, model creation and presentation and therefore ultimately the beneficial or detrimental affect of the record for our understanding of the archaeology. Despite this being the case with traditional approaches, it is accentuated for high technology and high impact techniques (sections 3.2; 5.1-5.3; 7.4.1).

- Failure to engage with new modes of presentation (if not recording) will distance archaeological practice from both other disciplines and wider audiences. The archaeological community has a professional responsibility to encourage wider engagement in archaeological discourse and to challenge inappropriate uses of archaeological material for political or social ends as well as respecting the diverse conceptions of the past that exist locally and globally (sections 2.6; 6.6).

Three dimensional models, especially in interactive VR contexts, radically change the perceptions of both scholar and layman, but they present both dangers and opportunities. To most, the potential benefits of three dimensional models and sophisticated Virtual Reality presentations of these models are undeniable. These technologies represent a significant step forward in our ability to produce records of Early Medieval sculpted stones that are useful for archaeologists, historians, conservators and the general public alike. The advantages that have already been highlighted include:

- Accurate recording and facsimile production without the need for physical contact with the surface of a monument.
- True three dimensional representations of three dimensional objects, presented in a manner that allows a fuller appreciation of the monument's morphology.
- Recontextualisation of monuments by presenting them in conjunction with representations of their landscape contexts.
- Improved access to the record for those with diverse abilities via multi-modal VR and on-line presentation.
- The development of teaching and research tools that exploit the new component of interactivity in the record.
- The enhancement of conservation and heritage management via the generation of base-line records, improved monitoring and archiving of data.

The areas where caution needs to be exercised relate almost entirely to unelaborated models that blur the boundaries between 'real' and 'realistic'. The Arts and Humanities Data Service *Guide to Good Practice* for creating and using Virtual Reality states clearly that "VR images, like other graphical illustrations are merely vehicles for elucidating, or clarifying information to the user. It is clarification, not realism or accuracy, that is at the centre of any illustration…." (Fernie and Richards 2002, 2.6.1). Despite this, the thrust of much VR work, even in archaeology, is still focussed on trying to produce 'accurate' and 'realistic' representations of past environments. This is symptomatic of the entertainment, training and gaming industries' legitimate goal of realism in VR environments being adopted uncritically into archaeological applications. Our understanding of Early Medieval sculpted stones and their contexts will not necessarily be enhanced by models that neglect scale, orientation and solidity. Models that allow interaction using unnatural modes of movement and temporality can be actively misleading and inexplicit reconstruction and interpretation may result in models that make it more difficult to reinterpret sculpted stones and context in the future not less.

9.1 The attitude of professionals

The power of ICT as a media creates unconscious or conscious impressions regarding the veracity of both the underlying data and the interpretation of that data. The novelty of Virtual Reality environments - the depth of information they can carry and the impact of new levels of interactivity - combine with a powerfully seductive media to create a formidable form of record. It is exactly the power and impact of these technologies (some of which may fade as they become commonplace) that should encourage us to take special care when using them in academic discourse or as a mode of public information.

There is an additional significant factor that has not yet been addressed because it is nebulous and difficult to define, but it will nevertheless have a very important influence on how the field of three dimensional recording evolves. This factor is the negative attitude of professionals in the field to both a new recording paradigm and more importantly to a new mode of information dissemination. All comment on such attitudes must obviously, like the attitudes themselves, be subjective in nature and it is worth noting that there is no universal set of attitudes to the approach of new technologies, nor is there any implication that attitudes are so concrete that they will never change. Despite this, it would be an omission in the thesis if it were not pointed out that during research and discussion with professionals it became clear that computer technology, three dimensional models and VR can be seen as gimmicky, transient and insubstantial. It would be incorrect to assume that such attitudes are related to any particular specialism, generation or gender; they appear to be more related to self-perception and a perception of the role of heritage professional. Researchers into the past may even feel that adoption of technologies unavailable in the past distance themselves even further from the objects of their study. This is undoubtedly a valid position and chapter 7 discusses how the unreal landscapes created by virtual reality present the world to us in a uniquely 21st century fashion and how a critical approach to such media is prerequisite for its usefulness. The world of books, sketches and drawings had changed only incrementally from the introduction of moveable type until the introduction of photography. Photography itself has been embedded in archaeology and related fields for a century, it has only been relatively recently that entirely new forms of data have been available for mass distribution and only within the last decade that electronic publication has become acceptable for certain types of academic material via organs such as *Internet Archaeology** and *Art History**. Thus, prior to the last decade it has been entirely possible to be fully engaged in academic discourse in the field of Early Medieval sculpture whilst being completely disengaged with any form of digital technology. The advent of types of data, such as three dimensional computer data, that can only be fully accessed and appreciated via computer screens means that for the first time those who are unwilling or unable to engage with this technology will find themselves excluded from a source of information that may be relevant to them. Perhaps it is not surprising then that some may seek to trivialise the importance of new forms of record or distribution. It would be wrong to exaggerate the pervasiveness of this attitude, whether it is conscious or subconscious, and it would be equally wrong to denigrate it. Without exaggerating it or dismissing it, it is enough to point out that there is some resistance to new technologies and approaches that is not predicated in any way on their effectiveness.

It should be noted that the converse attitude towards three dimensional modelling and technology in general also exists and that it could be equally damaging to its positioning as an acceptable form of archaeological record and dissemination medium. This is a stance that uncritically accepts each new change in technology as an ‘advance’ or an ‘improvement’. In the rush to adopt new technologies, some heritage professionals may be guilty of what Jeremy Huggett describes as ‘technological fetishism’. An assumption that new technologies must have a useful archaeological application is as flawed as the assumption that they do not. The danger is that archaeological projects adopt three dimensional recording and virtual reality presentation as a means of showing off the technology rather than as a means of demonstrating an archaeological theory or providing a tool for archaeological interpretation. The exploration of the technology in an archaeological context may be a perfectly legitimate end in itself, but can be perceived as a solution in search of a problem.

There is a considerable danger for archaeology in not engaging with three dimensionality, VR and digital forms of presentation in general. Just as the nature of the interface to a database partly dictates the longevity of the data, on a wider scale archaeologies interface with the public will dictate the level of public engagement with archaeology. Thus as digital media and VR become more embedded in other public realms such as entertainment, broadcast news and workplace technologies, the public, and archaeologists themselves, will expect similar forms of interface with archaeological information and theory. Concentrating on the dangers and difficulties of absorbing new forms of information and presentation into archaeological discourse runs the risk of sidelining archaeology entirely if it results in the discipline no longer reflecting the ways in which people access information generally.

