The Govan Stones Revealed: Digital Imaging in the Analysis of Early Medieval Sculpture

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Abstract

This work explores the utility of digital imaging techniques as research tools in the study of early medieval carved stones. Often three-dimensional imaging is seen primarily as a means of recording an object for preservation, illustration or outreach. The approaches developed here use these digital resources to gain a new perspective on the carving of the stones to address questions relating to the presence or absence of a 'Govan school'.

The terms 'Strathclyde Style' or 'Govan School of Carving' are used as a convenient shorthand to describe the 9^{th}-11^{th} century carved stones in the Strathclyde area; however, it has also been suggested that the traits shared by these monuments indicate that the carvers were either trained in or worked in a centralised location. The thesis presented here provides a new perspective on these questions through a digital lens.

The thirty-one carved stones housed at Govan Old have experienced varying degrees of wear. Three-dimensional imaging and Reflectance Transformation Imaging (RTI) were instrumental in recovering worn patterns on many of the stones. This has led to the recognition of several trends in the Govan collection that had been previously overlooked. These digital techniques were also used to determine whether templates had been employed in the replication of figures, which could indicate that tools were shared by members of a single workshop. Finally, Kitzler Åhfeldt's Groove Analysis was applied to the 3D models to identify the carving 'signatures' of individual carvers. These strands of research were then considered together to determine whether a centralised school or workshop is likely to have been connected to Govan.

This research demonstrates that digital imaging techniques are invaluable research tools; their flexible and infinitely replicable nature offer new insights into carved stone that would be otherwise untenable. While these applications are by no means restricted to stone in the early medieval period, the digital corpus of the Govan collection presented here demonstrates that these new avenues of investigation facilitate new analyses from which all early medieval sculpture in Scotland would benefit.

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Author's Declaration

I declare that, except where explicit reference is made to the contribution of others, that this thesis is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

Megan Nichole Kasten

1 Introduction

This thesis is a study of an important but neglected assemblage of early medieval sculpture at Govan Old in Glasgow, Scotland. It attempts to provide a complete 3D documentation of the carved stones and to undertake a range of digital analyses. This is innovative in terms of its application to this type of material, in its comprehensiveness, and its focus on the analytical benefits of digital imaging, not simply on its uses in recording and preservation.

The ‘Govan School’ is a label now commonly used to refer to the early medieval sculpture found in Strathclyde, (a region defined as ‘pre-1975 Lanarkshire, Renfrewshire and Dumbartonshire’ (Driscoll et al. 2005, 135). Some consider the term ‘school’ solely as an art historical term, one that suggests the different carved stones in this region share similar features, whether in characterisation of the monument forms or their interlace. The ‘Govan School’ can be described as exhibiting median-incised interlace and free-ring patterns, while the forms of the monuments vary from free-standing crosses to the prevalent recumbent cross-slabs, some of which have incorporated prominent angle-knobs to adopt a shrine-like appearance. While ‘Govan School’ is a useful descriptor, the question is whether the prevalence of these decorative features reflects a physical reality: were the carvers of each of these stones trained in a similar location? Was there a centralised workshop where these pieces of sculpture were produced? Or is this simply the result of several carvers drawing inspiration from existing monuments? Due to the lack of relevant historical records, previous research has relied on art historical interpretations to address these questions at Govan, but a closer inspection of the carving styles can offer a new perspective on the ‘Govan School’. This is what the research presented here accomplishes through the application of digital imaging techniques.

Three-dimensional (3D) imagery has been seen primarily as a means for the creation of detailed records for conservation, 2D images for paper publications, and digital outputs for public outreach. This has changed in recent years; in different branches of archaeology, 3D imagery has been increasingly utilised as a research tool. However, this application has been limited within the study of early medieval sculpture from the British Isles. This thesis seeks to investigate the research applications of different digital imaging techniques in the analysis of the Govan stones. Laila Kitzler Åhfeldt is one researcher who has thoroughly embraced laser scanning in its analytical capacity in her multifarious studies of Swedish runestones (Kitzler Åhfeldt 2009a; Kitzler Åhfeldt 2002b). Identifying the work of individual carvers and understanding whether cooperating carvers were organised as a workshop formed a central theme of her work, which made it an important source of inspiration for several facets of this study (especially in consideration of the research aims described more fully in Sections 1.3, 1.4, and 1.6 below).

In addition to considering the research applications of these digital imaging techniques to early medieval sculpture, this thesis considers the feasibility of creating a digital corpus of early medieval sculpture in Scotland and incorporating a 3D component for each stone. Issues regarding ideal archival practice, current dissemination methods, and accessibility and usability of these datasets for research purposes are addressed.

1.1 Research Agenda and Questions

As stated above, the primary aim of this thesis is to explore the research potential of three-dimensional imaging techniques to the study of early medieval sculptured stones, focusing on the Govan stones located in Glasgow, Scotland. The central research questions of this thesis are:

1. Which three-dimensional imaging technique is best suited to record a large collection of sculpture to a standard acceptable to multiple lines of archaeological research?

2. Can photogrammetric models provide enough detail to support Groove Measure Analysis to identify individual artisans?

3. What analytical insights into the decoration and biography of the monument can three-dimensional techniques offer?

4. Can digital imaging techniques be used to reconstruct eroded or damaged monuments in a critically acceptable manner?

5. Can high-resolution three-dimensional models be used to identify the presence of carving processes shared by the ‘Govan School’ of sculptors?

6. Can a typology of the recumbent cross-slabs be constructed based on physical characteristics, and can this be validated by Groove Measure Analysis?

7. How can a high-resolution, large digital corpus best be managed and made accessible to other researchers in digital heritage and in art history?

1.1.1 Which three-dimensional imaging technique is best suited to recording a large collection of sculpture to a standard acceptable to multiple lines of archaeological research?

While there are now many non-contact techniques available that create three-dimensional models, photogrammetry was adopted here after critically assessing alternative approaches, including structured light scanning and terrestrial laser scanning. Simply put, photogrammetry involves taking many overlapping digital photographs of an object; the software can then find features shared between these photographs and create a three-dimensional model. This process is described in more detail in Chapter 5. Photogrammetry was adopted because it is a more affordable, accessible, and flexible imaging technique than structured light scanning or laser scanning. The flexibility of photogrammetry is demonstrated by its ability to capture surfaces that would otherwise be inaccessible using other imaging techniques. For instance, the undersides of three of the five hogbacks have been hollowed out to varying degrees to create a concave surface. Because these hogbacks are displayed on small blocks that are approximately 17 centimetres high, it is impossible to view the bottom surface in its entirety without the use of lifting equipment. Using a camera of a cellular phone, photogrammetry can incorporate this surface into the model, allowing the shape of the void to be visualised for the first time. Another example is one of the worn cross-shafts (Stirling Maxwell’s 10), which is currently positioned so that one face exhibiting a carved surface is too close to the wall of the church to view. This hidden face was incorporated into the three-dimensional model using a cellular phone and “selfie-stick.” The three-dimensional model of the cross reveals details which are otherwise impossible to view without physically moving and inverting the stone with heavy lifting equipment.

1.1.2 Can photogrammetric models provide enough detail to support Groove Measure Analysis to identify individual artisans?

This research will seek to determine Groove Measure Analysis's applicability to three-dimensional models of the stones produced by photogrammetry as opposed to laser-based techniques; the efficacy of the latter was established by Laila Kitzler Åhfeldt and the team at the Archaeological Research Laboratory at Stockholm University, Sweden (Kitzler Åhfeldt 2010). If individual sculptors can be identified based on their carving technique through this procedure, this will aid considerably in clarifying the chronology of the Govan collection, among other uses.

1.1.3 What analytical insights into the decoration and biography of the monument can three-dimensional techniques offer?

While three-dimensional models have become increasingly commonplace in early medieval sculpture studies for the purposes of presentation and preservation, their analytical potential is often overlooked. For example, simply removing the colour from a three-dimensional model allows faint interlace patterns and worn carving to be identified. Free software packages offer rendering options which increase the contrast between carved and un-carved surfaces and highlight these subtle patterns even further. Closer inspection of the actual patterns in this way allows for the reassessment of our current understanding. While J. Romilly Allen categorised Govan's interlace according to his mathematical interlace pattern designations, it has become apparent through this research that his categories are inadequate as descriptions of Govan's decoration. In addition to gaining insight into the form of Govan's interlace, this analytical process has aided in examining areas of reworking, especially when considering the recut hogbacks.

1.1.4 Can digital imaging techniques be used to reconstruct eroded or damaged monuments in a critically acceptable manner?

Reflectance Transformation Imaging (RTI) is used alongside photogrammetry to attempt to reconstruct particularly worn Govan Stones in a critically acceptable way. As an aid to pattern recognition, the models of well-preserved panels of interlace from the Govan collection are digitally “eroded” using a software package called *Zbrush*. By digitally eroding the intact interlace, the deepest carved portions of the pattern can be recorded. These “eroded” patterns can then be used to recognise the arrangement of carved features on weathered stones in the collection, and a hypothetical reconstruction can be produced. By reconstructing these overlooked stones, we will gain a more thorough understanding of the Govan Stones collection.

1.1.5 Can high-resolution three-dimensional models be used to identify the presence of carving processes shared by the ‘Govan School’ of sculptors?

The question of whether templates were used in the carving process is one of the oldest in the study of early Christian sculptured monuments. It is possible that templates were used in the construction of some of the decorative motifs found on the Govan stones. As discussed in Section 4.2, there is a distinction between the use of a template and the use of motif-pieces. Templates are physical objects which are used in the construction of decoration by leaving gaps in the material to allow for a direct transfer of the shape of the motif by tracing it as a stencil. In this project, the outlines of these figures are compared to each other, and the amount of overlap observed indicates whether the use of templates would have been likely. Primarily, this aspect of my research focuses on the sarcophagus and the cross-shafts. The use of three-dimensional models allows for outlines to be compared accurately without coming into contact with the stone, unlike more traditional approaches to template exploration, which usually includes the creation of rubbings.

1.1.6 Can a typology of the recumbent cross-slabs be constructed based on physical characteristics that can be validated by Groove Measure Analysis?

As detailed in Section 3.4 and Chapter 8, very little attention has been paid to the cross-slabs housed within Govan Old until recently (Cramp 1994; Bailey 1994; Thomas 1994; Higgitt 1990); the sarcophagus, hogbacks, and crosses are the most unique and best preserved monuments, and so have already been the subject of intense discussion. The most recent typology of the recumbent cross-slabs is not refined enough to contribute to understanding the chronology or the designs of the collection. Each typology has attempted to place these stones within a wider context before fully understanding how each stone fits within the collection itself. This research will propose a new typology and will test it against the findings of the Groove Measure Analysis. It is hoped to correlate the work of individuals with macroscopic features of the carved stone, decorative motifs in particular.

1.1.7 How can a high-resolution, large digital corpus best be managed and be made accessible to other researchers in digital heritage and in art history?

This project also explores the best ways in which to disseminate 3D models in a way that will not only serve as a resource for future academic researchers but will also appeal to other audiences. While third-party platforms, like Sketchfab, might act as a viable medium in the short-term, they are often based on companies who may or may not have continued success in the future. The datasets resulting from this research will be archived with the University of Glasgow's Enlighten and Historic Environment Scotland and made available to the public through methods explained more in Section 5.7.

1.2 Thesis Structure

This thesis is divided into ten chapters. The first chapter offers a brief summary of the context of the Govan stones and the implications of the term 'Govan School'. It highlights the potential for digital imaging techniques in further exploration of this concept and clearly states the research aims for this thesis.

Chapters 2, 3 and 4 provide a review of the literature relating to the three foci of this study. Chapter 2 considers the archaeological remains from Govan alongside what little historical documentation we have pertaining to the Kingdom of Strathclyde. This information is compared to the archaeological evidence from two other sites with significant collections of sculpture dating to the 9th-11th centuries to establish Govan's political and ecclesiastical significance in the area.

Chapter 3 considers past research that has focused specifically on the carved stones from Govan. It begins with an overview of the three different numbering systems that have been used to label the stones. Subsequently, the chapter is divided according to the four broad monument types present at Govan; in each of these sections, the previous interpretations and analyses of each group are laid out and critiqued. Special attention is given to the potential for the sarcophagus's use as both a sarcophagus and a reliquary. Finally, a summary of the challenges of classifying the recumbent cross-slabs is also presented, followed by further discussion in Chapter 8. A concordance of the Govan stones with images and filenames for the 3D models of each is included in Appendix A.

In Chapter 4, a review of how three-dimensional imaging has generally been employed in different archaeological contexts is discussed, including the few instances in which these techniques have been applied to address a specific research question in early medieval sculpture. This discussion is followed by a short summary of art historical perspectives on the identification of a master carver's work. The chapter concludes with a brief summary of Kitzler Åhfeldt's results from using three-dimensional models to identify individual sculptors on Swedish runestones.

Each of the methodologies employed in this thesis are described in detail in Chapter 5. First, the three different three-dimensional imaging techniques explored at the beginning of the project (photogrammetry, white-light scanning, and laser scanning) are defined. The discussion of each approach includes a description of the technology involved in capturing geometry of an object and the advantages and the limitations of the three techniques. Comparisons of the results of each technique using CloudCompare revealed that they all produced analogous datasets; consequently, photogrammetry was chosen as the method of data capture for this project. This section is followed by the workflow adhered to for data capture, processing, and export of the three-dimensional products. A description of Reflectance Transformation Imaging is then presented, accompanied by a demonstration of its utility in identifying moderately worn patterns from the stone surface. After detailing the workflow used for each of these digital imaging techniques, the methodological approaches behind each component of the analysis are explained, including: the recovery of patterns from significantly worn stones using a 3D comparative collection, the identification of potential template implementation using accessible software, and the application of Groove Analysis to the Govan material. Chapter 5 concludes with a consideration of issues surrounding data management and archival of the digital material and especially how to make these resources available for future use and research.

Chapters 6, 7, 8 and 9 focus on the application of digital imaging techniques to address specific research questions. Chapter 6 offers a comprehensive list of new interpretations available after the weathered areas of the carved stones are investigated with digital imaging techniques. The reconstructions required different levels of investment dependant on how much of the decoration remained; a table is provided to indicate which techniques were required to identify the worn detail. A few of the stones were too damaged for much insight to be gained from these techniques, but enough was recovered from many of the recumbent cross-slabs to support the construction of a new typology, which is fully described in Chapter 8.

Some have previously argued that the use of templates between stones could indicate the presence of a centralised workshop where carvers shared tools and templates between them (Bailey 1996, 114). In Chapter 7, the potential for the use of templates to replicate images between stones in the Govan collection is addressed, focusing specifically on the horsemen depicted on the sarcophagus and crosses and the deer-like beasts on the sarcophagus.

Chapter 8 lays out the various traits that were initially considered in the development of the recumbent cross-slab typology, giving reasons for their inclusion or rejection from the final typology. The designation of the three traits chosen for the typology is explained, and the process of identifying groups based on these traits is thoroughly demonstrated. Several phases of standardisation within the collection of recumbent cross-slabs are now evident from the typology, supporting the idea of a centralised authority in the production of this monument type.

After adapting Kitzler Åhfeldt's Groove Analysis to better suit the Govan material, as described in Chapter 5, the analysis is applied to Govan 1, Govan

12, and Inchinnan 1 to identify the carving styles of individual carvers in Chapter 9. This includes brief descriptions of the statistical analyses and their outputs and justifications for the decisions made in dividing samples by type, the definition of clusters, and combining carving profiles under a single individual. Additional outputs from the statistical processes are provided in Appendix C.

Finally, the separate strands of evidence discussed throughout this research are considered together in Chapter 10. The results are summarised and then framed in terms of whether they support the interpretation of a centralised early medieval school or workshop in the Strathclyde region. Chapter 10 concludes with several promising areas for future research that have been highlighted in the process of this project.

Ultimately, this thesis explores the research applications of digital imaging techniques in the analysis of early medieval sculpture. While these digital records are inherently useful for conservation, illustration, and outreach purposes, it is argued here that they have the potential to be indispensable research tools for analysts of all periods and interests, if used creatively.

2 Govan in the Early Medieval Period

It is clear from multiple lines of evidence that Govan was a politically and ecclesiastically significant location during the early medieval period. The site's importance from the ninth through eleventh centuries can be inferred through other lines of evidence, including a single reference by a medieval text, archaeological investigations, and place-name evidence. However, the strongest attestation of the site's influence lies in the significant amount of sculpture recovered from the churchyard (Dalglish & Driscoll 2009; Macquarrie 1994; Driscoll 2004). Thirty sculptured stones are now displayed in Govan Old Church, and a single recumbent slab of a probable medieval date remains in the graveyard; however, at least forty-six stones dating to the early medieval period have been recorded from the site at different points in history (Stuart 1856; Stirling Maxwell 1899; Allen & Anderson 1903; Craig 1994a). While fifteen of the original forty-six recorded in Stirling Maxwell's volume were thought to have been lost, recent investigation of the churchyard has identified at least three of these 'missing' stones: Stirling Maxwell's 30, 38, and 40. While 3D models and analysis of these stones are not included in the present thesis, there is scope to apply these approaches after the stones have been fully excavated and conserved. Because this discovery occurred after the thesis was submitted, these stones will be referred to as the 'misplaced' stones throughout the thesis. Govan is one of the largest collections of early medieval sculpture in Scotland, exceeded in number only by Iona and St. Andrews (Radford 1967a; Radford 1967b; Driscoll et al. 2005). While the unique pieces of sculpture have received a great deal of attention, the whole collection has more to contribute to our understanding of the site. The following sections will review the historical and archaeological evidence that has been recovered from Govan; this will be compared to the evidence recovered from Whithorn and York to attempt to broadly define Govan's political and ecclesiastical significance in the 9th and 11th centuries AD.

2.1 Political Significance

It is evident that Govan was a politically significant place from the ninth through the eleventh centuries. The only mention of Govan to survive in the historical record comes from an eighth century source which was included in Simeon of

Durham's *Historia Regum Anglorum*, which he compiled sometime in the twelfth century. Simeon describes the return of the Northumbrian army from *Ovania* after a devastating attack on Dumbarton in 756 (Breeze 1999, 133–134; Forsyth 2000, 29). Dumbarton has been described in several historical sources to have been the political centre of the British kingdom of Al Clud, potentially from the 6th century AD until the Annals of Ulster recorded the destruction of Dumbarton Rock by a Viking raid in 870. After this, the kings of Clyde Rock no longer appear in historical records (Alcock & Alcock 1990, 98–99; Clancy 2006, 1818). Instead, in 872, the Annals of Ulster begin to refer to the kingdom of Ystrad Clud, the kingdom of Strathclyde (Clancy 2006, 1819). The date currently attributed to the earliest of the sculpture found at Govan roughly coincides with this major event, and it has been suggested that the political centre formerly seated at Dumbarton shifted upstream to Govan after the destructive events of the late 9th century (Driscoll 1998, 112–113; Clancy 2006, 1819).

Further evidence for Govan's political and social eminence is suggested by the now-demolished topographical feature which was known as Doomster Hill. Thomas Clancy has proposed that the name of "Govan" comes from the Brittonic word "gwovan", which would translate to "small hill, little crest," which could have referred to Doomster Hill (Clancy 1996; Clancy 1998). Doomster Hill was a substantial artificial mound located approximately 150 metres southeast of the churchyard and probably functioned as an assembly site or moot hill during the early medieval period (Davidson Kelly 1994, 1–3; Ritchie 2004, 1; Driscoll 2004, 17; Crawford 2005). Unfortunately the hill was destroyed in the late nineteenth century through the activity related to a dyeworks (Davidson Kelly 1994, 3) and the later expansion of Napier's shipyard (Driscoll et al. 2008, 10). Its connection to the church is supported by evidence from the 1996 archaeological excavations, which revealed a metalled roadway that led from the southeast corner of the churchyard at Govan Old in the general direction of the former location of Doomster Hill; the roadway was dated between the early eighth to late ninth centuries by a radiocarbon sample (Driscoll 2004, 17).

In addition to its status as a regional meeting place, it is likely that Govan had ties with a royal residence across the River Clyde in Partick. While it is known that there was a royal estate in Partick in the twelfth century (Macquarrie 1994, 29; Driscoll 1998, 105), there is also historical evidence to suggest that royalty resided in Partick much earlier. In Jocelin of Furness's *Life of Kentigern*, which was written during the late twelfth century, King Rhydderch Hael was described as passing away at his royal estate in Partick sometime around 612x614 (Macquarrie 1993, 19; Driscoll 2004, 20). Considering the amount of early medieval sculpture in the churchyard at Govan and the patronage that would have been required to commission these monuments, a royal presence in Partick at least from the ninth through the eleventh centuries, if not from the seventh through the twelfth centuries, seems likely.

2.2 Ecclesiastical Significance

Excavations that took place at Govan Old between 1994 and 1996 suggest that a church was present at the site before its first visible period of greatness, due to the presence of presumably Christian burials, with their heads oriented to the west, which were radiocarbon dated to between the fifth and sixth centuries AD (Driscoll 2004, 8). It remains uncertain as to Govan's exact ecclesiastical role during this early period, whether it began as a monastic settlement or began as the focus for burial in a Christian community. By comparing the results of the limited excavations at Govan to sites that have also produced significant collections of 9th-11th century AD sculpture and have been excavated more extensively, one can gain insight into how Govan might have developed into a significant 9th-11th century AD ecclesiastical site. The sites that will be explored here will be Whithorn and York Minster.

2.2.1 Whithorn

Whithorn has been interpreted by many as an early monastic site with foundations likely dating back to the later-fifth to early sixth centuries (Hill 1997, 38, 67–69). The earliest probable reference to Whithorn and its monastic origins is made by Bede in his *Historia Ecclesiastica Gentis Anglorum* when discussing Nynia, his pre-Columban missionary work converting the Picts, and his founding of a church at a place referred to as the "White House" (Colgrave et al. 1991, iii.4). Bede also makes reference to the site's status at the time of his writing in 732 AD, which had developed into a Northumbrian episcopal see (Colgrave et al. 1991, v.23). In addition to these, Peter Hill describes how two other documents tell the life of Bishop Nynia (*Miracula Nynie Episcopi* and *Vita Niniani*) and frame certain episodes, especially the miracle of the leeks, in a monastic setting; Hill argues that this, combined with Bede's references, supports the idea that Whithorn was the site of an early monastery, especially when considered alongside the archaeological evidence (Hill 1997, 1–4). However, because there are no existing contemporary records describing Whithorn as a monastery, Hill refers to this earliest stage as a *monasterium* (Hill 1997, 30).

The archaeological evidence obtained from the 1984-91 and 1992-1996 excavations of Whithorn has led to conflicting interpretations of the earliest phases of the site, whether it began as a monastery or as an elite Christian settlement. As suggested above, monasteries are primarily identified based on relatively contemporary historical references to their founding, but the recognition of unrecorded monasteries based solely on archaeological evidence has not been conclusive. The presence of the structural remains of a church and supporting buildings, an enclosure or *vallum* surrounding the settlement, monuments from an early sculptural tradition, evidence for the practice of literacy, imports and high status goods, and the remnants of craft-working are typically considered to be monastic indicators (Clarke 2012, 90–95).

From the earliest phase at Whithorn, there is evidence for craft-working, including ferrous and non-ferrous metalworking, high-status trade contacts with Continental Europe and an extensive number of clustered burials from the 5th-7th centuries AD (Hill 1997, 28–40). The excavations identified a series of enclosures relating to different phases of the site; Hill has attributed the earliest ditch to his Phase 1 of Period I, which he dates roughly to the early 6th century AD (1997, 28–30). Between the early 6th century and the early 8th century, Hill proposed that this single ditch enclosure was extended and then surrounded by an additional enclosure, which resulted in two concentric oval enclosures (1997, 30–33). Later investigations into Fey Field, a field to the southwest of the site, could only identify a segment of a rectilinear enclosure, despite the trench intersecting with several of Hill's hypothetical oval boundary projections (McComish & Petts 2008, 6.3, 14.2.1). However, it is pointed out by McComish and Petts that not all monastic settlements have a consistent, substantial vallum

(2008, 14.2.1). After reassessing the burial evidence from the excavations at Whithorn, Adrian Maldonado indicated that many male burials were present in the earliest phase (2011, 204), although only 21 of 118 graves were complete enough to determine the sex of the individual (McComish & Petts 2008, 14.2.2). Several pieces of sculpture from the site's earliest phase of activity exhibit Latin inscriptions (Craig 1992, 4, 203–208), which confirms the nearby presence of at least semi-literate individuals during this early phase, although the epigraphy and the formulae used in the inscription of the Latinus stone may represent a less ecclesiastical and more secular use of the Latin language (Forsyth 2009, 36–37).

While the features listed above are often archaeological indicators of monastic sites when there are no contemporary records of the founding of the monastery, Maldonado argues that there is no diagnostic evidence for Whithorn to be considered a monastery until the late 7th or 8th century, and that the site actually begins as an elite settlement that had been influenced by Christianity as early as the 5th century AD (2011, 206, 220–221).The works of Bede and other historical records indicate that the site was a Northumbrian minster from 730-845 AD (Hill 1997, 40), confirming its ecclesiastical significance during this period. The artefactual evidence recovered from both Hill's and Pollock and Clarke's excavations indicate that a certain amount of craft working was taking place, including evidence for comb manufacture and metal and lead-working (Hill 1997, 138; McComish & Petts 2008, 6.4.6, 6.4.7). Reliable written sources do not discuss Whithorn after this point, although archaeologically there is evidence for a period of burning around 845 AD, followed by the reorganisation of the settlement and the rebuilding of several ecclesiastic buildings (Hill 1997, 48).

By this later phase of activity, from 845-1050 AD, manufacturing became increasingly specialised and focused primarily on the production of antler combs and textiles (Hill 1997, 185–186), with evidence for other types of crafting (Hill 1997, 186–208). The settlement continued to be an important ecclesiastical site, especially evident through its sculptural tradition, and some have argued that Whithorn could have continued as a bishopric (Davies 1998, 9). The vast majority of the sculptural collection from Whithorn dates to around the mid- to late-tenth century and has been dubbed the "Whithorn School" (Hill 1997, 11, 48; Craig 1992, 4, 208–211). Some of the finest examples of these carved stones share features with the Govan collection, including multiple-ringed plait and 'stopped plait' strands (Bailey 1994, 117). Approximately twenty crosses were found at the site of Whithorn (Craig 1992, 4, 212), which suggests that Whithorn was, in addition to the apparent source of a school of sculpture, the focus of a high-status burial ground. Like Govan, this pattern of a sudden appearance of a great deal of sculpture has been interpreted as evidence for an influx of elite patronage for this favoured church (Hill 1997, 52–55).

In summary, Whithorn developed from a possible elite Christian community, into a late 7th or 8th century monastery, to a significant 9th – 10th century mother church, which seems to have created a prominent sculptural school. If Govan and Whithorn shared a similar 9th - 11th century ecclesiastical status, did they develop in a similar way?

2.2.2 Govan – Monastic foundations?

It is unclear if Govan began its ecclesiastical life as a monastery. Some medieval historical sources have indicated that St Constantine founded an abbey at Govan sometime before 576 AD (Radford 1967a, 186; Skene & Skene 1871, 111), although the source has been determined to be unreliable. John of Fordun was writing in the 14th century, and his account of Scotland's origins has been heavily criticised (Broun 2007, 256–257). Recent research has also contested Fordun's identification of the saint as the King of Cornwall, but recent research on who St Constantine might have been will be discussed more thoroughly in Section 3.1.1. As mentioned above, several small-scale excavations have taken place at Govan Old Parish church, but it remains unclear if activity at Govan began in a monastic context. The excavations at Govan have encountered what appears to be an early church of indeterminate size, the *vallum* on the southern and eastern boundaries of the churchyard, and evidence for craftworking, all features that suggest a monastic foundation. One could argue that the presence of a substantial amount of sculpture also supports this interpretation, because the individual designing the carving would have had 'access to current intellectual and ideological networks, manuscripts, metalwork, wooden carvings and possibly pattern books that would serve as a corpus of designs and motifs from which to work' (Gondek 2006, 110). However, the lack of evidence for elite goods and literacy from the site suggests that Govan's development was more complex.

The 1994 excavations identified the drystone foundations of a timber building (Cullen & Driscoll 1995, 25–26); this excavated area was revisited and extended during the 1996 excavations, which resulted in the discovery of two burials beneath the foundations of this structure (Driscoll & Will 1997, 5–12). Due to the presence of burials at the site and the lack of mortar in the composition of the stone foundations, this building has been interpreted as a pre-twelfth century church with an east-west orientation (Cullen & Driscoll 1995, 18–26, 42; Driscoll & Will 1997, 10–12). While the presence of an early church foundation is one of the archaeological features that might identify an un-recorded monastery, the structure clearly post-dates the two 5th – 6th century AD inhumations (Driscoll 2004, 8) and so could feasibly belong to the 9th-11th centuries AD like the sculpture.

Two trenches situated on either side of the existing southern churchyard boundary wall revealed a ditch which appears to have formed the original boundary surrounding this early church (Cullen & Driscoll 1995, 9–15). While no datable material was recovered from the vallum for this earliest phase, a secondary ditch fill provided a calibrated radiocarbon date of AD 886-983 and a hearth adjacent to the bank dated between AD 775-887. While this indicates that the vallum and the associated ecclesiastical institution were in place by the late 8th century AD (Driscoll 2004, 8), this still does not account for the earliest use of the site.

The primary fill of this ditch also produced evidence of shale manufacture, consisting of two worked pieces and one unworked piece of oil shale. A total of eighteen pieces of oil shale were recovered from the 1994 excavations; five of these were worked but none was a finished object (Cullen & Driscoll 1995, 34). Two additional worked pieces of oil shale were recovered from the 1996 excavations, although these were recovered from disturbed contexts in the fill of more recent burials (Driscoll & Will 1997, 5–9, 29). Shale jewellery has been found on both Late Iron Age sites and early medieval ecclesiastical sites (Hunter 2008, 197–202; Maldonado 2011, 115–116). Additional crafting activity appears to have taken place inside the boundary of the churchyard, as there was a small amount of evidence for ironworking in the form of slag, hammerscale, and a furnace-like structure (Cullen & Driscoll 1995, 35). However, it is unclear when this activity was taking place; the largest concentration of the shale manufacturing debris was sealed by the stratigraphic layers containing the aforementioned hearth which produced the AD 775-887 date (Cullen & Driscoll 1995, 34), but we cannot be more specific than this.

While excavations have identified the presence of the foundations of an early church, a vallum surrounding the site, and evidence for craft-working, none of this can be securely dated prior to the late eighth century or associated with the earliest identified activity at the site, the two east-west oriented burials. Govan also lacks several other features that are expected of an early monastery. To date, the site has not produced any imported high-status goods, evidence for literacy in the early medieval period, or an earlier tradition of carved sculpture. This could be due to the limited excavation that can be carried out in the churchyard, but perhaps Govan began as something other than a monastic settlement.

As demonstrated in the previous discussion on Whithorn, even extensive excavations at a relatively undisturbed, known 7th – 8th century monastery does not give a clear picture of its origins. Could Govan have originated as a non-monastic Christian community like Maldonado's interpretation of Whithorn's earliest phase and developed into a monastery or other significant ecclesiastical settlement in the 8th century (2011, 240), or are there other possibilities?

2.2.3 York Minster

Looking further southeast, several sites in York have produced recumbent monuments similar in form and date to those found at Govan. One of these sites, the Cathedral and Metropolitical Church of Saint Peter in York, more commonly referred to as York Minster, was extensively excavated between 1966 and 1973 to facilitate the strengthening of the cathedral's foundation (Atkinson 1985, xv). While the oldest foundations encountered during these investigations were primarily Roman and Norman in date, excavators were under the impression that the pre-Norman church lay nearby, based on the way Hugh the Chanter discussed

Archbishop Thomas of Bayeux's initial reconstruction of the pre-Norman cathedral (Phillips 1985, 4). Derek Phillips suggests that this earlier church may lay just to the north of the present Minster (1985, 1, 4–5); the significant amount of pre-Norman sculpture recovered during these excavations, some in situ (Lang 1995, 433–434), supports the idea that the earlier church is in the vicinity.

The first historical record for a church to St Peter in York comes from Bede, who describes how King Edwin had a wooden church built in York specifically for his own baptism in 627 AD (Colgrave et al. 1991, ii, 14). While we know that York became an archbishopric in 735 AD and that there are records for the presence of an established *monasterium* in York in 741 AD, it is significant that York Minster's importance is primarily and subsequently emphasized as a place of royal burial by various authors and a variety of historical texts, including Bede in his *Historia Ecclesiastica*, in the writings of Alcuin, and from the Northumbrian annals preserved by Simeon of Durham in his *Historia Regum*. There are even records for the burial of kings in this church during the Danish occupation of the city, although only for those who had converted to Christianity (Harrison 1960, 233–241, 244).

While a significant amount of early medieval sculpture was recovered from the excavations, very little occupational evidence could be reliably dated to the 5th-11th centuries AD. In the Roman *basilica*, it was noted that after the Romans left, it had been used briefly as an agricultural building and for some metalworking in the late 4th and early 5th centuries AD. Carver put forward several models which might represent the post-Roman archaeological evidence recovered from the excavations, though his preferred sequence for the site suggests that the site was abandoned from the 6th to 8th centuries AD, followed by the 9th-10th century appropriation of the ruined barracks for industrial activity, including smithing, both ferrous and non-ferrous metalworking, bone working, and possibly jet and shale working. It is during this time that the former *principia* area becomes a high status cemetery (Carver 1995, 193–195). While the pre-Norman church was not encountered in these excavations, it is apparent from the location of the 9th-10th century cemetery that it must have been nearby.

The sculpture recovered during the York Minster excavations indicates that this site had an earlier sculptural tradition dating to the late 7th and early 8th centuries AD, followed by another dating to the early 10th century (Lang 1995, 443). Of the forty-eight pieces of sculpture uncovered during this excavation, the latter portion of the collection shares several attributes with the Govan collection, including the use of median-incised interlace and the presence of recumbent grave-covers and two hogback fragments. Significantly, several of these recumbent cross-slabs were found in-situ over burials, even if they were not necessarily large enough to cover the grave (Lang 1995, 440), which supports the idea that the Govan cross-slabs were most likely designed as grave covers. The 10th century sculpture from York, referred to as the "York Metropolitan School," is often discussed in terms of "mass-production" (Lang 1995, 440), which is understandable when some fragments seem to be identical to other recumbent slabs in design (especially in the case of York Minster 35 and 36) and the dimensions of the slabs are so similar (Lang 1991, 72–73; Lang 1995, 440). These monuments are suggested by Lang to have been produced for a secular elite, while the earlier phase of carved stelae, some with inscriptions, reflects the preferences of a literate, likely ecclesiastical, elite (1995, 443). This analogy with York and its "mass-produced grave covers" made in a brief period of carving has sometimes been applied to the recumbent cross-slabs at Govan (Craig 1994b, 80). One might argue that enough variation exists between these recumbent grave-covers that similarity between monument design might be indicative of other factors, like the social positions of or the relationships between the deceased individuals covered by these monuments, or similar monuments might have been created by the same carver.

2.2.4 Govan's potential ecclesiastical origins

While the early ecclesiastical foundations of York Minster were not encountered in the excavations, we still have a great deal of evidence to compare against the situation at Govan. What is particularly striking is that, despite York Minster's ecclesiastical significance as an archbishopric from the 8th century onwards and the presumed presence of a monastery before this, historical records focus on the church's origin as a 7th century site of royal baptism and its continued role as a site of royal burial. Is it possible, then, that the church at Govan might have been erected in the same way, by a recently converted royal for baptism?

Considering the apparently secular figures that feature prominently on the sarcophagus and crosses of Govan, the connections between Govan and Partick discussed above, and the likely identification of St Constantine as a martyred royal (as discussed later in Section 3.1.1), an earlier tradition of royal burial would not be out of the question. Clearly, as indicated by Adrian Maldonado, distinguishing between 'secular' and 'ecclesiastical' is not necessarily the most useful tactic when they are significantly intertwined (2011, 204).

Of course, all of this is not to say that Govan was never a monastic institution; most of the documentary evidence from Ireland indicates that craftspeople were based at monasteries (Ó Carragáin 2014, 14). However, the exploration of the archaeological evidence from these sites serves to frame our current knowledge of Govan and our current academic expectations of certain site types. By reviewing the evidence from Whithorn, we can see that labelling a site as an early monastery is not an easy process, even if the archaeological markers we would expect are present. And recorded monasteries do not necessarily produce the same archaeological signatures; Lang tells us that, even after the excavations, comparatively fewer pieces of sculpture from this earlier period were found than from the later phase (1995, 433–434, 443–463). The current absence of a previous sculptural tradition at Govan alone should not prevent us from potentially describing Govan as a monastery at some point in its development.

Due to the lack of evidence in terms of historic references and the sparse interpretation that can be gleaned from the archaeological excavations at the site, it is unclear what sort of role Govan played during its earliest phase. While Govan clearly flourishes in the 9th – 11th centuries, it is unclear how it developed. The lack of evidence for literacy, high quality imports, or an early sculptural tradition suggests that Govan did not begin as a monastery. There are similarities between Whithorn and Govan's sculptural traditions during the 9th-11th centuries, and our current knowledge suggests that Whithorn began as a Christian community drawing on Roman ties to legitimise their influence. The similarity in the form of the recumbent monuments found in York Minster in conjunction with the lack of inscriptions associated with the 10th century sculpture might indicate that Govan and York Minster functioned in the same way during this period – as an ecclesiastical centre and the burial place for secular elite patrons. This later tradition for royal burial might reflect Govan's earliest foundations in the same way that York Minster was remembered for its foundation through royal baptism and subsequent royal associations.

3 Govan Stones and their context

The thirty-one stones are currently visible at Govan Old Church include one sarcophagus, two cross-shafts, two upright cross-slabs, five hogbacks, and twenty-one recumbent grave-slabs. The majority of the collection is made up of locally available sandstone with a variety of grain sizes and colours, while some of the recumbent stones are made of fine-grained siltstones (Chadburn 1994, 146). The collection emulates wider sculptural trends that can be seen in Northern Britain during the Viking Age, as identified by Richard Bailey, where a site suddenly retains a significant amount of formulaic sculpture (Bailey 1994, 113). As explained above, the sheer quantity of sculpture is the primary indicator of Govan's status as an important early medieval ecclesiastical centre.