9.2 Hardware approaches

Leaving aside, as far as that is possible, the social context of these emergent technologies and returning to the practicalities of the SEMSS project, what would be the most apt technologies for such a large and ambitious project to adopt? An important factor to emerge from Pringle's work on the PastScape project (section 6.6.2) was the development of an Application Identification Method (AIM) which formalises the process of identifying the purpose and intention of a project and selecting appropriate technologies (Pringle 2000). The SEMSS project would benefit from the application of such a formal methodology in identifying audience, data capture and delivery technologies. At this stage no single uniform solution presents itself, but there is a range of techniques for data capture and for modelling that may fulfil the varied needs of such a project. For data capture, the initial phase of any such project should be to evaluate whether all the stones are to be treated equally, for example is it necessary that every Early Medieval stone is recorded as a genuine three dimensional surface model with an accuracy of 0.1mm? Or is there a hierarchy within the body of material that would allow some to be recorded using image based techniques such as QTVR, some to be recorded at a resolution nearer 1cm and only a few to be recorded at the highest possible resolution. For portable items this decision is purely pragmatic because high resolution scanning using either structured light, laser triangulation or time of flight scanning are all able to offer very high resolution scans as long as the item can be moved to the recording equipment. Once a high resolution scan is archived the nature and extent of any modelling, reconstruction and recontextualisation can be decided on at a later stage. Perhaps post-processing could be implemented in stages or several different versions of models could be created for various tasks. For large monuments that are earth fast or permanently on display the decisions will be informed by the wide range of technical and practical issues discussed in chapters 3 and 4. Probably the first question regarding a large immovable monument will be whether or not there is a good quality cast already in existence and can the cast be used to create the digital record? If there is no cast or if there is no confidence in the accuracy of the cast such issues as access, lighting, presence of metallic structures and scale of the monument will help to narrow down options until the most suitable is settled on. This process would have to take place on a case by case basis

It should be remembered that a variety of recording techniques could be applied to single stone at one time. This could be particularly appropriate in the case of some stones, for example, Class I Pictish Symbol Stones that have only small carved sections in a fairly large monument. In practice however, if a high resolution recording device were on site then it would seem logical to capture as much data as possible, for consistency and to lessen the potential for future visits. The possibility that it could be many years before another project systematically recorded this corpus of material again would necessarily weigh heavily on any decision making process. Creating a hierarchy of monuments implies that some are of more intrinsic archaeological or art historical interest than others. This is obviously a subjective (though presumably well informed) decision and would inevitably solidify the relative importance of various monuments in the minds of the audience. This is a significant responsibility to be taken on. Often what is considered significant today need not necessarily be what is considered significant in just a few years time. If the SEMSS project did embark on a large scale recording process to produce a new corpus, then it would be in the centenary year of the creation of the last corpus. It is not inconceivable that it could be another hundred years before another attempt is made at this process.

Once a data capture phase has generated a digital record the post processing decision making process begins. Of course, just as audience and intention dictate the selection of a recording process so it will dictate the post-processing, presentation and delivery processes. Unlike the pressure to create the best possible record during the data capture phase (which results from an understanding of the desirable levels of resolution and the infrequency of record creation), the pressures facing those making decisions about post-processing relate to professional responsibility as to how the record is presented, how interpretations are indicated and explained and in ensuring interaction with the model does not create false impressions or allow spurious interpretation. It was the intention of chapter 7 to highlight these issues and when considered together with the developments and enhancements such as fully immersive, multimodal VR or volumetric displays discussed in chapter 8 it should be apparent that presentation and dissemination of the data is not going to be a process that allows the development of universally applicable presentation standards that have a significant life span. Instead it is more likely that as technologies continue to develop, what is considered appropriate uses of it will similarly develop and change, never settling on a single set of rules for long before being challenged by even more radical technological changes. There is now an appropriate framework in place for the debates and decisions relating to good practice to take place in the

CVRO. Hopefully its inception will have a calming influence on some of the more blatantly inappropriate uses of CGI, VR and three dimensional recording in the near future. Already the notion of an ‘archaeological model’ and how it might be constituted as outlined in chapter 7 (7.4.3) may be beyond the set of norms that the CVRO has so far encompassed.

Modern digital technology changes, and apparently improves, with such dazzling speed that it has sometimes been likened to an up escalator, constantly on the move. For any project making decisions about what technology to adopt there is always a temptation to wait for something better to come along before stepping on board. Manufacturers and software houses always hold out the promise of great improvements just around the corner, and often they deliver. It can be very difficult to identify a hiatus in the constant movement of the technology escalator offering a window in which current technology will not be superseded as soon an investment has been made in it. This may help to explain why most three dimensional recording projects in archaeology are very focused, concentrating on individual sites, monuments or buildings rather than larger long term projects.

The conclusion this points to is a pragmatic one. It is likely that technology in this field will improve significantly in the short term, both in relation to data capture and in terms of presentation. The fact that software, data handling and computational power will also improve is equally certain, but less significant since this affects only how the original data set is manipulated and presented not necessarily how it is captured, it is the data capture technology that is most prone to being rendered obsolete. Given that there is so much change on the horizon which seems likely to come to fruition in time scales of one or two years, it would be advisable for any project to delay a decision, especially one that involved spending significant money, until there is some level of confidence that ‘next year’s model’ will not be so improved that it makes last year’s record seem wholly inadequate.

Even where good solutions seem available now, for example where portable objects and casts could be scanned at high precision using the ModelMaker laser trigonometry scanner described in 4.2.2, there is no guarantee that the advances in rendering using captured reflectance values would not necessitate re-scanning in the near future. For portable objects it is not the ability to capture high resolution surface records that is the issue, it is the potential to use sophisticated rendering techniques in the future, that require information that was not captured at the initial recording phase. This is not a matter of capturing more detail for higher levels of realism, rather it is an issue of how flexible the resulting data will be.

Having established the utility of three dimensional models as well as the potential impact of the media via which they are presented, the question remains as to which of the possible VR paradigms will be most appropriate for presentation? The divergent directions in which VR is developing can be characterised as:

- Realism based on the record. Models and environments are constructed in such a way that interpretation is not consciously engaged in and what is presented is based entirely on data captured from the real world. These are the simple forms of model that will be most likely to act as access points to other datasets.
- Realism based on appearance rather than record. This is the most widely adopted approach. The object is to present the recorded data in a VR environment that appears to be ‘real’, or at least photorealistic. Our understanding of what the world was actually like in the past is so fragmentary that, despite looking ‘realistic’, this approach actually requires high levels of interpretation in order to construct an environment.
- Cognitive approaches which accept that our experience of reality is not derived entirely from the simple physical geometry of the world, but is also socially and culturally constructed. Attempts to quantify these components of human experience and somehow replicate them in VR seems to misunderstand both the complexity and the fluidity of an individual’s world view let alone the dynamics of larger groups.

- Critical approaches to the pursuit of ‘reality’ represented by the previous three points, recognising that even where VR looks like reality it does not feel real. It is another type of experience altogether. This allows a more illustrative approach, unrestricted by the drive for realism. Such environments would be specifically designed as exploratory tools, where the levels of interaction inherent in the model facilitate and encourage user interpretation of the various elements of the model. The extreme manifestation of this approach would include emotionally charged, surreal, experiences that are as creative as they are archaeologically illuminating.

Despite the apparent divergence in these approaches noted above, they are not necessarily mutually exclusive. Virtual Environments can be multi-modal, not only meaning that multiple senses can be used, but also that multiple forms of presentation can be generated from the same underlying data, but presented together. This could be seen as an important extension of the critical approaches mentioned in the paragraph above. The intention of such multi-modal and multi-layered models is to give the user the ability to switch between modes of presentation. This will have the affect of not only allowing the user to explore and interact with the data through the filter of multiple presentation paradigms, but the complexity inherent within such a environment may generate an experience that transcends any particular mode of presentation.

Ultimately it will be the tensions between ‘real’ records, ‘hyperreal’ presentation environments and apparently ‘surreal’ use of environment variables to convey metadata and explanatory detail that will deliver archaeologically useful applications. An acceptance of the limitations of virtual reality as a means of representing the real world, present or past should encourage the development of more explicitly illustrative models. These models will combine elements of record, reconstruction and interpretation in such a way that the processes used to create the model are clearly signified and are seen to be vital to its value as an archaeological record. This approach will re-situate three dimensional models and VR environments as elements of the archaeological process rather than simply products of it. As Barceló puts it, "VR reconstruction…. should not be seen as a way of doing reconstructions, but as a simulation of archaeological reasoning…. Interactivity…. is not a way of moving through a computer representation, (but) a 'manipulation' of an archaeological interpretation" (2000). The notion that the *process is the product* is ample justification for experimenting with and developing three dimensional records in the future irrespective of their other perceived benefits.