The Govan stones have been recorded using several different numbering systems since the rediscovery of the Govan sarcophagus in 1856. The earliest record of the Govan stones was created by John Stuart in his *Sculptured Stones of Scotland*, although he only numbered and had eleven of the monuments illustrated via lithography. In his numbering system, the two thinnest hogbacks, the two upright cross-slabs, and five of the many recumbent cross-slabs were given numbers. The sarcophagus was not given a number, and the Jordanhill cross was listed separate from the others due to its location in Jordanhill at the time (Stuart 1856, 32, 43, Pl. CI, CXXXIV–CXXXVII). The next and most complete record of the collection was commissioned by John Stirling Maxwell, who had each of the forty-six monuments cast in plaster and photographed. These photographs were numbered, measured, and published with a map of the monuments' locations in the churchyard in 1899 (Stirling Maxwell 1899). The stones were given another numbering system in 1903 by J. Romilly Allen in his corpus of the *Early Christian Monuments of Scotland* (which will be referred to in shorthand as ECMS; (Allen & Anderson 1903)). Allen used and referenced many of Stirling Maxwell's photographs of the stones, although only thirty-eight of Maxwell's forty-six Govan monuments were included in the ECMS.

In the ECMS, some of the monuments were given the same number as that given by Stirling Maxwell, while others were not. The Jordanhill cross-shaft was again listed separately from the other monuments, although its origins from Govan churchyard were noted (Allen & Anderson 1903, vol 2, 459). One additional stone not seen in Stirling Maxwell's corpus was also briefly described (ECMS 24), although it is now missing. It is unclear why the eight monuments included by Stirling Maxwell but were excluded by Allen, and all but one of these were 'misplaced' until recently. From Stirling Maxwell's images, it appears that those that were omitted by Allen because they did not exhibit interlace, although one retained the clear outline of a cross.

Because of the accessible and comprehensive nature of ECMS, this numbering system is usually utilised by researchers. In his description of the monuments, C. A. Ralegh Radford included both labels: the ECMS number first, followed by Stirling Maxwell's in parentheses if it differed from the ECMS (Radford 1967a). The Govan hogbacks were given another set of numbers by James T. Lang in his research on the Scottish hogbacks as a monument type (Lang 1974, 212–214). It should be noted that the Collections provided in the online record for Govan Old via Historic Environment Scotland's Canmore (Canmore ID 44077) uses both the ECMS and Stirling Maxwell numbering systems interchangeably. In *Govan and its Early Medieval Sculpture*, the ECMS labels were primarily used in each paper, although a detailed concordance between the three different numbering systems (Stirling Maxwell, ECMS, and Lang) was provided (Craig 1994a).

This thesis will ensure that all identification numbers are included based on Derek Craig's concordance of the Govan Stones contained in Appendix 2 of the results of the Govan Conference (1994a). One minor correction will be made here, as the No. 28 in ECMS actually corresponds to Stirling Maxwell's No. 28, and ECMS's No. 15 corresponds to Stirling Maxwell's No. 19. In ECMS, the figures were attributed to the incorrect textual descriptions in the corpus, likely because both slabs bear the inscription "TA.EA 1723". However, ECMS No. 28's distinctive interlace (No. 601) makes its misidentification in the text clear. While the ECMS numbering of carved stones in Scotland is usually preferred over Stirling Maxwell's system, in the case of Govan the ECMS system is inferior to Stirling Maxwell's. As described above, several stones (most of which are now missing) were only recorded by Stirling Maxwell, and the Jordanhill Cross was recorded separately from the rest of the collection in ECMS. Stirling Maxwell's photographs have also recently become accessible digitally; since 2008 the *Sculptured Stones in the Kirkyard of Govan* has been digitised by Google and is now freely accessible online (1899). In order to include all of the early medieval stones recorded as originating in Govan Old Church, Stirling Maxwell's numbering system will be primarily utilised throughout this paper, although the ECMS numbers may occasionally be included for easy reference and correlation, especially in cases where previous studies utilised the ECMS referencing system. An illustrated concordance is provided in Appendix A to facilitate this.

In addition to the stones housed within the church, there are further carved stones which exhibit such strong similarities that they can be described as belonging to the same 'school' of carving. This includes the two recumbent monuments found at Dumbarton Castle, five sculpted stones from Inchinnan, and several crosses or cross fragments from the area surrounding Glasgow, namely: the Mountblow cross, the Old Kilpatrick cross-shaft, the Cambusnethan fragment, the Netherton cross, the Barochan cross, the Arthurlie cross, the Capelrig cross, the Stanely cross fragment, two cross fragments from Newton Woods, the Lochwinnoch cross, and two cross fragments from Kilwinning (Macquarrie 2006, 8–18). These are by no means the only stones which might fall under the 'Strathclyde style'; Derek Craig's handlist of stones from the Glasgow area includes a few non-cross specimens, including the Fairlie stone (1994b, 81–91), which appears to exhibit animals very similar to those found on Inchinnan 3 (Allen & Anderson 1903, 2, 475). Later it will be argued that St Blane's on Bute, which was not included in his handlist, should be considered related to the Govan material. These may be referenced in the text when important connections between the Govan collection and stones from the surrounding area highlight certain aspects of their context.

3.1 Govan 1 – The Sarcophagus

Arguably the most famous of the Govan stones, and most likely the earliest at the site, though it has not been previously stated outright (Davies 2010, 3; Forsyth 2008), the sarcophagus (Govan 1) represents a monument type which is otherwise unknown in Scotland prior to the twelfth century AD. The sarcophagus was rediscovered in 1856 (Stuart 1856; Davidson Kelly 1994, 10–11), and was moved into the church in 1908 to the table designed by R. Rowand Anderson, where it sits today (Davidson Kelly 1994, 11). (James Cruickshank Roger reported the loss of two other 'sarcophagi' in the destruction of the church in 1762, though this cannot be corroborated (Spearman 1994, 33)). The form of the monument is not evenly shaped – one end panel is taller and wider than the opposing end, which gives the impression that there is a “head end” (the larger and elevated face) and a “foot end”. The current orientation of the monument has the foot end facing north, towards the communion table. The sarcophagus is decorated on all four sides with a combination of interlace and various figural motifs. On both the head and foot of the sarcophagus there is a panel of interlace delineated from the plain, dressed stone by an incised rectangle. The ‘west’ side, currently facing away from the wall of the church, is decorated with two panels of interlace alternating with a hunting scene which features a mounted figure pursuing a deer with what is probably a dog, and a scene of a beast with an interlaced tail, its body decorated with an incised line combined with diagonal key pattern (Allen & Anderson 1903, 2, p. 462), crushing another beast and a snake. Just behind and above the rider and to the left of the triumphant beast are boundaries of step pattern which delineate these panels from the panel of interlace between them (Figure 3.1). The east side of the sarcophagus is also segmented into four panels, from left to right, with a panel of interlace interspersed with what appear to be snake’s heads, a panel of four beasts with each of their tails interlaced above their backs, possibly incorporating their ears. The two beasts on the top are upright, while the two on the bottom are inverted. Next is another panel of interlace, although this one is bounded by an undecorated band on three sides. The fourth and final panel depicts two beasts with crossed necks. The tail of the beast on the left appears to be interlaced with the ear of the beast on the right, and the tail of the beast on the right is interlaced with the tongue of the beast on the left (Figure 3.2).

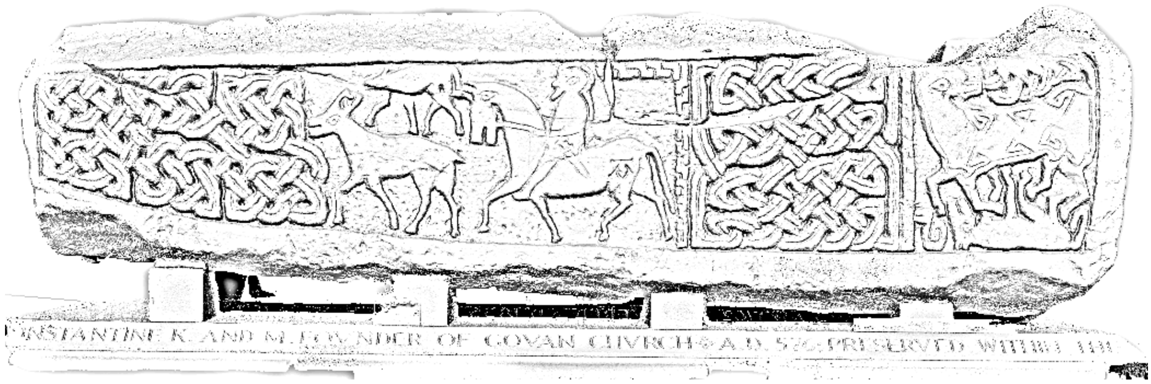


Figure 3.1. West face of the sarcophagus depicting the riding scene.

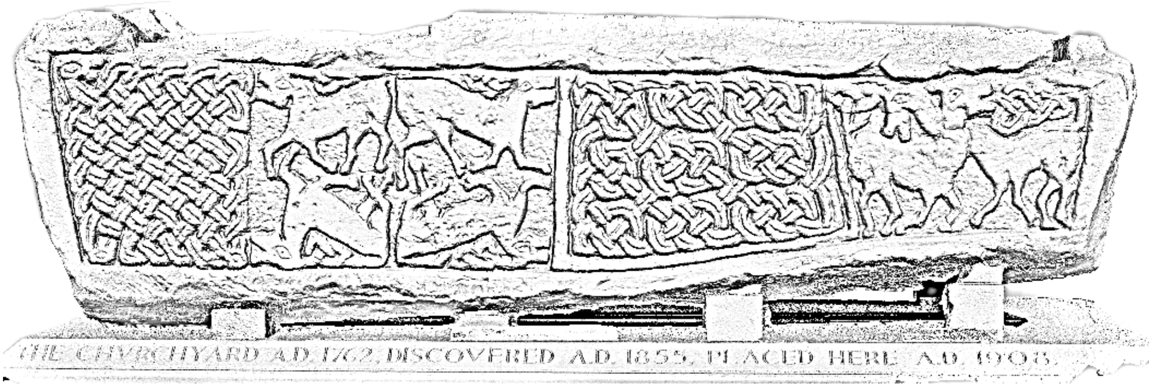


Figure 3.2. East face of the sarcophagus depicting different arrangements of beasts.

In an attempt to determine the source of inspiration for the sarcophagus, it has been compared to a variety of monuments, including composite corner-post slab-built shrines, like that which was found on St Ninian’s Isle, Shetland, solid recumbent shrines, and monolithic Classical sarcophagi most often found in Continental contexts (Spearman 1994, 38–39; Thomas 1994, 25). Sarcophagi crafted in a similar manner to Govan’s dating to the Roman occupation of Britain have been found and are relatively common regionally; in the gardens surrounding the Yorkshire Museum, a number have been used in the landscaping as either garden features or as planting beds (Figure 3.3). The Govan sarcophagus would have been covered with a lid, although it is uncertain what form this would have taken. Several other monuments within the Govan school of carving have been proposed as potential sarcophagus lids, including a recumbent slab with angle-knobs from nearby Inchinnan (Spearman 1994, 39), although this monument in particular has been argued to merely be imitating the corner-post shrines and probably did not act as a lid (Bailey 1994, 114). Another monolithic sarcophagus from Derby, known as St Alkmund’s sarcophagus, dates to the 9th century and is the closest parallel we have to the Govan sarcophagus. St Alkmund’s sarcophagus retains a fragment of its flat lid (Davies 2010, 7–8). It is likely that the Govan sarcophagus originally contained human remains due to its size and the presence of an apparent drainage hole in the base of the monument.

Figure 3.3. Several Roman sarcophagi reused as flower beds in the York Museum Gardens.

Today, there are two complete holes in the base of the monument, though one is much larger, towards the foot end of the monument, and more funnel-shaped than the other. The larger of the holes, described as a drainage hole, is a common feature in coffins dating after this period, as can be seen in the photo of the 13th century stone coffins exposed at St Andrew's Cathedral (Figure 3.4). The smaller hole of the Govan sarcophagus is closer to the head-end of the monument and is accompanied by an even smaller, incomplete 'hole'. MacGregor Chalmers' drawings, which he began in 1883 and completed sometime toward the end of 1885 (Spearman 1994, 43–45; MacGregor Chalmers 1902, 1–2), depict only the largest of the holes and his description only mentions the one. In his book he described the interior of the sarcophagus in detail, again reiterated the presence of one drainage hole, and specifically cited that "The tool marks show that this opening was cut when the Sarcophagus was made," (MacGregor Chalmers 1902, 11), and John Stuart had only described the presence of one hole shortly after its discovery (Stuart 1856, 43). It then seems likely that the two smaller 'holes' (one hole, one incomplete) were added sometime after 1883. This leads to the question then, when were these additional attempts at holes created, and why?

Figure 3.4. Stone Coffins dating to the 13th Century located at St. Andrews Cathedral. Two drainage holes are visible; these are located towards the centre or foot-end of the coffins.

After MacGregor Chalmers's drawings were complete, J. Romilly Allen visited Govan churchyard in 1891. Although the graveyard had fallen into disrepair by the 1880s, including the "monument house" protecting the sarcophagus and several hogbacks, Allen reported that it had been much improved by the time of his visit (Davidson Kelly 1994, 12–13; Allen 1903, 395). Allen mentions the presence of a single hole in ECMS (Allen & Anderson 1903, 2, 462), although this might be based on his earlier observations. The sarcophagus was brought into the church in 1908 and placed on its current display table (Davidson Kelly 1994, 13). It seems unlikely that the holes would have been carved into the stone after it was brought into the church, especially considering the level of concern for the preservation of the carved stones left outside, recorded in subsequent Kirk Sessions (Davidson Kelly 1994, 14). These two holes should then have been added sometime between 1892 and 1908, unless MacGregor Chalmers and Stuart had dismissed their presence out of hand as later additions due to their odd placement in comparison to later stone coffins (MacGregor Chalmers 1902, 11), but this seems unlikely. It is also possible that the sarcophagus was not very clean when he was making his drawings, so these smaller holes might have been packed with soil at the time (Frazer Capie, pers comm). Finally, it could be that these were added to aid in drainage of the sarcophagus, especially if the “monument house” was so damp that the other stones had begun to suffer for it (Davidson Kelly 1994, 14). Unfortunately the interior of the cast created by Henry Laing in 1856 (Spearman 1994, 34) does not appear to be a record of the actual surface; the interior is much wider and brush strokes are prominently recorded in the plaster (Adrián Maldonado Ramírez, pers comm).

While the larger hole was likely originally carved to allow for drainage of the body it contained, it is also possible that the sarcophagus held the bones of a king or relics relating to St Constantine (Ritchie 1999, 8–9; Davies 2010, 13–15). The hole in the base of the monument could have allowed for the creation of secondary relics, by allowing oil or some other substance to come into contact with the relics and to pass through to be collected in a container below (Thurlkill 2016, 104; Yasin 2009, 165–167). The creation and distribution of secondary relics (and sometimes even tertiary relics) became a significant aspect of early Christian belief, especially as it related to pilgrimage, throughout the Christian world with the introduction of saint’s cults. In Ireland, the translation of corporeal remains to reliquaries seems to become particularly popular in the eighth and ninth centuries, and again in the eleventh and twelfth centuries (Ó Carragáin 2010, 67). Reliquaries across Europe and the Middle East containing saint’s relics were designed to allow access to the relics so that portable items or substances could come into contact with the remains and become “spiritually enhanced” (Thurlkill 2016, 104). Even relatively small, fifth-century churches in Syria have been found to have one or more of these small, sarcophagus- or stele-shaped reliquaries capable of dispensing holy oil blessed through contact with the saint’s relics (Yasin 2009, 167–170). Gregory of Tours seems to have commented on the production of secondary relics at the Vatican at the tomb of St Peter, where one could lower a piece of cloth into the tomb through a hole at the top. He claimed that if one's faith was strong enough, the cloth would weigh more after it emerged, as it had been "soaked with divine power" (Van Dam 2004, 24).

Secondary relics were also desirable in the British Isles, as Bede attests in his *Ecclesiastical history of the English people*. Although he provides a multitude of examples of secondary relics and their miraculous capabilities (Colgrave et al. 1991, iii.2, iii.9, 11), his description of St Chad's wooden coffin, which was carved in the shape of a small house, allowed access to the saint's remains through "an aperture" in the side of the coffin. Visitors were permitted to take dust through this hole, which, when combined with water, held healing powers (Colgrave et al. 1991, iv.3). The continued significance of saints and their relics in Britain throughout the early medieval period provide a context in which the sarcophagus could have been instrumental in the ritual production of secondary or tertiary relics for pilgrims and others visiting the site. If Bede is to be believed, this could have taken the form of water or even soil that had come into contact with the remains.

Comparisons can be made between the Govan sarcophagus and St Alkmund's sarcophagus. St Alkmund's sarcophagus is located in Derby and has been attributed to the early ninth-century (Davies 2010, 7). As mentioned above, unlike the Govan sarcophagus, St Alkmund's sarcophagus retains a fragmented corner of its decorated, flat lid. Additional differences arise when one compares the construction of the two monuments: while they are both carved from a single block of stone, the Govan sarcophagus also features a draining hole and chamfered rim. R. M. Spearman (1994, 38) has suggested that the finish of the chamfered rim could indicate that the sarcophagus was topped by a pitched lid, which would have resulted in a shape similar to the house reliquary shrine. If this was indeed the case, this would have resulted in a different shape than that which can be inferred from St Alkmund's flat-topped lid fragment. Although both monuments were likely used to house the remains of a king or a saint's relics, the basic structure of each differed. In addition, while both monuments are decorated on all sides and were likely meant to be seen above ground, the decoration covering St Alkmund's sarcophagus does not incorporate figural scenes or animals like those prevalent on the Govan sarcophagus, only non-median-incised interlace. While the creators of each sarcophagi were likely drawing on similar inspiration from Continental examples which led to the choice of creating the monument from one slab of stone, their local traditions were the deciding factor in the ultimate designs of their respective sarcophagi. Intriguingly, St Alkmund's sarcophagus does not exhibit a drainage hole; as indicated above, there could have been other means of creating secondary relics without the presence of a drainage hole, like lowering a piece of fabric through a hole in the lid, but, without the entire lid, we lack the evidence to confirm this was the case here. The lack of a drainage hole in St Alkmund's sarcophagus makes the presence of two in the base of the Govan even more intriguing.

By framing the Govan sarcophagus in this ritual context, it becomes clear that it could have been designed first as a coffin for the body of a royal saint, and then acted a receptacle for the saint's relics. These holes could have been involved in the production of secondary relics for pilgrims (Davies 2010). On the off-chance that the holes omitted by Stuart and MacGregor Chalmers date to the early medieval period, this shift in function might be reflected in the presence of two holes that go through the bottom of the container instead of only one (although these additions would not be necessary to this change in function, the single drainage hole would have been enough to be used in this way). While the larger of the holes is situated where one might expect in a stone sarcophagus, the second is nearer the head-end. The areas immediately surrounding these holes demonstrate enough wear that the surface has lost its pecked quality, visible in the three-dimensional model. It is possible that this wear was caused by the desiccation of the original occupant, but the erosion could have also been accelerated if the creation of secondary relics involved the repeated drainage of oil, water or soil after coming into contact with the relics.

3.1.1 Saint Constantine

Govan's association with Saint Constantine has long been discussed in academia, especially over which "Constantine" is meant to have been commemorated by or contained within the sarcophagus. Constantine could refer to Emperor Constantine the Great, the first Christian Roman emperor, whose feast day falls quite close to that of St Constantine's in Govan (Woolf 2007, 9–10). Another option could be Constantine, the son of King Rhydderch Hael as told by Jocelin of Furness in the late 12th century, but this is an assertion generally thought to have little merit by most scholars due to the specific political gain this would have afforded Glasgow Cathedral, for whom Jocelin produced the text (Macquarrie 1994, 31; Woolf 2007, 9). Finally, it has been noted that several candidates lie within the early Scottish kings of the Dalriadic dynasty, and those thereafter who sought to connect themselves with the Dalriadic lineage (Macquarrie 1994, 31–32).

Another possible identification for the Govan St Constantine comes from Kilchousland in Kintyre, where he was martyred, who shares the same feast day with St Constantine at Govan. It has been argued that this St Constantine's relics left Kintyre and were brought to Govan to escape inland from the Vikings around the late ninth century. This would neatly coincide with the beginning of the sculptural tradition in Govan (Radford 1967a, 186–188; Macquarrie 1994, 31; Woolf 2007, 11–12). However, there do not appear to be many shared characteristics or stylistic similarities between the sculpture of Kintyre and that which is so prevalent in Govan. If this is the correct identification for Govan's St Constantine, the transferral of these relics may have acted as the impetus for the development of the Govan school of carving.

John Davies (2010, 10) has suggested that the St Constantine referred to in Govan's dedication might share similar attributes with St Alkmund, who falls under the category of "martyred royal saints." This type of saint was particularly common in Northumbria and Mercia from the early seventh century through the late tenth century (Rollason 1982). Davies argued that the focus of this saint's cult in Govan was most likely Constantine I, son of Cinead mac Ailpín (Kenneth mac Alpin), because of his identification as "King Constantine the Martyr" in the 'Dunkeld Litany' by Thomas Clancy (2002, 420). Considering the lack of ecclesiastical figural sculpture in the Govan collection (apart from one extant panel on Govan 10) and the apparent preference for depictions of elite horsemen, regardless of which historical figure it is based on, it is likely that St Constantine's royal associations were emphasised.

3.2 Govan's Crosses and Upright Cross-slabs

Govan's collection of early medieval sculpture also includes what have been previously described as two cross shafts and two upright cross-slabs. These are numbered as Govan 7, 8, 9 and 10 (ECMS Jordanhill, ECMS Govan 4, ECMS 5 and ECMS 29 respectively). Govan 7 and 10 have been described as cross-shafts largely because they are (or were) decorated on all four faces. Govan 8 and 9 have typically been referred to as 'upright cross-slabs' because they are only decorated on the two broader faces; the other two faces are left largely untreated. Neither of the cross shafts retain their cross heads, and Govan 10 has been largely effaced except for two panels of interlace on the uppermost segment of the monument on opposing faces (although Govan 10 is currently displayed upside-down so that these appear to be decorating the base of the monument), and the panels on the narrow edges of the monument, which still survive.

Despite Govan 10's poor condition, it can still be identified that Govan 7 and Govan 10 share certain pattern types – both exhibit variants of key pattern (Allen & Anderson 1903, 1, 308), plaits, free-ring interlace (Cramp 1984b, xxxi) and Stafford knots (Allen & Anderson 1903, 1, 148). Plain rectangular boundaries between interlace panels were consistently utilized in the carving of the edges of Govan 10; while they were only occasionally employed in the decoration of Govan 7. Both crosses also depict figural images, though Govan 7's is a mounted horseman, while Govan 10's appears to be an ecclesiastic scene; it has been interpreted as Samuel anointing David in apparent reference to the joining of the Church and State (Fisher 1994, 49–50; Macquarrie 2006, 7).

Govan 9 is significantly plainer than the other monuments in the collection. On one face is the carved remnants of an undecorated cross-shaft with a plain incised border, but with no discernible terminus at the bottom. The opposite carved face only shows part of a rider on a horse or donkey, both with strangely curved feet. The rider was more intact when it was illustrated for John Stuart's volume on Scottish sculpture (1856, Pl. CXXXVI). Govan 8 is also decorated with a cross, though it is decorated with a series of plaits and flanked on either side by two twists in the shape of snakes. Below this cross is another horseman, whose horse exhibits curved feet similar to those on the horse from Govan 9. On the opposite face, the top portion of Govan 8 is decorated with a sort of snake boss – three of the snake heads face one direction, while the snake closest to the top of the stone faces the opposite way; altogether these snakes form a rough swastika arrangement. Beneath this feature is an irregular angular plait. Govan 8 still retains a tenon on top, and Stuart's aforementioned illustration suggests that Govan 9 once had the same feature.

It is likely that these monuments would have been situated in areas of the landscape surrounding the church that were visible as one approached or left the sacred space (Macquarrie 1997). Unless socket stones for the individual crosses and cross-slabs are found in future excavations, such as those examples from the Iona school and the decorated socket stones known from Ireland, including Clonmacnoise (Fisher 2005), it is unlikely that we will ever be able to identify where these monuments originally stood.

3.3 Govan's Hogbacks

After his reassessment of monuments previously classified as 'hogback monuments', Jamie Barnes has estimated that there are approximately 147 confirmed hogbacks recorded from the British Isles (2019). Five hogback monuments are present at Govan Old. Four of the five are the heaviest and largest of the known hogbacks, and they are also the largest single collection of hogback monuments in Scotland (Ritchie 2004, 1). The smallest of the Govan hogbacks, Govan 2, is unique in that it displays horizontal bands of interlace along its base. Lang (1994, 125–126) has argued that the 'stopped plait' treatment reveals Anglo-Scandinavian connections and suggests that the design of Govan 2 might have been subject to Cumbrian influences. Others have pointed out that stopped plait and the filler pellets present in Govan 2's interlace are also popular in Galloway (Bailey 1994, 118–119). Other designs, such as the swastika pattern on one end of this monument, indicate that the monument is closely related to other monuments within the Govan School, including the Barochan and Cambusnethan crosses (Macquarrie 2006, 23). Govan 6 is uncharacteristically concave on one end and so appears to have been damaged, while both Govan 3 and 4 have each been redesigned at some point to appear more like one beast (Lang 1994, 127). Govan 5 still retains its severely worn end beasts, although the central portion of the ridge of the monument has been worn severely into a distinctive bowl-shaped recess. While some have argued that this appears to have been used as a hone for a scythe (Lang 1994, 129; Ritchie 1999, 18), others have suggested that a turning stone or bullaun stone, stones which rest in a depression and are physically turned as a prayer is said, sometimes as part of a pilgrimage, could have created similar wear (David 2013, 19–20). It is possible that Allen witnessed one of the stones being treated in this manner, although he had a rather negative view of the practice and did not mention which stone had received the treatment (Allen 1897, 148).

All except Govan 2 and Govan 4 show evidence for a carved, concave base of the monument, to varying depths; this difference appears to be noted by John Stuart shortly after their discovery when he states that these two hogbacks have "marks…which would lead to the supposition that they fitted into other stones (Stuart 1856, 43)." Anna Ritchie suggests that the hollowing out of Govan 3, 5 and 6 was likely done early in the process, before the sculptor began to work (Ritchie 1999, 18). While this could have been done to decrease the weight of the stone just after the slab was first quarried, the most massive of the five hogbacks, Govan 5, has a minimal amount of stone removed from its base in comparison to Govan 3 and 6. Therefore, it seems unlikely that this was done simply to reduce the monuments' weight. Stephen Driscoll has suggested that this was done to increase the stability of the monuments (pers comm), although this raises the question as to how the thinner hogbacks stayed upright and in place without this feature.

Hogbacks are conventionally viewed as a 'Viking colonial monument' (Crawford 1994, 103) due to a combination of factors: the vast majority of the hogback stones are located near waterways and areas where place-name evidence suggest the presence of Scandinavian influence during this period (Lang 1974, 209; Crawford 1994, 104). However, there are no precursors to this monument type in pre-Christian Scandinavia and no hogbacks have been found on the Isle of Man, even though a clearly significant tenth-century Scandinavian influence and associated sculptural tradition was present there (Crawford 1994, 103; Williams 2015, 250–252), though this might have more to do with the type of stone that was available for carving (Stephen Driscoll, pers comm). While hogback monuments are traditionally thought to represent tenth-century longhouses from southern Scandinavia (Schmidt 1973, 76), others have pointed out that the house-shape is not unique to this monument type during the early medieval period; the house-shape is also adopted by metal early Christian reliquaries and the caps of some early Irish crosses (Williams 2015, 253), although these usually portray straight-ridged buildings as opposed to the curved ridges of the hogbacks. It has been proposed that these house-shaped monuments do not necessarily indicate Scandinavian influence, but instead derive from an Early Christian tradition. Similar forms of the tegulated decoration prominent on these hogbacks can be found in several illuminated texts depicting the temple at Jerusalem (Whitworth 2016). As research into hogbacks continues, it is becoming increasingly clear that these monuments are critically important to our understanding the 10th-11th centuries (Barnes 2019).

3.4 Govan's Recumbent Cross-slabs

The largest proportion of the collection of early medieval sculpture in Govan consists of recumbent graveslabs. This monument type is regionally distinct to Strathclyde, and about 75% of the stones of this type belong to the Govan collection (Driscoll et al. 2005, 143). While these appear quite similar, they do vary from one to the next in terms of decoration, size, and overall shape. The recumbent cross-slabs in particular offer themselves well to building various typologies.

Typologies are a type of classification defined by certain attributes to form discrete groups or categories to address a specific research question (Adams & Adams 1991, 47–48; Hurcombe 2007, 55). Typological classification has its roots in evolutionary thinking and has become a long-standing traditional approach in archaeology (Lucas 2001, 75). Its use as an explanatory framework has changed alongside archaeological theory, from defining a cultural group by a certain widespread artefact form by culture-historians (Lucas 2001, 82–85), to the present day approach, which acknowledges that these typologies are arbitrary classification tools designed by the archaeologist to better understand how some objects relate to other objects, though the differences we identify may have held little significance to the people who used and interacted with the objects (Lucas 2001, 96). As such, a typology cannot be measured by how 'correct' it is, but rather how well it answers a research question and its consistency in its description of each type (Adams & Adams 1991, 4–8).

Prior to this thesis, two typologies have been developed for the recumbent cross-slabs at Govan. Allen and Anderson were the first to begin categorizing the Govan stones based on certain stylistic attributes. They began by grouping the stones based on the overall shape of the monument. This resulted in the sarcophagus, hogbacks, and cross-shafts belonging to their own respective groups. The recumbent slabs were classified according to their overall shape, which resulted in three groupings. The slabs Govan 11 (ECMS 9) and Govan 24 (ECMS 6; Figure 3.5) formed their own classification because both had rounded ends. The second, and the group of recumbent slabs that tends to receive the most attention, is characterized by the presence of circular knobs at each corner of the rounded border of the stone (Figure 3.6). Finally, Allen and Anderson lumped the rest of the recumbent stones into a group described as “ordinary,” and “nearly rectangular in shape” (1903a, 2, 467; Figure 3.7). While grouping by shape has led to a solid foundation for a typology for this monument type, further significant subdivisions can be made within these groups.

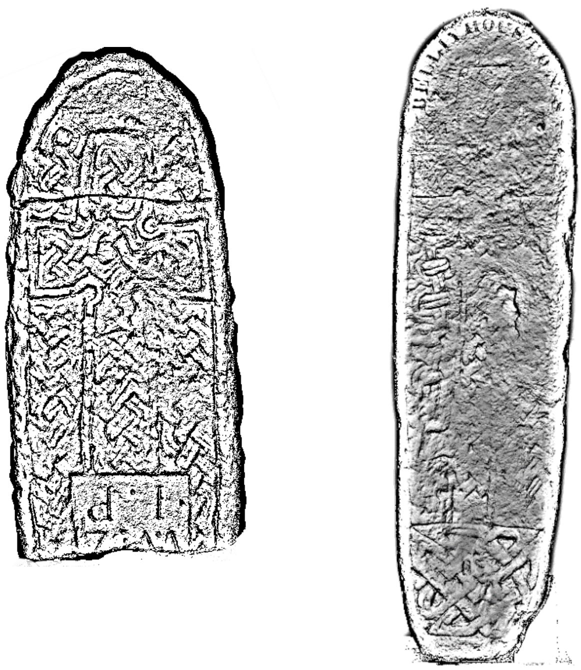


Figure 3.5. Allen and Anderson's Rounded End Recumbent Cross-slab Group (not to scale; Allen et al. 1903a, 2, p. 465): (left) Govan 11, (right) Govan 24.

Figure 3.6. Allen and Anderson's Angle-Knob Recumbent Cross-slab Group (not to scale; Allen et al. 1903a, 2, p. 466): (from left to right) Govan 12, Govan 17, Govan 18, Govan 23, Govan 25, and Govan 35 (misplaced).

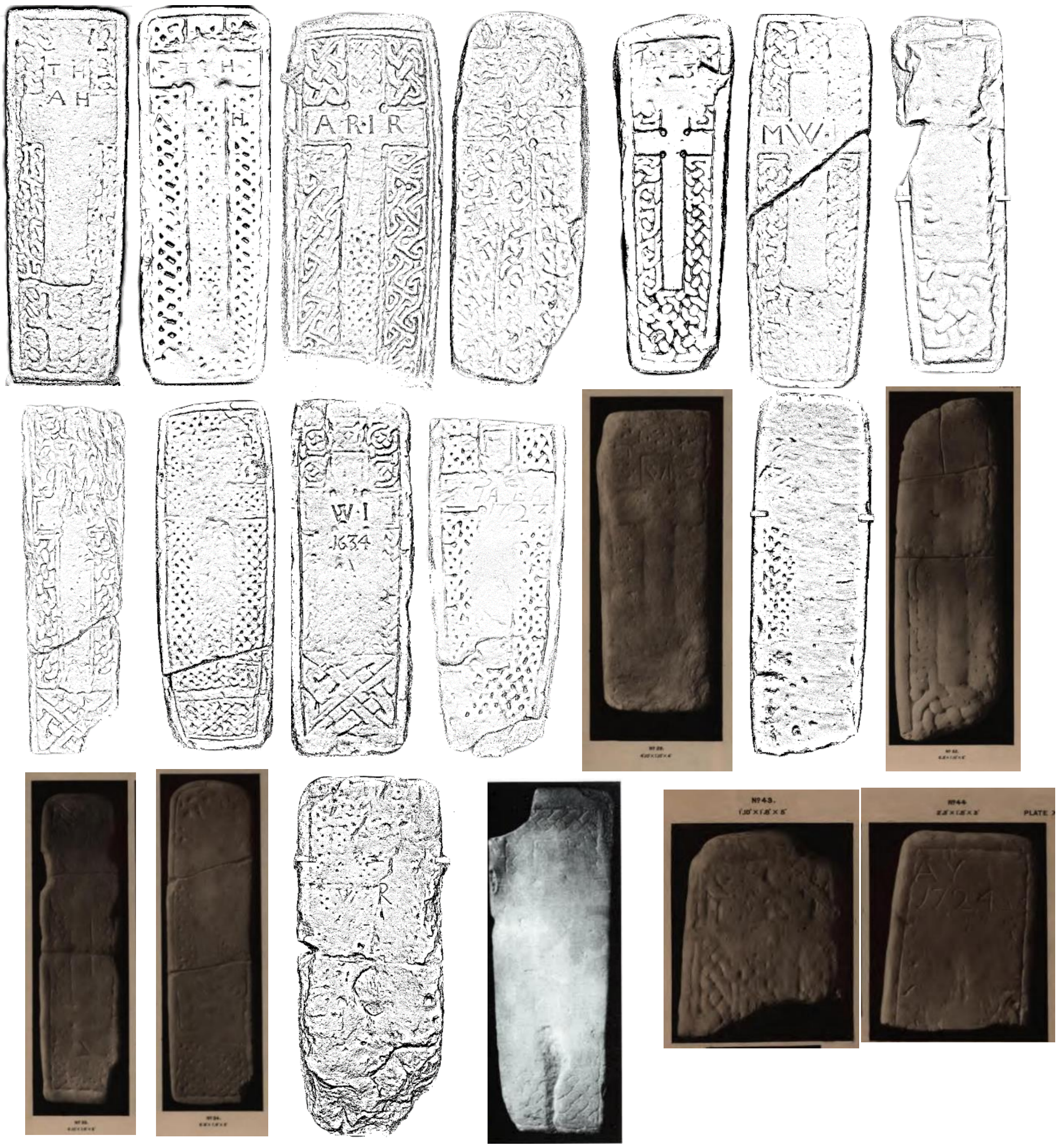


Figure 3.7. Allen and Anderson's Nearly Rectangular Recumbent Cross-slab Group (not to scale; Allen et al. 1903a, 2, p. 467); Top (left to right): Govan 13, Govan 14, Govan 15, Govan 16, Govan 17, Govan 20, Govan 21; Middle (left to right): Govan 22, Govan 26, Govan 27, Govan 28, Govan 29 ('missing', (Stirling Maxwell 1899, pl. XX), Govan 31, Govan 32 ('missing', Stirling Maxwell 1899, pl. XXI); Bottom (left to right): Govan 33 ('missing', Stirling Maxwell 1899, pl. XXII), Govan 34 ('missing', Stirling Maxwell 1899, pl. XXII), Govan 36, Govan 40 ('missing', Stirling Maxwell 1899, pl. XXV), Govan 43 ('missing', Stirling Maxwell 1899, pl. XXVII), Govan 44 ('missing', Stirling Maxwell 1899, pl. XXVII).

Rosemary Cramp (1994, 56) has provided the most detailed treatment of the recumbent slabs as a group by demonstrating that these monuments have more distinguishing qualities than the presence or absence of angle-knobs (Thomas 1994, 25; Bailey 1994, 114). She divided the recumbent monuments into three groups based on several characteristics: those which display angle-knobs and are decorated with interlaced panels containing free-ring interlace surrounding plain crosses (Group A); those which have crosses that are decorated with interlace, whose crossheads reach the top of the frame, and are surrounded by panels of interlace (Group B); and those plain slabs which appear to be narrower with chamfered edges, which she designated as dating from the 11th century (Group C; Cramp 1994, 56).

In Group A she includes Govan 12, 17, 18, and tentatively Govan 25 (ECMS numbers 13, 35, 7, and 23 respectively). Others which she cited as sharing characteristics with Group A included Govan 19, 20, 22, and 27 (ECMS numbers 15, 8, 27, and 17 respectively), although these lack angle-knobs and contain different variants of interlace (Figure 3.8). She also indicates that this group was carved with a ‘grooved technique,’ which she defines as the creation of ornament using a point to “peck the outline from the surface” (Cramp 1994, 56).

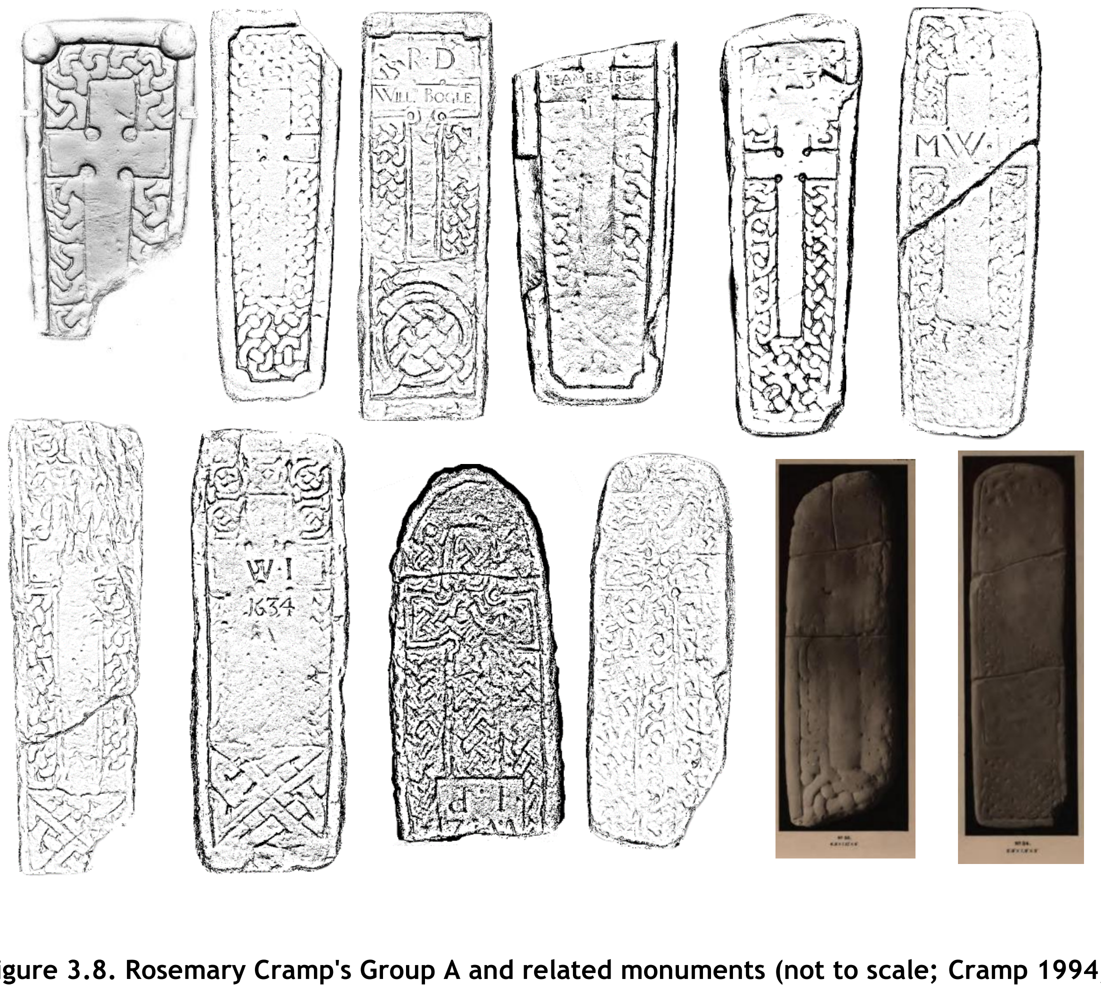


Figure 3.8. Rosemary Cramp's Group A and related monuments (not to scale; Cramp 1994, 56); Top (left from right): Govan 12, Govan 17, Govan 18, Govan 25, Govan 19, and Govan 20. Bottom (left from right): Govan 22, Govan 27, and possible Group A members Govan 11, Govan 16, Govan 32 (missing, Stirling Maxwell 1899, pl. XXI), and Govan 34 (missing, Stirling Maxwell 1899, pl. XXII).

The characteristics of Cramp’s Group B are defined primarily by Govan 14 and 26 (ECMS 32 and 21), although she states that Govan 15, 16, and 28 (ECMS 34, 14, and 28 respectively) should also be included (Figure 3.9). This group is characterised by interlace-decorated crosses which extend upwards to the edge of the plain border, effectively dividing the upper portion into two separate panels of interlace. She also describes the carving technique in Group B as deeper than the ‘grooved technique’ of Group A because of the use of both a chisel and a point. Group B provides more evidence for a planned approach to the ornamentation, as grid points are still visible. Cramp suggests that, although there is decoration covering their crosses, Govan 11 and 16 (ECMS 9 and 14) are decorated with interlace more closely related to that of Group A (Cramp 1994, 56). Her Group C consisted of “several which are so worn as to be incapable of linking with any other category” and “narrower plain covers with bevelled edges” (1994, 56).

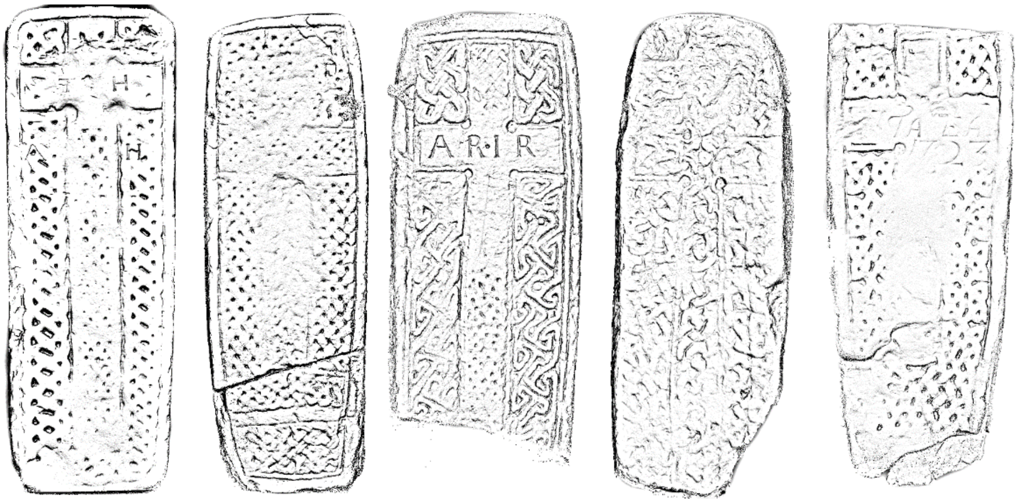


Figure 3.9. Rosemary Cramp's Group B (not to scale; Cramp 1994, 56): (left to right) Govan 14, Govan 26, Govan 15, Govan 16 (also could be in Group A), Govan 28.

Cramp cites several areas of Scotland as possible sources of inspiration for the Govan carvers, but argues that Group B would have been influenced by upright slabs from eastern Scotland and would have pre-dated Group A, whose free-ring decoration and grooved interlace appears to have been affected by 10^{th} century Anglo-Scandinavian influences. Cramp further suggests that the plain slabs in Group C (Govan 42, 44 and 46, of which the latter two are now missing) would not date earlier than the eleventh century (Cramp 1994, 56–59). A summary of Cramp’s groups are tabulated in Table 3.1 below.

Table 3.1. A Summary of Rosemary Cramp's Govan Recumbent Monument Typology.

Group A		Group B		Group C		Stones not included in Rosemary Cramp's analysis	
Characteristics	**Stones**	**Characteristics**	**Stones**	**Characteristics**	**Stones**	**Stones**	
▪Angle Knobs	12	▪Interlace decorated crosses	14	▪Plain slabs	42	13	35*
▪Interlaced Panels with free-ring interlace	17	▪Crosses reach top of frame	15	▪Bevelled edges	44*	21	37*
▪Plain crosses	18	▪ Use of chisel and point, Deeper than grooved technique	16	▪Date to 11th century?	46*	23	38*
▪'Grooved technique': Pecked outline from the surface	25	▪Grid points visible	26			24	39*
	19		28			31	40*
	20		32*			36	41*
	22		34*			29*	43*
	27					30*	45*
	11†					33*	
	16†						

All stone numbers given refer to Stirling Maxwell's numbering system
†Rosemary Cramp indicated that, while these stones have interlace covering the crosses, the interlace used is more closely related to Group A
*Stone now missing, although recorded by Stirling Maxwell

A more comprehensive critique of Rosemary Cramp's recumbent cross-slab typology is given in Section 8.1, but it can be summarised as follows. There are primarily three weaknesses that can be identified in her assessment. First, only a select number of the recumbent monuments were considered in her typology; at least two of the excluded slabs were largely intact and pictured, but not directly classified. Secondly, several stones had been 'misplaced' since the destruction of the adjacent shipyard in the 1970s were included in her typology, apparently based on their images from Stirling Maxwell's publication. After the newly rediscovered slabs have been recovered and conserved, their placement in Cramp's typology can be reassessed. Finally, and most importantly, the worn and damaged nature of the cross-slabs were not fully considered before they were classified.

While the vast majority of Govan-centred research only began with C. A. Ralegh Radford in 1967 and flourished within the past fifteen years, there has been a longer tradition of general interest and recording of the stones. The following section will highlight these phases, describe the nature of the records and how these have influenced our knowledge of the stones today.

3.5 Records of the Govan Stones

Since the 18th century, early medieval monuments have been recorded using many different techniques, including rubbings and lithographs. Rubbings were commonly used as reference material for the artist to produce a representation of the monument. In the early 19th century, some antiquarians questioned the accuracy of these illustrations. Images from the early 18th century had shifted from an empirical, science-based tradition to the romanticised view of antiquities (Piggott 1978, 44). In 1814, John Pinkerton stated that Mr. Cordiner's "representatives cannot be trusted, his imagination being strangely perverted by some fantastic ideas of the picturesque, while those of Mr. Gordon are too rude and inaccurate (Chalmers 1848, x; Henderson 1993, thirteen; Ritchie 1998, 9)". Patrick Chalmers of Aldbar had lamented that it was difficult to convince an artist that accuracy was more important than creating a beautiful work of art (Chalmers 1848, v). While Chalmers had focused on creating an accurate record of the Early Christian monuments of Angus, John Stuart widened his scope and aimed to record the sculptured stones of Scotland. He had initially employed the same artist and lithographer who had illustrated Chalmers' publication, but P. A. Jaztresbski was 'removed' to Australia and was subsequently replaced by A. Gibb (Ritchie 1998, 11–12). Gibb had apparently found Jaztresbski's work lacking in detail, and it was decided that Gibb would redo many of the figures his predecessor had completed. There is clearly a sense of frustration with the accuracy of visual records during this period. It was Gibb who John Stuart would then commission for creating the lithographs in his *Sculptured Stones of Scotland,* and who was the first to illustrate the Govan Stones (Stuart 1856, xvi).

At the turn of the 20th century, photography was advocated as the ideal technique by which Early Christian monuments should be recorded. However, it was quickly realised that photography was not infallible, nor the "absolute truthfulness" for which many were hoping, especially in cases where the decoration was weathered or obscured by vegetation. Photographs do provide an accurate record of the contemporary condition of the sculptured stone (Ritchie 1998, 20). Despite earlier scrutiny of the accuracy of these records, drawings and lithographs isolate the decoration and present the artist's interpretation of the monument. In addition, some of the earliest records can convey what some stones looked like before stones were broken, weathered, or were lost entirely

(Ritchie 1998, 2, 7). Both means of recording can provide valuable information about the early medieval monuments of Scotland.

As mentioned above, the first illustrations of the Govan Stones were done by A. Gibb in John Stuart's 1856 *The Sculptured Stones of Scotland*. Interest in this group of stones was piqued by the discovery of the sarcophagus in December 1855 (Stuart 1856, 43). He had eleven of the stones illustrated, including all four sides of the sarcophagus (Govan 1), two hogbacks (Govan 2 and 4), both carved faces of the Sun Stone and Cuddy Stane (Govan 8 and 9), a selection of recumbent gravestones (Govan 24, 18, 20, 11 and what appears to be Govan 30, which was recently rediscovered), and the Jordanhill Cross, which he recognised as having come from the churchyard at Govan. Stuart does not state how many sculptured stones were identified at that time, although he acknowledges that the stones he depicted are only a sample of a larger collection. As stated above, A. Gibb was striving for accuracy when illustrating these monuments for John Stuart, as a comparison of his compositions to the extant stones will demonstrate. While the images are not necessarily an exact representation of the monuments, we are fortunate to have these images as they record the completeness of these stones in 1856. Without these sketches we would not know what the lower fragment of Govan 11 (ECMS 9) looked like, as it was lost sometime between 1856 and 1899 (Figure 3.10).

Figure 3.10. Illustration of Govan 11 before lower half was lost (Stuart 1856, pl. CXXXVII).

P. MacGregor Chalmers also strove for accuracy by using rubbings and measurements of the sarcophagus to inform his detailed drawings of the Govan sarcophagus in 1883, which had taken "nearly a year's patient labour on my part, undertaken for my own private study, and carried on in the early mornings before breakfast (MacGregor Chalmers 1898).” This claim was made after a Mr. John Honeyman published the drawings in “The Regality Club” and did not attribute the drawings to Mr. MacGregor Chalmers, although MacGregor Chalmers had indicated that his drawings would be used in the publication in a “Letter to the Editor” of the *Glasgow Herald* in five years earlier (MacGregor Chalmers 1893). MacGregor Chalmers’s drawings not only capture the decoration of the sarcophagus, but they also record the presence of the drain-hole and the areas of damage to the rim of the sarcophagus (Spearman 1994, 35).

After, Sir John Stirling Maxwell funded a comprehensive photographic catalogue of the ancient Govan stones, a collection which totalled forty-six at the time. These photographs were taken by T. & R. Annan & Son in 1899 (Allen 1897, 148; Stirling Maxwell 1899; Driscoll et al. 2005, 137; Driscoll 2016, 76). J. Romilly Allen described the process by which the stones were recorded: first, moulds and plaster casts were created of each of the stones by Robert Foster of Stirling (Foster 2015, 74), then it was the casts that were photographed (Allen 1897, 148). In this privately published book, of which there were only seventy-five copies made, he provided a map of the stones’ locations in the churchyard at the time and measurements and photographs of each of the stones. He states in the note at the beginning of the catalogue that these plates were “printed in order to preserve their designs, and to bring them within the reach of students (Stirling Maxwell 1899).”

While the excellent black-and-white photographs provide a detailed record of the stones and their decoration, including the only images we have today of fifteen stones which were thought to have been missing, there are several ways it could have been improved. Most of the photographs are not to scale; while sets of photographs of a single stone, like the four carved sides of the sarcophagus, appear to be scaled in relation to each other, separate stones are not scaled in relation to each other. This disparity becomes blatantly apparent when comparing Stirling Maxwell’s measurements of the recumbent cross-slabs, especially between Plates XIII and XIV. It is unclear why this was done, as the plates are inconsistent in size and shape even on opposite sides of the same page, and so it does not seem to be due to a printing requirement. Finally, Stirling Maxwell offers no interpretation or even a textual description of the collection; while he meets his stated objective of recording the patterns present on the stones and making them accessible to antiquarians, he does not provide much else in the way of historical or ecclesiastical context.

Whatever his intent, we are lucky to have these photographs, because they provide the only images for fifteen of the stones that had been misplaced, seven of which were not described by Allen and Anderson in 1903. Allen mentions one that was not recorded by Stuart or Stirling Maxwell which apparently had ‘plain raised borders and angle knobs’ (Craig 1994a, 151) and ‘the figure of an angel at one end of the slab’ (Allen et al. 1903, 2, pp. 465–466; ECMS 24), although he did not provide an illustration of this stone. In fact, many of the photographs published by Stirling Maxwell were used to illustrate the Govan section in *The Early Christian Monuments of Scotland* (Allen & Anderson 1903, vol 2, 459-460, 462-471). Unlike Stirling Maxwell, Allen provides a great deal of detail in his description of most of the carved stones at Govan. However, it is clear that Allen’s primary purpose behind recording the Govan monuments was to firmly affix it in its national context through comparisons between monument form and especially ornamental motifs. In his quest to fit Govan into the national narrative, he generalised these patterns to fit his ornament typologies. It will be argued later that this approach, while a solid foundation for characterising these ornamental patterns, oversimplifies the construction of these motifs and loses the vision and voice of the early medieval sculptors who designed them.

Allen lauded the efforts undertaken to record the Govan stones using casts and photography; as mentioned above, all of the images included in Allen’s section on Govan came from Stirling Maxwell’s publication. Allen firmly believed that the other sculptured monuments of Scotland should receive the same treatment because it brought out the carved patterns better than photography of the stone itself. Without the production of a cast, details could easily be lost in photographs with any stone discolouration, without proper lighting, or through the interference of lichen (Allen 1897, 148; Allen 1903). The production of casts allowed for perfect lighting to be applied in the Annan studio. Unfortunately, the process of creating casts was far too time consuming for this to be applied to Allen’s vision to become reality. In echo of his sentiment, it is argued here that each monument would benefit from being recorded with three-dimensional imaging. Without the potentially destructive process of traditional cast-making, three-dimensional imaging captures the structure of the surface much in the same way, and the distracting colour of the stone can be removed. The nature of sculptured stone lends itself well to these imaging techniques and should be utilised for the benefit of researchers and the general public alike.

The casts of the Govan collection were donated to Glasgow Museums in 1903, but the vast majority have not survived (Batey 1994, 71). At the start of this project, it was hoped that casts of some of now missing stones could have been recorded in 3D to incorporate them into this research. However, after contacting Sally Foster and Glasgow Museums, it was determined that the seven casts that remain only correlate to extant monuments (Foster 2015, 90–91). Though many of the 'misplaced' Govan stones might yet be recovered, extant casts for other missing stones could be recorded in 3D to retrieve as much information as possible.

It was after the work of Allen and Stirling Maxwell that T.C.F. Brotchie published *The History of Govan*. He highlighted the primary sources relating to the earliest mentions of Govan and collates extant illustrations of Govan, including a depiction of Doomster Hill (1905, 6–16); however, the colourful language used to describe the pre-Christian inhabitants reflects an outdated perspective. The illustrations focus primarily on the sarcophagus, but two photographs of the hogbacks and recumbent cross-slabs lined up against the churchyard wall by W. Milne are included; several of the recumbent cross-slabs can be identified as those that were 'misplaced' (1905, 4–5).

While Allen focused on describing the ornamentation at Govan, Radford made clear connections between features shared by the carved stones at Govan with other pieces of sculpture to contextualise the collection (Radford 1967a) and made the first real attempt to identify Govan's place in the ecclesiastical landscape of Strathclyde (Radford 1967b). His interpretation of the site remained undisputed until the next watershed moment for research at Govan: the 1992 conference initiated by the minister of Govan Old at the time, Tom A Davidson Kelly. The papers from this conference were collated in the 1994 volume *Govan and its Early Medieval Sculpture*, which can now be described as the fundamental text on Govan.

Today, the type of photography recommended by archaeologists and art historians for recording sculpted stone is black-and-white with details enhanced by raking light, produced either by sunlight or artificial light (Gray 1997, 6). Raking light is lighting which illuminates the surface of the stone at an angle of somewhere between 5 to 15 degrees, or even less if the carved surface is high-relief (Gray 1997, 7). Tom E. Gray, who has produced many descriptive photographs of early medieval sculpted stones in Scotland. Gray's excellent photographs provide the basic visual record for the Govan Stones, which were published in *Govan and its Early Medieval Sculpture* and are available on Canmore. While this technique produces a highly detailed record, it is not ideal for use in photogrammetry, for reasons that will be explained below in the Methodology chapter.

Each of these different approaches to illustration is still used today; each has its own benefits and drawbacks. Raking-light photographs highlight the carved surfaces of the stone in one instantaneous image, although these can vary in quality and on occasion a cast-shadow will obscure some carved detail. Hand-drawn illustrations can capture any details the illustrator observes, although researchers are reliant on the illustrator's interpretation of the presence or absence of worn carved sections. Three-dimensional imaging has recently become more accessible and is useful in understanding the carved surface. In fact, John Borland has used both laser scanning and raking light as aids in his recent illustrations of the Govan stones. Three-dimensional imaging comes with its own benefits and drawbacks, which will be discussed more thoroughly in Section 5.1.

4 Three-Dimensional Imaging in Archaeology

Three-dimensional imaging has become embedded in various aspects of archaeology, whether it is used to record the provenience of features and artefacts encountered during excavation (Doneus & Neubauer 2005), recording the condition of fragile artefacts just after they are excavated (Chapman et al. 2013, 21–25) or as a sophisticated curation tool for museums that can provide access to the artefacts, even when they are not on display (Chapman et al. 2013, 17–21; Mantegna 2015). These techniques are often implemented in outreach and community engagement projects as well, as data capture for techniques like photogrammetry and RTI are relatively easy to learn in a short period of time (Glasgow School of Art 2016; Inchinnan Historical Interest Group 2018; Foster et al. 2018).

Those who study early medieval sculpture have also found that three-dimensional imaging has many benefits, including the ability to monitor changes in the surface of the stone (caused by weathering or other destructive factors), to create two-dimensional images of sculpture for publication without struggling with lighting conditions, to increase accessibility to the stone, and to allow for the creation of full replicas of the sculpture without touching the stone (Carty 2005, 373–374; Maxwell 2005, 171–172). The production of replicas could protect the stones by allowing the stone to be brought inside and placing a representation of the stone to remain in its original position in the landscape; this allows the monument’s community to retain its connection to the past while still protecting the monument (Foster 2005, 7–8). However, consideration must be given to the distance to which the monument is removed from its original community, as this has a large effect on whether the replica is assigned a comparable level of social value or whether it is the source of a great deal of tension between the community and heritage officials (Jones 2006).Three-dimensional images also allow the user to experience the sculpture in a way that allows one to “walk around” the stone (Jeffrey 1998; Jeffrey 2005, 354). Although two-dimensional drawings can be incredibly accurate, the re-examination of stones can yield new information, especially areas with worn surfaces (Borland 2005, 202–203).

An aim of this project is to lay the groundwork for a digital corpus of early medieval stones in Scotland with an archive of three-dimensional images, like the one advocated for in *Able Minds and Practised Hands* (Higgitt 2005). Some digital collections of early medieval sculpture have already been created, a particularly good example being the Ogham in 3D project, which has created over 150 three-dimensional models of ogham stones from Ireland (Dublin Institute for Advanced Studies: School of Celtic Studies 2017). As the collection at Govan was once at the forefront of technology at the turn of the 20th century and inspired J. Romilly Allen to advocate for the photography of Scotland's early Christian sculptured monuments, it is hoped that this project will again set the standard for the recording of the carved stones in Scotland.

While three-dimensional imaging has many practical benefits for the purposes of curation, image publication, and public outreach, it is argued here that these models have the potential to answer research questions that might have been considered laborious or untenable, or that might have caused damage to the stone under study, until the present. The following section will discuss how a variety of digital imaging techniques have been used in archaeological research and how these might be useful to those who study early medieval sculpture.

4.1 Digital Imaging as a Research Tool

The use of digital imaging techniques as a research tool has recently become more accessible to the academic community, although some of these techniques already have a relatively long history within the discipline. The approaches and technologies adopted vary widely based on the scale and focus of the research; these different levels of research engagement can be divided into landscape-level visualisations, site-level visualisations, and object-level visualisations. The following section will indicate which technological approaches are most commonly used at each level and provide examples of how each level of archaeological investigation is utilising these digital techniques for research, how these techniques have been implemented in the study of early medieval sculpture in the UK, and what applications will be further explored in this thesis.

Landscape visualisations often use LIDAR data, drone based images and satellite imagery to create Digital Elevation Models to aid in the identification of sites, analyse viewsheds and better understand how past peoples experienced their landscape (Silver 2016, 26–29). Some types of landscapes are inaccessible to pedestrian survey, like in the case of Montserrat, where a portion of the island cannot be easily accessed due to volcanic activity; in these situations, LiDAR can be instrumental in identifying archaeological features that would otherwise be difficult to locate during a pedestrian survey due to difficult terrain and dense understory growth (Opitz et al. 2015, 11). By importing digital elevation models into GIS software, archaeologists can calculate viewsheds, the visibility of other features of the surrounding landscape from a given point on the model (Van Leusen 1993; Eve 2014, 55–69). For a slightly less computational and a more phenomenological experience of the landscape, Stuart Eve has argued for the introduction of augmented reality, through which one can digitise features (like a series of prehistoric houses) and place them in the landscape (Eve 2014, 85–103). With the increasing availability of declassified military satellite imagery (CORONA) and other open access sources of satellite imagery, satellite images have been incredibly useful in identifying previously unknown archaeological features. With the use of the multispectral imaging, Sarah Parcak and other researchers have been able to detect a significant number of previously unidentified sites remotely (Parcak 2009, 147–172). Digital imaging techniques have clearly contributed a great deal to landscape researchers in archaeology.

On a site-level visualisation, digital imaging techniques have begun to offer a new perspective on the excavated remains. Some sites have begun to use photogrammetry as a means of recording each context so that different stages of an excavation can be recreated digitally (Opitz 2015, 73–76; Opitz et al. 2017). This can be done through terrestrial laser scanning, drone-based aerial photogrammetry, terrestrial photogrammetry, or three-dimensional modelling based off of recorded GPS points; these digital visualisations can aid in better understanding the three-dimensional relationships between stratigraphic contexts, the spatial distribution of finds at the site, and reconstructions of structures or features based on the results of excavation (Poller et al. 2017; Opitz 2015; Ask 2012). Features uncovered during excavation can be given new visual meaning through the digital reconstruction of the missing above-ground components based on the archaeologist’s interpretation (Ask 2012; Poller et al. 2017). While the transition towards incorporating these digital imaging practices in the field for most projects has been slow due to the significant expenditure required to implement these approaches and store the resultant data, its benefits to the later interpretation of the site are apparent.

Digital imaging techniques used to capture objects will vary depending on the size and material of the object, but often laser scanning, structured light scanning, photogrammetry, multispectral photography, and reflectance transformation imaging (RTI) can be used to address different research questions. Recently, Structure-from-Motion (SfM) photogrammetry has become popular for capturing three-dimensional data of artefacts. Research applications vary depending on the object, but recent studies have addressed the calculation of the original volume of artefacts that have been damaged or have degraded over time, like weights meant to be used with scales so that units of measurement can be identified (Thibaud 2015), or the study of microwear analysis on flint artefacts (Halbrucker et al. 2017). Patay-Horváth has used both 3D and VR to reinterpret the arrangement of sculpture on the East Pediment in the Temple of Zeus (2015). Other photography-based approaches, including the use of filters and multispectral imaging, have been useful in the study of the manufacture of beads, objects that are typically not suitable for photogrammetry due to their reflective and often translucent nature (Christie 2019). Overall, the use of different types of digital imaging in artefactual studies is quickly becoming more common.

While not technically a three-dimensional imaging technique, Polynomial Texture Mapping, the basis for Reflectance Transformation Imaging, was developed by Hewlett-Packard Laboratories in 2001. This digital imaging technique was first presented at the Special Interest Group on Graphics and Interactive Techniques (SIGGRAPH) Conference demonstrated its applicability in viewing archaeological artefacts specifically, including a 4000-year-old neo-Sumerian tablet and a 3000-year-old Egyptian funerary statuette (Malzbender et al. 2001, 6–7). Since then, RTI's capability to analyse the surface of an object has been recognised, and the technique has been used in a variety of projects, frequently to study surface wear on artefacts and to identify areas of worn lettering or decoration, frequently on stone (Molina Sánchez 2014; Jones et al. 2015; York Archaeological Trust n.d.). While the manual approach to RTI is often only applied to objects or several small sections of a monument (largely due to the limited control one can have over the lighting of anything larger than this, and the necessity of a black reflective ball large enough to record the various lighting positions), some researchers have developed a way to create RTI files digitally (Eve 2012; Zelinsky 2018). RTI can then be applied to nearly any type of object for which a three-dimensional model has been created. While not technically a three-dimensional imaging technique, RTI is a valuable research tool, especially in the study of worn and carved surfaces.

Since the start of this project, the value of 3D recording and its potential for research have been recognised (ScARF 2016, 3.3), but there are relatively few instances where digital imaging approaches have been clearly applied to the study of early medieval sculpture for the express purpose of research. Tom Goskar has used three-dimensional imaging to clarify inscriptions and carvings on monuments of varying date, including the early medieval monument known as the Ignioc Stone (2018, 180–181). Andy Hickie has recently been experimenting with RTI and photogrammetry in the production of different visualisations to highlight stone carving from different periods and disseminating the results via the Avoch Community Archaeology Facebook page (2015). Kate Colbert, who at the time of writing is a PhD student at the University College Cork, has been using digital imaging techniques to analyse the multiple lives of the early medieval sculpture of southeast Ireland (2017). Comparisons between several panels have been made using laser scan data from the ‘Cross of the Scriptures’ from Clonmacnois and the ‘Cross of Durrow’ from the St Columba monastery, both in Co. Offaly (Daubos & Ó Cróinín 2009; Stalley 2014); this will be considered in more detail below. The two pieces of sculpture from Neston, Cheshire, were laser scanned in order to determine whether the pieces could feasibly fit together or not (White 2013). Laila Kitzler Åhfeldt, whose work will be discussed in more detail below, is the most prolific researcher using three-dimensional imaging techniques to study Swedish runestones and their carvers (1998; 2000; 2001; 2002a; 2002b; 2009c; 2010; 2012a; 2012b; 2013; 2015). It is argued here that digital imaging techniques have a great deal to offer the study of early medieval sculpture, especially when attempting to identify individual sculptors.

4.2 Pursuing the Identification of Individual Sculptors and 3D Perspectives

In the study of early medieval sculpture, groups of stones with similar characteristics in terms of their style or decorative motifs are identified as belonging to the same “school,” or “workshop,” the meaning of which varies depending on the author. While there is little documentation from the early medieval period to determine the way in which carvers may or may not have been organised, there are records for workshops commissioned to complete high-status tombs of varying materials in London in the fourteenth century (Badham 2010, 14). It is unlikely that workshops outside of large cities would have functioned in the same way, so these records have limited value to the present study. There are also earlier historical references to the work of sculptural masters and their students as early as the 5th Century B.C. in Greece (Pausanias 1918, 5. 10. 8), although the attribution of identity of the Master sculptor at the temple of Zeus of Olympia to Pheidias and his students Paionios and Alkammenes has been hotly debated in classical art historical circles (Dörig 1987; Holloway 2000; Patay-Horváth & Christiansen 2017, 494). There are historical documents from a mid-eighth century AD Irish context that establish that craftspeople were often organised into workshops (O’Meadhra 1987, 99–107; MacLean 1995, 126–130), and these sources suggest that most of these were stationary and likely based at monasteries (Ó Carragáin 2014, 6, 12–13). However, it was not common practice to record the name the masters of these workshops before the 11th century in these Irish historical documents, and only the inscriptions from the Kinnitty Cross and the Cross of the Scriptures from Clonmaconois have identified a specific person, in this case Colmán, as the ‘artificer’ (MacLean 1995, 141). With very little historical evidence to suggest how the early medieval carvers might have been taught and organised, art historians and archaeologists often rely on a combination of stylistic and occasionally geological analyses to identify regional similarities, which are then defined as ‘workshops’. Whether this term is used out of convenience to describe a stylistic similarity or with the implication that there was an organised team of carvers, there is clearly a historical precedent for workshops or schools in the British Isles during the early medieval period.

On very few occasions does the archaeologist or art historian venture to suggest that specific portions of a particular early medieval stone sculpture have been worked on by separate individuals (Lang 1976, 75–6; Lang 1978, 146; Lang 1983, 186–7). In some cases, idiosyncrasies in design in the style of figural sculpture will be cited as evidence for a single “master”. James Lang and Richard Bailey have argued that several pieces of sculpture found at Gosforth were likely carved by a single person, the Gosforth Master. They cite the shared features of the “chin/beard of the egg-shaped head sink below the line of the shoulders” found on the front-facing figures on the Gosforth cross, the Saint’s tomb, and the Fishing Stone (Bailey & Lang 1975, 291–2). Lang and Bailey also point out the presence of what they term a “fleshy plait” with strands that terminate in a curl on the same three pieces of sculpture (1975, 292) and a shared theme of contrasting Scandinavian and Christian iconography. While this analysis did well to emphasize these similarities, they need not necessarily be classified as the work of one person. This could also be the result of a team of sculptors, each working closely on one aspect of the carving; one working on the figures, one working on the plaits, etcetera. MacLean has identified the potential for such a hierarchy in the Irish law tracts (1995, 135–138), so it is not outside the realm of possibility.

Gwenda Adcock has suggested the identification of a master who appears to have been inspired by St Oswald’s cross in their creation of the Durham grave cover, two more pieces of sculpture from Durham, one from Hart, one from Hexham, one from Gainford, and possibly one from Billingham (Adcock 1974, 329). In addition to utilising the six interlace designs and an animal pattern from St Oswald’s cross in these related pieces, Adcock describes the nature of the carving of this interlace. She describes the master’s work in terms of the size, shape and smoothness of the carving technique, and gives some consideration to the type of tool that appears to have been used (Adcock 1974, 329). This method of distinguishing carved sections by referring to the overall profile shape is now used as a supporting characteristic in the distinction of different categories of sculpture (Cramp 1994, 56), although most do not go so far as to argue that this similarity in form is indicative of individual sculptors.

In some cases, three-dimensional data of monuments have been used to argue for the identification of a single sculptor's work. Some, like Daubos and Ó Cróinín, and subsequently Stalley (2014, 141–142), apply a more subjective approach in identifying a 'master's work'; in their article, Daubos and Ó Cróinín use the 3D data to clarify several panels from two different crosses and argue that the rare scenes in some of these panels appear to have been executed in reference to the same pattern book. In this case, the 3D data was primarily used for a clearer 2D picture, but it is unclear from the article if any more direct comparison was done. In classical sculpture, a technique called '3D Digital Form Comparison Method' was developed to determine which of the three Amazon statues was more likely to have been sculpted by Polykleitos; Pliny states that Polykleitos had used one model for much of his work, so the 3D shapes of different anatomical features were compared to identify where the same model was used (Sengoku-Haga et al. 2015). Because the stones at Govan have experienced varying stages of wear, it would be more difficult to identify individual approaches to carving simply through the shape of the carved sections.

Laila Kitzler Åhfeldt has used a combination of laser scanning and multivariate statistics to tentatively identify carvers of Swedish runestones based on the microtopographies of the grooves which form the runes or decoration (Freij 1990; Kitzler 2000; Kitzler Åhfeldt 2002a; 2002b; 2009a; 2010; 2012a; 2013). The underlying assumption is based in psychological and neurophysiological research that suggests craftspeople develop their own individual motor performance when working with their respective materials (Kitzler Åhfeldt 2002b, 8–9). The technique requires sub-millimetre measurements, which necessitates the production of a high-resolution three-dimensional model. This approach offers a more objective and measurable method to attribute certain areas of carving to different people. This analysis is based on the concept that, while the thematic content, design, and inscription of a runestone is a conscious manipulation that can be controlled by those in authority, there is an unintentional component in the execution of the carving that can lead to the identification of individual sculptors (Kitzler Åhfeldt 2002b).

Because most of the runestones in Kitzler Åhfeldt's studies are outdoors, samples were taken with casts for small, unweathered segments of carving ranging in length from 50-150 mm. These casts were then laser scanned to compare the profiles against each other to determine if individual carvers could be identified. In order to provide a control group to test the validity of the analysis, two modern rune carvers, one who worked with assistants and one who carved alone, donated several specimens of their own work to demonstrate the variance that can occur in a single carver's work (Kitzler Åhfeldt 2002b, 27).

The results from Laila Kitzler Åhfeldt's research indicate that by taking several variables relating to the cross-section of the groove and the direction in which the decoration was cut, one can begin to identify individual carvers (2002a; 2002b). However, through this work it was revealed that other factors can cause variation in an individual sculptor's work. As the sculptor gains more experience, as the decoration increases in difficulty, if the stone changes position (vertical/horizontal), or as the sculptor fatigues, an individual's cut may deviate from his or her usual pattern (Kitzler Åhfeldt 2002a; Kitzler Åhfeldt 2002b). It is also likely that the type of stone used in carving would affect the results (Kitzler Åhfeldt 2012a).

If this analytical technique can be applied to the Govan stones, it could help to identify individual sculptors, which in turn could allow for the construction of a relative chronology of the monuments. This approach could also elucidate features of individual stones; in the case of Govan 2, the pattern of interlace changes several times across the bottom of the monument. On this stone, it appears as though sculptors with different visions or different levels of expertise were working on opposite ends of the monument.

Kitzler Åhfeldt believes that "runographers are easier to identify as individuals, but at the same time they are more mobile, whereas artists are more locally recruited" (Kitzler Åhfeldt 2012a, 96). Because the runestones she and her team sampled were from a wide-ranging area of Sweden, it is possible that the Govan stones present a unique opportunity in which a large collection from a single locality and relatively narrow timeframe can be analysed to identify individual artists. This project also offers the opportunity to compare results from the profile analysis between stones which display a variable amount of wear.

Three-dimensional imaging also has the capability to explore the methods of design, for instance, whether templates were used (Kitzler Åhfeldt 2002b; Kitzler Åhfeldt 2009a; Kitzler Åhfeldt 2013). When discussing templates, there is an important distinction to make between templates and motif pieces. Uaininn O'Meadhra defines a motif-piece as "a small portable raw piece, or scrap, of any material…or waste fragment of a disused artefact, with carved or incised, discrete, positive, patterns comprising art motifs, sporadically positioned over its surface (1987, 11)." These would have been used to practice or work out designs for other artefacts, and often seem to have been discarded. This generalised term includes artefacts such as models and model books, trial pieces, and sketches. These objects could have many functions; they could act as a record of a pattern that an artist might wish to transport to another location, as teaching aids for young craftsmen in training, or as a way for an artist to practice the intricacies of the decoration.

Templates, on the other hand, are objects which were more formal and could be used in design work repeatedly. The use of a template would have been a direct means of transmitting decorative concepts across distance or time. Templates, in the context of this research, will be defined as 1:1 scale images of a motif created from a malleable material (like leather or cloth) which will allow for its use as a stencil to guide the carving of a motif on stone. There is at least one possible example for a lead template for interlace from Monkwearmouth, though it may have been a glass and lead ornament instead (Adcock 1974, 39). The possibility of template-use at Govan has been suggested in the reproduction of the "deer" motif in several panels of the sarcophagus (Craig 1994b, 79). Although horsemen appear on four different stones in the collection, it has been stated that it is unlikely that the horseman motifs were carved using a template due to their obvious differences; the horse found on the "Sun Stone" (Govan 8) has even been likened to "a monkey running on its hands (Craig 1994b, 79)." These possibilities and their implications will be discussed further in Chapter 7.