9.3 Conclusion

Throughout this thesis I have concentrated on the practicalities of capturing data on, and creating models of, Scottish Early Medieval sculptured stones. This source material has highlighted the gap that currently exists in available recording technologies. Small portable complex artefacts or works of art can now be recorded three dimensionally at very high resolutions. Larger works of art, in museums or galleries can also be recorded with impressive levels of resolution using custom built rigs. Similarly large buildings or even entire archaeological sites can be recorded at much lower (but appropriate) resolution. The gap exists in conveniently applying the very high levels of resolution required for, say erosion monitoring or tool-mark analysis, to large intricately carved monuments in the field. In truth, this gap is going to be very short lived; within months rather than years, the hardware will have improved to the extent that robust, portable devices will be able to generate high resolution three dimensional records in almost any physical environment. When these improvements arrive it will open up the possibility of recording a whole range of archaeological material from many time periods and many countries which currently fall into this gap, being large, yet intricate and located in the field. As well as the Early Medieval sculpted stones of Scotland, there are those of England, Wales and the rest of Europe, classical sculpture and prehistoric rock-art from around the world all spring to mind as candidate resources. When three dimensional recording of a wide range of material begins to take place routinely and the resultant process and products move into the mainstream of archaeological practice, questions of authenticity, the competing modes of presentation and the ensuing subtle (and obvious) changes in archaeological perception will form the central threads in a debate that, although already active, will become even more vigorous.

10 Bibliography

Abbot, E.A. 1884 *Flatland. A romance in many dimensions*. London.

Abdelguerfi, M. (ed.) 2001 3*D Synthetic Environment Reconstruction*. Kluwer, Boston.

Adkins, L.and R. A. 1994 (reprint) *Archaeological Illustration*. Cambridge University Press, p.43.

Alcock, E. 1989 Pictish Stones Class I: Where and How?, *Glasgow Archaeological Journal*, 15 (1988-9).

Allen, J.R. and Anderson, J. 1903 *The Early Christian Monuments of Scotland*, 3 parts. Edinburgh.

Arnold, P. 1998 Waldau Flood Bridge Project (Visuplan) http://photomodeler.co.kr/PROJS/StoneBridge/StoneBridge.htm accessed 12/12/2000

Banchoff, T.F. 1990 From Flatland to Hypergraphics: Interacting with Higher Dimensions, *Interdisciplinary Science Reviews*, 15, No.4, 1990, 364-72.

Banks, I and Hooper, J 1998 Chapel Hill, Ballachly, Dunbeath (Latheron parish), ?Early Christian monastic site. *Discovery and Excavation*, Scotland, 1998, 56.

Barceló, J. 2000 Visualising what might be: an introduction to virtual reality techniques in archaeology. in Barceló *et al.* 2000, 9-37

Barceló, J., Forte, M. and Sanders, D. (eds.) 2000 *Virtual Reality in Archaeology*. CAA. BAR International Series 843, Archaeopress, Oxford.

Bateman, J. 2000 Immediate Realities: an anthropology of computer visualisation in archaeology, *Internet Archaeology* Vol.8 Summer 2000. http://intarch.ac.uk/journal/issue8/bateman/index.html, accessed 1/9/02.

Bell, T., and Lock, G. 2000. *Topographic and cultural influences on walking the Ridgeway in later prehistoric times*. in Lock 2000, 85-100.

Beraldin, J.A., Guidi, G., Ciofi, S. and Atzeni, C. 2002 *Improvement of Metric Accuracy of Digital 3D Models through Digital Photogrammetry. A Case Study: Donatello's Maddalena*. Presented at 3D Data Processing Visualisation and, Padova, Italy. www.vit.iit.nrc.ca/References/NRC-44911.pdf , accessed 17/3/03.

Borg, C. E. and Cannataci, J.A. 2002 Thealasermetry: A Hybrid Approach to Documentation of Sites and Artefacts. *Close-Range Imaging, Long-Range Vision, ISPRS Commission V, Symposium 2002*, Greece. http://www.isprs.org/commission5/workshop/part5.pdf accessed 02/2/03.

Borland, J. 2002 The Graphic Recording of Early Medieval Carved Stones By RCAHMS – A Brief History. in *Monuments on Record (Annual Review 2001 – 2002)*, RCAHMS, 46-49.

Bouras, C. and Filopoulos, A. 2000 *Distributed Virtual Reality Environments Over Web For Distance Education.* Computer Technology Institute, Greece. http://ru6.cti.gr/Publications/269.pdf , accessed 28/3/01.

Bowden, M. 2000 Virtual Avebury Revisited. *Archaeological Dialogues* 7 No 1 2000, 84-8.

Bradley, R.1997 Working the land: imagining the landscape, *Archaeological Dialogues* 4 No.1 1997, 39-48.

Bradley, R.1998 *The Significance of Monuments. On the shaping of human experience in Neolithic and Bronze Age Europe*. Routledge, London.

Breeze, D, Clancy, T and Wellander, R. (eds.) 2003 *The Stone of Destiny*, Edinburgh: Historic Scotland. (In press).

Brewster, S.A. 2001 The Impact of Haptic 'Touching' Technology on Cultural Applications. in *Proceedings of EVA2001*. (Glasgow, UK), Vasari UK, s28, 1-14 Academic Press.

Brown, A., D. Brown, G. Coles, D. Dawson, A. Dodd, J. Gardiner, G.Lock, C. Longworth, N. Merriman, P. Miller, D. Murray, J. Reeve, and A.Wise 1999, *Digital Archives from Excavation and Fieldwork: A Guide to Good Practice, version 1*, Archaeology Data Service. http://ads.ahds.ac.uk/project/goodguides/excavation/ accessed 1/3/2003

Bryan, P.G. and Clowes, M. 1996 Surveying Stonehenge By Photogrammetry. *Photogrammetric Record*, 1997, 15(89), 739-51.

Campbell, E, Driscoll, S. and Huggett, J. 1998 *Sculptured Stones of Early Medieval Scotland*, University of Glasgow. http://www.gla.ac.uk/Acad/Archaeology/resources/SSEMS_web/, accessed 31/3/3.

Campbell, E. 1999 *Saints and sea-kings: the first kingdom of the Scots*. Canongate, Edinburgh.

Campbell, E. 2003 *Royal Inauguration in Dál Riata and the Stone of Destiny*, in Breeze *et al.* 2003

Carver, M. 2001 Tarbat Discovery Programme, Highland (Tarbat parish), Early Medieval settlement. *Discovery and Excavation*, Scotland 2001, 2, 64-65.

Carver, M., Garner-Lahire J. and Roe, A. 1997 Tarbat, Portmahomack (Tarbat parish), Early Medieval settlement. *Discovery and Excavation*, Scotland 1997, 51-2.

Carver, M., Garner-Lahire J. and Roe, A. 1998 Tarbat, Portmahomack (Tarbat parish), Early Medieval settlement. *Discovery and Excavation*, Scotland 1998, 63.

Castells, M. 1996 The Net and the Self. *Critique of Anthropology*, 1996,SAGE, London, Thousand Oaks, CA and New Delhi, Vol.16 (1), 9-38.

Century, M. 2001 Beyond the virtual museum: towards ART (augmented reality telepresence). Centre d'Innovation en Technologies de l'Information (CITI), Quebec, www.music.mcgill.ca/~mcentury/Papers/ART.html, accessed 11/1/01.

Chalmers, A and Lalioti, V. (eds.) 2001 AFRIGRAPH 2001, *ACM SIGGRAPH*, November 2001, ACM publishing.