In her exploration of the Gotland stones, Kitzler Åhfeldt (2009a, 501) argued that in order to demonstrate that two carvings shared the same template, at the very least the outline of the figural carving and the points at which the legs and arms start and cross on the figure should match. However, certain portions of the motif may have been altered due to the nature of the stone, weathering, or human error. Richard N. Bailey (1980, 246–254) has provided evidence for the use of templates on stone sculpture in Northumbria. He compared rubbings taken of the two birds from the surface of the Brompton cross-shaft: these appear to have an almost-identical outline, apart from the feet. He also compared the two Middleton warriors: these motifs are located on two separate fragments of sculpture, were equipped with different weapons, but largely appear to be the same figure, although with a longer torso in one example. He cites a similar stretching or shortening of a template evident in the comparison of the stag motifs found at Sockburn and Brompton (Bailey 1980, 243, 247–8; Lang 2001 Illustration 41). If this altering of a template was widespread practice, either to fit a motif to the stone surface that might be smaller or larger than the template itself, the outline might not match at exactly the same points. However, one might expect the outline to match at least in a piecemeal fashion.

Depending on what sort of material the template was made of, repeated use could also result in deviations from the original. While some have suggested that the sharing of a template would indicate that the two monuments were carved within a generation of each other by either the same travelling sculptor or by a sculptor from the same workshop (Bailey 1980, 249–253), others insist a pattern book could remain in use for several generations as long as the book was passed on through the school or between itinerant sculptors (Kitzler Åhfeldt 2009a, 499). It is also possible for an individual to create a template from the original stone carving hundreds or thousands of years on, simply by tracing or creating a rubbing of the figure or motif onto cloth. This clearly creates complications in the ability of evidence for templates to indicate where a stone belongs in relation to another chronologically. However, an analysis of template use might help us better understand different stages of the carving process, which will be discussed in more detail below.

This discussion also raises the question of why a template would be used for a seemingly simple motif, as Bailey points out in the case of the Brompton birds (1980, 246). Most of those who have explored the potential for template use have suggested that the sculptor might have been less experienced, especially in Kitzler Åhfeldt's analysis of the D-stone category of the Gotland picture stones, where the mathematical principles were not followed when applying interlace (Kitzler Åhfeldt 2015, 420). Others have argued that they might have been used to ensure an exact replica, especially in the case of mirror imaging (Lang 2001, 33). It could be that the use of a template was used as a signature for the school or sculptor it belonged to, or it could be that the direct comparison between two panels or pieces of sculpture had significance to the meaning behind the motif. If the images produced through the use of these templates were similar enough in final design, it could be that the sculptors were ensuring that this direct reference would be identified and would allow for easier identification of the figure with little intervention from knowledgeable persons. The use of templates might also serve a more practical function in the planning phase of the sculpture to ensure that the individual components would be ideally situated in the space allocated. The possibilities for template use and their implications are explored for the horsemen of the Govan collection and the “beasts” of the Govan sarcophagus more thoroughly in the Chapter 7.

4.3 Conclusions

Digital imaging techniques, while frequently used only for conservation or outreach for early medieval sculpture, have the potential to produce highly-accurate representations of the sculpture and can aid in many facets of research. This thesis will demonstrate that these digital resources can offer new insight into misinterpreted carved patterns and worn sections of carving. High-resolution, scaled, three-dimensional models allow for a variety of metric analyses that would be too time consuming to be feasible without the assistance of computers. Laila Kitzler Åhfeldt’s Groove Analysis approach (with some alterations to better fit the different carving style) will be applied to the Govan collection to attempt to determine how many carvers worked on each stone. Scaled sections of the three-dimensional models containing animals or horsemen will be compared to determine whether these could have been carved with the aid of templates. By having an idea of how many individuals had a hand in carving these stones, whether they were organised as a school or workshop (or not), and how they approached their subject, we can refine the relative chronology of the stones, better understand the carving process and gain some insight into the meaning behind these stones. While only one from Inchinnan is included in this portion of the analysis, it is hoped that this research will be the foundation for further studies into how the carvers interacted with other ‘Govan School’ sites. The next chapter will discuss the benefits and disadvantages of the various digital imaging techniques that were available to the researcher, why photogrammetry and Reflectance Transformation Imaging were chosen for this project, and how these were used in pattern reconstruction, in the search of template-use, and in Groove Analysis.

5 Methodology

In the previous chapter, the inclusion of three-dimensional imaging in archaeological contexts was discussed in general terms. Here, the different imaging techniques that were considered at the start of the PhD will be described in detail, contrasting each of their drawbacks and benefits. This will be followed by the specific workflows utilised by the chosen imaging techniques. Then, the methodology behind the three analyses utilised in the following chapters, specifically Pattern Recovery, Template-use identification, and Groove Analysis, will all be discussed, focusing on each step and the technical details within the software. The chapter will conclude with information on where the data produced for this project will be archived and how it will be made accessible.

5.1 Imaging Techniques

There are now many techniques through which digital heritage researchers can create three-dimensional models, although many approaches are suited to imaging objects of different scales and materials. For example, Aerial LIDAR (Light Detection and Ranging) is restricted to imaging areas at a landscape-scale (Parcak 2009, 76–78; Bennett 2014), rather than individual stone monuments. Many digital imaging techniques were suited to image stone monuments, but were rejected for other reasons; some techniques, like Coordinate Measuring Machines (Luigi et al. 2001; Jeffrey 2003, 102–104), were excluded due to their reliance on contact with the surface of the object to create the model. In some respects, casts are the “original” approach to creating three-dimensional records of artefacts, but the creation of casts poses a threat to the surface of early medieval sculpture, which can be fragile (Maxwell 2005, 171; Reinhard 2015, 31–33). Other technically advanced methods are too expensive or not suited to this sort of material. For instance, the use of computed tomography (CT) scanning, so successful in revealing the internal structure of an object (Hughes 2011, 59), would be of little value in the study of solid stone. This study has considered three types of non-contact three-dimensional recording techniques: laser scanning, structured light scanning, and photogrammetry.

While laser scanning, structured light scanning and photogrammetry capture data via different means, they share a certain amount of terminology relevant to the processing and manipulation of data. After capturing the data, each approach initially calculates and produces a *point cloud,* which can be defined as a collection of measured, three-dimensional coordinates positioned in relation to each other, where each coordinate represents a point on the surface of the recorded object (Jeffrey 2003, 63–64; Grussenmeyer et al. 2016, 306). Triangular polygons can then be generated, using these measured points as vertices of each polygon. These polygons form the three-dimensional representation of the object's surface, which is called the *mesh* (Grussenmeyer et al. 2016, 330). The density of the point cloud directly affects the quality of the mesh – the higher the density of points forming the point cloud, the more detailed the mesh will be. The mesh can be thought of as the 'topography' of the object, which may or may not be visualised using colour depending on the approach used. To make the rendered image more attractive, a *texture* can be applied. A texture is generated from the data captured by each of these techniques and, after the mesh has been created, this texture can be applied to create a more realistic appearance for the model (Grussenmeyer et al. 2016, 332). While these basic steps might be subdivided or combined depending on the technique used to capture the data (or even the manufacturer of the processing software), creating the point cloud, building the mesh, and applying the texture underlie the workflow for all three imaging techniques.

Photogrammetry, structured light scanning, and laser scanning each have advantages and limitations, which will be assessed in the context of how this affects the recording of early medieval sculpture. As a part of this project, the results of these techniques were compared using the software "CloudCompare," which was created by Daniel Giradeau-Montaut in 2006 to compare different point clouds of the same object and identify any variation between them. The software was developed specifically to compare laser scan datasets of industrial sites (DGM et al. 2012, 1), but has become indispensable in many industries, including digital heritage and archaeology, after it was subsequently made freely available online. The results of this comparison, which is discussed more thoroughly below, suggest that each technique creates closely comparable models.

5.1.1 Photogrammetry

The simplest definition of photogrammetry is the "technology to derive measurements of objects from their images" (Konecny 1985, 922). The technique is now used in many disciplines, though its origins lie in topographic mapping and architectural recording. The available narratives of the development of photogrammetry vary in levels of detail. Historical discussions of photogrammetry usually begin with the invention of photography by Daguerre and Niepce in 1839. Within decades, plane table photogrammetry, the process of utilising photographs and geometric principles to determine spatial relationships between features, was being used as a surveying technique, although the photographs needed to be taken from a high elevation (Konecny 1985, 924–925; Schenk 2005, 7; Foster & Halbstein 2014, 8). The invention of the parallel stereocomparator by Carl Pulfrich in 1901 revolutionised photogrammetry as a discipline, as it led to the development and use of stereoplotters, which automatized the elevation contours and made aerial stereophotogrammetry more efficient as a mapmaking tool in difficult terrain (Konecny 1985, 926; Schenk 2005, 8; Foster & Halbstein 2014, 8). The invention of the computer allowed for the development of analytical photogrammetry, in which the underlying mathematical principles were refined to improve the accuracy of the measurements derived from photographs (Schenk 2005, 8; Foster & Halbstein 2014, 9). The advent of digital photography has led to the most recent phase of photogrammetric development, digital photogrammetry. It is no longer necessary to develop and print the photographs before scanning them individually (Foster & Halbstein 2014, 9). The metadata associated with the photograph (Aperture, Focal Length, ISO, Shutter speed, and others) is generally embedded in the digital image as EXIF (Exchangeable Image File) data, which most photogrammetric algorithms now draw on to aid in aligning cameras. As a result, the photogrammetric process has become almost entirely automated (AgiSoft PhotoScan Professional 2016; Stylianidis et al. 2016, 289–290).

Photogrammetry has had a long, though sporadic, relationship with archaeological excavation. In the 1970s, photogrammetry was still too expensive and technically demanding to be used on most excavations (Conlon 1973, 67). By the 1980s, photogrammetry had "been used on a number of excavations to supplement, or largely replace, the time-consuming chore of detailed planning in the field (Wilson 1982, 19).” At this point, a three-dimensional image could be produced with a stereoscope, and measurements and plans could be obtained after scaling the images (Wilson 1982, 23). In the late 1990s and early 2000s it was still considered an “unusual recording technique,” (McIntosh 1999, 81) although its accuracy and usefulness in certain situations was recognised, especially in the case of recording upstanding architectural details where access was difficult (Roskams 2001, 129–130).

In these earlier examples, photogrammetry has been used in archaeology primarily as a surveying and recording tool for excavations and standing buildings. It was not until relatively recently that digital photogrammetry was used to create three-dimensional models of artefacts and individual monuments. Even as recently as 2003, Stuart Jeffrey did not consider close-range digital photogrammetry to be accurate or accessible enough to create detailed models of early medieval sculpted stones. At the time, it was necessary for the researcher to manually pick out points in common between photographs, although Jeffrey did recognise the technology was likely to swiftly develop in the future (2003, 132–134). Today, as mentioned above, digital photogrammetry software has become almost entirely automated; this advanced form of automated photogrammetry is called Structure-from-Motion (SfM), because the structure of an object can be recorded by taking photographs from different locations around the object. SfM is now capable of recognising the camera’s specifications and constructing the three-dimensional structure of the monument without the user doing anything apart from selecting the photos. These developments make SfM photogrammetry one of the most accessible three-dimensional imaging techniques (Stylianidis et al. 2016, 290).

Many different companies and working groups have put out their own version of SfM photogrammetry software. AutoDesk had produced 123D Catch, which was often used by academics because it was accurate and free (Reinhard 2015, 27–28). However, AutoDesk has since discontinued the software and now offers a photogrammetry software called Recap, which requires a paid, yearly subscription (although, at the time of writing, students and educators can obtain the software for free for three years) (Autodesk 2018). A number of open source programmes have also been developed, like Meshroom, which was made freely available by a group called AliceVision in 2018. However, the data capture for this thesis began in 2015, and it was decided that the industry standard photogrammetric software “Agisoft Photoscan” (2016), would be used.

Agisoft Photoscan (which, at the time of writing, has recently rebranded as ‘Agisoft Metashape’; however, the version of the software used throughout the PhD was Photoscan and shall be referred to as such from this point onward) uses a proprietary “Structure from Motion” (SfM) algorithm to determine camera positions from a series of still, overlapping photographs of an object. After identifying the camera locations, the algorithm can construct a basic point cloud representing the object’s three-dimensional geometry (Doneus et al. 2011). The software then refers to the aligned photographs to generate additional points to create a dense point cloud. Triangular polygons are then created between these points to form the three-dimensional mesh, the framework for the model. In the professional version of Agisoft Photoscan, one can scale the model in metres. The model can be textured to appear more realistic, or it can be left as a plain model in order to emphasize the structural elements of the object. It can then be exported into other software in order to analyse the model in greater detail. When exporting to other software, it is important to compensate for the fact that models created by Agisoft Photoscan are scaled in metres, while many 3D software packages automatically scale imported objects to millimetres. While the equipment needed for this technique is relatively inexpensive, easy to learn, and flexible in terms of working space, the processing of the data obtained from these photos requires a great deal of processing power and can take a long time if high resolution models are required.

In order to create a high-quality, measurable, three-dimensional model with Agisoft Photoscan, one requires a computer suited to the task (ideally a laptop that can be taken into the field). The laptop used in this project is a Lenovo ThinkPad P70 with a P70 Intel Core i7-6820HQ processor, a NVIDIA Quadro M3000M 4GB graphics card, 32GB of RAM and a 512GB solid state hard-drive. These exceed the recommended settings offered by Agisoft for the use of Photoscan. An Educational License of the Professional version of Agisoft Photoscan costs c. £415. Digital cameras range in cost; the DSLR cameras used in this project was a Nikon D5300, (cost c. £450) and a Nikon D5500 (cost c. £475).

A tripod should be used where possible to enable the use of manual settings. Ideally, the object to be photographed should be illuminated with flat, daylight balanced light from at least two sources to minimise shadow. Shadow on the object creates noise which obscures the detail of the monument. Two daylight balanced LED lamps were used in the process of photographing the stones for this project.

Unlike structured light scanning and laser scanning, digital photogrammetry is relatively easy to learn and has been a productive source of community projects, as has been the case with Roscommon 3D and ACCORD (Archaeology Community Co-Production of Research Data) projects (Roscommon 3D 2015; Jones et al. 2017; Hale et al. 2017). To ensure that the three-dimensional model is high-quality, however, a basic understanding of photographic principles is essential. As a rule, the lower the ISO, the narrower the aperture (and therefore the higher the F-stop), the less 'noisy' and sharper the photograph will be. This leaves shutter speed as the flexible variable to ensure an even exposure (Verhoeven 2016, 204–206). A tripod should be used to stabilise the camera for longer exposure times. Capturing the necessary set of photographs can be relatively quick, depending on the size of the monument. For the hogback Govan 3, the photography of both the top and bottom of the monument took approximately one hour to complete. In the case of the Govan sarcophagus, over three hours was required to capture all four sides and the interior of the monument.

Agisoft Photoscan's biggest advantage over the other approaches considered in this study is that it has the flexibility to incorporate digital images from different cameras in the creation of a single three-dimensional model. This was particularly useful in the case of Govan's hogback monuments, as the DSLR cameras were too big to fit underneath the monuments. Here, the camera from a thin mobile phone was used to capture images of the underside of four of the five of the hogbacks and the back of the 'Inverted Cross' (Govan 10). The camera on a phone can be used as long as the metadata (ISO, focal length, aperture, and shutter speed) remains attached to the photograph. While in most cases mobile phone cameras have a lower megapixel (MP) count than point-and-shoot cameras, the stationary lens of the camera and the thin structure of a cellular phone are well-suited to the capture of particularly hard to reach places. The mobile phone used in this project is a Samsung Galaxy A3 (Model number SM-A300FU) with an 8MP camera. More on this will be discussed below when discussing workflow in Section 5.2.

There is also the option to alter the photographs through other software packages, which can have some research applicability depending on the object one is photographing (for a discussion on photographic filters and their use in the study of small finds, see Christie 2019). In this project, the photographs were white-balanced to create a more accurate depiction of the colour of the monuments, although a colour card was not used, as discussed below, and the reflectivity of certain surfaces occasionally caused issues. Digital photogrammetry has come a long way since the option was rejected for the Scotland's Early Medieval Sculpted Stones project (Jeffrey 2003, 100, 133). The process is reliant on the quality of the photograph used in the creation of the model, and in 2003, cameras with a 6.3MP sensor were considered top of the line. In an age where 20MP cameras are becoming the norm, digital photogrammetry has the potential to create highly detailed models if the conditions for photography are ideal.

Despite its flexibility in terms of data capture, the photogrammetric technique does have its drawbacks. Shadows in the photograph obscure minute details from the software, so professional lighting is required to diminish the amount of noise registered by the software. When working with a large object, like the monuments of Govan, with differing amounts of space available around each monument, consistent levels of lighting are difficult to ensure. While including a black-and-white scale in the photograph provides a convenient card from which to white-balance, the models produced by this project are not claimed to be calibrated for optimum colour constancy. This would require purchasing an expensive colour card, finding space in many of the photographs for it and ensuring consistent lighting in those photos (McCamy et al. 1976; Pascale 2017). This process would take too much time, especially because accurate recording of the colour of the Govan stones is not the aim of this project and would have limited research applicability; in addition, the stones themselves likely would have been plastered or painted during the early medieval period, negating the importance of the colour of the stone (Hawkes 2003, 26–28), and their exposure to the elements in the intervening period has had a significant impact to this characteristic.

As indicated above, the use of photogrammetry requires a great deal of computer processing, especially in the case of models which are produced using several hundred photographs. A computer with a top-of-the-line processor and a great deal of RAM (random access memory) is required to process large datasets at high levels of accuracy, although a dataset with less than one hundred photographs can be handled by some mid-grade laptop computers (For instance, my personal computer has an Intel® Core™ i5-3210M CPU @ 2.50 GHz and 6GB of RAM and could handle the processing of Govan 24). The computer obtained for this project has an Intel® Core™ i7-6820HQ CPU @ 2.70 GHz and 32GB of RAM. Sufficient overlapping coverage between photographs is essential, and ideally this is checked in the field. While the initial aligning of photographs can take a great deal of time, it is vital to ensure that there are no areas of missing data. It is recommended that the operator align the photographs at the lowest setting in the field to ensure that full coverage has been achieved. This can make a difference of hours: in the case of the top part of Govan 3, the initial alignment of the photographs at the high accuracy setting with no limits set on tie points or key points took approximately 22 hours for the top and another two hours for the base of the monument, while the alignment of the same dataset at the lowest accuracy setting with the auto-filled 400,000 key points and 10,000 tie points took approximately eight minutes. Some materials are not conducive to photogrammetry, especially those which are solid black in colour, or have reflective or transparent properties (Frischer 2014, 138), although advancements have recently been made on this topic (Christie 2019). In the case of the Govan stones, even the capture of the darkest of the monuments was feasible, although some patches, like the patinated ridge of the hogback Govan 2, required special attention because of its reflective nature.

Photogrammetry generates a large amount of data, all of which must be archived, including all of the photographs, a record of each photo’s associated metadata, the file used to create the model and the finished model itself. Some might argue that as cameras continue to take more detailed photographs, these models will quickly become obsolete. While this technology will undoubtedly progress, the SfM models produced here are highly accurate and will have a long analytical use-life. The archival details will be provided in more detail at the end of this chapter.

5.1.2 White-Light Scanning

Structured light scanning is a technique which consists of projecting light with a known pattern onto an object. The scanner recognises this distortion, measures it, and uses an algorithm to map the geometry of the object (McPherron et al. 2009). This process also produces a detailed point cloud and automatically creates a mesh. Colour and texture information are also captured, which can be applied subsequently after the initial data capture. There are several types of structured light scanning, but the type that available for use in this project through the Glasgow School of Art: School of Simulation and Visualisation is referred to as “white-light scanning”. The type of white-light scanner used in this project is an Artec MHT 3D Scanner, and the data from this capture was processed using Artec Studio 10.

White-light scanning (WLS) has some benefits over photogrammetry. The technique does not require any additional lighting, as the light is integral to the handheld unit. Because the scanner projects a known pattern onto the stone, it also scales the model automatically (in millimetres). The use of the Artec white-light scanner has the added benefit of allowing the user to see the results of a scan after only a few minutes of processing to easily identify any gaps in coverage during the data capture process.

The use of WLS does have some drawbacks. The use of the Artec MHT is relatively simple, although for objects as large as the Govan hogbacks it is easier to complete with two people. When the scanner is no longer in range or cannot “see” the surface of the object, it will alert the user. In fact, while capturing the bottom edge of Govan 3, the scanner lost track of the scan as it was simultaneously imaging what lay beyond the stone, i.e. the floor of the church. This was a problem with most edges and areas of significant height difference, as was the case in attempting to record one of the legs of Govan 3’s end-beasts where it has sustained some damage (currently the southwest corner of the monument). Much like the Nikon D5300 DSLR, the handheld module cannot fit in some spaces and cannot capture data from the base of the Govan hogbacks. Finally, during the post-processing, Artec aims to create a “water-tight” model for ease of 3D printing, which introduces errors through assumption. The hole-filling function in the software itself does not offer the option to change the colour of the ‘estimated patch’; this can be construed as an unintentional deception in terms of accuracy if others wish to reuse the dataset and are unaware of the holes that were filled.

Another weakness to this approach is that the equipment required is comparatively expensive. While the Artec MHT 3D Scanner is no longer sold by Artec, a comparable model called the Artec Eva is sold for €13 700 (c. £11,500) (Artec Europe 2016). The Eva is thinner than the MHT, but has the same 3D resolution (up to 0.5 mm) and 3D point accuracy (up to 0.1 mm) and still works at a similar distance (0.4m – 1.0m) (Freedspace/Thinglab 2016; Artec Europe 2016). The processing requirements for the Artec imaging software are not as high as that required for Agisoft Photoscan, but the amount of time needed to register multiple scans is still significant. To capture the data for both Govan 3 and Govan 5 (excluding the base of the monument, due to accessibility issues for WLS), it took approximately two hours to initially capture and register the data to ensure that there were no obvious holes. Additional post-processing was required before the final models could then be viewed and exported using the bespoke Artec processing software.

In conclusion, while WLS is quicker than SfM photogrammetry in terms of data capture, the equipment is much more expensive and more limited in its ability to record obstructed surfaces. A qualitative difference in experience also became apparent during the project: while using the white light scanner, the user’s primary concern must be holding the module a consistent distance away from the object at all times. If the module is held outside of the ideal range, the scanner beeps incessantly at the user until this is rectified. This becomes the primary focus for those using the scanner, rather than the monument itself. With photogrammetry, the process of altering the position of the lighting equipment to ensure flat lighting leads the user to a better appreciation and understanding of the carved patterns. If other projects wish to capture the easily accessible structural surface of an object, then WLS would be sufficient. But if a researcher wishes to gain a new understanding of an object, then photogrammetry is the better option.

5.1.3 Laser Scanning

Laser scanning is one of the most well-known three-dimensional imaging techniques. A ScanStation C-10 Leica laser scanner was used to create point clouds of two of the hogbacks to compare the results with those generated from photogrammetry and white light scanning. This laser scanner uses the “time-of-flight” principle for capturing data. The C-10 Leica is mounted on a tripod and passes a line of lasers vertically while rotating horizontally. These lasers reflect from the surface of the object and a sensor in the scanner records how long the reflected light takes to return to the unit (Jeffrey 2003, 126; San José Alonso et al. 2011, 378). A used C-10 scanner can cost up to £18,000 through online retailers, but newer Leica models are available. No additional equipment is required, but a not-insignificant amount of training is required to understand how to operate the scanner, where the ideal locations for the scanner would be, and how to process the laser scan data in external software packages, including Cyclone to align the individual scans and 3DReshaper to mesh the resultant point cloud. At a distance of 100 metres on low resolution, the scanner records every 20 centimetres both vertically and horizontally (Leica Geosystems 2012, 101). Twelve low-resolution scanning positions were used to create comparative point clouds for two hogbacks, Govan 3 and Govan 5. Using the C-10 Leica laser scanner, low-resolution scans only take a few minutes to record, individual medium-resolution scans often take over ten minutes to record, and high-resolution scans would require approximately thirty minutes to record.

While the point clouds produced by this approach initially appeared to be quite impressive, the mesh created from this point cloud lacked the detail produced by photogrammetry and white-light scanning. This “time of flight” technique with this scanner is better suited to capturing larger objects, especially buildings or other architectural features. Others have noted that the C-10 produces accurate scans but is not suited to recording very small details (San José Alonso et al. 2011, 385). Specialised hand-held laser scanners, like the ModelMaker MMDx digital laser scanner, would be better suited to capturing smaller details.

However, the retail cost for this model is c. £18,000 and was not available through the Glasgow School of Art: School of Simulation and Visualisation at the time of this project (Nikon 2017). Because the C-10 Leica scanner must be mounted on a tripod, capturing the underside of the hogbacks was not an option with this approach. Even if one could afford something similar to the ModelMaker MMDx digital laser scanner, the handheld unit appears to be of a similar scale to the Artec MHT unit; it can be extrapolated that this high-resolution equipment would not be able to capture hidden surfaces either. Because of its reputation for accuracy, however, the point cloud was still included in the comparisons between datasets with CloudCompare below.

5.1.4Comparisons with CloudCompare

The point clouds produced by these separate techniques were evaluated via the freely available software *CloudCompare* (DGM et al. 2012, 1). The comparison was made to assess whether SfM photogrammetry (Agisoft Photoscan) can produce accurate, comparable point clouds as accurate as those created by white-light and laser scanning. While other projects have clearly demonstrated its relative accuracy (Olson & Placchetti 2015, 17–18), it was necessary to demonstrate that this is the case with this type of material and to quantify its accuracy. *CloudCompare* identifies the differences between two point clouds and identifies where the models differ. It determines these disparities by measuring the *Hausdorff* distance between clouds, which essentially means that it determines the distance of a point to its nearest neighbour in the opposing cloud. The software can also compare three-dimensional meshes, but it does so by treating the vertices of the mesh as a point cloud (DGM et al. 2012, 1–2). Point clouds, regardless of which technique produced them, are the most accurate measurement of a surface because they are directly calculated or captured by the imaging technique; the triangular polygons generated between points have no basis in reality, even though they are a very near approximation of the real surface.

When the 3D models produced by photogrammetry, white-light scanning and laser scanning for Govan 3 were compared using *CloudCompare*, it became apparent that digital photogrammetry was the best option for this project. A series of Cloud-to-Cloud comparisons were carried out between each of these 3D models, with the largest point cloud acting as the reference data in each case. The combination of twelve low-medium scan stations produced by the terrestrial laser scanner was not well-suited to the task; this resulted in a point cloud consisting of approximately 534,440 points for hogback Govan 3. When comparing the distance between the High accuracy dense point cloud created through photogrammetry (excluding the underside of the hogback, this consisted of 9,102,074 vertices/points) to the vertices of the 3D model produced by white-light scanning (13,589,684 vertices/points), *CloudCompare* indicated that there was an average difference of 0.0018m with a standard deviation of 0.002m (Figure 5.1). Comparisons between the results of the laser scan and the WLS indicated that there was an average difference of 0.0018m with a standard deviation of 0.0019m between the two point clouds (Figure 5.2). Finally, the comparison between the laser scan and the photogrammetry results revealed that there was an average difference of 0.0017m with a standard deviation of 0.0015m between their point clouds (Figure 5.3). What this comparison demonstrates is that each of these three methods produce very similar three-dimensional images of the same stone, with the main deviations evident along the edge of the 3D model (in green in Figure 5.1 and Figure 5.3). Methods that are often seen as ‘the most accurate’ 3D data capturing approaches (in this case referring to laser scanning and WLS) exhibit the same amount of difference between point clouds as they do when compared to the 3D model produced by SfM photogrammetry.

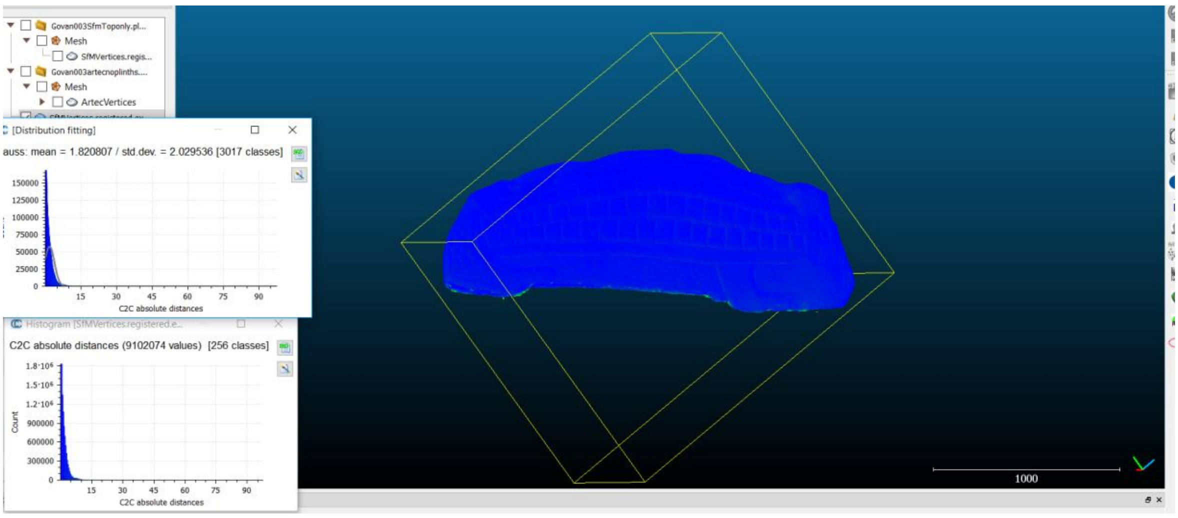


Figure 5.1. Photogrammetric and WLS 3D models of Govan 3 compared through CloudCompare. The main deviations occur near the edge of the 3D model (2-3 mm difference between points), largely because photogrammetry was able to capture more of the stone than WLS.

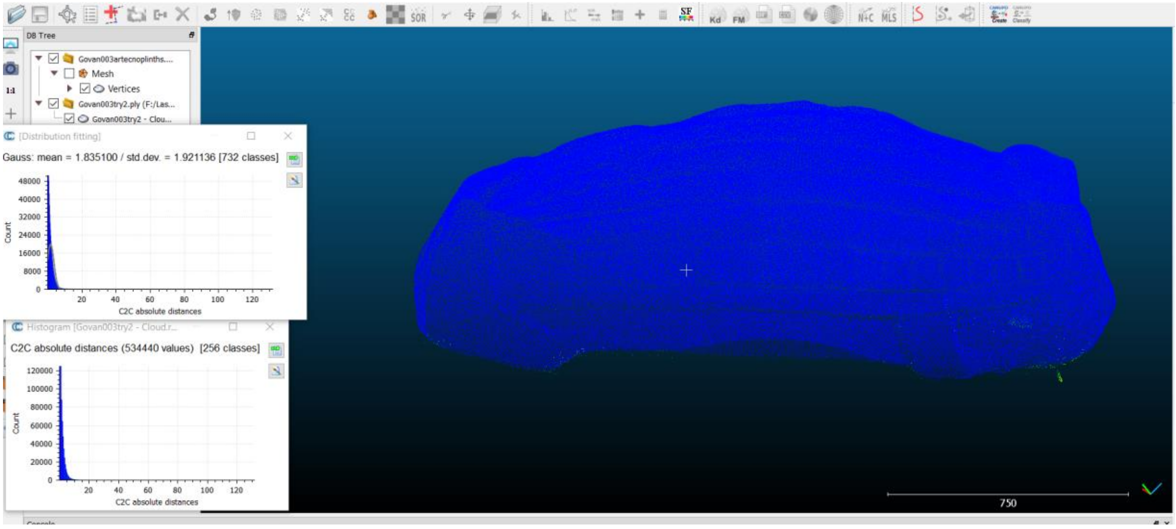


Figure 5.2. Point cloud of Govan 3 produced by laser scanning compared to that produced by WLS. A virtually identical result to the previous comparison, there is a 2-3 mm distance between corresponding points when the two point clouds are compared.

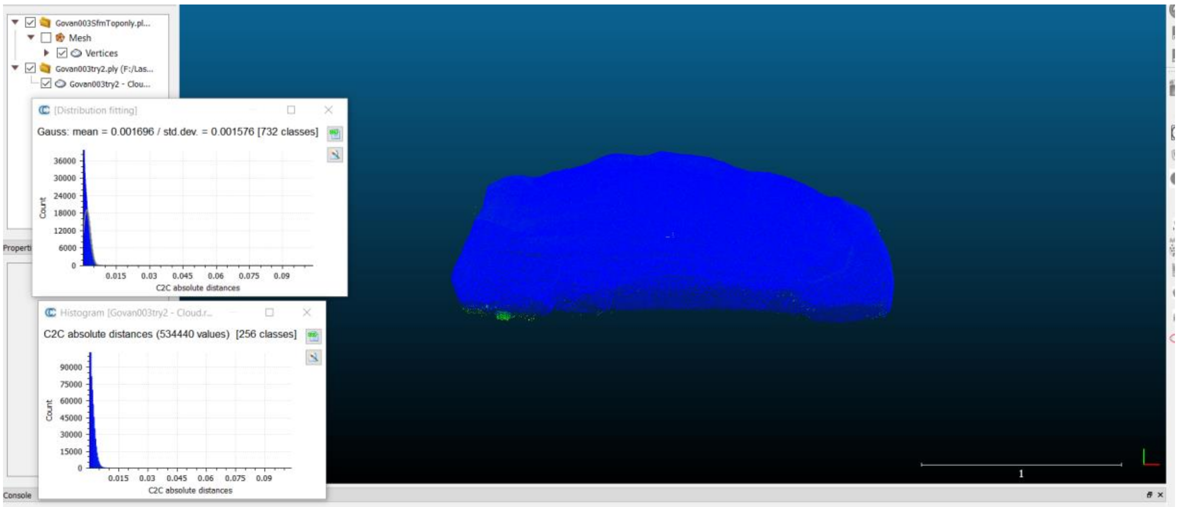


Figure 5.3. Laser scan point cloud of Govan 3 compared to the SfM photogrammetric point cloud. Again, a 2-3 mm average distance was found between corresponding points, with most of the inaccuracy relating to the bottom edge of the monument.

From this comparison, it is apparent that photogrammetry can produce a model as accurately and with greater flexibility than white-light scanning and terrestrial laser-scanning. Photogrammetry is one of the most affordable and accessible three-dimensional imaging techniques without the employ of external contractors. The SfM photogrammetric process also offers the user a more intimate understanding of the carved stones than the other digital imaging approaches explored in this project. For these reasons, it was decided that photogrammetry would be the technique utilised in this research.

5.2 Photogrammetry Workflow

The workflow procedure followed for the creation of three-dimensional models via digital photogrammetry in this project was as follows. To ensure the sharpest photographs, the DSLR camera was mounted on a tripod, using manual settings, which are recorded in the metadata. The method of data capture used in this project deviated slightly from the approach recommended by Agisoft Photoscan. The guidance provided in the 'Help' document indicates that photographs should be taken perpendicular to the surface that needs to be captured; from the outset of the project, it was known that Groove Analysis would be applied to these models and that the carved grooves would need to be as accurate as possible. From each camera position, three photographs were taken: the recommended straight-on photograph perpendicular to the stone's surface, one with the camera tilted up, and one with the camera tilted down (where reasonable; the uppermost positions only required angling downwards to include data from the monument, and the lowest positions only needed to be tilted upwards). This ensured that the 'walls' of the carved grooves were captured as well as the groove bottoms, providing a more accurate depiction of the geometry of the grooves.

The above method for data capture pertains to the capture of the accessible faces of the monuments. In the case of the least accessible surfaces of the Govan collection, including the bases of four of the hogbacks and the back of Govan 10, a phone camera was used. Because the hogbacks are conveniently raised on two plinths on each end, there is approximately 17 centimetres between the lowest portion of the stone and the floor. While this allows a minimal amount of visual access for the enthusiastic and spry observer, these details can only really be captured with a smaller digital camera, or in this case, a smartphone camera, as discussed above. Due to the restricted amount of space, issues pertaining to adequate lighting and incorporating photographic scales become more complicated, and so, in most cases, the phone's flash was used. While this resulted in a less accurate colouring of the stone surface, this method has produced more satisfactory results than attempting to consistently apply external lighting underneath the hogbacks. In the case of Govan 10, a cross-shaft, it was known that when the stones were imaged in the early 20th century, the now-inaccessible face of the stone retained some carving. Luckily there is sufficient space between the stone and the wall to enable a smartphone to image the back (apart from an area where an electrical box impeded access to the surface – this caused the sizable hole in Govan 10's dataset). However, to ensure full coverage of this stone face, it was necessary to use a more systematic approach than attempting to reach behind the stone with one's arm and take the photograph. With the use of a 'selfie stick' it was possible to exert more control over the positioning and stability of the phone behind the stone. This equipment consists of an adjustable mount for the smartphone, a telescopic frame that can extend to 1.2m, and a Bluetooth connection to the smartphone to enable its use as a remote shutter. There are many brands of 'selfie stick' available because of their popularity for more conventional uses (like, as the name suggests, enabling the taking of 'selfies'), but the model used in this project is the 'ReTrak EUSelfieB Bluetooth Selfie Stick'.

The photographs from the DSLR camera were captured in RAW format and white-balanced in Adobe Photoshop, then exported into JPEG format for use in processing by Agisoft. The photographs from the smartphone were created in the JPEG format. As mentioned above, in the cases of some monuments, reflectivity became an issue, especially in the case of the patinated surfaces of the hogback Govan 2; reflections in the photograph cause white space where the photogrammetry software has difficulty finding the surface of the object. In these cases, photographs of these areas would have to be taken again with different lighting positions to minimise the effect.

Once the final photographs were added to the workspace in Agisoft, the quality of the photographs was assessed by the program. If the projected quality of a photo fell below 0.49, it was likely that the photo was not focused; if this was found to be the case after visual inspection, the individual photograph was included in the file, but blocked from contribution to the model, as recommended by Agisoft Photoscan. Where possible, the mounting brackets holding the monument to the wall were removed to capture of the full surface. In Agisoft, photographs retaining the presence of the brackets were masked so that the brackets were ignored by the software. This will allow the condition of the stone to be monitored in the future. As these brackets were replaced, protective plastazote foam was placed between the brackets and the stone to prevent direct contact with the monuments.

After adding the photographs to the Agisoft workspace and manually blocking low-quality images, the ‘Align Photos’ function was then selected and set to ‘High’ accuracy, which produced a sparse point cloud. According to Agisoft Photoscan’s Help files, setting this to ‘High’ causes the software to search for tie points at the photos’ original size; setting this lower causes the photos to be downscaled by factors of 4, reducing the quality of the photos. This can also be put to ‘Highest’, which enlarges the original photographs by a factor of 4, but this also increases the processing time exponentially (for the hogback Govan 4, aligning photographs at ‘High’ took approximately 8 hours; when set to ‘Highest,’ the processing time increases to over 8 days (AgiSoft PhotoScan Professional 2016)). It was decided that the ‘High’ results were sufficient for the requirements of this thesis; the Agisoft Photoscan files will be archived along with the finished models and the JPEG images, so if in the future it is identified that ‘Highest’ is required, then this can be replicated at this level.

The sparse point cloud often contains a great deal of background information from the photographs; points that are not relevant to the monument being imaged were deleted at this stage. Occasionally it is beneficial to use some of Agisoft Photoscan’s built-in “Gradual Selection” tools to remove “lower-confidence tie points” (Mallison 2015a). While Agisoft Photoscan’s description of these tools indicates that these tools target the removal of points based off common sources of noise (including false matches, points reconstructed from nearby photos with small baseline, points that are only visible on two photos located with poor accuracy, and poor localization), the ‘Help’ document does not indicate what constitutes as a “high” Reprojection Error, Reconstruction Certainty, Image Count or Projection Accuracy. Undoubtedly Agisoft’s silence on the matter indicates that these tools can be used to refine their proprietary SfM algorithm, but this is speculation. Mallison admits that he is not certain to what level these tools should be set. Most of the initial point clouds produced for this project resulted in a Reprojection Error scale that ranged from 871 to 0 units, but it is unclear how this is being measured. But as Mallison demonstrates in another related blog post (2015b), the use of these tools can in fact increase accuracy – the reduction of tie points by 50% in his model results in a reduction of estimated error of the scale bars by 57% (from an error of 0.000557m to 0.00032m). Whether this is significant enough of an improvement in accuracy or not is up for debate.

To take Govan 2 as an example, after aligning the photos at ‘High’ accuracy, a sparse point cloud consisting of around 2.5 million tie points was produced, and the amount of error measured by the scaling of the model suggested that there was an error of 0.000004m (or 0.04mm). By selecting Gradual Selection and setting the Reconstruction Uncertainty to a level of 10, deleting the highlighted points, choosing the “Optimize cameras” option, setting the Projection Accuracy to a level of 10, deleting those highlighted points, “Optimizing cameras” again, setting the Reprojection Error to a level of 1.0 and deleting these points (the recommended amount of reduction suggested by Mallison), and “Optimizing cameras” one final time, I was left with a sparse point cloud of only 587,000 tie points, but with an estimated error of 0.000002m (or 0.02mm). While the significant loss of points from the sparse point cloud during this stage is initially alarming, in this case it appears that proceeding to the dense cloud usually remedies the lack of points. The introduction of this process has significantly improved the quality of the models of this project.

Following the use of these optimization tools, any additional background points were deleted, and the dense point cloud for the monument was created. Agisoft uses the aligned photographs and the estimated camera positions to “calculate depth information for each camera to be combined into a single dense point cloud (AgiSoft PhotoScan Professional 2016)”. At this point, points can be removed based on colour to remove any unwanted background features that the software has included. This step only succeeds if the background features differ in colour significantly from the object being recorded; if this is not the case, these will have to be removed manually. As discussed above in Section 5.1.4, point clouds are the most accurate representation of a three-dimensional model metrologically; by calculating a dense point cloud based on the original camera alignment, there is less space to fill with triangular polygons between the individual points, resulting in a more detailed mesh.

After the dense point cloud has been edited, the three-dimensional mesh can be produced. Polygons are generated between the points produced from the dense point cloud. Of the options available in the “Build Mesh” dialogue box in Agisoft Photoscan, each of the models was built with “Arbitrary” selected for the Surface Type, “Dense Cloud” for the Source data, and with a High face count. Under the “Advanced” tab, I have decided to leave “Interpolation” enabled, although there has been some discussion as to how this affects the accuracy of the three-dimensional model (Štuhec 2017). Some holes were left where image data could not be captured (see Figure 5.4 below). Decimation was sometimes necessary if the size of the model was too large to be viewed and manipulated without significant lag; this tool allows the researcher to choose how many polygons the model should consist of, simplifying the mesh. Because this diminishes the quality of the mesh and reduces the usability of the model for some of the analyses in this project (especially Groove Measure Analysis), this step was avoided wherever possible. This will be noted in the metadata of the models where this was necessary.

Once the mesh appears to be satisfactorily representative of the monument, i.e. does not exhibit areas of missing data, which appears stippled as seen in the case of the plinths under Govan 3 in Figure 5.4, a texture can be produced. The texture has little research applicability for this project, as the primary focus is on the carving itself and this is most easily viewed using only the mesh. The texture is valuable for display and interpretation, because it adds a realistic appearance to the model. There is an argument to be made that the inclusion of a series of realistic elements often gives the viewer a greater appreciation for the original object (Galeazzi 2018). The texture can be used to track certain types of changes in the condition of the monument’s surface, like if the monument has become scratched. To produce the texture, Agisoft Photoscan refers to the original photographs that were used to create the three-dimensional model. There are a variety of options available for texturing have differing results depending on the monument. While the “Mosaic” option often resulted in the most aesthetically pleasing representation of the monument, the “Blending” option frequently occluded obvious details, like the carved inscription from the monument’s reuse. The removal of “Blending” from the texturing process requires one to use the optional "Colour Correction" to avoid the delineations of overlap between each individual photograph.

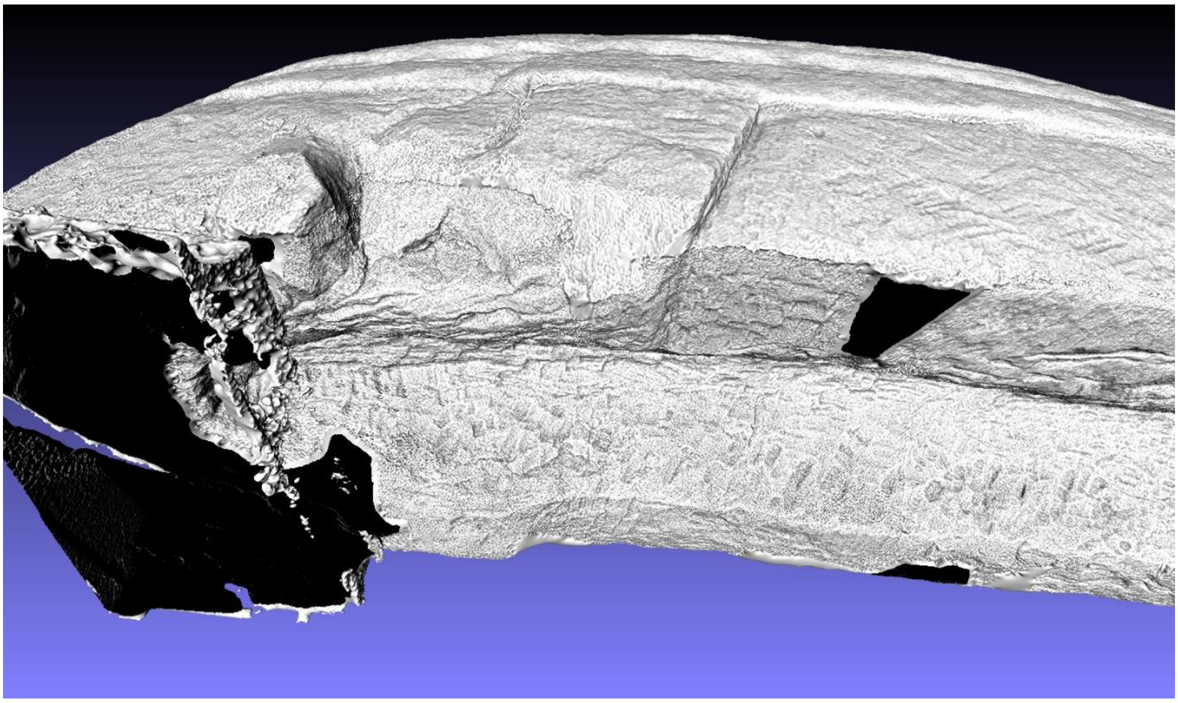


Figure 5.4. The underside of the model of Govan 3, where areas of low data capture (the plinth in the left portion of the image) and holes which have been filled (smooth areas along the edge of the stone) can be identified.

Particularly worn models, like Govan 31, will have two separate models produced – one which is the result the same photogrammetric process, and a second enhanced model which has been manipulated or 'recarved' to emphasise potential patterns that have been identified through the reconstructive process described in Section 5.4.2. These "enhanced" models will be clearly labelled, because, while they are informed reconstructions of worn monuments, they are not true records (Denard 2012; Jones et al. 2017, 17). They are particularly valuable for informing the art historical interpretation of the stone and for public presentation.

5.3 Completeness of the 3D records of the Govan stones

When discussing three-dimensional models of sculpted stones, some would argue that a "complete" model of each side of these stones is not absolutely necessary. For the research undertaken in this project, this may be true, and in most cases the focus will be on the exposed, carved faces of the monument.

However, in order for these models to be useful to future researchers, it is argued here that having the complete picture could help inspire and address future research questions, especially those pertaining to the quarrying of the stone (How much attention did the sculptor pay to the back or underside of the monument? Is it roughly hewn, and what can this tell us about quarrying practices? Why are the bases of three of the Govan hogbacks concave to differing degrees?), the overall shape of the monuments (Was one end left thicker than the other?), and how they would have appeared when originally placed in the landscape (Did they lie flat on the ground? Would one end have sat higher than the other? How does this compare to the other stones in the collection?). Unfortunately, the vast majority of the Govan recumbent cross-slabs are mounted to the church wall in such a way that a complete, watertight model is not possible without removing the stones from the wall. However, in the case of those that are more accessible, i.e. the sarcophagus, cross-shafts and hogbacks, nearly complete models can be achieved. The three-dimensional datasets produced for the purposes of this research will be designed to be accessible and reusable, even after the completion of the initial project. If, in the future, the stones are moved for curatorial reasons or for redisplay, these areas which were previously obstructed can be recorded and combined with this dataset to produce complete models with little additional effort.

5.4 Reflectance Transformation Imaging (RTI)

Although not a three-dimensional imaging technique, Reflectance Transformation Imaging (RTI) is a digital imaging technique that was indispensable in the analysis and reconstruction of worn monuments in the Govan collection. RTI is an overarching approach that has grown from and includes a process known as Polynomial Texture Mapping, which was originally developed by HP Laboratories (Malzbender et al. 2001; Earl et al. 2010, 2040). In contrast to SfM photogrammetry, the numerous photographs required for RTI are taken with a camera from one position while the light source is moved. By including a static, reflective ball in all the images, the *RTIBuilder* software can identify the varying positions of the light source and combine all of the images of the object into a single file. Essentially, Polynomial Texture Mapping compares how the light reacts which each individual pixel in each of the images (Gabov & Bevan 2011, 4). In the combined file, the light source can be manipulated to artificially highlight or shadow certain sections of the surface, revealing worn details (Earl et al. 2010; Molina Sánchez 2014). This technique is particularly valuable for the Govan collection because of the high level of wear on stones such as Govan 31 and 36, because RTI provides an image where one can create raking light across the monument in a controlled manner to reveal subtle variations in the elevation of the stone surface.

There are a number of different rendering modes available for use in RTIViewer version 1.1.0, but only three of these have been particularly useful in the analysis of early medieval carved stones: Default, Diffuse Gain, and Specular Enhancement. In the Default setting, the interactable file appears much the same as the original images. Diffuse Gain is a 'transformation that exaggerates the diffuse reflectance properties by a gain factor...keeping the surface normal estimate constant (Malzbender et al. 2001, 7)', while Specular Enhancement 'uses the surface normal and a specular shading method to make the object recorded artificially shiny (Earl et al. 2010, 2042–2043).' By experimenting with the lighting positions and settings for each of these rendering options, close inspection of the damaged and worn patterns in the Govan collection was possible, enabling the reconstruction of some of the degraded ornament (Figure 5.5).

Figure 5.5. Side-by-side comparison of the different RTIViewer rendering modes used most often in this PhD, here on the base of Govan 21: (left to right) Default, Diffuse Gain, and Specular Enhancement.

5.4.1 Digital Reconstructions

Reconstruction is a well-established practice in experimental archaeology. By creating a replica of the object, researchers gain insight into how the original creator would have had to interact with materials to create the end product. While physical scaled models of sites and their interpretations have been employed in research and museum displays for much longer, the increased accessibility of three-dimensional modelling software since the 1990s has led archaeologists to create digital reconstructions to address a variety of different research questions. Some examples include: both virtual and physical scaled reconstructions based on the excavated features of an Iron Age house at the site of Slæbæk Sydøst in Denmark, which was done to determine roof pitch and length and to better understand the house-building process (Larsen 2016); virtual reconstructions of several hypothetical reimaginings of the above-ground structures of a Neolithic ritual monument found on Jutland, Denmark, based on the excavated features for both research purposes and for dissemination to the public (Ask 2012); or the modelling of the Chetro Ketl great kiva in Chaco Canyon to determine how much timber would have been required to build a roof (Kantner 2000, 52). In each of these cases, the 2D plans of the excavated remains were the base for these virtual 3D models, upon which 3D polygons were drawn and shaped into the archaeologists' interpretation of the site.

Digital reconstructions of early medieval sculpture in Great Britain have also been created, although for different research purposes. In one case, fragments of cross from the site of Neston, Cheshire, were laser scanned so that the pieces could easily be rotated to test whether from the same site could have feasibly been a part of the same cross. Although it was eventually determined that in the case of the cross fragments were not part of the same monument, the fragments were used as the starting point to create a hypothetical resin replica cross, using elements from both. This reconstruction then became the focus of a community display at the Grosvenor Museum Chester (White 2013, 33). Although this reconstruction was empirically inaccurate, it did provide sense of the form a similar monument might have taken.

Three-dimensional models have also been used to visualise how early medieval monuments may have looked with colour. As mentioned above, it is currently thought that early medieval sculpture would have looked quite different from the way they are presented today, as they would have had plaster or paint applied (Hawkes 2003, 26–28). Three-dimensional models provide a blank canvas on which this concept can be applied as was done for Constantine's Cross and the Forteviot Arch in the 'Cradle of Scotland' exhibition, which was held at the Hunterian Museum in Glasgow from the 3 September 2015 – 3 January 2016 and Perth Museum and Art Gallery from 2 February 2016 – 26 June 2016. These have since been made available on a website as a part of the Cradle of Scotland's virtual exhibition (University of Glasgow 2017a; University of Glasgow 2017b). The colours chosen for the reconstructions were informed primarily by the colours used in metalwork from the same region during this time, though in the future X-ray fluorescence (XRF) might help better inform these reconstructions by identifying the pigments that were used, as has been done recently for the Antonine wall distance slabs (Campbell 2018).

In each of these instances, the purpose of these digital reconstructions of early medieval sculpture is to help visualise a more 'complete' interpretation of the monuments themselves. In the case of the worn and damaged Govan stones, RTI and 3D imaging were integral to developing a more thorough understanding of the patterns in their ornamentation through the methods described below.

5.4.2 Recovering Heavily Worn Surfaces

Many of the Govan stones have been severely worn, but even the most worn stones retain traces of the original carving, and often appear as isolated pits on a smooth surface. Carving can be considered what the STONE project, led by the Edinburgh College of Art, has referred to as a 'reductive' (STONE project 2007) or '"subtractive" mode of thinking' (Harvey 2011, 15). The basic definition of this process given by the project on their website is that "meaning is created by stripping something away, or where a new form takes shape by means of removal" (STONE project 2007). While the primary purpose of the STONE project was to identify, document and preserve traditional stone carving techniques from around the world for future generations, this 'reductive' thinking is a useful concept to apply to the analysis of worn carving. This is a concept more thoroughly explored by Cynthia Thickpenny in her doctoral thesis (2019). She emphasizes that early medieval sculptors would have been interacting with the negative space of the design, the carved pits and grooves of a sculpted stone, to create the positive space, the stone surfaces elevated by creation of these grooves. This unaltered positive space then forms what the viewer perceives as the ornament.

This distinction between positive space and negative space is important. When a stone has been worn by external forces, either by human intervention or natural processes, portions of the carved area may still remain. These remnants are often the deepest part of the negative space, which were not necessarily the portion on which the sculptors intended the viewers to focus. Because of this, it is often quite difficult to interpret worn decoration on early medieval stones. Many of the stones in the Govan collection have been significantly worn, but some panels can be at least partially reconstructed, as will be discussed here and applied in Chapter 6.

The use of Reflectance Transformation Imaging has revealed that, by manipulating the light source and using different rendering options provided by the RTIViewer software, one can often find carved negative details sufficiently to allow the recovery of the original unworn pattern. In situations where RTI does not offer enough context to connect the dots, it is possible to create a "worn comparative collection" from the three-dimensional models of the better-preserved stones at Govan. By comparing the old remnants of decoration to the newly worn known patterns, it is possible to identify which motif was once carved into the worn stone's surface. By recovering these patterns, it is possible to gain a more complete understanding of the art historical context of the collection (For examples, see case studies in Chapter 6 and how this can offer new insights in Chapter 8).

As outlined above, it is possible to identify the remnants of decoration by changing the positioning of the light in the RTI file and switching between the different rendering modes as described above in Section 5.4. These small, recognisable details are highlighted on a still image of the stone in Adobe Photoshop; one can then begin identifying the worn pattern of this sculpted section. Once the definitive attributes of the carving have been identified, one with a detailed familiarity with the interlace types of the Govan school can begin to identify more subtle changes in the shadows and features that are highlighted by RTI. Through this process, one can slowly build a picture of how the stone might have looked. In some cases, the RTI has even proven sufficient to recover the entire decorative motif (See Table 6.1 for quantification of techniques required to recover worn patterns).

Some examples of the subtleties mentioned above can be best illustrated in the images below (Figure 5.6). The recognisable details clearly identifiable from the RTI are highlighted in green. Along the left edge of the panel of interlace, triangular shaped pits represent the space where two strands turned from the edge and crossed either over or under each other. Similar triangular spaces can be identified along the right edge of the panel, which has been nearly effaced towards the top of the panel, but these distinctive features can be more clearly identified towards the bottom right of the panel. The identification of these triangular traces indicates where the panel would have ended and, if this cross-slab can be presumed to adhere to the layout shared by the others in the collection, where the exterior outline of the pecked cross would have begun. The interior strands of interlace are formed by the carving of sub-rectangular shapes that narrow at one end, sometimes so much that they appear triangular. The shapes of these negative spaces indicate where one strand will travel above or under another. After the mode of carving is understood, most of the motif can be recovered, although the corners of panels and areas where two panels of interlace are joined together are often more difficult to predict due to the creativity of the original carvers.

Figure 5.6. (Left) RTI snapshot of the interlace panel of Govan 31; (middle) Green highlighting the positively identified carved sections; and (Right) The 5-cord plait (with an additional strand) recovered.

Once a two-dimensional map of the recovered pattern is created, it is useful to take the three-dimensional model of the stone produced in Agisoft Photoscan and apply the changes tracked in the RTI image by using the Standard carving tool in Zsub mode in the *Zbrush* software (Alon & Rimokh 2015), so that a 3D model of the hypothetical reconstruction is produced (there are a number of software packages available that have these capabilities, but Adobe Photoshop and Zbrush are the industry standards).This is essential as it 'tests' the 2D interpretation in a 3D space. Due to the overall nature of the decoration of the Govan stones, which is less than symmetrical in almost all cases, this method is well-informed but could still be considered hypothetical interpretations. These reconstructed sections of ornamentation can be compared to that which is found on better preserved stones within the Govan School to gain a better understanding of how these stones might have related to each other in an art historical sense.

In cases where very little of the carved surface remains, it is possible to compare known patterns of decoration found within the collection to these worn patterns. A technique developed here exploits the ability to duplicate and manipulate the three-dimensional model. It is possible to digitally wear away the models of well-preserved stones to the point where only the deepest carving remains as isolated pits. This digital erosion is applied using the “Trim Dynamic” function in the software *Zbrush*. This leaves the deepest of the chisel marks intact, which are sufficiently distinctive to compare to the carved remnants on the actual worn monument (Kasten In press a).

By creating these worn versions of well-preserved patterns which are prevalent in the Govan collection, they can be used as a simulated comparative collection to allow for the identification of similarities between the remnants of the known worn patterns and the deepest points of carving on a worn stone. The shapes and relative arrangement of these points can then be compared after they are highlighted, as shown in the digitally eroded patterns from Govan 7 below (Figure 5.7). For example, of the four patterns provided below, key pattern is the most distinctive and is composed of triangular and perpendicular straight-line remnants. If different sculptors carved the same pattern on a different stone, these depths for different parts of the motif might vary, but certain portions of the carving, like crossing points in interlace, appear to be deeper than other features consistently.

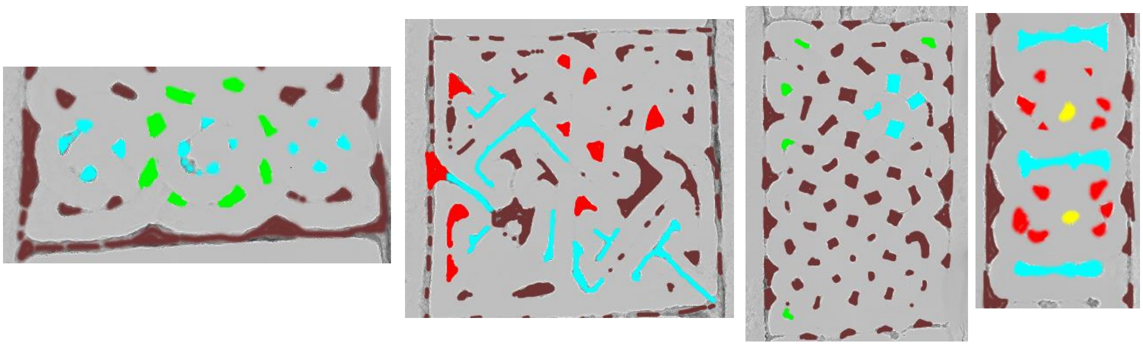


Figure 5.7. Digitally worn examples from the Jordanhill Cross (Govan 7) with identifiable patterns highlighted in colour; (left) Free-ring interlace; (centre left) Key Pattern; (centre right) Plait; (right) Inward-facing Stafford knots.

These reconstructions are particularly valuable for their potential to shed new light on the recumbent cross-slabs. As summarised in Section 3.4 and discussed in Section 8.1, the most recent attempt to order these monuments by Rosemary Cramp (1994) excludes several of the worn stones. By recovering the patterns from these worn stones, these monuments can once again be brought into the discussion, allowing for a fuller analysis. The illustrations of the reconstructions will be as true to the physical remnants as possible; the textual description of these patterns will aim to reflect any 'errors' or 'complications' as possible in a move away from the 'idealised' descriptions used in the ECMS or in the A-S corpus. In this way, the reconstructions will aim to contain the spirit and voice of the early medieval sculptors who created them (Fisher 2011, 120).

5.5 Workflow of Analysing Potential Template Use

Due to the similarity of figures and designs on stones in the Govan collection and throughout the Govan school, it has been suggested that templates were used to replicate them. While the creation of rubbings of the carved figures in question was the most common method of determining whether templates were used, scaled three-dimensional models of the figures can be compared instead (Kitzler Åhfeldt 2009a) and have the added benefit of avoiding contact with the stone surface. While there are undoubtedly many ways to compare segments of different three-dimensional models, the freely available *Meshlab* software is the most conducive to this process (Cignoni et al. 2008). If the 3D models have been previously scaled, they will remain at that scale when imported into Meshlab. Each 3D model also remains a separate entity and each can be manipulated individually. While the Meshlab software is not initially intuitive, it is powerful software that is incredibly useful in this type of comparison.

To determine whether or not templates were likely used, it is first necessary to scale the photogrammetric models. This will require the Agisoft Photoscan Professional version, as the Standard version does not allow for scaling. The 'chunk' (the term Agisoft uses for an individual workspace within the file) containing the model in Agisoft is duplicated; the sculpted figure in question is isolated by deleting the rest of the model. Each of these segments is then exported into a .ply file format, which seems to be most compatible with Meshlab (Cignoni et al. 2008). All of these are then individually imported into the same Meshlab project; the different 3D models retain their measurements, and so are "life-sized" in relation to each other, as if they had been shorn from their sculpture and placed side by side. The sections then need to be rotated until they all lie on the same plane; while time-consuming, this keeps the perspective and depth of the different models as similar as possible (Figure 5.8; Figure 5.9). It is beneficial to apply the “Radiance Scaling” render so that the distracting colour of the stone is removed and the carved surface is clearly visible (Vergne et al. 2010).

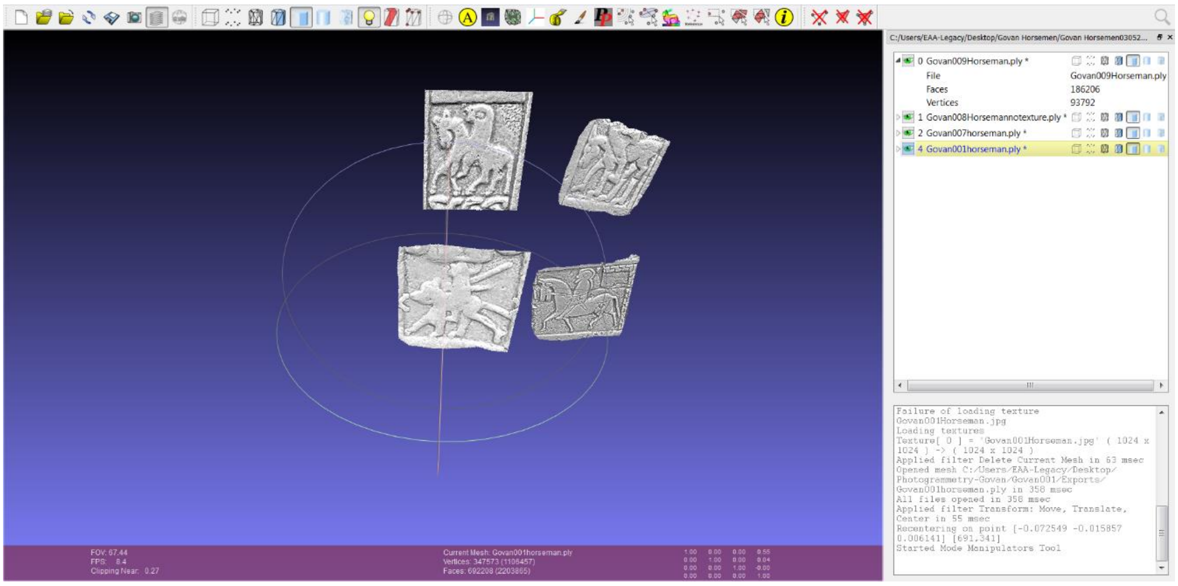


Figure 5.8. All four Govan Horsemen aligned in the same Meshlab project, maintaining scale.

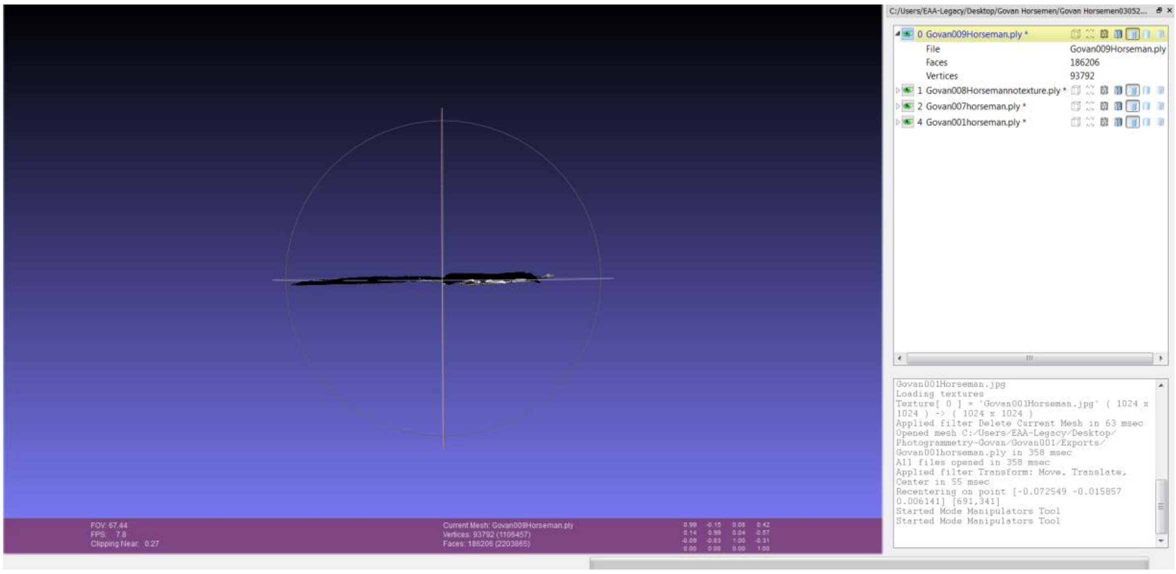


Figure 5.9. Top view of all four Govan Horsemen meshes aligned to keep depth and perspective as similar as possible.

Unfortunately, comparing the figures within the Meshlab project itself is not feasible; it is not possible to alter the transparency of a model within Meshlab, so one cannot float one image over the other to search for similarities. It is also impractical to use *CloudCompare* to compare the different pieces of sculpture, because *CloudCompare* can only really compare two separate point clouds or meshes of the same object; initial alignment could not be achieved between the different horsemen. This software would be unable to pick up on creative alterations that the artist might have made to the basic templated figure because the software searches for exact correlation.

Because of the above complications, it was simplest to take the sculpture out of the third-dimension and back into the second. A screenshot was taken of the scaled, compared figures, side by side, on the same plane, and brought into Adobe Photoshop. Outlines of each of the compared figures were made in the program on separate layers in different colours (Figure 5.10). These outlines were then manipulated to overlap with the other figures to determine if they shared any characteristics in common. Adobe Photoshop was particularly useful in the comparison of the sarcophagus “beasts” because of the software’s ability to flip and rotate layers individually. However, it is important to refer to the three-dimensional mesh during the process of creating the outlines as not all of the intricacies are fully captured by a single, two-dimensional image.

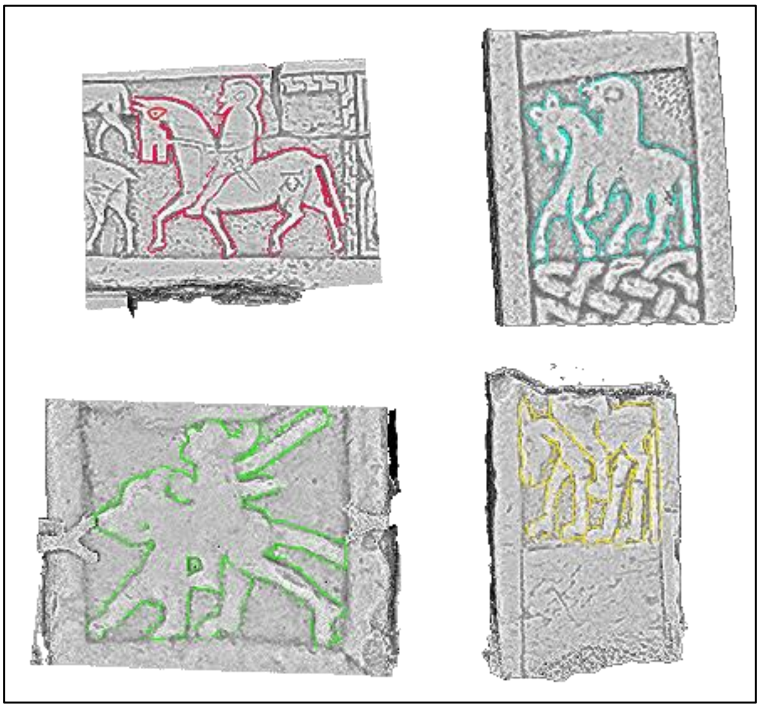


Figure 5.10. The Four Govan Horsemen (to scale) outlined in Adobe Photoshop for comparison.

Laila Kitzler Åhfeldt suggested that the use of templates could be identified if the outline of the figure and the points at which the image's limbs started and crossed matched (Kitzler Åhfeldt 2009a, 501). However, this may be too restrictive, as templates could have been used partially or flexibly. For instance, some early medieval sculptors could have adapted elements of a template and incorporated them into their own design. Indeed, certain situations would have required the template to be incorporated in a more creative way, especially if the template did not fit within the available space. It is also important to emphasize that the act of carving is a reductive process (Thickpenny, pers comm), so if the templates were applied early in the process, the sculptors could have removed additional material to alter the final figures.

Taking these considerations into account, in this analysis, instead of comparing the figures as a whole, the outlines of individual limbs were compared. Attention was focused on the Govan horsemen and the beasts represented on the sarcophagus. In some instances it appeared that the figures might have been composed of different templated sub-sections, much like Richard Bailey has demonstrated in the case of the cross-heads at Durham (Bailey 1996, 114–115); though he argues that this is evidence supportive of the concept of 'schools', he does not postulate whether this would be representative of a single artist's work or not. In some areas around the figures, there are small troughs visible that appear to have been created by a punctate tool putting the finishing touches along the edge of the relief. In some cases, like the front foot of the top-left beast on Panel B of the back of the sarcophagus, this might indicate a deviation from the initial design (Figure 5.11). These 'troughs' are given a separate outline based on the possibility that these might have overwritten or occluded earlier stages of carving. In certain areas, there are portions of relief that are at a stepped, middling depth. These are also included in the outlines, as they might reflect adaptations to the template made by the sculptor. In some template studies it is assumed that the use of a template would indicate the work of a sculptor who has not mastered the construction of interlace without an aid (Kitzler Åhfeldt 2009a, 502–503). However, at Govan it seems more likely that templates were used in the planning stages of carving to ensure that figures fit the available space. Also, it is possible that certain templates were used to ensure the appearance of symmetry, the potential significance of which is discussed further below in Section 10.4.

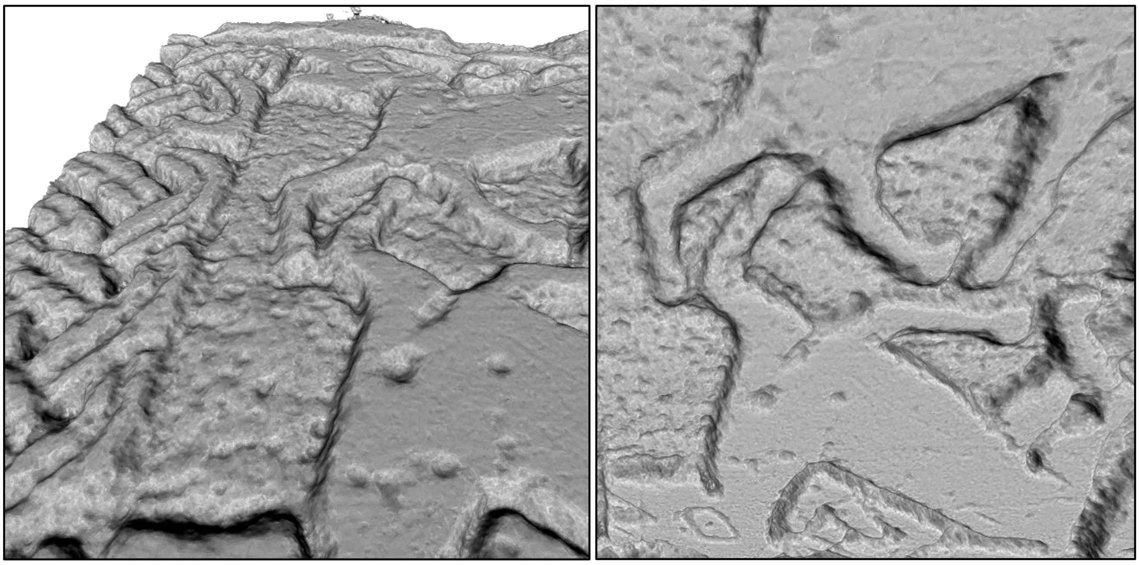


Figure 5.11. Screenshots showing where the front hoof of the top-left beast is thinner and more deeply carved than most sharing the panel.

5.6 Groove Analysis

One of the great benefits of high precision three-dimensional models is that they allow for fine-grained analysis of carving techniques. Laila Kitzler Åhfeldt has shown that detailed analysis of the carved surface can reveal the carving technique of different individuals on runestones. This analysis relies on neurophysiological and psychological research that indicates that craftspeople develop their own consistent motor performance when they gain experience in their craft. While decorative motifs and runic inscriptions can be imitated by other members in a workshop, their carving signature is non-intentional and not easily replicable (Kitzler Åhfeldt 2002b, 8). Kitzler Åhfeldt was able to discern between individual carving signatures by taking a multitude of measurements from three-dimensional models of carved stones and calculating ten variables for each groove sample; these were then subjected to a battery of statistical tests, which identified which samples were most similar and likely to have been carved by the same person. Because this is a method that has not been employed on insular sculpture before, it is necessary to describe each variable used in this analysis and how it is measured and calculated. The process involves specialised software, *DeskArtes,* paired with a specific plugin called 'Groove Measure' which was developed for Kitzler Åhfeldt. The differences between the Swedish rune-stones Laila sampled and the Govan stones and how these differences affected my methodological approach will be considered. The statistical analyses utilised by Kitzler Åhfeldt in her various implementations of this approach and their conclusions will be summarised below, but these will be considered in more detail in Chapter 9.