Chalmers, A. (ed.) 2000 *Graphics and Archaeology: Interpreting the Past*. Pre-conference Proceedings ACM SIGGRAPH / EUROGRAPHICS, Snowbird, May 2000 (Unpublished)

Chalmers, A. 2002 Very Realistic Graphics for Visualising Archaeological Site Reconstructions, in *Proceedings of the 18th Spring conference on Computer Graphics*, Budmerice, Slovakia. http://www.sccg.sk/pages/proceedings/2002/ accessed 14/3/03.

Chalmers, A. and Rushmeier, H. 2002 Computer Graphics in Art History and Archaeology. *In IEEE Computer Graphics and Applications*, Vol. 22, No. 5. www.computer.org/cga/cg2002/g5toc.htm, accessed 26/3/03.

Champion, E. 2002 *Applying Game Design Theory to Virtual Heritage Environments.* Submitted to the Computer Games and Digital Cultures Conference, Tampere, June 6-8, 2002.www.student.unimelb.edu.au/~erikc/Papers/ApplyingGameDesign.pdf, accessed 11/3/03.

Chapman, H. and Fenwick, H. 2002 Contextualising Previous Excavation: The Implications of Applying GPS Survey and GIS Modelling Techniques to Watton Priory, East Yorkshire, *Medieval Archaeology*, Volume XLVI 2002, 81-89

Christensen, R.R., Hollerbach, J.M., Xu, Y. and Meek, S.G. 2000 Inertial-Force Feedback for the Treadport Locomotion Interface. *Presence: Teleoperators and Virtual Environments, 9,* pp. 1-14. http://www.cs.utah.edu/~jmh/Papers/ChristensenXet_al.pdf accessed 14/3/03.

Clough, D. and Long, D. 2000 *3D Kilmartin, bringing high technology applications to ancient culture in the Kilmartin valley: a pilot project*. Privately published by Kilmartin House Trust.

Creath, K. and Wyant, J.C. 2002 Moiré and Fringe Projection Techniques. www.optics.arizona.edu/jcwyant/Optics513(2002)/ChapterNotes/Chapter04/MoireChapterSecured.pdf, accessed 12/3/03

Dai, F. (ed.) 1998 *Virtual Reality for Industrial Applications*. Springer, Berlin.

De Napoli, L., Luchi M.L., Muzzupappa M. and Rizzuti S. 2001 A Semi-Automatic Procedure for the Recognition and Classification of Pieces of Archaeological Artefacts. Presented at XII ADM International Conference, Rimini, Italy. adm.ingfo.unibo.it/Papers/B2/3-ADM01-B2-071.pdf , accessed 13/2/03

Debevec, P. 2002 The Light Stage: photorealistic integration of real actors into virtual environments. In Ollila, M., (ed.) 2002

Debevec, P., Hawkins, T., Tchou, C., Duiker, H., Sarokin, W. and Sagar, M. 2000 Acquiring the Reflectance Field of a Human Face. In *SIGGRAPH 2000 Conference Proceedings*, (forthcoming). www.debevec.org/Research/LS/ debevec-siggraph2000-high.pdf , accessed 28/3/03.

Defense Advanced Research Projects Agency, 2002. *Support Technologies* (pdf) www.darpa.mil/dso/trans/pdf/Abmt5.pdf accessed 31/3/03.

Desmond, L. G. 1994 The use of close-range photogrammetry for archaeological documentation: Chichen Itza and Uxmal 1989. In, Virginia M. Fields, Ed., *Proceedings of the Seventh Palenque Roundtable Conference*, Vol. IX, pp. 43-48. San Francisco: Pre-Columbian Art Research Institute.

Devlin, K. and Chalmers A. 2001 Realistic Visualisation of The Pompeii Frescoes, In Chalmers and Lalioti 2001, 43-7.

Driscoll, S. 1991 The archaeology of state formation in Scotland, in Hanson 1991, 81-109.

Driscoll, S. 1998 *Political Discourse and the Growth of Christian Ceremonialism in Pictland: the Place of the St. Andrews Sarcophagus.* in Foster 1998, 168-178.

Driscoll, S. 2000 Christian Monumental Sculpture and Ethnic Expression in Frazer and Tyrell, 233-252.

Edwards, N. 2001 Early Medieval Inscribed Stone and Stone Sculpture in Wales: Context and Function *Medieval Archaeology*, Volume XLV 2001, 15-39.

Eiteljorg II, H. 2000 The Compelling Computer Image – a double-edged sword, *Internet Archaeology*, Issue 8, http://intarch.ac.uk/journal/issue8/eiteljorg_index.html, accessed 1/9/02.

Eos Systems Inc., 1997 PhotoModeler Pro User Manual (ver 3), Eos Systems Inc. Vancouver.

Fernie, K. and Richards, J. (eds.), 2002 *AHDS Guides to Good Practice – Creating and using Virtual Reality a Guide for the Arts and Humanity* AHDS, York. http://vads.ahds.ac.uk , accessed 31/3/3.

Finnemann, N.O. 1999 *Modernity Modernised – The Cultural Impact of Computerisation.* in Mayer 1999, 141-159.

Fisher, I. 1994 The Govan cross-shafts and early cross-slabs, in Ritchie 1994, 47-55.

Fisher, I. 2001 *Early Medieval Sculpture in the West Highlands and Islands*. RCAHMS and The Society of Antiquaries of Scotland, Monograph Series 1, Edinburgh.

Fisher, P. and Unwin, D. 2002 *Virtual Reality in Geography.* Taylor and Francis, London.

FitzPatrick, E. 1997 *The Practice and Siting of Royal Inauguration in Medieval Ireland.* Unpublished Thesis, Trinity College, Dublin.

Forte, M. 2000 *About Virtual Archaeology: disorders cognitive interactions and virtuality,* in Barceló *et al*. 2000, 247-60.

Forte, M. 2002 *Archaeology, museums and tourism: which "virtual" for the territory.* In Niccolucci 2002.

Foster, S. (ed.) 1998 *The St. Andrews Sarcophagus, a Pictish Masterpiece and its International Connections*. Four Courts Press, Dublin.

Foster, S.M. 2001 *Place, Space and Odyssey. Exploring the future of Early Medieval sculpture.* Groam House Museum and Historic Scotland.

Foster, S.M., 1996 *Picts, Gaels and Scots. Historic Scotland*, Batsford ,Bath.

Frazer, W.O. and Tyrell, A. (eds.) 2000 *Social Identity in Early Medieval Britain*, Leicester University Press, London.

Frischer, B., Niccolucci, F., Ryan, N. and Barceló J.A. 2000 From CVR to CVRO: The Past, Present and Future of Cultural Virtual Reality. In Niccolucci, F. (ed.), *Virtual Archaeology between Scientific Research and Territorial Marketing, proceedings of the VAST EuroConference, Arezzo, Italy*.

Gaitatzes, A., Christopoulos, D. and Roussou, M. 2001 Reviving the Past: Cultural Heritage Meets Virtual Reality. To appear in *Proc. Virtual Reality, Archaeology and Cultural Heritage (VAST'01).* http://www.makebelieve.gr/mr/research/papers/VAST/vast_01/VAST01_vr_final.pdf accessed 01/2/03

Gidlow, J. 2000 Archaeological Computing and Disciplinary Theory in Lock and Brown (eds.) 2000, 25-30. http://www.wac.uct.ac.za/wac4/symposia/abstracts/s043.pdf accessed 11/3/03

Gilbert, I. 1995 *The symbolism of the Pictish stones in Scotland : a study of origins*. Speedwell Books, Edinburgh

Gillings, M. 2000 *Plans, Elevations and Virtual Worlds: The development of Techniques for the Routine Construction of Hyperreal Simulations.* in Barceló *et al.* 2000, 59-69.