5.6.1 Groove Analysis Variables

There are ten variables which are central to Kitzler Åhfeldt's work, nine of which were initially utilised by her former supervisor, Henry Freij (Kitzler Åhfeldt 2002b, 9), though these have since been refined by Kitzler Åhfeldt. These variables can be broken up into two groups: those that represent the cross-section of the groove (AvgX, AvgY, AvgZ, v, and D), and those that refer to the cutting rhythm (w, k, mindiff, plusdiff, and meddiff (Kitzler Åhfeldt 2002b, 28–33)). The measurements relating to the cross-section of the groove define the average shape of the sampled groove. Variables "AvgX", "AvgY" and "AvgZ" relate to the average depths of the groove below the uncarved surface of the stone five, three, and one units respectively from the base of the groove (See Figure 5.12). These are measured on either side of the base of the groove, and the two corresponding measurements are averaged together (for example, AvgX = (x1+x2)/2).

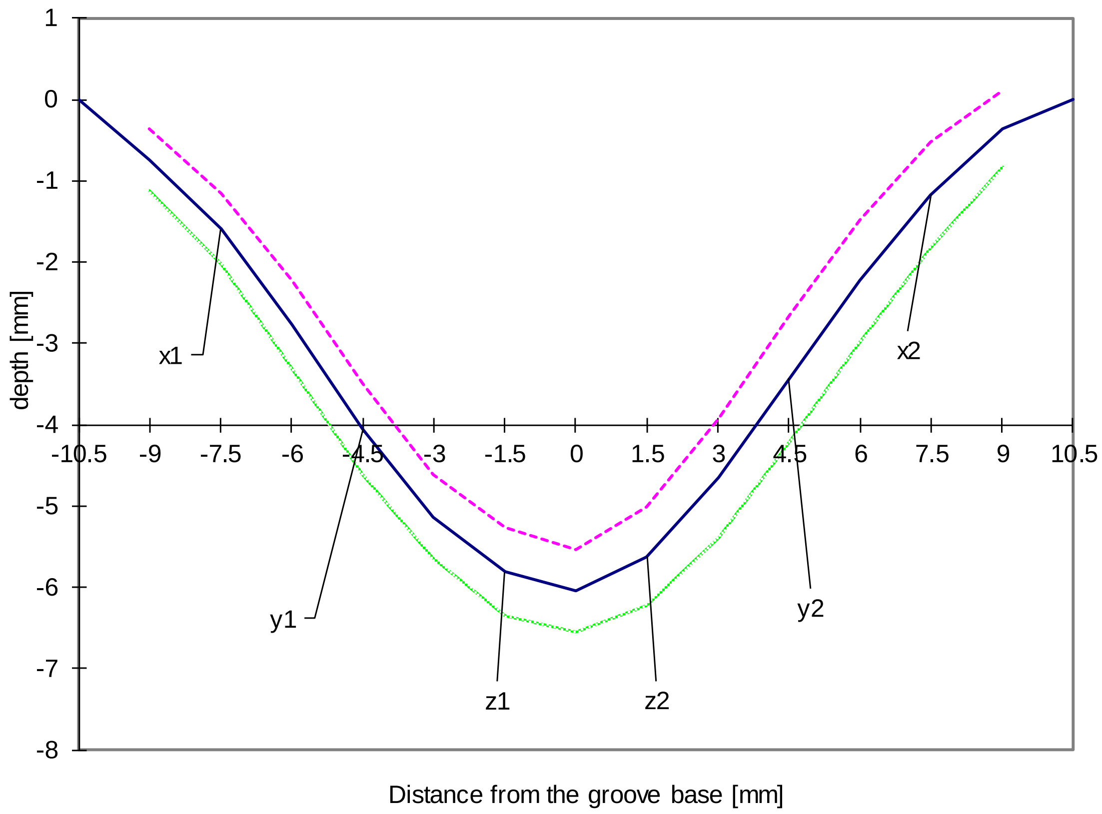


Figure 5.12. Diagram of Govan 14 sample 8 Groove Profile with labelled measurements required to calculate variables AvgX, AvgY, and AvgZ, adapted from Laila Kitzler Åhfeldt (2002, 8a).

The variable "v" is the angle formed by the groove itself; this is calculated by finding the measure of the exterior angles on either side of the average groove profile on either side of the base of the groove (for example, angle α in Figure 5.13, then flipping and repeating the process on the other side) and subtracting these from 180 degrees, the angle measure of a straight line. By finding the angle of the groove in this way, this avoids assuming symmetry in the profile of the groove. This measurement is taken from the mid-section to avoid the effects of erosion along the top edge of the groove and to account for the loss of a sharp edge on the carving tool in the base of the groove.

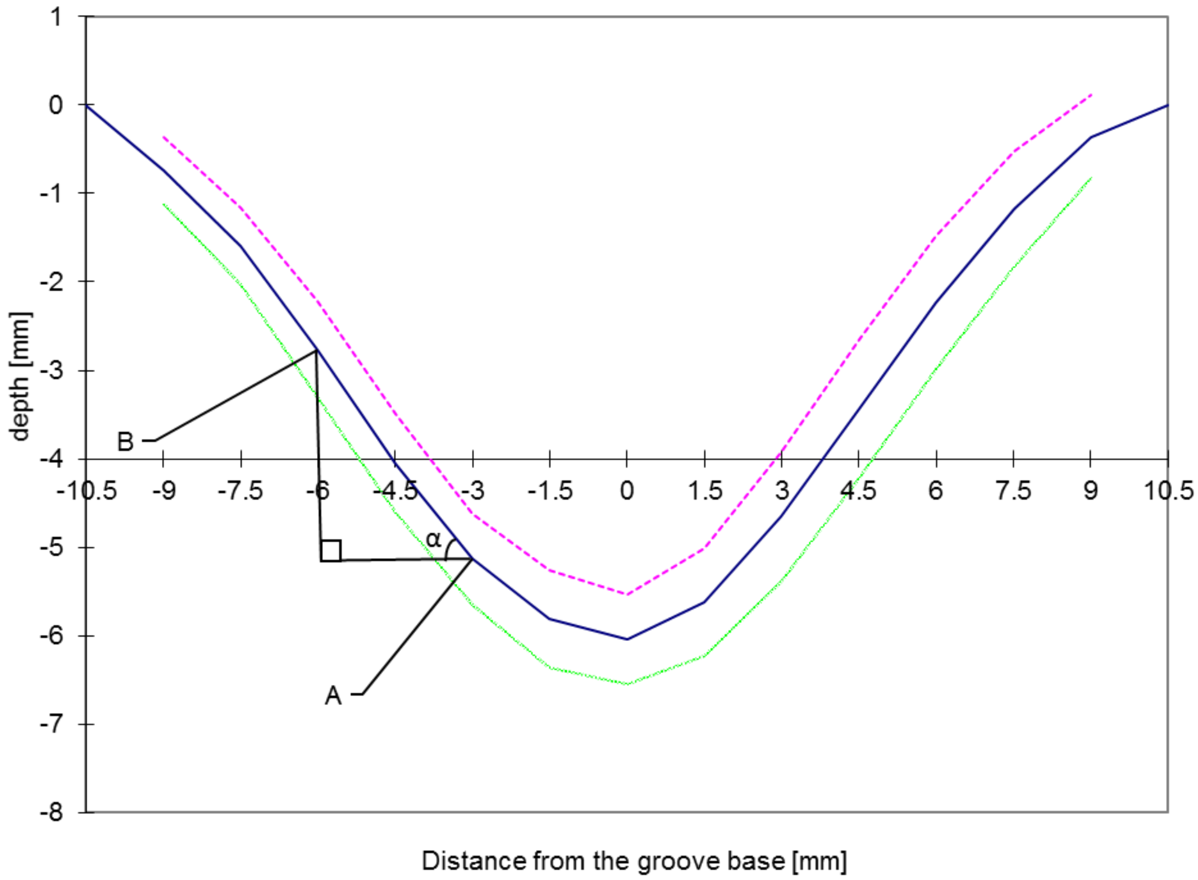


Figure 5.13. Diagram of Govan 14 sample 8 Groove Profile, demonstrating how Groove Angle variable v is calculated.

The variable "D" represents the "hypothetical groove depth", which is described as "the depth achieved if the groove-angle flanks are projected until they meet (Kitzler Åhfeldt 2002b, 31)." This variable is considered to be the depth a groove would reach if the tools used were 'perfectly' sharpened, which would presumably take a "V" shape instead of a "U" shape (Kitzler Åhfeldt 2002b, 31–33). Kitzler Åhfeldt noted that this variable can be particularly useful in identifying different sculptors on the same stone. She stated that Freij, in his unpublished manuscript, had found that Viking-Age carvers sought to create grooves with consistent widths and were less concerned about similar depths (Freij 1996; Kitzler 2000, 87). Because it takes less effort for a professional carver, who has presumably become accustomed to the repetitive motions involved with their craft, to remove more stone to create deeper grooves than an inexperienced sculptor, Laila often attributes deeper cuts in the sample to a professional (Kitzler Åhfeldt 2002b, 32-33). To calculate variable "D", the segments of the average groove profile used in the calculation of "v" are extended; the depth of the point at which they intersect is "D" (Figure 5.14).

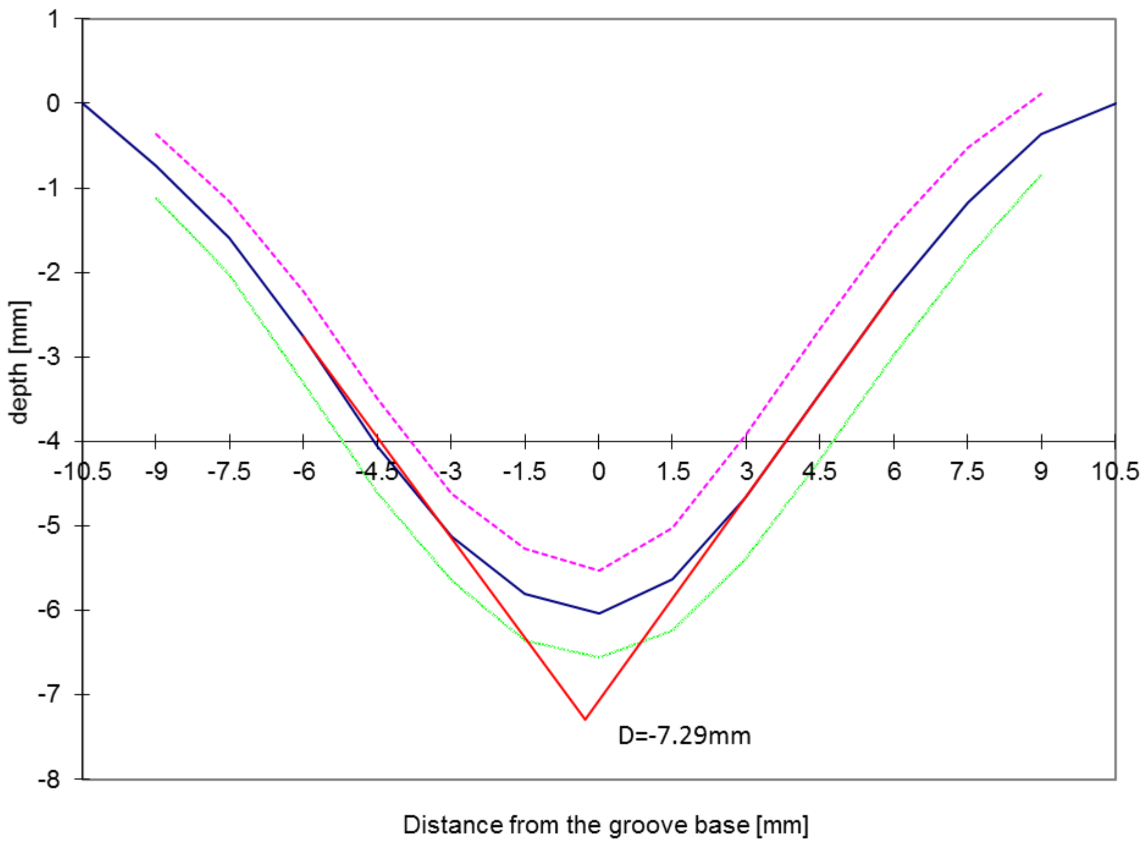


Figure 5.14. Diagram of Govan 14 sample 8 Groove Profile, demonstrating how variable D is calculated (adapted from Kitzler Åhfeldt (2002b, 8a).

The variables relating to the cutting rhythm are drawn from the measured base of the groove and its "continuous mean value"; the calculations for each of these are visualised in Figure 5.15 below. By using the continuous mean, one can identify the deepest pits from each individual hit despite the fluctuating surface of the stone (Kitzler Åhfeldt 2002b, 30). The variable "w" represents the hit interval, or the length of the wavelength of one entire cycle from when the bottom of the groove drops below the continuous mean, rises above the mean, and ends just before the base declines below the 'continuous mean' again to begin another cycle (Kitzler 1998, 92–94). In plain terms, this measures the average length of the wavelength of a single peck from the carver, including the indentation that the chisel makes, and the space or 'hump' that is left before the carver made the next peck. The variables "mindiff" and "plusdiff" break this wavelength into two segments and measure how much of the base of the groove drops below and rises above the "continuous mean value," respectively (Kitzler 1998, 92–93). Mindiff, then, represents the length of w that is formed by the peck itself – the length of the surface that falls below the continuous mean value. Plusdiff measures the length of the 'hump' or the space that was left before the carver created another peck, ie. before the groove falls below the continuous mean again. While these variables are measured in mm, he variable "k" is a ratio. It represents the "cutting rhythm," which is calculated by dividing the "plusdiff" by "w". This demonstrates how close together or far apart the pecks are from each other; if the carved indentations are consistently close together, then k will fall below 0.5 because plusdiff (the surface above the continuous mean value) is small. If there is a significant amount of space left between pecks, and plusdiff is larger than mindiff, then k will rise above 0.5. Laila refers to this as a "symmetry factor" which is thought to be a "part of motor performance that is unobservable to the unaided eye," and so can help when comparing differences in the hit interval (Kitzler Åhfeldt 2001, 137). Finally, the variable "meddiff" represents the average of the measured differences above and below the continuous mean value; essentially, this quantifies how even or 'bumpy' the base of the groove is.

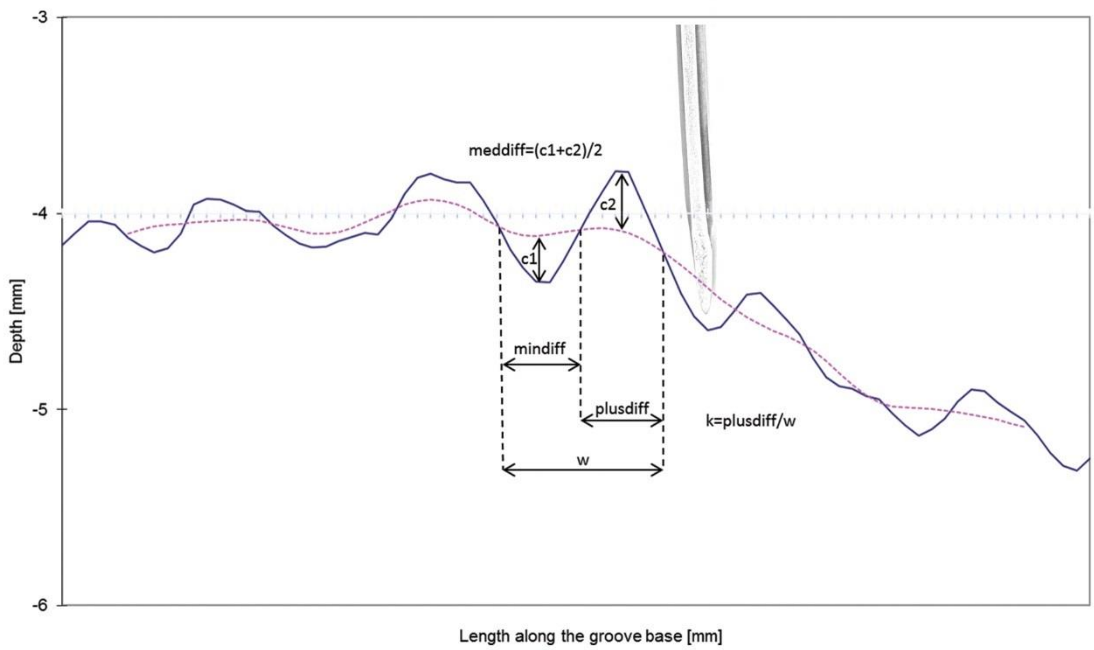


Figure 5.15. Adapted from Figure 2 in Kitzler 2000, 87; demonstrates how each of the 'hit interval' variables are calculated from the measurements taken from the base of each groove sample (sample 5 from Inchinnan 1 pictured).

5.6.2 DeskArtes Design Expert: Groove Measure Tool

Specialised software was required to obtain the measurements required for calculating these variables in a consistent way. Kitzler Åhfeldt worked together with a software designer to create a *Groove Measure* tool for use with *DeskArtes Design Expert* (Mäkelä 2007; Kitzler Åhfeldt 2009c, 90). The tool was designed to automate the data recalculations initially described by Kitzler Åhfeldt's supervisor, Freij (1996) (an unpublished manuscript cited in (Kitzler 2000, 86)). These recalculations will be described in more detail as they become relevant to the process. In addition to step-by-step tutorials in the use of the *Groove Measure* tool, Laila Kitzler Åhfeldt generously provided an Excel spreadsheet to support this research. This spreadsheet, once supplied with the output from the *Groove Measure* tool, automatically graphs the average groove cross-section and longitudinal view of the base of the groove. The tutorial provided by Kitzler Åhfeldt will be referred to as "Groove Measure Tutorial" (Kitzler Åhfeldt 2017a) and the spreadsheet will be referred to as "Groove Analysis spreadsheet" (Kitzler Åhfeldt 2017b).

In order to use this *Groove Measure* tool in *DeskArtes Design Expert*, one must first have the three-dimensional model in an STL (STereoLithography) format (the surface of the three-dimensional model is pink in Figure 5.16), as this is the only format that the software will accept. Luckily, most software packages used to create three-dimensional models will have an export option matching this file format (as Agisoft Photoscan does). After ensuring that the model is scaled to millimetres, one must align the plane of the groove to the Z axis. One then draws a curve in what appears to be the deepest part of the groove (the central, light blue line in Figure 5.16). The *Groove Measure* tool can then be activated (Kitzler Åhfeldt 2017a, 1–3).

At this point, one must choose the sampling intervals for their analysis, the parameters of which must remain the same for each sample for each stone that is to be compared. In this project, it suited the Govan collection for the cross-sections to be made every 1mm longitudinally along the groove (each of the cross-sections are visible in white in Figure 5.16 below), for fifteen samples to be taken from each cross-section, and for each of these fifteen samples to be 1.5mm apart. This resulted in cross-sections which are 21mm wide, spaced every

1mm along the groove (Kitzler Åhfeldt 2017a, 4–5). These groove samples vary in length; when taking samples, in the case of Govan, the aim was to include the longest sample possible but to avoid visibly worn areas and junctions where multiple grooves intersected. These junctions are usually much deeper than the rest of the groove, so the incorporation of these sections of the groove resulted in larger standard deviations when measuring the deepest portions of the groove.

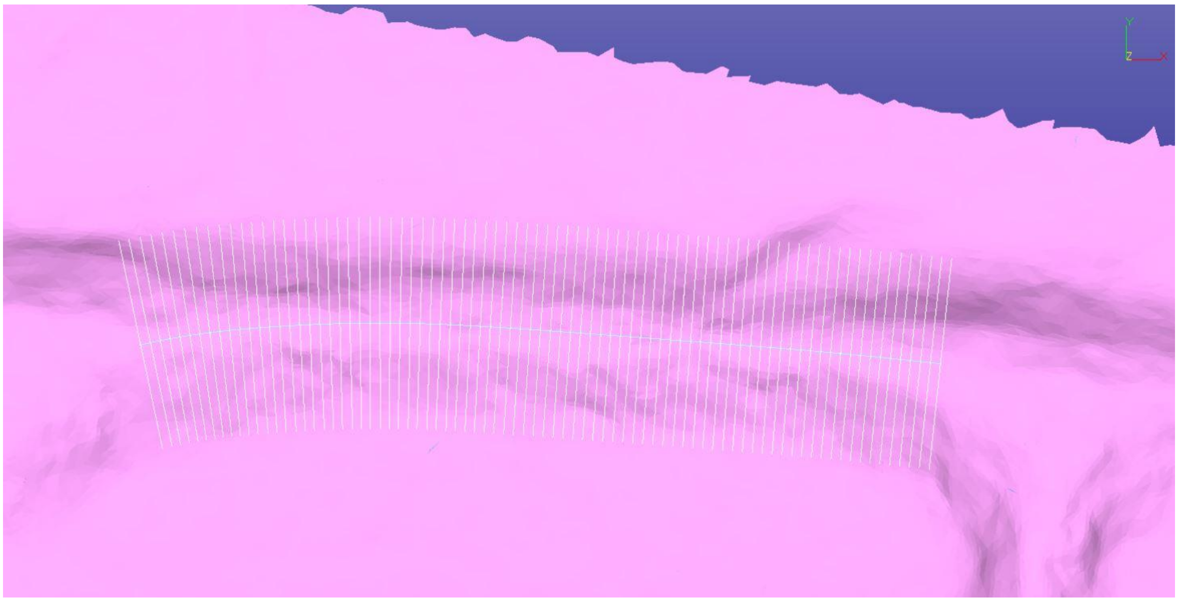


Figure 5.16. Example of Groove Sample in Deskartes software from Govan 14, with groove junctions being avoided on either end.

The software calculates the measurements and exports them into a comma-delineated text file that can be opened by most spreadsheet-based software packages, like Microsoft Excel. Behind the scenes, the software 'straightens' the groove (Kitzler 2000, 86; Kitzler Åhfeldt 2012a, 69); this results in a fifteen-column-wide spreadsheet of measurements for each cross-section with the deepest measurements aligned in the centre of the spreadsheet. An example of this will be added in Appendix B. This data is then directly copied into the template so generously provided by Kitzler Åhfeldt, which then produces a diagram of the average groove profile, a diagram of a longitudinal section of the groove, and calculates each of the variables according to the principles outlined above (2017b).

5.6.3 Statistical Analysis

The following will describe the general statistical methods by which Laila Kitzler Åhfeldt analysed her runestone samples in various studies. She worked with two groups of modern runecarvers and their carved work to test and refine her statistical approach in identifying individual carving techniques. It is also essential to note here that, in her research, these statistical analyses were applied to the samples taken from decoration of the runestone and samples from the runes themselves separately. She argued that one carver might have two different carving techniques for these separate elements of the runestone's design (2002b, 35). She also developed a method for matching these separate signatures to a single individual, which will be discussed more thoroughly in Section 5.6.4 below.

Laila Kitzler Åhfeldt first carried out Principal Component Analysis (PCA) on the reference material sampled from the work of modern runestone carvers to identify the variables which accounted for the most variation in the samples. PCA is a statistical process used to reduce many variables to fewer variables that can be better interpreted by researchers and represents the overall patterns of variation in the dataset. Essentially, PCA identifies sets of variables 'that all show strong correlations with each other area all responding to the same underlying thing and that these variables could, in some sense, be replaced in the dataset by a single variable with little damage to the overall patterning…that characterises the original dataset' (Drennan 2010, 300). Reducing the number of factors involved in the analysis helps to avoid overrepresenting certain elements of the groove measurements – in Kitzler Åhfeldt's analysis, AvgX, AvgY, AvgZ, v and D were all identified as correlating variables under PC1, which she defined as those that represent the "Groove Profile Shape". After plotting the first two factors (representing ~51.7% of the total variance explained by the Groove Profile Shape, ~25.9% of the variance explained by the Cutting Rhythm (specifically variables w (wavelength), plusdiff (space between pecks) and mindiff (length of carved indents))), it became apparent that the Groove Profile Shape most clearly distinguished between the individual modern carvers. Factor 3 accounted for ~12.3% of the total variance and was most influenced by k, the rhythm of the groove cutting, and Factor 4 accounted for ~6.3%, which was most influenced by ADIFF (meddiff), which represents the 'amplitude of the variation in a longitudinal direction' (Kitzler Åhfeldt 2002a, 88–90), or the smoothness or bumpiness of the base of the groove.

Because the variables relating to Groove Shape clearly distinguished between the work of the modern sculptors, to apply these statistical findings to the samples from ancient runestones, she began by visually identifying clusters in plots of the variables representing groove profile shape (AvgX, AvgY, AvgZ) (Kitzler Åhfeldt 2002a, 90–91, 98). Once these clusters were identified, she used Discriminant analysis to determine if any clusters on the same stone belonged to the same carver and removed any outliers. For each of these clusters, she calculated the mean for the v, AvgZ, k, w, and meddiff (then labelled ADIFF) variables for each cluster (Kitzler Åhfeldt 2002a, 98). These were then standardized, a statistical process that allows for a more real comparison between variables of different measurement types (for example, comparing length to weight, or in this case, the measurement of an angle to depth). To do this, "for each variable, the mean of the batch for that variable is subtracted from each number in the batch, and the remainder is divided by the standard deviation (Drennan 2010, 275)." Even in variables that are measured in the same units, but with different scales of difference between each example, this process of standardization makes these variables more comparable to each other. The differences between individual samples for a particular variable are then measured by their Euclidean distance in terms of standard deviations from the mean (Kitzler 1998, 93; Drennan 2010, 275–276).

After the variables for each cluster were standardized, Kitzler Åhfeldt used Hierarchical Cluster Analysis by Ward's method and Euclidean distances to amalgamate similar clusters between stones within a potential workshop, treating runic and ornamental samples separately (Kitzler Åhfeldt 2002a, 92–93, 98). The number of clusters then theoretically corresponds to the number of individuals that worked on a group of stones. In some cases she was able to link the style of a runographer with the type of carving used to create ornament by considering the relative distances in the Discriminant analysis and creating case profiles by standardizing the mean values of the variables v, AvgZ, k and w and graphing them (Kitzler Åhfeldt 2002a, 94–96, 98). When comparing two probable workshops (indicated by different runic signatures), she created a table comparing the mean variables between different clusters and the group/workshop as a whole (Kitzler Åhfeldt 2002a, 96, 98). While this process is incredibly complex, it has offered new insight into the organisation of Viking Age runestone carvers.

Her studies have overwhelmingly indicated that in most cases, no matter the size of the monument, multiple carvers have worked together to produce these runestones (Kitzler Åhfeldt 2001, 154; Kitzler Åhfeldt 2002a, 100). When comparing runestones signed with 'Öpir' to those signed 'Fot,' the greatest difference in carving technique was between individuals, rather than between the groups. Kitzler Åhfeldt also suggested that individuals within a workshop do not develop similar cutting techniques, and that the greatest similarities could be between the masters of each workshop. She also posited that the same group of sculptors could have carved both groups of runestones, although under different authority figures (Kitzler Åhfeldt 2002a, 99). While she often stated that there are issues with comparing samples from runes and ornament (Kitzler 1998, 93; Kitzler Åhfeldt 2000, 113), in the case of the Sparlosa monument she surmised that three carvers were present: one who carved a much later runic inscription, and two that created the original runic inscription and ornament. One of the original carvers cut deep, narrow grooves whether it was runic inscription or ornament, while the other's grooves were much shallower (Kitzler Åhfeldt 2000, 116). It is hoped that the application of this analysis to the collection of carved stones at Govan will offer similar insight into how the individual carvers were organised.

5.6.4 Difference in Datasets: Rune stones vs. Govan methodology

Initially it was unclear if this analysis would be compatible with the sculpted stones of Govan due to the differences in material and form from Kitzler Åhfeldt's runestones. Most of the stones used in her analyses were made from crystalline rock, apart from eleven sedimentary rune stones analysed in her thesis (Kitzler Åhfeldt 2002b, 21, 40–41, 45), and so the vast majority are more resistant to weathering and wear than the sandstones and siltstones that make up the Govan collection (Chadburn 1994, 146). The carving technique also differs between the two groups – the runes and decoration of the rune stones are characterised by incised carved lines, while the Govan stones have been cut in a deeper, shallow relief technique with liberal use of pecking, where more stone has been removed to form the patterns. Finally, runestones have the benefit of exhibiting runes, which can be roughly dated by form and can sometimes include a signature, although whether the signature belongs to the master carver, the workshop, or someone else entirely is still up for debate (Kitzler Åhfeldt 2001, 130–132). Nevertheless, the presence of runes provides another source of relative dating that is absent in the case of the Govan stones; the relative dating of the Govan sculpture relies on art historical analyses which are largely based on comparisons with other groups of artefacts and monuments from other sites.

The most significant difference between the two groups is that many of the Govan stones have been significantly and, most importantly, differentially worn, while the majority of the Swedish runestones are minimally-worn granite. When choosing sample locations, the least visibly worn areas of the decoration were chosen, but it became apparent that it was necessary to test whether or not wear would have a significant impact on identifying different carving techniques. To combat these differences, the best option was to wear down a model, in this case Govan 7, to simulate an estimation of a millennia of weathering and/or footfall (Figure 5.18). While the application of this ‘digital wear’ was not necessarily based on geological studies, it was informed by Laila Kitzler Åhfeldt’s discussion of Swantesson’s work and Kitzler Åhfeldt’s projected impact by trampling and weathering on grooves (Figure 5.17; Kitzler Åhfeldt 2002a, 87). While these weathering processes might have affected these surfaces in different ways, the base of the groove is the least likely area to be affected by these processes. The visible tooling in the base of the grooves is testament to this. For these reasons, it can be confidently stated that statistically significant results can be obtained from the Govan material as long as these factors are taken into full consideration.

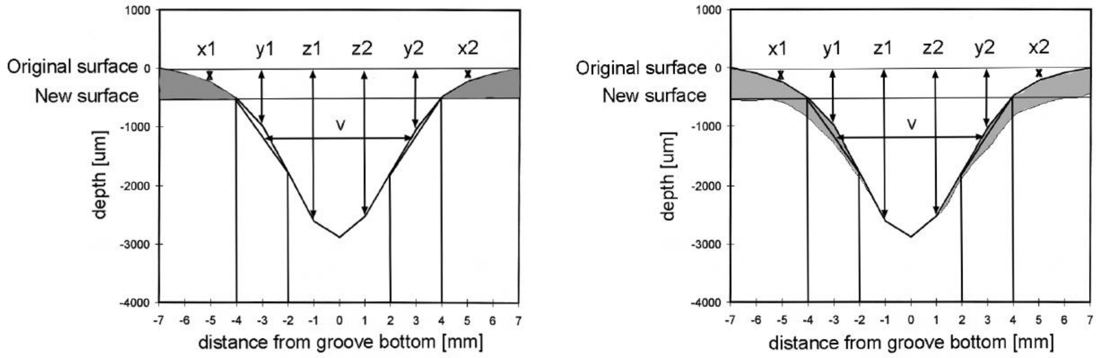


Figure 5.17. Example of how trampling and weathering may influence a groove, from Figure 10 and 11 in Kitzler Åhfeldt 2002a.

To test how differential wearing of the stone might influence the allocation of a worn groove sample to an incorrect carver group, eight samples were taken from three ornamented panels of Govan 7 (Jordanhill Cross). The same 3D model of this stone was then worn using the procedure outlined in Section 5.4.2, using the 'Trim Dynamic' tool in Zbrush to digitally 'wear' the stone down. The corresponding grooves were then sampled on this worn model, resulting in a small dataset of 8 worn and 8 unworn paired samples (See Figure 5.19 and Figure 5.20; Table 5.1 and Table 5.2). If this analysis can allocate the corresponding worn and unworn pairs to the same 'carver signature', then the effects of wear can be mitigated against in Groove Analysis.

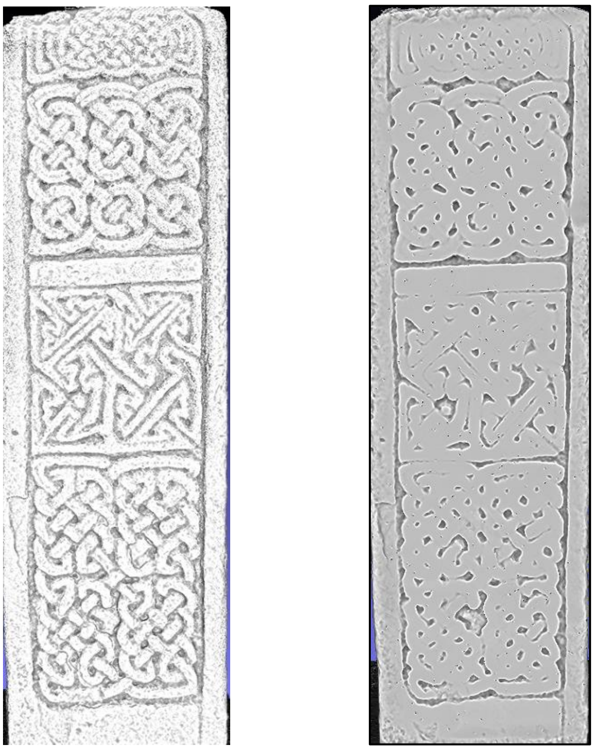


Figure 5.18. Unworn (left) and worn (right) images of the Govan 7 3D model.

Table 5.1. Variables corresponding to the set of unworn/worn samples illustrated above in Figure 5.19 and Figure 5.20. Several variables appear to be more resistant to wear than others, especially those that rely on measurements taken from the base of the groove.

SAMPL _NR	V	D	AVGX	AVGY	AVGZ	MIN DIFF	PLUS DIFF	MED DIFF	W	K	N
701	111.66	-6.54	-1.89	-4.51	-6.56	4.38	4.75	0.15	9.13	0.52	16.00
710	131.67	-2.77	-0.24	-1.05	-2.40	3.56	4.56	0.15	8.11	0.56	18.00

Table 5.2. Table showing the pairs of corresponding unworn and worn samples (note - 703 and 712 were deemed unreliable, likely from an error in the software, and were removed).

Unworn Samples	Worn Samples
701	710
702	711
704	713
705	714
706	715
707	716
708	717
709	718

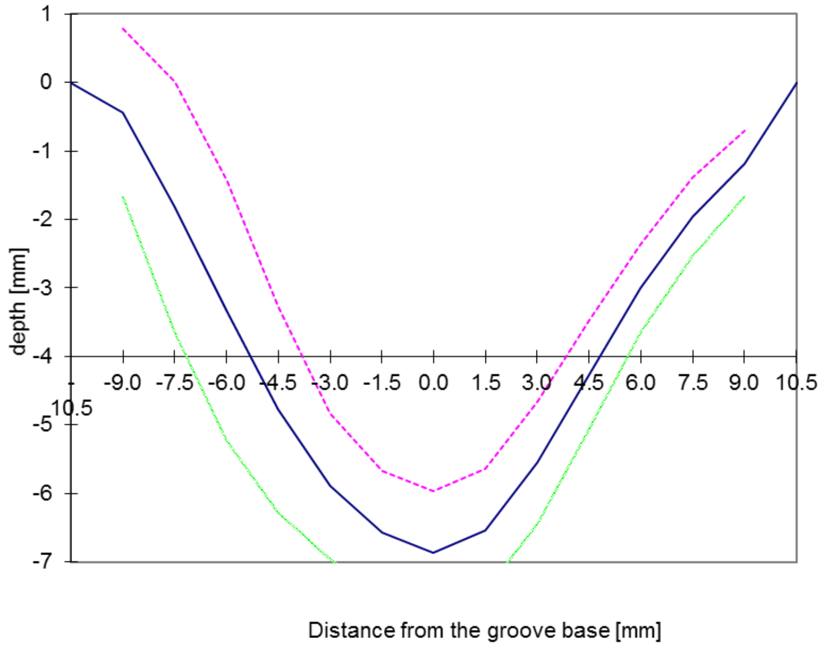


Figure 5.19. Groove profile of one unworn sample from Govan 7 (SAMPL_NR701).

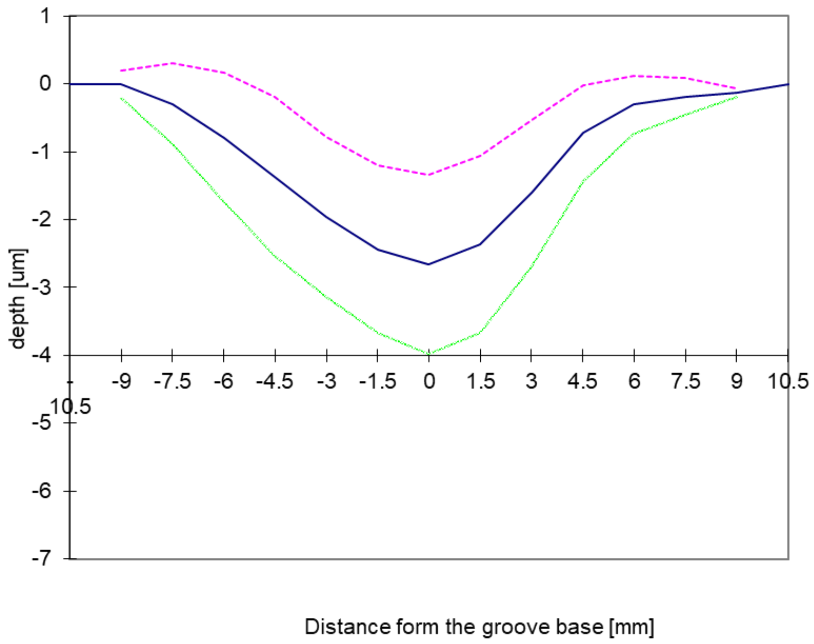


Figure 5.20. Groove profile from the same carving segment as above in Figure 5.19, although digitally worn (SAMPL_NR 710).

As mentioned above, in Kitzler Åhfeldt's analysis, she treats the samples from the runes and the decoration of the runestones as separate populations; she states that 'runes are usually more deeply carved but with a longer hit interval than in the ornament' but that sometimes the runographer can be connected to their ornament through the development of a ‘case profile’ (Kitzler Åhfeldt 2002b, 35). She standardizes the variables for the runes and ornament separately, identifies clusters separately, then compares the standardized means of the variables of their case profile to determine if they were created by the same individual.