Gillings, M. 2002 *Virtual archaeologies and the hyper-real: or, what does it mean to describe something as virtually-real?* in Fisher and Unwin 2002, 17-34.

Gillings, M. and Goodrick, G.T. 1996 'Sensuous and Reflexive GIS: exploring visualisation and VRML', *Internet Archaeology*, Issue 1, http://intarch.ac.uk/journal/issue1/gillings_index.html, accessed 1/9/02.

Gillings, M. and Pollard, J. 1998 Romancing the stones: Towards a virtual and elemental Avebury, *Archaeological Dialogues* 5 No.2 1998, 143-164.

Gillings, M. and Pollard, J. 2000 'Erecting Altars to Unknown Gods': a reply to Bowden. *Archaeological Dialogues* 7 No 1 2000, 88-93.

Gillings, M. and Pollard, J.1999 Non-portable stone artefacts and contexts of meaning: the tale of Grey Wether. *World Archaeology* Vol. 31(2), 179-83.

Gondek, M. 2003 *Invisible Cities/Alternative Cities: Monuments, Wealth, and Power in Scotland and Ireland, AD 600-1100*. PhD Thesis for submission to the University of Glasgow in 2003, (unpublished).

Gondek, M. and Jeffrey, S. 2003 The Reuse of a Figurative Panel from Eigg, *Journal of Medieval Archaeology* 2003 (Forthcoming).

Gray, T. and Ferguson, L. 1997 *Photographing Carved Stones: A Practical Guide to Recording Scotland's Past.* The Pinkfoot Press, Angus.

Habermann J, Schilles T, Kalchgruber R, Wagner GA., 2000 Steps towards surface dating using luminescence, *Radiation measurements*, 32, 847-851.

Henderson, I. 1958 The origin centre of the Pictish symbol stones, *Proceedings of the Society of Antiquaries of Scotland*, 91 (1957-8), 44-60.

Henderson, I., 1967 *The Picts. Ancient Peoples and Places.* Thames and Hudson, London.

Henderson, I., 1998 *Primus inter pares: the St Andrews Sarcophagus and Pictish Sculpture*, in Foster 1998, 97-168.

Henderson, I., 2000 Towards defining the function of sculpture in Alba: the evidence of St. Andrews, Brechin and Rosemarkie. In Taylor, S. (ed.) *Kings, Clerics and Chronicles in Scotland 500 – 1297*, Four Courts, Dublin, 35 – 47.

Henderson, I., 2002 Stage 2: Preliminary assessment of the material recovered and a consideration of Stage 3 objectives. *Hilton of Cadboll chapel Site. Art-Historical Analysis of Sculpture found during the excavations of Summer 2001*. Historic Scotland (Ref. HS/C/53228/2972)(unpublished).

Hodder, I. 1999 *The Archaeological Process: and introduction,* Blackwell Oxford.

Howe, R. 2001 Introduction to Haptic Display: Tactile display. *Haptics Community Web Page* haptic.mech.northwestern.edu/intro/tactile/, accessed 1/9/02.

Huggett, J. and Ryan, N. (eds.) 1994 *Computer Applications and Quantitative Methods in Archaeology* 1994, BAR International Series 600, Tempvs Reparatvm, Oxford.

Ingold, T. 1997 The picture is not the terrain: Maps, paintings and the dwelt in world, *Archaeological Dialogues* 4 No.1 1997, 29-32.

Jackson, A. 1984 *The Symbol Stones of Scotland*. Stromness.

Jacobsen, I.K. 2001 PC-Based Digital Photogrammetry. Presented at UN/COSPAR/ESA/GORS Workshop on Data Analysis and Image Processing Techniques Damascus, GORS. www.ipi.uni-hannover.de/html/publikationen/2001/Jacobsen/jac_PC_DigPhot.pdf , accessed 21/3/03

James, E. 1998 *The Continental Context*, in Foster 1998, 240-51.

James, H. F. 2001 (a)Hilton of Cadboll, Highland (Fearn parish), chapel; Pictish stone; enclosure. *Discovery and Excavation*, Scotland, 2, Figs. 21, 55.

James, H.F. 2001 (b) *Investigation of the Setting and Context of the Hilton of Cadboll Cross-Slab, Recovery of the Stump and Fragments of Sculpture.* GUARD, Glasgow University.

Jeffrey, S. 2001 A Simple Technique For Visualising Three Dimensional Models in Landscape Contexts, *Internet Archaeology* Vol.10 Summer 2001. http://intarch.ac.uk/journal/issue10/jeffrey_toc.html accessed 1/9/02.

Jones, S., MacSween, A., Jeffrey, S., Morris, R. and Heyworth, M. 2001 *From The Ground Up: the Publication of Archaeological Projects, a user needs survey*. CBA. http://www.britarch.ac.uk/pubs/puns/index.html accessed 23/3/03

Kemp, K. 2001 BP Seeks its extra dimension. *Sunday Herald*, 18th March 2001, Glasgow, (Scottish Media Group).

Kinetix 1997 *3D Studio Max r2, Users Guide and Reference* (3 Vols.). Kinetix (AutoDesk, Inc.). USA.

Kosslyn, S.M. 1980 *Image and Mind*, Harvard University Press, Massachusetts.

Krasniewicz, L. 2000 Immersive Imaging Technologies for Archaeological. in *Barceló et al*. 2000, 163-9.

Laing, L. 2000 The Chronology and Context of Pictish Relief Sculpture, *Medieval Archaeology*, Volume XLIV 2000, 81-113.

Laing, L. 2001 The Date of the Aberlemno Churchyard Stone, in Redknap et al. 2001, 241-51.

Lang, J. 1994 The Govan Hogbacks: a reappraisal in Foster 1994, 123-133.

Lemaire, T. 1997 Archaeology between the invention and destruction of the landscape, Archaeological Dialogues 4 No.1 1997, 5-22.

Levoy, M. and Hanrahan, P. Light field rendering In SIGGRAPH 1996 Conference Proceedings: Computer Graphics Annual Conference, ACM, 1996. http://graphics.stanford.edu/papers/light/ accessed 31/3/3

Levoy, M., Pulli, K, Rusinkiewicz, S, Koller, D., Pereira, L., Ginzton, M., Anderson, S., Davis, J. and Ginsberg, J.2000 The digital Michelangelo Project: 3D scanning of large statues. In SIGGRAPH 2000 Conference Proceedings: Computer Graphics Annual Conference, ACM, 2000.

Lloyd, C. 2001 Misrepresenting the Past: Virtual Reality and Archaeology. Panel Discussion, CAA (UK) 2001 http://www.cs.bris.ac.uk/Events/CAAUK2001/Program/panel.html accessed 31/3/3.

Lock, G. (ed.) 2000 *Beyond the Map, Archaeology and Spatial Technologies,* IOS Press, Amsterdam.

Lock, G. and Brown, K. (eds.) 2000 On the Theory and Practice of Archaeological Computing. *Oxford University Committee for Archaeology, Monograph No.51, Oxford.*

Mack, A. 1997 *Field guide to the Pictish symbol stones*. Balgavies, Angus.

Malzbender, T., Gelb, D. and Wolters, H. 2001 Polynomial Texture Mapping. in Chalmers and Lalioti, (eds.) 2001 AFRIGRAPH 2001, *ACM SIGGRAPH*, November 2001, ACM publishing.
http://www.hpl.hp.com/ptm/papers/PTM.pdf accessed 03/3/03

Mardon, A.P.1998 *3D Capture of Large, Sculptured Stones*, MSc. Dissertation University of Glasgow (unpublished).

Maxwell, I. 1992. The Preservation of Dark Age Sculpture, *The Proceedings from the Conferences of the Pictish Arts Society, 1992,* 5-19.

Mayer, P.A. (ed.) 1999 *Computer Media and Communication*. OUP, Oxford.

McBryde, I. 1997. The ambiguities of authenticity – rock of faith or shifting sands? Review of Nara Conference in relation to the World Heritage Convention. Proceedings, edited by Knut E.Larsen. *Conservation and Management of Archaeological Sites* (1997) Volume 2, 93-100.

McElearney, G. 1999 Gardom's Edge Web Site, University of Sheffield
http://www.shef.ac.uk/~geap/qtvrmain.htm , accessed 10/05/00

McGee, M.R., Gray, P. and Brewster, S. 2000 The Effective Combination of Haptic and Auditory Textural Information. Presented at the *Haptic Human-Computer Interaction Workshop*, (Glasgow University 31 August – 2 September 2000). www.dcs.gla.ac.uk/~stephen/papers/HHCI-marilyn.pdf accessed 03/1/03

McGee, M.R., Gray, P. and Brewster, S. 2001 Feeling Rough: Multimodal Perception of Virtual Roughness. in *Proceedings of Eurohaptics 2001*, Academic Press, 29-33.

McLuhan, M. 1964. *Understanding Media.* Routledge and Kegan Paul, London.

Meek, T. 2001 *Final Fantasy: Blurring the lines of reality* (Reel.com) http://www.reel.com/reel.asp?node=features/articles/finalfantasy accessed 31/3/03.

Millard, A. 2001 Misrepresenting the Past: Virtual Reality and Archaeology. Panel Discussion, CAA (UK) 2001 http://www.cs.bris.ac.uk/Events/CAAUK2001/Program/panel.html accessed 31/3/3.

Miller, P. and Richards, J. 1994 *The good, the bad and the downright misleading: archaeological adoption of computer visualisation*, in Huggett and Ryan 1994, 249–254.

Murray, D. 2001 *Historic Scotland Properties in Care Minor Archaeological Works 2001: Hilton of Cadboll Chapel Site.* Kirkdale Archaeology 2001 (Unpublished)

Murray, D. and Ewart, G. 2001 Hilton of Cadboll, Highland (Fearn parish), excavation. *Discovery and Excavation*, Scotland, 2, Figs. 21, 55

Myers, B.A. 1998 A Brief History of Human Computer Interaction Technology. ACM *interactions.* Vol.5, no.2, March 1998, 44-54.

Niccolucci, F. (ed.) 2002 *"Virtual Archaeology - Proceedings of the VAST2000 Euroconference*, *Arezzo,* Archaeopress, Oxford.

Ollila, M., (ed.), *Proceedings from SIGRAD 2002*, *Linköpings universitet, Norrköping, Sweden*. Linköping Electronic Conference Proceedings, ISSN 1650-3686 (print), 1650-3740 (www).
http://www.ep.liu.se/ecp/007/, accessed 11/3/03

Orton, F. 1998 Rethinking the Ruthwell Monument: Fragments and critique; tradition and history; tongues and sockets, *Art History* Vol. 21 No. 1 March 1998, 65-106.

Pedersini, F., Sarti, A. and Tubaro, S. 2000 Automatic monitoring and 3D reconstruction applied to cultural heritage. *Journal of Cultural Heritage* 1 (2000), 301-13.

Peterson, E. 1996 *The Message of Scotland's Symbol Stones* PCD Ruthven Books, Ruthven.

Pieraccini, M., Guidi, G. and Atzeni, C. 2001 3D digitizing of cultural heritage. *Journal of Cultural Heritage* 2 (2001), 63-70.

Pitt-Rivers, A. 1889 Paper given to the Society of Antiquaries. *Proceedings of the Society of Antiquaries of London* 2nd Ser. 13, 1889-91, 174-181.

Pope, J. and Chalmers, A. 2000 *Pre-rendering Acoustics and Illumination for Archaeological Reconstructions*. In Barceló *et al*. 2000, 105-11.

Pringle, M.J. 2000 *The Use of Virtual Reality for the Visual Presentation of Archaeological Information* PhD Thesis, Cranfield University http://www.pringle.org/com/webthesis/contents.html accessed 31/3/3.

Proni, D. and Weisman, T. 1999 *The VR Worx Integrated Authoring Environment for QuickTime VR, User's Manual* VR Toolbox Inc. USA.

Pryor, F. 2002 Interview with the President of the CBA. CBA website: http://www.britarch.ac.uk/sosnewport/ [opinions and views pop-up] accessed 29/8/02.

RCAHMS 1999 *Pictish Symbols. An Illustrated Gazetteer.* Royal Commission for Ancient and Historic Monuments of Scotland, Edinburgh.

Reynier, M. 2002 Computer Based Learning in Archaeology: Putting the Learning Back into CBL. http://www.le.ac.uk/archaeology/ltsn/cblarticle060802.html, accessed 10/7/02

Ritchie, A. (ed.) 1994(a) *Govan And Its Early Medieval Sculpture*. Allan Sutton Publishing, Stroud.

Ritchie, A. 1994(b) *Perceptions of the Picts: from Eumenius to John Buchan*. Groam House Museum Trust, Rosemarkie.

Roberts, J. and Ryan, N. 1997 *Alternative archaeological representations within virtual worlds* http://www.cs.ukc.ac.uk/people/staff/nsr/arch/vrsig97/vrsig.html. accessed 1/9/02.

Rock Art Pilot Project (RAPP) 2000 *Initial Report* English Heritage, Bournemouth University, School of Conservation Sciences and Institute of Archaeology, UCL. (unpublished).

Romilly Allen, J. 1900 The Early Christian Monuments of the Glasgow District. *Proceedings of the Society of Antiquaries of Scotland*, 394-405.

Roussou, M. 2001 Immersive Interactive Virtual Reality in the Museum. In *Proceedings of TiLE 2001(Trends in Leisure Entertainment),* www.makebelieve.gr/mr/research/papers/ tile_01/mr_TiLE2001_paper.pdf , accessed 12/12/02.

Rushmeier, H. and Bernardini, F. 2000 Documentation, discovery, communication: Can 3D technology help the art historian. In Chalmers 2000, 40-50.

Rusinkiewicz, S. and Levoy, M. 2000 Qsplat: A Multi-resolution Point Rendering System for Large Meshes. In *SIGGRAPH 2000 Conference Proceedings,* (forthcoming). http://www.cs.princeton.edu/courses/archive/spring01/cs598b/papers/rusinkiewicz00.pdf accessed 16/1/03

Ryan, N. 2000 Back to reality: augmented reality from field survey to tourist guide. In Franco Niccolucci, (ed.), paper in *Virtual Archaeology between Scientific Research and Territorial Marketing, proceedings of the VAST EuroConference, Arezzo, Italy* (forthcoming). http://www.cs.ukc.ac.uk/pubs/2000/1264/index.html, accessed 26/3/03

Ryan, N. 2002 *Documenting and Validating Virtual Archaeology.* CAA Virtual Archaeology Special Interest Group (VASIG), Presented at CAA2002, Heraklion Crete (Forthcoming)

Samson, R. 1992 *The reinterpretation of Pictish symbols*. JBAA CXLV (1992), 29-65.

Scott, I. G., 1997 Illustrating Early Medieval Carved Stones. In Henry, D., *The Worm, the Germ and the Thorn,* Pinkfoot Press, 129-32.

Shirley, P. 2000 Open problems for archaeological visualisation in Chalmers (ed.) 2000, 1-3.

Sinclair, P. and Martinez, K. 2001 Adaptive Hypermedia in Augmented Reality. Presented at *Twelfth ACM Conference on Hypertext and Hypermedia*, Arhus, Denmark, Aug 14-18.
http://wwwis.win.tue.nl/ah2001/papers/sinclair.pdf accessed 12/1/03

Smyth, M., Collins, A.F., Morris, P.E. and Levy, P. 1994 *Cognition in Action* Lancaster University.