The worn and unworn samples of Govan 7 can be treated in much the same way. By standardizing the worn samples separately from the unworn samples, the values of the variables from the worn samples reflect their relative distance from the new mean, 0, but are scaled to be more accurately comparable to the unworn samples, whose new mean is now also 0. All sixteen standardized samples can now be analysed as one population. By conducting a Hierarchical Cluster Analysis based on Ward’s method and the squared Euclidean distance between points using the standardized zAvgZ variable, which measures the depth closest to the base of the groove, these samples can be separated into three distinct clusters (Figure 5.21**Error! Reference source not found.**). The paired worn and unworn samples have been allocated into the same carver groups, despite AvgZ being one of the most heavily impacted variables by the digital wear (see Table 3 for correlating pairs). In fact, when worn and unworn groups were subjected to Hierarchical Cluster Analysis separately, AvgZ is the only single variable that reliably resulted in the corresponding pairs of worn and unworn samples being assigned to the same groups alone. However, the variation in the other cluster analyses based on different variables may be reacting to underlying relationships between the carver groups 1 and 3. This relationship between these two groups is still apparent when viewing the dendrogram comparing the standardized AvgZ values, but their subgroups (Group 1 = carvers 1 and 4 and Group 3 = Carvers 3 and 6) more accurately group the pairs of worn and unworn samples (see Table 5.4, Table 5.5, Figure 5.22, and Figure 5.23).

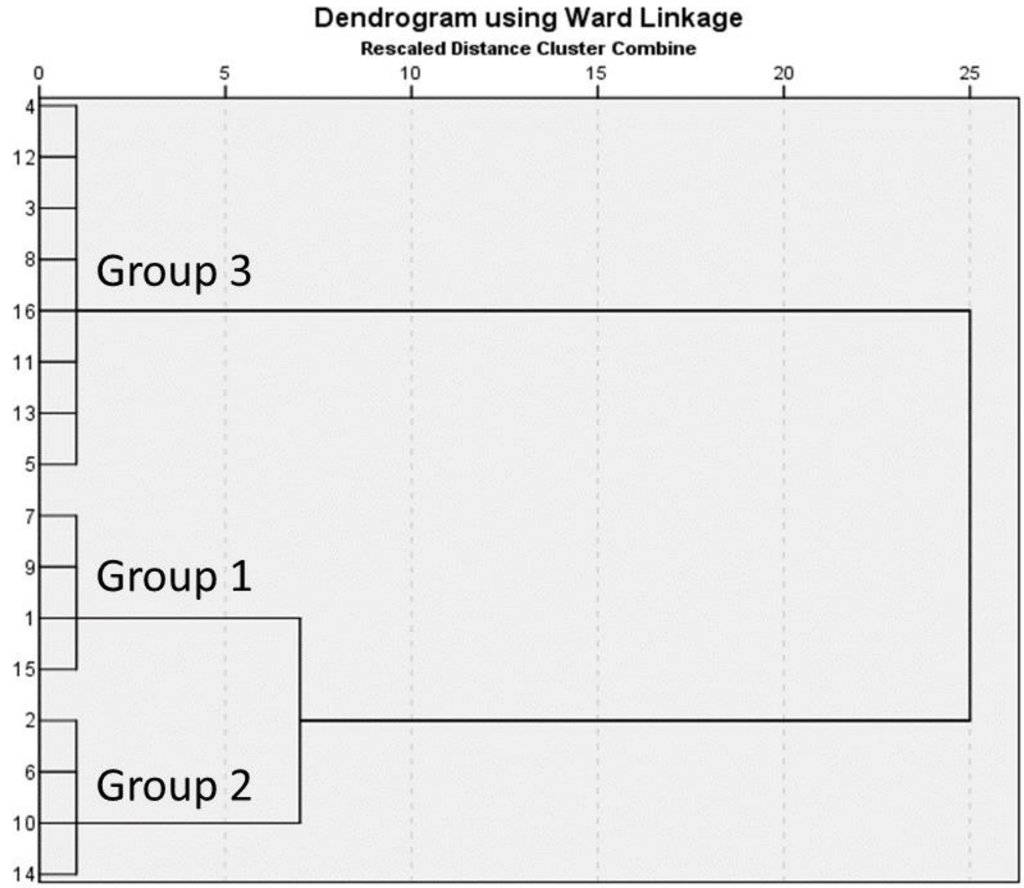


Figure 5.21. Hierarchical Cluster Analysis Dendrogram using Ward Linkage based on the standardized AvgZ variable, which shows the consistent clustering of the corresponding standardised worn and unworn samples (Refer to Figure D.1 for guidance on how to read Dendrograms).

Table 5.3. Concordance for SPSS sample numbers used in Figure 5.21.

Unworn Sample	SPSS Sample	Worn Sample	SPSS Sample
701	1	710	9
702	2	711	10
704	3	713	11
705	4	714	12
706	5	715	13
707	6	716	14
708	7	717	15
709	8	718	16

Table 5.4. Unworn groove carver profiles based on the above groups in Figure 5.21. Standardised variables are preceded by the letter 'z'.

Carvers	v	mindiff	AvgZ	plusdiff	k	w	zv	zmindiff	zavgz	zplusdiff	zk	zw
1	115.0	5.4	-6.4	6.0	0.5	11.4	0.6	0.7	-0.1	1.1	-0.5	0.8
2	91.2	2.9	-7.9	5.3	0.6	8.2	-1.2	-1.1	-1.0	-0.7	1.2	-1.1
3	113.3	5.0	-4.7	5.4	0.5	10.4	0.5	0.5	1.0	-0.4	-0.7	0.3

Table 5.5. Worn groove carver profiles based on the above groups in Figure 5.21 (Carver 4 corresponds to Group 1, Carver 5 to Group 2, and Carver 6 to Group 3). Standardised variables are preceded by the letter 'z'.

Carvers	v	mindiff	AvgZ	plusdiff	k	w	zv	zmindiff	zavgz	zplusdiff	zk	zw
4	135.5	3.3	-2.2	4.9	0.6	8.2	0.1	-0.3	0.1	-0.7	-0.2	-0.5
5	103.3	3.0	-4.5	5.0	0.6	8.0	-1.0	-0.8	-1.1	-0.5	1.1	-0.7
6	159.1	4.0	-0.7	5.7	0.6	9.7	0.9	1.1	0.9	1.1	-0.9	1.1

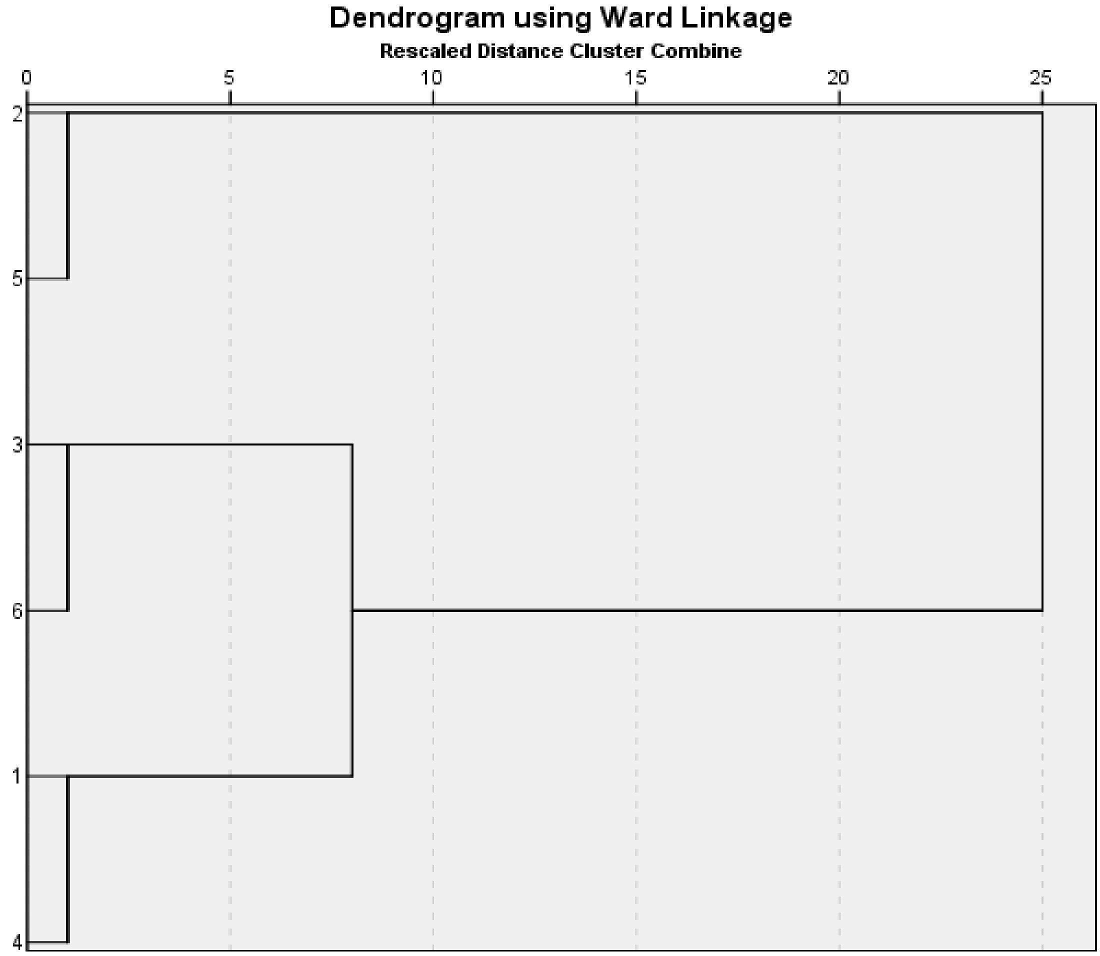


Figure 5.22. Hierarchical Cluster Analysis Dendrogram using Ward Linkage based on only the standardized zAvgZ variable. This method results in the worn and unworn pairs being assigned to the same groups (Clusters 2 and 5, 3 and 6, and 1 and 4 are paired).

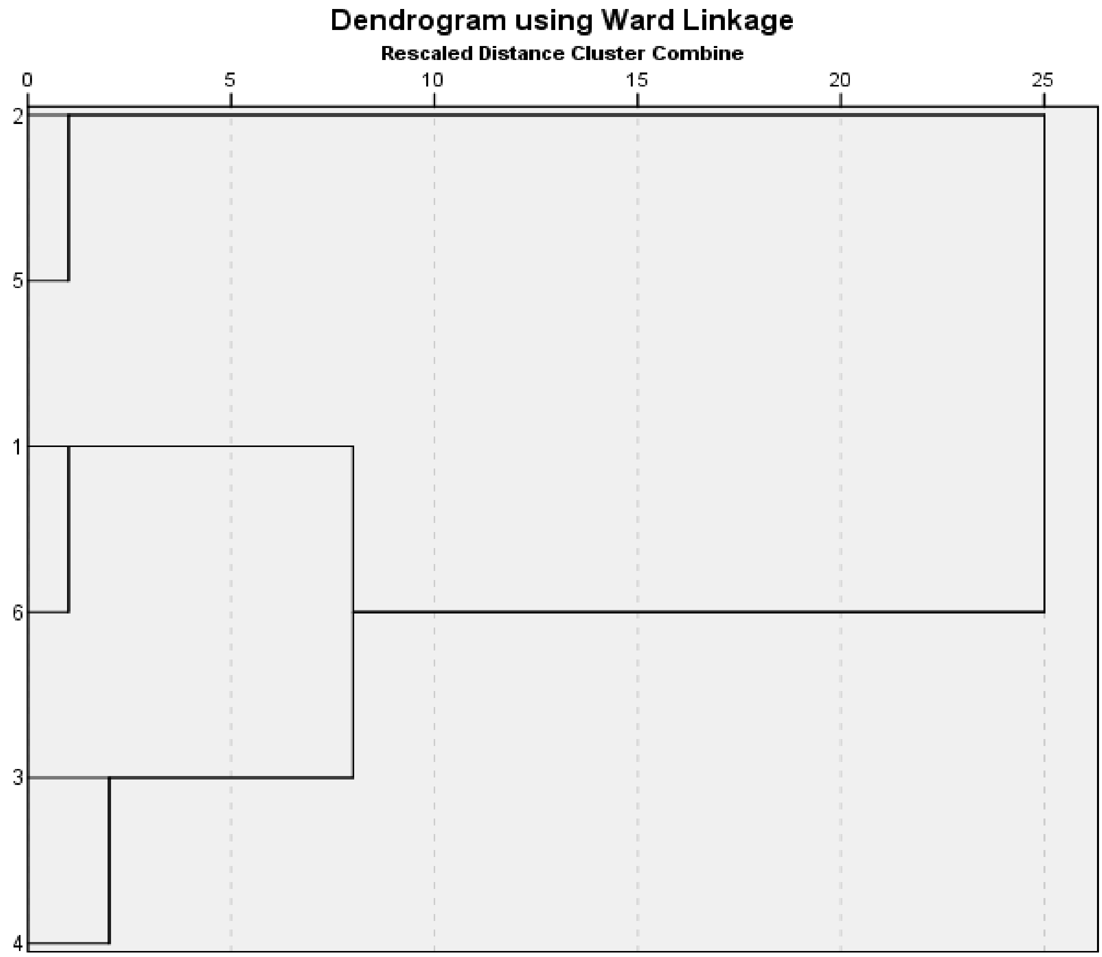


Figure 5.23. Hierarchical Cluster Dendrogram using Ward Linkage based on all standardized variables (zv, zAvgz, zmindiff, zplusdiff, zk, zw), showing the close relationship between carver profiles 2 and 5, 1 and 6, and 3 and 4. This method does not result with the worn and unworn samples in the same clusters.

The standardized values for each of these clusters can be considered as a 'case profile'; when compared side-by-side, it is apparent how similar they are and how the hierarchical cluster analysis grouped the profiles. Below, it is apparent why clusters 2 and 5 are routinely paired by the analysis – their profiles match in almost every categorical variable (Figure 5.24). However, when the other profiles are compared directly, those relationships become less clear. If we take the other 'more correct' clusters that group the most correlating unworn and worn pairs together based on the standardized AvgZ alone (Clustering 1 and 4 together and 3 and 6 together), AvgZ and k are the most influential variables holding these clusters together (See Figure 5.25 and Figure 5.26). Out of the two pairings, clusters 3 and 6 appear to be more closely related in overall case profile shape than clusters 1 and 4, apart from the large 1.5 standard deviation difference between their standardized plusdiff variables.

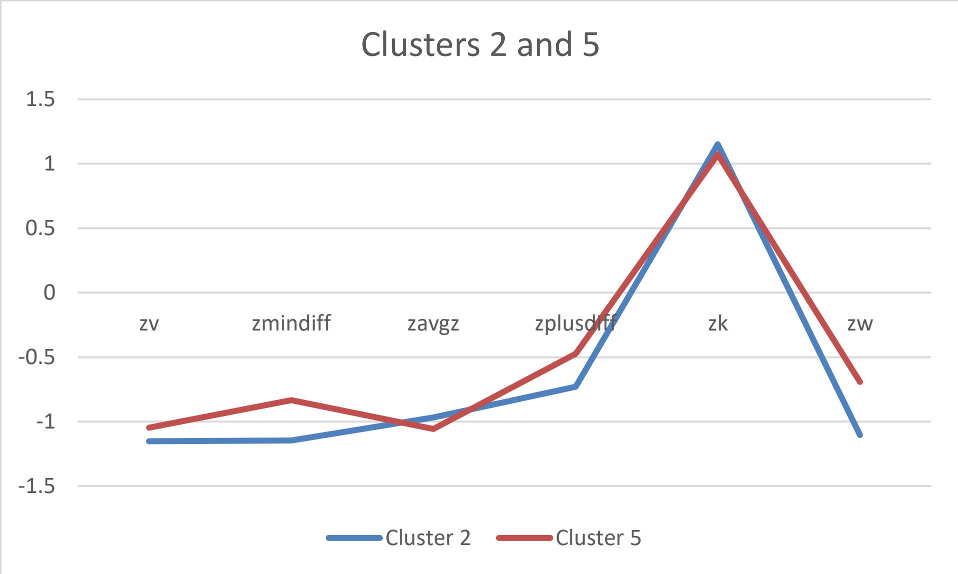


Figure 5.24. Case profiles of Clusters 2 and 5 compared; paired using HCA with Ward Linkage based on zAvgZ. These case profiles are virtually identical in every variable, despite the random wear applied to the samples in Cluster 5.

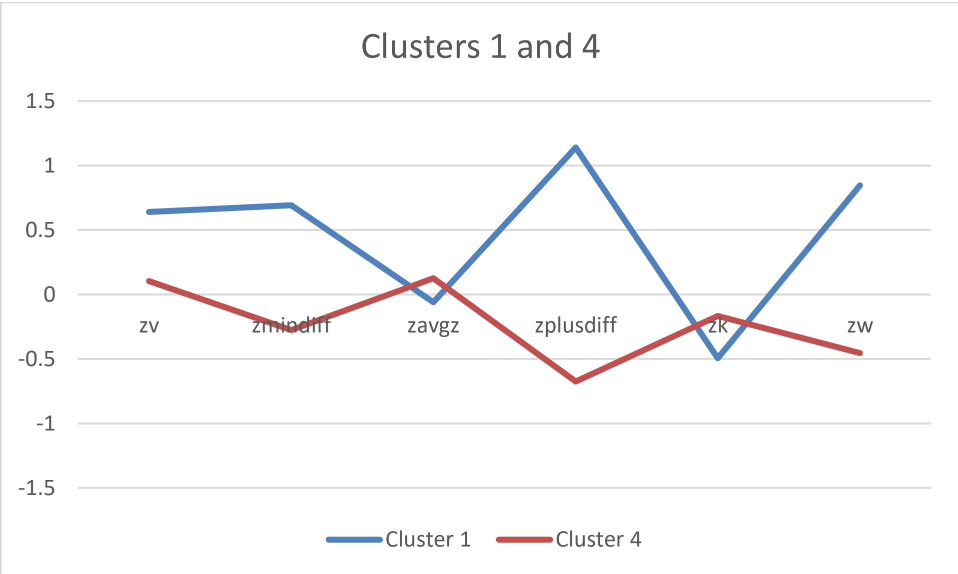


Figure 5.25. Case profiles of Clusters 1 and 4 compared; paired using HCA with Ward Linkage based on zAvgZ. ZAvgZ (depth 1.5mm from the base of the groove) and zk (carving rhythm) offer the closest correspondence between the case profiles; the lack of consistency in other aspects of carving suggests the work of a novice.

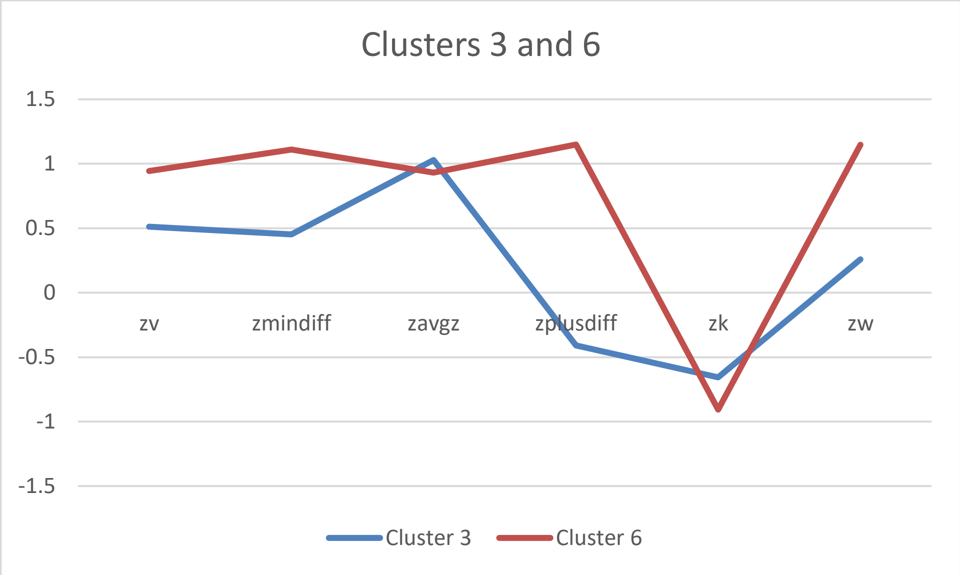


Figure 5.26. Case profiles of Clusters 3 and 6 compared; paired using HCA with Ward Linkage based on zAvgZ. Again, zAvgZ and zk are providing the closest similarities between the case profiles, though zv (groove angle) and zmindiff (length of the carved peck) are less than a standard deviation apart.

If we instead look at the pairings of case profiles suggested by the Hierarchical Cluster Analysis using all six standardized variables, we see again that the case profiles for clusters 2 and 5 are paired together again because they are nearly identical (Figure 5.27). The comparison between the case profiles of clusters 1 and 6 appear much more similar in overall shape (Figure 5.28), as do the case profiles of clusters 3 and 4 (Figure 5.29), although they differ greatly in terms of their AvgZ (unsurprising, as the software took all six variables into consideration when comparing these groups). In both dendrograms, the relationship between clusters 1, 3, 4, and 6 is suggested; when all four case profiles are plotted on a line graph, while it initially appears to be jumbled, each of the four profiles have something in common with the other three (Figure 5.30). This situation highlights the subjectivity of determining the number of clusters based on the Hierarchical Cluster Analysis Dendrogram (Kitzler Åhfeldt 2002b, 34). If these six groups of samples were attributed to two carvers, clusters 2 and 5 may have been created by a more skilled carver, while clusters 1, 3, 4, and 6 belong to a less skilled carver.

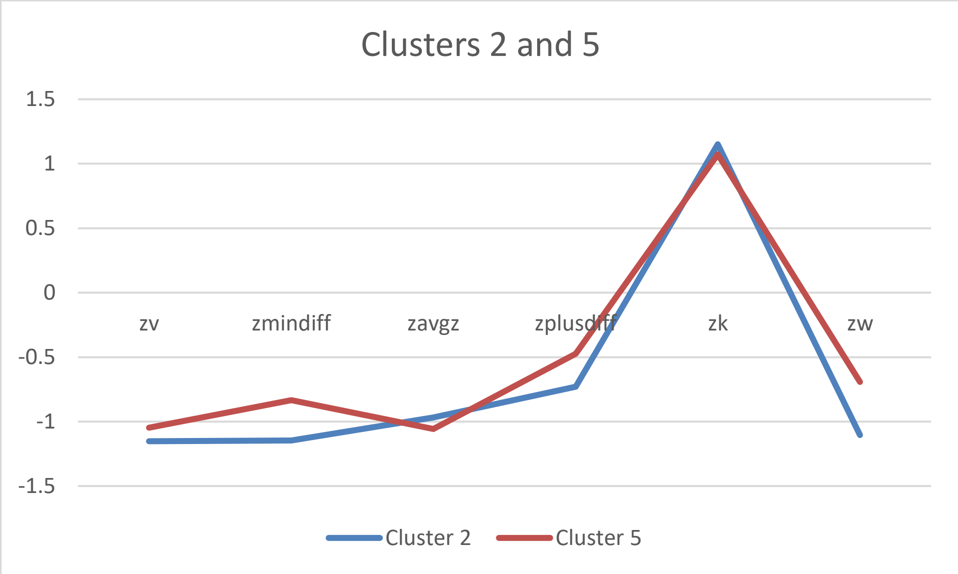


Figure 5.27. Clusters 2 and 5 paired using HCA with Ward Linkage based on all six variables. As above in Figure 5.24, their profiles are virtually identical.

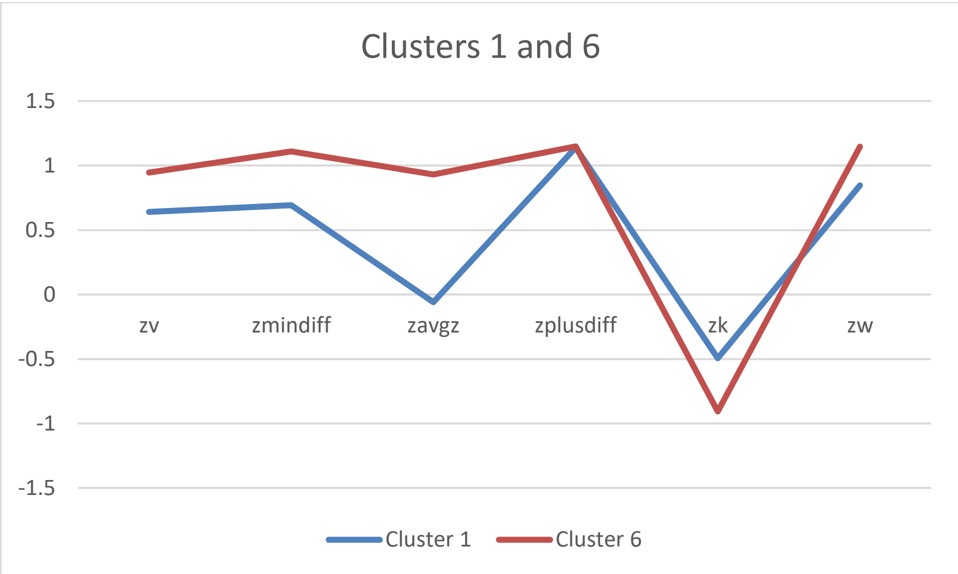


Figure 5.28. Clusters 1 and 6 paired using HCA with Ward Linkage based on all six variables. Because more variables are involved defining the HCA, a more similar match is made than in Figure 5.25 and Figure 5.26.

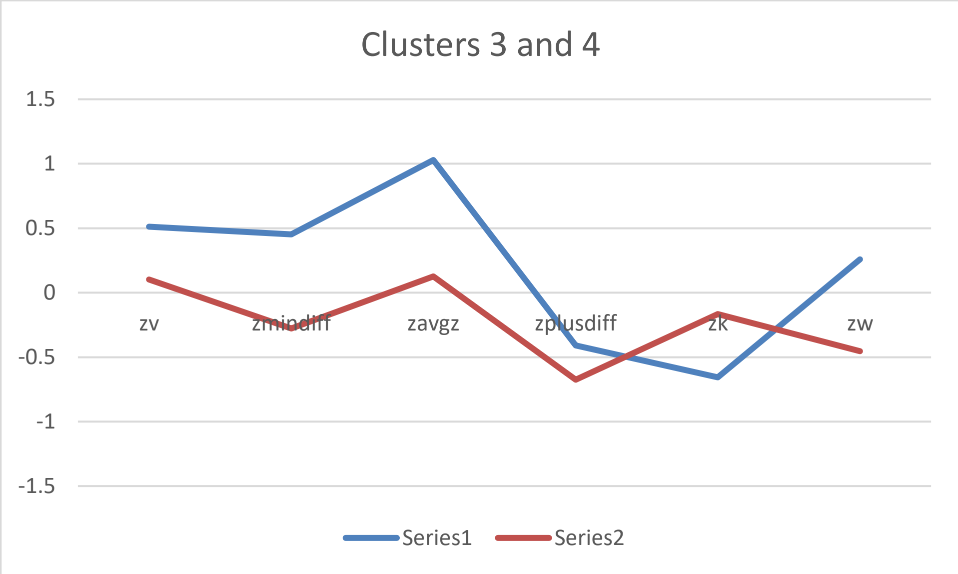


Figure 5.29. Clusters 3 and 4 paired using HCA with Ward Linkage based on all six variables. Because more variables are involved defining the HCA, a more similar match is made than in Figure 5.25 and Figure 5.26.

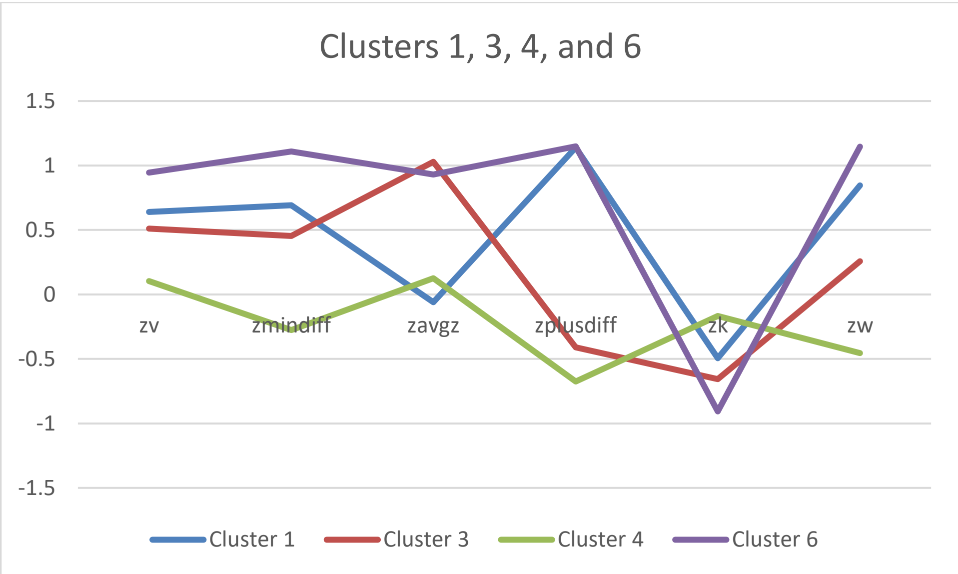


Figure 5.30. Clusters 1, 3, 4 and 6 compared. By including all on the same graph, it is clear that all four profiles coincide at different points. It is likely that clusters 1, 3, 4 and 6 were all carved by the same carver, but the inconsistency in technique suggests the carver was a novice.

Because each pair of worn and unworn samples are known to have been carved by the same individual (the only difference being the extreme application of wear), and the application of the methodology outlined by Kitzler Åhfeldt (2002a, 98) has assigned these pairs to the same clusters after standardizing the worn and unworn samples separately, it is clear that Groove Analysis can be applied in a way that is resistant to the effects of differential wear. This analysis can offer new insight into the carvers of the Govan school of sculpture, despite the interference introduced by differential weathering. This separation of samples is also quite useful when samples are taken from carving intended to be done at different depths – as will be seen in Section 9.4.1 in the analysis of Govan 1, where samples were taken from grooves forming the shape of interlace and those bisecting strands of interlace.

The reason so much of this discussion has been spent determining whether these variables are reliable in the case of worn stones is because, as described above, Laila Kitzler Åhfeldt has found that the work of the modern rune-carvers could be distinguished from each other primarily through the variables relating to the groove depth/shape (Kitzler Åhfeldt 2002a, 89–90). In the case of worn monuments, Kitzler Åhfeldt recommended that the research should 'give consideration to the shape of the groove angle rather than the depth values' (Kitzler Åhfeldt 2002a, 88). However, from the above exercise, it is apparent that if the worn samples are treated as a different 'type' of carving than relatively unworn carving, there is still the potential to identify shared carvers between them. With the amount of wear that has undoubtedly affected the sedimentary stone forming the Govan collection, it was important to establish that this can be mitigated against.

In addition to the differences in the sampled material, the methodology used here differs in terms of data capture. Although Kitzler Åhfeldt's work initially used a combination of plasticine casts and a laser scanning probe (Kitzler 2000, 86) and now uses a newer, more portable laser scanner (Kitzler Åhfeldt 2009c, 89–90; Kitzler Åhfeldt 2012a, 67), this analysis will be using Structure-from-Motion photogrammetry. While Kitzler Åhfeldt does mention early on that it is possible that the groove analysis could work with photogrammetry (Kitzler 2000, 96), often there are doubts as to photogrammetry's accuracy at the millimetre level in the digital imaging community (for examples, see Lerma et al. 2014; Rabinowitz 2015, 28, among others). It is clear after taking samples from the three-dimensional models created for this project that the photogrammetric workflow outlined above in the methodology produces models that are sufficiently accurate for this analysis.

Finally, there are difficulties in deciding how to interpret the results if clusters can be matched between stones and case profiles built up for the individual Govan sculptors. While Kitzler Åhfeldt used runic inscriptions as a means to date the runestones and provided potential interpretations as to the meaning of the inscriptions (like the name of master carvers, the workshop, or different authorities), the carved stones at Govan lack any sort of inscription. The collection at Govan does have the benefit of being from a relatively restricted location in comparison to the Swedish runestones, but subtle changes in phasing over time or identifying sub-groups of sculptors may be difficult. A certain degree of inference may be possible through art historical comparisons or by considering the results in context of the newly developed typology from Chapter 8. Although there will be differences in the information that can be gleaned from the Govan collection in comparison to Kitzler Åhfeldt's analysis, the principles are the same.

In conclusion, while there are many differences between the Govan stones analysed in this study and the Swedish runestones of Kitzler Åhfeldt's pioneering work, it is believed that this Groove Analysis and the other analyses outlined in the preceding sections of this chapter, the exploration of these digital assets will offer new insight into the Govan stones and how their creators approached their work.

5.7 Data Management and Accessibility

As outlined by the London Charter for the Computer-Based Visualisation of Cultural Heritage, not only should the methods of data capture and use in research be rigorously described, but so should one's process, formats, and standards be recorded (Denard 2009, 4; ScARF 2016). After spending an extensive amount of this chapter discussing the data capture and research methods, the management of this data and plans for making it accessible must also be addressed. For digital resources, it is especially difficult to ensure that the information does not fall out-of-date and cease to be useful (Jeffrey 2018, 53; Richards et al. 2013, 312). Plans for the continued use and maintenance of the dataset should be decided early in the process of proposing a project. To prevent loss of knowledge, digital data should be archived with services like the Archaeology Data Service (ADS) in the United Kingdom or Digital Antiquity in the United States. These services protect the data from a range of issues, including data corruption, where the physical media containing the data become damaged or degrade, and obsolescence, where once-popular file formats or software fall out of use and are replaced (Jeffrey 2012, 556). The cost for this archival should be worked into the project's budget well beforehand. The Corpus of Anglo-Saxon Stone Sculpture project and CRSBI (The Corpus of Romanesque Sculpture in Britain & Ireland) are examples of digitisation projects that have successfully survived intact for over fifteen years. In the case of this research, the files created for this project will be archived with both the University of Glasgow's data repository (known as Enlighten) and Historic Environment Scotland.

Due to the nature of this project, a relatively large digital dataset has been produced, including thirty-one scaled photogrammetric 3D models, which are composed of 7,866 individual photographs in total, and 20 RTI files, which, between them, consist of 1,322 photographs. File names for the Agisoft Photoscan projects and the finalized 3D models follow a consistent naming pattern drawing on the Stirling Maxwell numbering system: the Agisoft Photoscan projects will be named 'Govan0##_SfMfinal' and the finalized 3D models will be given the name 'Govan0##_3Dfinal.obj'. Because of the size of the stones, RTI of a single stone was often broken up into several sessions; as such, the file naming convention for these projects will follow the following pattern: 'Govan0##top/middle/bottom_RTIFinal'. The file names of the images used in these projects will not be changed from their original designations. The 'recarved' 3D models that reflect the newly recovered worn patterns will be saved as 'Govan0##_3Drecarved.obj'. Groove Analysis has also produced a large amount of data; the Excel spreadsheets for each sample and the images indicating where each sample was taken from will be included in the archive. The Groove Analysis-specific files have been named following the convention '!Sample_NR GrooveMeasure Govan001section#sample#.xlsx'.

The increased accessibility and subsequent application of advanced digital approaches in archaeology has led to a significant amount of discussion on the standards that should be established for the archival of this data. In addition to the final scaled outputs, Adam Rabinowitz argues that the raw data used in the creation of the 3D model, metadata, and process history all be provided in the archive to enable the complete reusability and replicability of a dataset (2015, 35–36), though there are several subjective, creative decisions made by the operator in the process of capturing and processing these 3D models that would also need to be included, which are often referred to as 'paradata' (Jeffrey 2018, 49–50). The amount of data included becomes a not-insignificant amount of money to incorporate into the budget, especially if one considers the RAW photographs prior to their conversion to JPEG format as an essential inclusion, to allow the highest resolution for reprocessing.

For this project, only the JPEG photographs will be included in the archive solely based on cost. For comparison, the total storage size required for the JPEG versions of the photographs, Agisoft Photoscan Pro files, exported OBJ models, and RTI files requires less than 200 gigabytes; including the RAW photographs would increase the total size of the project's archive by over 110 gigabytes. The metadata for each individual component of the project (with the metadata for each individual photograph included) is recorded on a spreadsheet, an example of which is provided below (Figure 5.31). Digital imaging specialists will be aware that there are almost an infinite number of possible workflows in photogrammetry, even in the same software package. While the basic photogrammetric approach employed here is described above in Section 5.2, there are a number of specific detours that were necessary dependant on the complexity of the stone being imaged (for example, stones with carving on multiple sides or difficult-to-access surfaces often required multiple phases of processing in 'chunks'). These additional processes will be described as needed in the corresponding metadata (Figure 5.32).

Another issue that has been especially prevalent in recent years is the issue of accessibility. Making 3D models openly available to the public requires a website or platform (or both) that support this medium. Many such platforms exist at the time of writing, though some focus on the commodification of 3D models for video games and other applications. One of the most prevalent platforms that receives the most attention in archaeology is known as Sketchfab. Not only is it possible to host your 3D model on Sketchfab for free (if the 3D model is under 50 MB in size), but it is also possible to embed the Sketchfab viewer on a website. Sketchfab links are also viewable on popular social media sites, including Twitter and Facebook, which makes it particularly useful when trying to reach a wider audience. One of the main benefits of Sketchfab is the ability to interact with the different layers of the 3D model – it is possible to remove the texture to view the underlying mesh, which is advantageous when dealing with carved stone and not clearly offered by many of its competitors at the time of writing. While this now allows researchers to easily share their 3D data, which had previously been considered a difficult task (Richards et al. 2013), this platform has started to slowly restrict the features that are freely accessible; in May 2018, Sketchfab announced that they would begin charging students for PRO features (including private uploads which require a password to view, 3D models exceeding 50 MB in size to an upper limit of 500 MB, and 3D models which feature more than 5 annotations) (Sketchfab 2018). The file size restriction limits the detail of the mesh that can be retained, and so has limited usefulness when attempting to make a very detailed mesh available for inspection and reuse, especially in an academic context. Finally, overreliance on one company can prove dangerous for the data, especially if Sketchfab is sold, goes out of business, or is deemed obsolete, as has been the case for many websites, including Geocities (Jeffrey 2012, 560–561). While Sketchfab exhibits an intuitive interface, allows for free uploads of 3D models of a specific size and enables wider engagement with the public through social media, any material that is put on Sketchfab should be safely archived, especially in case of unforeseen corporate abandonment. Several groups and projects, like the Corpus for Anglo-Saxon Sculpture through Prof Dominic Powlesland's Sketchfab account (2017) and Scotland's Rock Art project (Historic Environment Scotland 2019), are utilising this platform as they adopt 3D recording. Unfortunately, this is also the case with the recently published corpus of the early medieval sculpture from the Isle of Man. While the contextual information for the carved stones themselves is available in each description, none of the relevant technical information is provided on the Sketchfab entries nor the museum's website, not even the basic fact that they were produced using blue-light scanning. This resource also has limited research applications, as the 3D models are not available for download (Manx National Heritage 2018). It is hoped that a more secure and sustainable location for these projects will be established and publicised.