Spearman, R.M. 1994 The Govan sarcophagus: an enigmatic monument, in Ritchie 1994, 33-47.

Sterling, B. 1993 War is Virtual Hell, *Wired 1.01* March/April 1993
http://www.wired.com/wired/archive/1.01/virthell_pr.html accessed 31/3/3.

Suler, J. 2001 *The Psychology of Cyberspace – Overview and "Guided Tour".*
http://www.rider.edu/users/suler/psycyber/overview.html, accessed 13/5/00.

Sutherland, E. 1997 *The Pictish Guide*, Edinburgh.

Sutherland, K. 2000 *Registering Sculpted Stones. Aligning Photographs for QuickTime VR Object Movies.* MSc dissertation. University of Glasgow.

Terras, M. 1999 "A Virtual Tomb for Kelvingrove" *Internet Archaeology*, Issue 7, http://intarch.ac.uk/journal/issue7/terras, accessed 10/05/00

Thomas, C. 1984 The Pictish Class I Symbol Stones. in Friell, J.G.P. and Watson, W.G., (eds.) *Pictish Studies*, Oxford, 169-87.

Thomas, C. 1998 *Form and Function*. in Foster 1998, 84-96.

Tilley, C. 1994 *A phenomenology of landscape: places, paths, and monuments.* : Berg, Oxford ; Providence, R.I.

Tringham, R. 2000 Virtual reality, real and surreal places in the past. In Chalmers 2000, 3-10.

Unger, J., Wrenninge, M., Wänström, F. and Ollila, M. 2002 Real-Time Image Based Lighting in Software Using HDR Panoramas. In Ollila, M., (ed.) 2002

Uzzell, D.L. 2002 'The dialectic of past-present relations' in Cranstone D. and Palmer, M. *The Archaeology of Industrialisation*, Oxbow, Oxford. http://www.surrey.ac.uk/Psychology/staff/d.uzzell/archeol.pdf accessed 15/2/03

Veltman, K.H. 1998 *Frontiers in Electronic Media*. SUMS http://sumscorp.com/contemporary/frontiers.html, accessed 12/01/01.

Vince, J. 1995 *Virtual Reality Systems*. Addison-Wesley, Wokingham.

Von Bally, G., Dreesen, F., Roshop, A., Sommerfeld, W. and Funke, P., 1997 High Resolution Holography: a New Technology in Artwork Conservation. Presented at The Second International Conference on Lasers in the Conservation of Artworks, (LACONA II), 23-25 April 19997, Liverpool. http://www.merseyworld.com/laser_tech/lacona.html accessed 28/3/03

Warniers, R. 1998 Every Picture Tells a Story. *Computer Graphics World*. http://cgw.pennnet.com/ , accessed 10/05/00.

Watkinson, J. 1994 *The Art of Digital Audio*, 2nd edition, Butterworth-Heinemann, New York

Watson, A.1997 *Hearing again the sound of the Neolithic*, British Archaeology, No. 23 Council for British Archaeology http://www.britarch.ac.uk/ba/ba23/ba23feat.html, accessed 1/9/02.

Yates, T., Butlin, R., and Houston, J. 1999 *Assessment Methodology Handbook. Carved Stone Decay In Scotland*. Historic Scotland, Edinburgh.

11 URL Listings

3D Scanners UK	http://www.3dscanners.co.uk/
3DWinOGL	http://www.opengl.org/
Actuality Systems	http://www.actuality-systems.com/
Adobe	http://www.adobe.co.uk/
Archaeoguide	http://www.archaeoguide.it/
Archaeological Data Service	http://ads.ahds.ac.uk
Archaeoptics	http://www.archaeoptics.co.uk/
Art History	http://www.blackwellpublishing.com/
ArtCom	http://www.artcom.de/
Artefact Project (Victoria and Albert Museum)	http://www.i-dat.org/projects/artefact/project.html
Association for Computing Machinery (ACM)	www.acm.org/
AutoDesk	http://www.autodesk.co.uk
Breukmann GmbH	http://www.breuckmann.com/
Callidus Precision Systems GmbH	http://www.callidus.de/
CASSS Database	http://www.dur.ac.uk/corpus/
Chimera Web	http://www.mactia.berkeley.edu/chimera/
CIPA	http://cipa.icomos.org/
CISP	http://www.ucl.ac.uk/archaeology/cisp/
CNDE	http://www.cnde.iastate.edu/
Council for British Archaeology	http://www.britarch.ac.uk/
CRSBI	http://www.crsbi.ac.uk/
Cuneiform Digital Library	http://early-cuneiform.humnet.ucla.edu/
Cuneiform.net	http://www.eee.bham.ac.uk/cuneiform/
CVRO	http://www.cvro.org/
CyberAxis	http://www.axisartists.org.uk/cyberaxis/
Cyberedge	http://www.cyberedge.com/

Cyra	http://www.cyra.com/
Deepmatrix	http://www.geometrek.com/
Digital Michelangelo Project	http://graphics.stanford.edu/projects/mich/
English Heritage	http://www.english-heritage.org.uk/
EOIS (The Handy)	http;//www.eois.com/htm/handy.htm
EOS Systems (Photomodeler)	http:// www.photomodeler.com/
Faraday Centre	http://www.faraday.gla.ac.uk/
Foundation of the Hellenic World	http://www.fhw.gr
Geology Museum, University of Oslo	http://www.nhm.uio.no/geomus/engelsk/
GTCO Calcomp	http://www.gtco.com/
Hewlett-Packard Laboratories	http://www.hpl.hp.com/ptm/
Hilton of Cadboll Excavations	http://www.guard.arts.gla.ac.uk/1078/
Historic Scotland	http://www.historic-scotland.gov.uk/
HotPad Project	http://www.hotpad.org/
Hunterian Art Gallery	http://www.hunterian.gla.ac.uk/gallery/
Hunterian Museum	http://www.hunterian.gla.ac.uk/museum/online_exhibitions/stones/objects/objects.html
ImmersaDesk	http://www.fakespacesystems.com/
Immersion	http://www.immersion.com/
Inspeck Inc.	http://www.inspeck.com/
Intel	http://www.intel.com
Internet Archaeology	http://www.intarch.ac.uk/
ISO	http://www.iso.ch/i
Jamie Kurz (WCS)	http://www.3dnature.com/anims.html
Java3D	http://www.java3d.org/
Jorvik Centre	http://www.jorvik-viking-centre.co.uk/
JPEG	http://www.jpeg.org/
Kaidan	http://www.kaidan.com/
Kilmartin House (Theatron)	http://www.kilmartin.org

Kodak	http://www.kodak.co.uk/
Leica Geosystems	http://www.leica-geosystems.com/
Lidar Services	http://www.lidar.co.uk/
Logitech	http://www.logitech.com/
Marco Gualdrini (WCS)	http://www.3dnature.com/anims.html
MASSIVE	http://www.crg.cs.nott.ac.uk/research/
Measurement Devices Limited	http://www.mdl.co.uk/
Metronor	http://www.metronor.com/
Microsoft	http:///www.microsoft.com/
Minehowe Excavation (OAT)	http://www.oat.org.uk/Minehowe/
Minolta Vivid	http://www.minolta3d.com/
Mitutoyo	http://www.mitutoyo.com/
National Museums and Galleries, Merseyside	http://www.nmgm.org.uk/
NMRC	http://www.english-heritage.org.uk
Nvision Inc.	http://www.nvision3d.com/
Ordnance Survey	http://www.ordsvy.gov.uk/
Orkney Archaeological Trust	http://www.orkneydigs.org.uk/
Paraform	http://www.paraform.com/
Parallelgraphics	http://www.parallelgraphics.com/
PastScape (EH test site)	http://www.pastscape.org/
Philip Barker	http://www.maralex.co.uk/PAB/new/new/5.htm
Pictish Arts Society	http://www.pictarts.demon.co.uk/
Pictish Free State	http://www.pictland.freeserve.co.uk/
Pictish Trail (pdf)	http://www.higharch.demon.co.uk/leaflets/
Polhemus Inc.	http://www.polhemus.com/
Portmahomack Excavations	http://www.york.ac.uk/depts/arch/staff/sites/tarbat/
Qsplat	http://graphics.stanford.edu/software/qsplat/
Rhino	http://www.rhino3d.com/

RSI GmbH	http://www.rsi.gmbh.de/
Ruth Tringham	http://sscl.berkeley.edu/arf/main/tringham.html
SCRAN	http://www.scran.ac.uk/
SEMSS	http://www.gla.ac.uk/Acad/Archaeology/projects/SSEMS_web/i
SensAble Technologies	http://www.sensable.com/
SHAPE	http://www.lems.brown.edu/shape/
SimVis Project (University of Hull)	http://www2.dcs.hull.ac.uk/simmod/Topics/virtual_archaeology.htm
Steadicam	http://tonytang.com/steadicam/
SURRC	www.gla.ac.uk/centres/surrc/
Theatron	http://www.theatron.co.uk/
Unicode	http://www.unicode.org/
University of Vienna Institute for Prehistory and Early History	http://www.univie.ac.at/Luftbildarchiv/exhib/tempel/intro.htm
University of Oslo Museum of Geology	http://www.toyen.uio.no/geomus/engpage.html
University of Berkeley	Http://www.berkeley.edu/
University of Bristol	http://www.bris.ac.uk/
University of Callabria	http://www.unical.it/
University of Frankfurt	http://www.uni-frankfurt.de/
University of Glasgow	http://www,gla.ac.uk/
University of Munster	http://www.uni-muenster.de/
University of Southampton	http://www.soton.ac.uk/
University of Stanford	http://www.stanford.edu/
University of Utah, Treadport project.	http://www.cs.utah.edu/research/areas/immersive/Locomotion.html
Virtual Research Systems	http://www.virtualresearch.com/
Virtual Stonehenge model (zip)	http://www.stonehenge-avebury.net/V-R/vr.html

Vistapro	http://www.andromedasoftware.com
Visuplan	http://www.visuplan.de/
Vrealities (data glove)	http://www.vrealities.com/5dtglove.html
VRML	http://www.vrml.org/
VRToolbox Inc.	http://www.vrtoolbox.com/
Web 3D consortium	http://www.web3d.org/
Webpeodia	http://www.webpeodia.com/
World Construction Set	http://www.3dnature.com/
X3D	http://www.web3d.org/x3d.html/
XML	http:// www.xml.com/

12 Selected glossary

ACM	Association of Computer Machinery
ADS	Archaeological Data Service, part of the Arts and Humanities Data Service
AR	Augmented Reality
ASCII	American Standard Code for Information Interchange
BOOM	Binocular Omni-Orientation Monitor, an alternative to HMDs
BRDF	Bi-directional Reflectance Distribution Function
BRE	Babcock Rosyth Engineering
B-rep	Boundary representation, a 3D modelling technique
CAD	Computer Aided Design
CAVE	Cave Automatic Virtual Environment (first created by the NCSA)
CCD	Charge-Coupled Device, the semi-conductor based light recording mechanism in digital cameras
CGI	Computer Generated Imagery
CIPA	International Committee for Architectural Photogrammetry
CMM	Co-ordinate Measuring Machine
CNC	Computer Numerical Control, allowing computer control of machinery
CNDE	Centre for Non-Destructive Evaluation (US)
CSG	Constructive Solid Geometry, a 3D modelling technique
CV	Control Vertice, required for NURBS modelling
CVE	Collaborative Virtual Environment, another name for a DVE
CVRO	Cultural Virtual Reality Organisation
DARPA	Defence Advanced Research Projects Agency (US Military)
DEM	Digital Elevation Model
DTM	Digital Terrain Model
DVC	Digital Video Camera
DVD	Digital Versatile Disc

DVE	Distributed Virtual Environment, another name for a CVE
DXF	Drawing eXchange Format, AutoCAD proprietary file format
EDM	Electronic Distance Measurer
EH	English Heritage
FPX	Flashpix, Kodak proprietary image format.
FTP	File Transfer Protocol, internet standard protocol for transmitting large data volumes
GIF	Graphic Interchange Format, open image format
GIS	Geographical Information Systems
GPS	Global Positioning System
GUI	Graphical User Interface
Haptic	Relating to the sense of touch
HCI	Human-Computer Interaction
HMD	Head-Mounted Display
HRTF	Head-Related Transfer Function, a problem associated with stereo sound via headphones
HS	Historic Scotland
HTML	HyperText Mark-up Language, the dominant language for encoding text and images for the internet, the language being translated by a web browser.
ICOMOS	International Council on Monuments and Sites
ICT	Information and Communication Technology
I-Frames	Interpolated Frames, frames that are interpolated from preceding and succeeding frames in a sequence.
ISO	International Standards Organisation
JPEG	Joint Photographic Expert Group, and the image format they specify.
LED	Light Emitting Diode
Loss-less	Describes a compression algorithm in which no data is lost
Lossy	Describes a compression algorithm that results in loss of data
MDL	Measuring Devices Limited

MS	Microsoft Corporation
NMR	National Monuments Record (EH)
NMRC	National Monuments Record Centre (EH)
NMRS	National Monuments Record of Scotland (RCAHMS)
NMS	National Museums of Scotland
NTSI	Non-Topographic Surface Information
NURBS	Non-Uniform Rational B-Spline, a technique for representing lines and surfaces in three dimensions.
OED	Oxford English Dictionary
OGL	Open Graphics Language
OLE	Object Linking and Embedding, a software protocol allowing information linking and embedding across enabled applications
OSL	Optically Stimulated Luminescence, a scientific dating technique using lasers to cause crystals to luminese thereby allowing the time from their last exposure to sunlight to be calculated.
PC	Personal Computer, its use here includes all desktop machines rather than only those based on the original IBM PC architecture
PCD	Photo Compact Disc, a Kodak proprietary image storage system.
Plug-in	A small application that can be invoked by a web-browser when required to extent its capabilities.
PTM	Polynomial Texture Maps, texture maps containing information on a surface under several lighting conditions.
QTVR	Quick-Time Virtual Reality
RCAHMS	Royal Commission on the Ancient and Historic Monuments of Scotland
RGB	Red, Green, Blue, a standard technique for representing colour on a computer screen.
SCRAN	Scottish Cultural Resource Access Network
SQL	Structured Query Language, a language for interrogating databases.
SURRC	Scottish Universities Research and Reactor Centre

TAR	Tape Archive, a Sun proprietary compression technique
TIFF	Tagged Interchange File Format, a compressed graphics format.
TIN	Triangulated Irregular Network, a file format that describes a three dimensional surface as nodes and vertices in a triangular mesh.
UNESCO	United Nations Educational, Scientific and Cultural Organisation
VR	Virtual Reality
VRML	Virtual Reality Mark-up Language, a language for allowing VR objects and worlds to be transmitted via the internet and translated by a web browser plug-in.
X3D	The subset of XML dealing specifically with 3D data.
XML	eXstensible Mark-up Language, the predicted replacement for HTML that is infinitely extensible, allowing the definition of a vast array of different types of data.