One of the best online corpora of early medieval carved stones in the British Isles is 'Ogham in 3D', created by Dublin's Institute for Advanced Studies and the Discovery Programme (Dublin Institute for Advanced Studies: School of Celtic Studies 2017). The website not only provides a clear context for the ogham stones of Ireland, describing the significance of ogham in across the early medieval British Isles, but also gives an overview of past research for each of the individual ogham stones. At the time of writing, 154 of the ogham stones have been recorded in 3D, though the viewability and downloadability of the files varies from stone to stone. In some cases, the 3D model of the stone is available via an embedded Sketchfab viewer through the Discovery Programme’s account (a company which has produced and currently hosts a variety of 3D material for the 3D-Icons project (The Discovery Programme 2015)). In other cases, a 3D PDF file and 3D OBJ file are available for download. In some cases, all three are available for a single stone. This is the ideal combination to reach a wide audience: the embedded Sketchfab viewer is easily shareable online on multiple social media platforms and instantly viewable on most devices; the 3D PDF file is higher resolution than the Sketchfab viewer, does not require any additional software to download because most computers will have a PDF reader installed already (and PDFs have been seen as a suitable Dissemination Information Package for the past decade (Jeffrey 2010, 55–56), though the capability for recording 3D models in PDF form was not implemented until Acrobat 2017 (Adobe 2017)), and it requires a computer with comparatively less processing power than the third option; an OBJ file requires additional software to view the 3D model, but also allows a third party to work with or manipulate the 3D model for their own interests or research. Offering multiple methods of engagement with the 3D, each method requiring different levels of technical knowledge, allows for individuals from a range of different backgrounds to engage with the material. Ideally, Ogham in 3D’s format would be a great place to start with any future digital corpora of early medieval sculpture. However, one critique made here is that, while the different methods of data capture are clearly identified, it is not made clear where or how the significant amounts of data for the project are being managed or archived.

In conclusion, as three-dimensional models become more prevalent in archaeological research, how the data is archived and disseminated to wider audiences becomes increasingly significant. The data from this project will be archived with University of Glasgow’s Enlighten and Historical Environment Scotland to ensure that the data is stored safely and kept usable for the foreseeable future. There are many methods by which 3D models can be made viewable and downloadable, the most popular of which is currently Sketchfab. While it is a useful platform and tool for dissemination of 3D models, it should not be relied on for archival purposes. The online corpus of ogham stones entitled ‘Ogham in 3D’ not only provides a historical and linguistic context for the 3D models, but it also provides three different methods of viewing them, which allows for viewers of different technical abilities to engage with the 3D models. This would be the ideal way to disseminate the 3D models of the Govan carved stones produced in this thesis, including both the unaltered 3D models and those that have been ‘digitally recarved’ to exhibit newly identified patterns, which will be illustrated and discussed in more detail in the next chapter.

	Project	Sub-Project	File Name	Description	Subject	Canmore ID of Monument	Grid Reference of Monument	Creators	Capture Conditions	Camera Make and Model	Lense Type	Aperture	ISO	Focal Length	Shutter Speed (seconds)	Date Created	Last Date Modified	File Format	Nu
2	Govan Old	Govan036	_DSC0835	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	1.6	25/08/2016	25/08/2016	JPEG and RAW available	
3	Govan Old	Govan036	_DSC0836	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	1.6	25/08/2016	25/08/2016	JPEG and RAW available	
4	Govan Old	Govan036	_DSC0837	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	1.3	25/08/2016	25/08/2016	JPEG and RAW available	
5	Govan Old	Govan036	_DSC0838	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	1.0	25/08/2016	25/08/2016	JPEG and RAW available	
6	Govan Old	Govan036	_DSC0839	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	1.0	25/08/2016	25/08/2016	JPEG and RAW available	
7	Govan Old	Govan036	_DSC0840	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	1.3	25/08/2016	25/08/2016	JPEG and RAW available	
8	Govan Old	Govan036	_DSC0841	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	2.0	25/08/2016	25/08/2016	JPEG and RAW available	
9	Govan Old	Govan036	_DSC0842	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	2.0	25/08/2016	25/08/2016	JPEG and RAW available	
10	Govan Old	Govan036	_DSC0843	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	0.8	25/08/2016	25/08/2016	JPEG and RAW available	
11	Govan Old	Govan036	_DSC0844	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	0.8	25/08/2016	25/08/2016	JPEG and RAW available	
12	Govan Old	Govan036	_DSC0845	Photograph of Govan036 taken for photogrammetric purposes; white balance was adjusted in Photoshop	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED lamps	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	1.0	25/08/2016	25/08/2016	JPEG and RAW available	
	Govan Old	Govan036	_DSC0846	Photograph of Govan036 taken for photogrammetric purposes; white balance was	Govan036	44077	NS 55349 65917	Megan Kasten	Indoors, Darkened room with two daylight balanced LED	NIKON D5300	AF-S Nikkor 18-55mm 1:3.5-5.6G	F#13	250	18 mm	1.3	25/08/2016	25/08/2016	JPEG and RAW available	

Figure 5.31. Example of Metadata recorded for the photographs taken for photogrammetric model of Govan 36.

Software	Point Cloud							
	Accuracy	Pair Preselection	Key Point Limit	Tie Point Limit	Constrain Features by Mask	Adaptive Camera Model Fitting	Matching Time	Alignment Time
Agisoft Photoscan 1.4.4 build 6848	High	Disabled	0	0	No	yes	7 hours 24 minutes	6 seconds
Dense Point Cloud								
Points	Quality	Depth Filtering	Depth Maps Generation Time	Dense Cloud Generation Time				
50,703,470	High	Aggressive	16 hours 3 minutes	1 hours 40 minutes				
Model								
Faces	Vertices	Surface Type	Source Data	Interpolation	Quality	Depth Filtering	Face Count	Processing Time
6,437,299	3,224,233	Arbitrary	Dense Cloud	Enabled	High	Aggressive	10,140,690	32 minutes 49 seconds
Texturing Parameters								
Blending Mode	Texture Size	UV mapping time	Blending time					
Mosaic	4,096 x 4,096	1 minutes 50 seconds	2 minutes 51 seconds					

Figure 5.32. Metadata specific to the different processing steps applied in Agisoft Photoscan for Govan 36.

6 Recovered Worn Patterns

Three-dimensional imaging offers many benefits to scholars of early medieval sculpture. For some of the stones, the way in which they have been displayed leaves some surfaces inaccessible; with the application of photogrammetry, these can be visualised in their three-dimensional context. In addition, the ability to remove the texture and colour of the monument can be valuable in the study of early medieval carved stones. As detailed above in Chapter 3, several of the Govan stones have been exposed to a significant amount of wear caused by a variety of factors, including repetitive footfall, weathering, while some may have been intentionally defaced. For less worn examples, a close inspection of the three-dimensional model with no photorealistic texture is all that is required to recognise the worn patterns. For significantly worn stones, RTI can reveal enough for the pattern to be recovered by throwing into sharp relief the remains of the deepest remnants of the decoration. In the most extreme cases, it is necessary to compare the worn remnants with ‘digitally worn’ well-preserved examples of known patterns from other stones in the Govan collection, the process is discussed above, in Section 5.4.2. Table 6.1 records which approaches were necessary to recover patterns from each stone and which stones require more attention in the future.

Here we will examine the individual stones which have benefited from these digital imaging processes. As will be seen, some of the previously unknown patterns have contributed to the art historical interpretation of the collection, especially in the case of the recumbent cross-slabs. While this method cannot recover the patterns of all the worn stones in the collection, it does have the potential to be applied to other stones in the Govan school and beyond (Kasten In press b).

Table 6.1. Techniques required for Pattern Recovery by stone.

Techniques Required for Pattern Recovery				
Govan Stone Number (Based on SM Number)	**Texture Removal**	**RTI**	**Comparative Collection**	**Needs additional attention**
Govan 2	X			
Govan 9	X			
Govan 10	X			X
Govan 11	X			
Govan 13	X			
Govan 14	X	X	X	
Govan 15	X		X	
Govan 16	X			
Govan 17	X			
Govan 18	X	X		
Govan 19	X			
Govan 20	X			
Govan 21	X	X		
Govan 23	X	X		
Govan 24		X		
Govan 25	X			X
Govan 26	X		X	X
Govan 27		X		
Govan 31	X	X	X	
Govan 36	X	X	X	
Govan 42	X			X

6.1 The Govan pattern types

There are a number of different interlace patterns that recur throughout the Govan collection. Below is a visual summary of the most prevalent patterns; most often in this thesis these patterns will be referred to by their descriptive name, except in the cases where a correction is being made to J. Romilly Allen's pattern designations (Figure 6.1). In these cases, the original pattern number will be referenced along with the number for the corrected ornament. A more thorough discussion of these patterns and their construction is given in Chapter 9, as it is more relevant to the discussion of the new recumbent cross-slab typology.

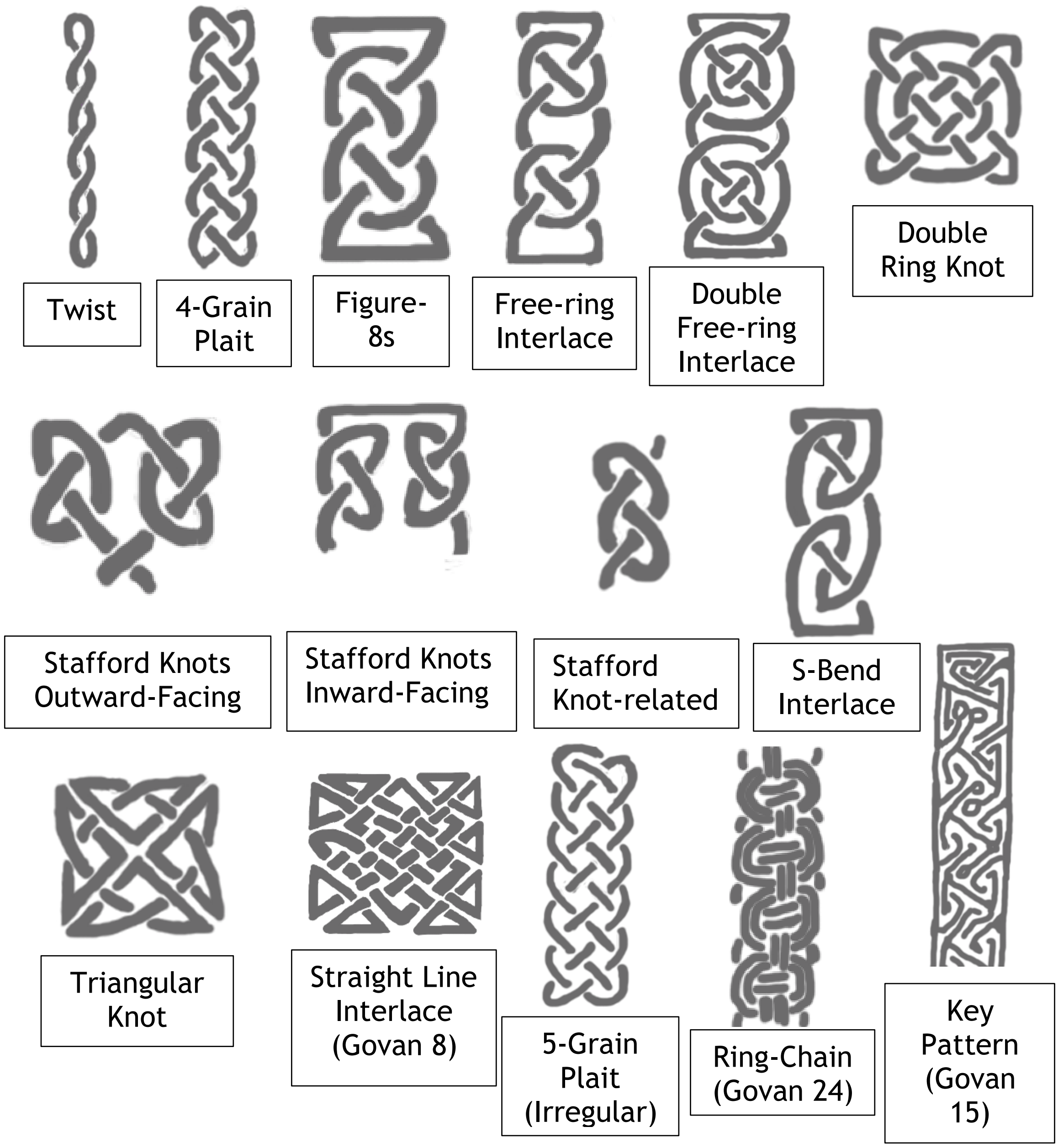


Figure 6.1. Diagrams of the various decorative motifs employed in the decoration of the Govan school; many adapted from Allen and Anderson 1903, Volume 1 (No. 501, 503, 568, 574, 575, DRK, 601, 598, 215, 544, 731, (Govan 8), 504, (Govan 24) and (Govan 15).

While some patterns in the Govan collection have been correctly identified by J. Romilly Allen in his analysis, he did have the tendency to generalise these identifications. Below, it will be clarified whether these patterns have been identified previously. However, the stone carvers at Govan had an unorthodox relationship with the ‘rules’ of interlace, and there are several instances where Allen has oversimplified the description. For this reason, even if the general pattern was correctly identified by Allen, these idiosyncrasies will be highlighted and ‘recarved’ into the 3D model. By describing and visualising these designs in the way the carver intended, we can gain more insight into the meaning behind these patterns.

6.2 Govan 2

The hogbacks of Govan have been the subject of intense study since James Lang’s original consideration of the Scottish hogbacks (1974); scholarly interest in this monument type has only increased since (Lang 1984; Lang 1994; Ritchie 2004; Crawford 2005; Williams 2015; Whitworth 2016; Barnes 2019). Govan 2 (Lang 1, ECMS 2), is one of the best preserved of the Govan hogbacks. A band of a variety of median-incised motifs has been carved along the bottom of the monument; while the art historical similarities with the Irish sea and Cumbria have been considered in previous discussion of these motifs (Lang 1994, 125), but it is also worth noting that the ring-chain utilised in the band is very similar to that found elsewhere in the Govan collection on Govan 24 (see Section 6.16 below). Above this band, two rows of concave tiles have been carved on each side. A small panel survives on one of the short edges of the monument, which has been decorated with a swastika motif. Two small panels of step pattern flank this panel. Two weathered beast heads remain, one on each short face of the monument. The ridge of Govan 2, however, is significantly worn. The digital three-dimensional model of the stone revealed that at least one side of the ridge had been previously decorated with step pattern, which has not been commented on previously (Figure 6.2). The identification of this pattern has recently been confirmed by John Borland, who has been illustrating the corpus of Govan monuments.

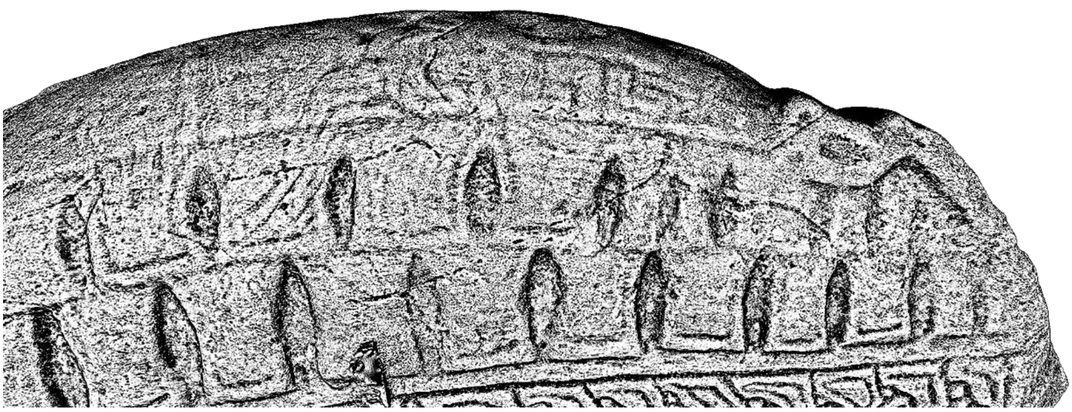


Figure 6.2. Faint remnants of step pattern can be seen on the ridge of Govan 2, above the uppermost row of tile-pattern.

6.3 Govan 9

Govan 9, also known colloquially as the Cuddy Stane, is one of the simplest monuments in the entire Govan collection. While the illustration of the stone from John Stuart's corpus suggests that the stone had been mostly intact in 1856, including a tenon at the top of the slab, it still exhibits the least ornament. It is decorated with a plain cross shaft on one face and a man riding a horse or donkey on the face opposite (Figure 6.3). Upon investigation of the three-dimensional model of the surface just below the horseman, an intriguing series of peck marks was identified. These are similar to the carving technique employed throughout the collection but particularly akin to those used in the creation of the horseman. This pecked detail is overlaid by what appears to be a later stray incision, which forms an 'X' which is normally visible without the use of digital imaging. The later style of carving is much smoother, like that which was employed in the application of the initials in the subsequent reuse of the monument. If this single stroke of later carving were to be ignored, the pecked details are so regular that they might represent a panel of interlace.

However, this raises a new issue – if this were an ornamented section of the stone, why is the adjacent carving apparently so well-preserved? The carved line which defines the frame of the stone is still intact and consistent on both decorated faces, and, though not the most impressively designed horseman, the divisions between man and horse are still clearly defined. This raises the question whether this panel of interlace was originally lightly pecked and so more susceptible to weathering, or whether this section was deliberately defaced for later reuse. Additional analysis of this stone is required before stronger statements can be made.

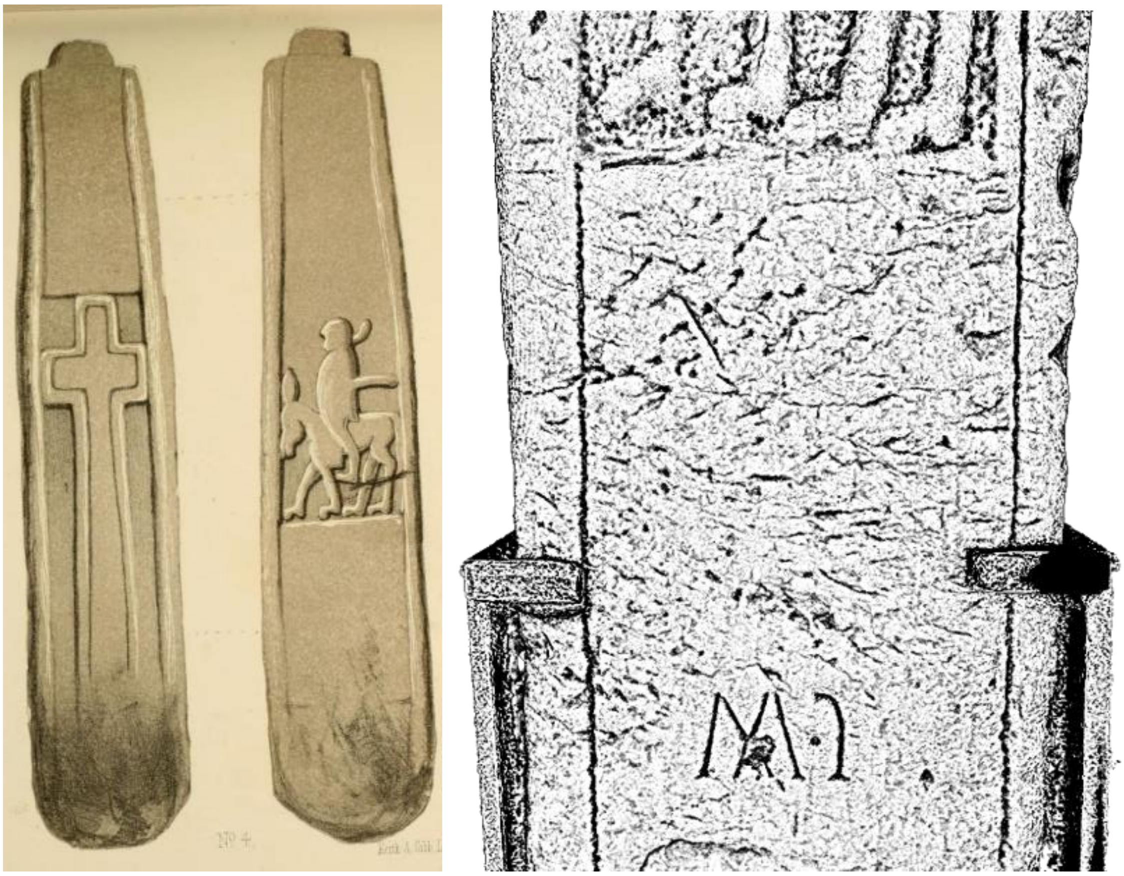


Figure 6.3. (Left) Illustration from Plate CXXXVI from Stuart 1856 depicting the Cuddy Stane; (Right) Image captured from the untextured 3D model of the stone, showing a potential previously unidentified panel of ornament and the initials employed in the monument's subsequent reuse.

6.4 Govan 10

Govan 10 is known as 'The Upside Down Cross' because the cross shaft is currently displayed upside down. It is also mounted against the wall of the church, which has left one of its broad faces inaccessible. The obscured face, in fact, retains more detail than the one that is currently visible; it was one of the three faces illustrated in Stirling Maxwell's book (1899, Plate X). The broad face that is currently visible has clearly experienced a peculiar sort of wear – the diagonal ridges across this face suggest that the surface was deliberately defaced. It is unclear when this might have occurred, but it may be a form of iconoclasm. This cross shaft is the only monument in the Govan corpus that depicts a biblical scene, interpreted by Ian Fisher as Samuel anointing David (1994, 49; Macquarrie 2006, 7). If additional biblical scenes had been present on this wide face, it is possible that they were considered idolatrous during the Reformation. However, it is also possible that this was done to smooth the surface of the monument for use as a recumbent; Stirling Maxwell's map of the churchyard suggests that Govan 10 was reused as a grave marker, despite the absence of an inscription.

Regardless of how this came to be, the broad face that is currently visible only exhibits half of an unidentified interlace pattern. The intact narrow faces retain the vast majority of Govan 10's preserved decoration, including one panel of key pattern, one panel of free-ring interlace, and one panel of inward-facing Stafford knots. Apart from the biblical scene described above, the other three panels contain a pattern which conforms to Allen's Pattern No. 509 (1903, 1, 205), and two irregular plaits (Figure 6.4).

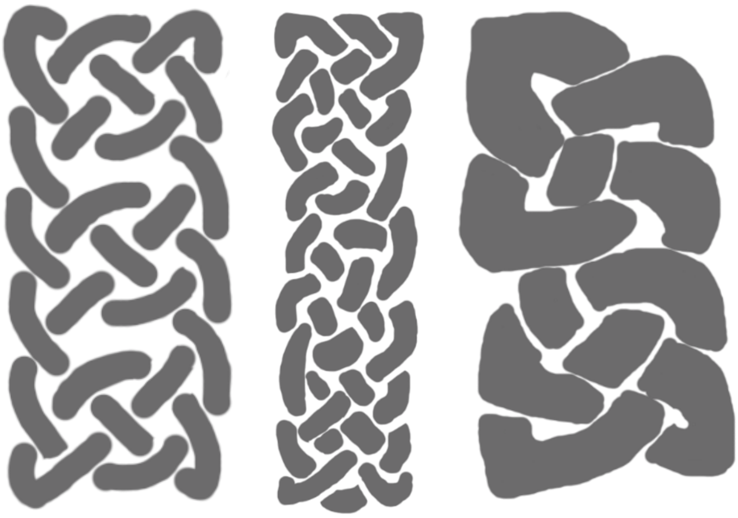


Figure 6.4. Additional Patterns from Govan 10 (Allen & Anderson 1903 Pattern 509 and two irregular plaits).

While the methodology described in Section 5.4.2 did not result in the recovery of any worn patterns from the exposed face of Govan 10, a smartphone camera was used to capture photos of the inaccessible face. This has revealed that the surface remains much the same as it was when the cast was made and photographed for Stirling Maxwell's publication (1899; Macquarrie 2006, 7). By highlighting the intact carved surfaces, the 'rectangular figure with double projections at each corner' (Allen & Anderson 1903, 2, 464) became visible (Figure 6.5). While it is currently unclear what this image might have been, the vague outline does suggest a house-shaped shrine with projecting gable ornaments, such as is depicted in folio 202v of the Book of Kells (The Board of

Trinity College Library Dublin 2012) and by some capstones of Irish High Crosses; a particularly fine example is found on the Cross of Muiredach at Monasterboice (Richardson & Scarry 1990, 10–13; Stalley 1996, 7–9, 15).

Digital RTI could feasibly recover more detail (Zelinsky 2018), but the model of the back of Govan 10 relied on the use of a 8MP smartphone camera. While this was sufficient to capture the overall geometry of the monument's surface, the lack of control over the settings might have introduced noise which would affect the microtopography of the surface. To apply RTI to this surface would require the relocation or redisplay of the monument. This tentative interpretation of a house-shaped shrine is nevertheless exciting, as it would be one of the first identified in Scotland.

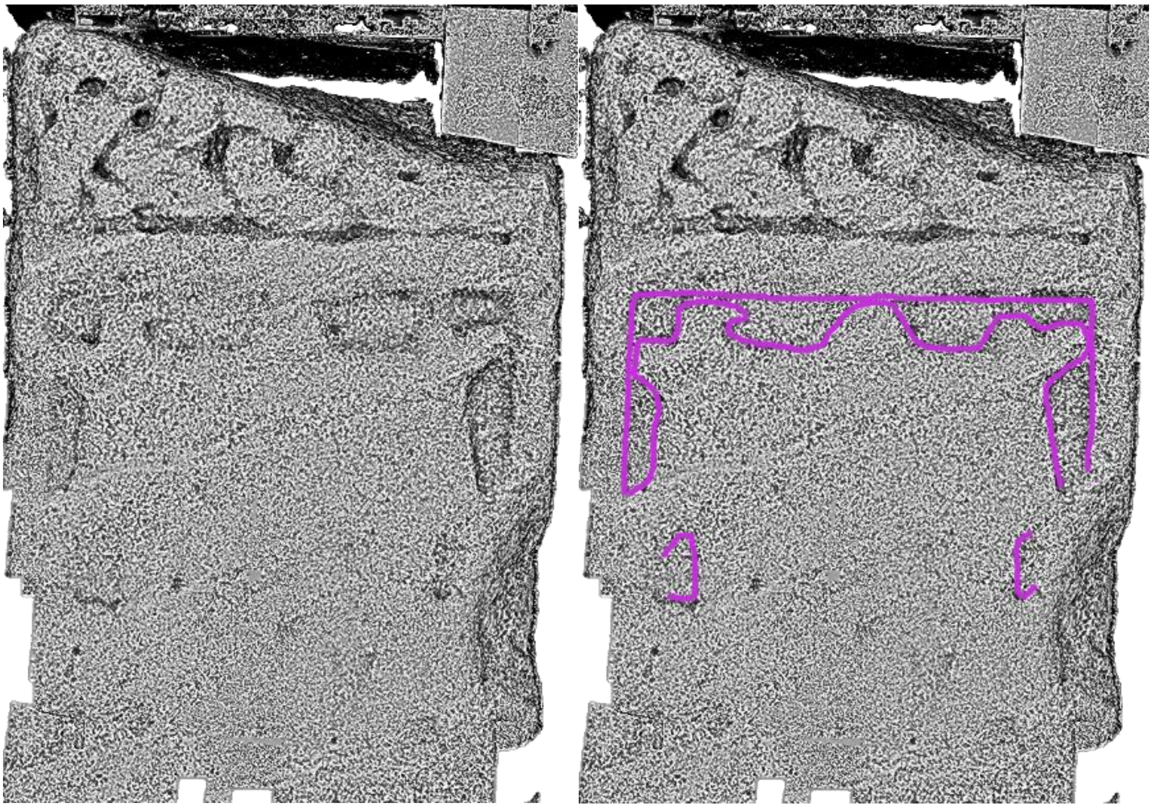


Figure 6.5. Back of Govan 10, inverted. The carved details are highlighted in the image to the right, revealing a sort of house- or shrine-shaped image.

6.5 Govan 11

Govan 11 is one of the better-preserved recumbent cross-slabs. Most of its decoration survives intact, but the detail of the designs is difficult to read. At several key points, like the patterns above the cross-head and filling the cross-head, the decoration has been partially effaced. While RTI was applied to the pattern above the cross, here the surface was worn smooth to the point where little additional information could be recovered. Examination of the 3D model with its texture removed clarified the four-grain plaits adjacent to the cross. The carver also seemed to employ unfinished pellets along the right edge of each of these panels. The cross-shaft itself was also decorated with a four-grain plait, though the transition of this pattern between the cross-head and the shaft is still difficult to ascertain (Figure 6.6).

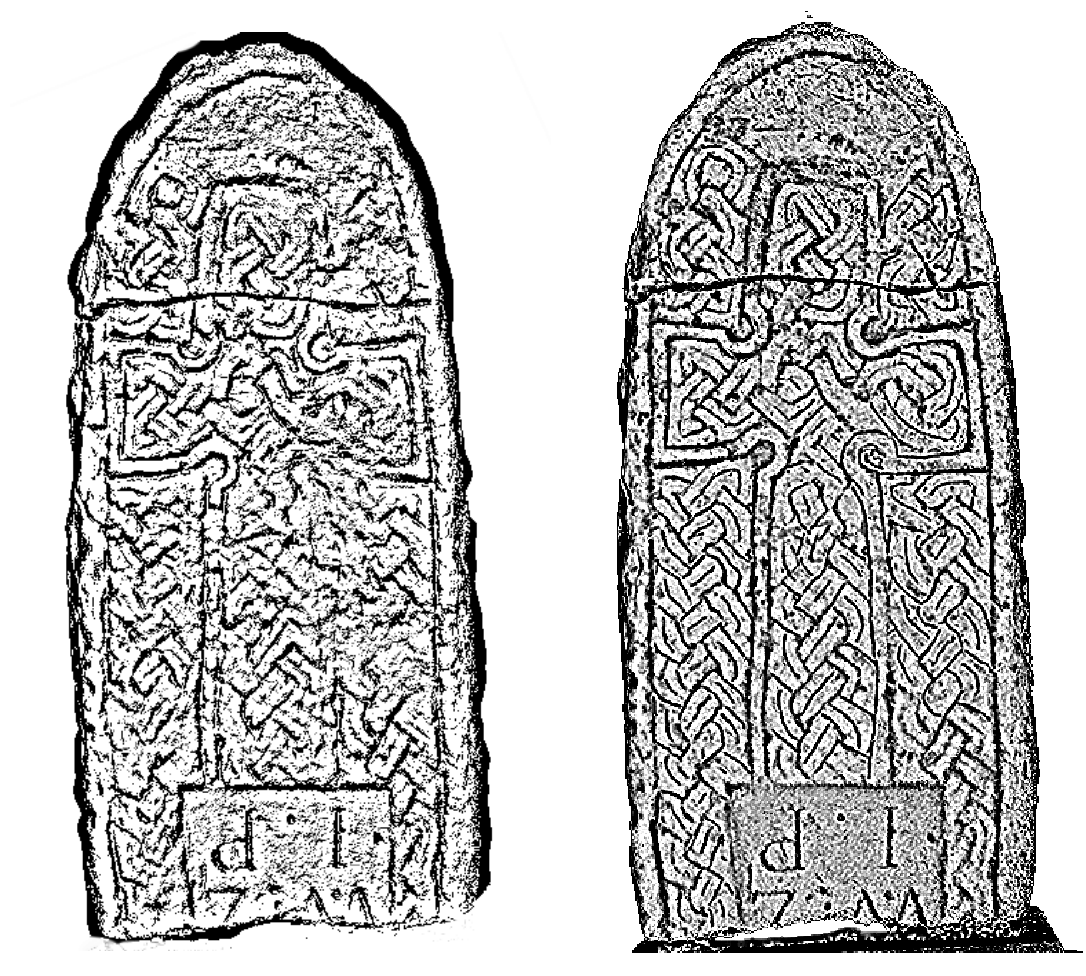


Figure 6.6. Black and white renderings of the 3D models of Govan 11 - left is the unaltered version, while the one on the right is the digitally 'recarved' version.

6.6 Govan 13

This recumbent cross-slab displayed a moderate amount of weathering, so clarifying the pattern was achieved by a careful inspection of the 3D model with its texture removed. The carver of this stone has left numerous loose ends in the design. At the bottom of the slab, a series of three loose-ended loops have been worked together to create six figure-eights. The two panels adjacent to the cross-shaft both exhibit a series of twists that have been interlaced together with one working strand. The stray strand from the right panel has been used by the carver to connect this pattern to the decorative motifs below.

The interlace pattern above the cross contains a series of free-rings and is one of the few examples of mirror-symmetry in the Govan corpus. While the central strand for the free-rings on the right side of the cross-head are oriented with the upper-end of the strand to the right, the opposite is true of the central strands for the two free-rings to the left of the cross. While the top three free-rings are all oriented the same direction, it is intriguing that the carver saw fit to complicate the pattern in such a way – if all of these had been oriented in the same direction, like in the case of the pattern above Govan 17's cross, no additional strands or manipulations would be required (Figure 6.7).

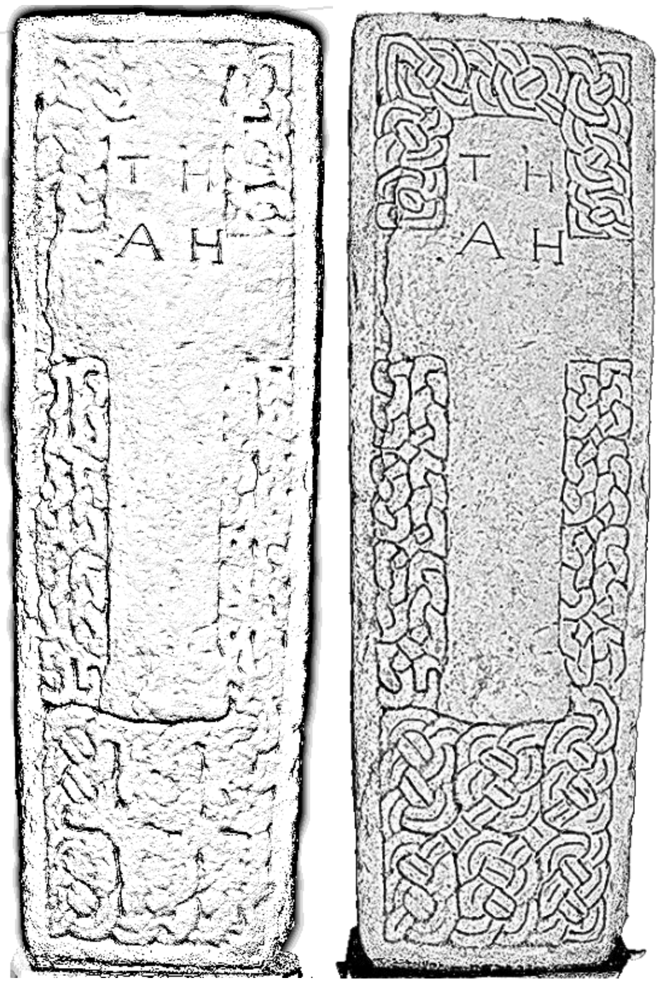


Figure 6.7. (Left) Black and white rendering of the 3D model of Govan 13 unaltered; (Right) Black and white rendering of the digitally 'recarved' 3D model of Govan 13.

6.7 Govan 14

Allen and Anderson described Govan 14 (ECMS 32) (1903, 470, vol 2) as exhibiting pattern number 766 above the arms of the cross (Figure 6.8), but closer examination using RTI suggests that the top left panel is more complex (Figure 6.9). An attempt to apply 766 to a digital image of Govan 14 (Figure 6.10) was problematic as the imposition of this pattern would require ignoring strands of interlace that have clearly been preserved. An alternative interpretation is proposed below (Figure 6.11), which attempts to provide a representation that more accurately captures the carver's intent.

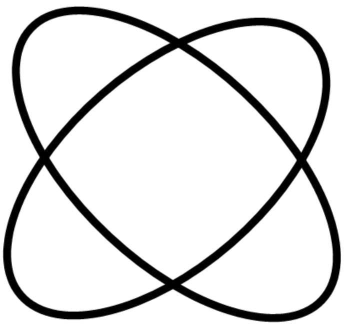


Figure 6.8. Allen and Anderson's Pattern number 766 (Allen & Anderson 1903, 297, vol 1.).

Figure 6.9. Screenshot of pattern in question from Govan 14 RTI.

Figure 6.10. Imposition of Pattern Number 766 on the screenshot of the RTI file for Govan 14.

Figure 6.11. New interpretation of the pattern based on analysis of RTI.

The four-cord plait filling the panels on either side of the cross-shaft were also relatively simple to recover using only the results of the RTI because enough depth was retained on several strands to allow confident identification of the under-over relationship between strands. Here, the damage to the bottom section of the monument introduces too much uncertainty, which prevented a reliable interpretation of this transition (Figure 6.12).

Figure 6.12. Recovery of four-cord plait along cross-shaft of Govan 14.

The deeply carved pits marking where interlace strands encountered others are the only surviving traces of the decoration of the cross-shaft on Govan 14. Each of these remaining pits was identified through RTI and recorded on a still image using Photoshop; then the shape and arrangement of these pits were compared to the three-dimensional comparative collection of known patterns. Comparison with the digitally worn patterns from Govan 28 (Figure 6.13) allowed this pattern to be identified as a series of outward facing Stafford knots. The over-under relationship of one of the better-preserved strands towards the base of the shaft was identified using RTI (Figure 6.14), which confirmed the reconstruction (Figure 6.14; Figure 6.15). This pattern probably continued up into the cross-head and arms where the later inscription of the initials “T▪H” has effaced the central part of the pattern. As a result, this section, much like the transition between the four-cord plaits at the base of the cross, cannot be reconstructed.

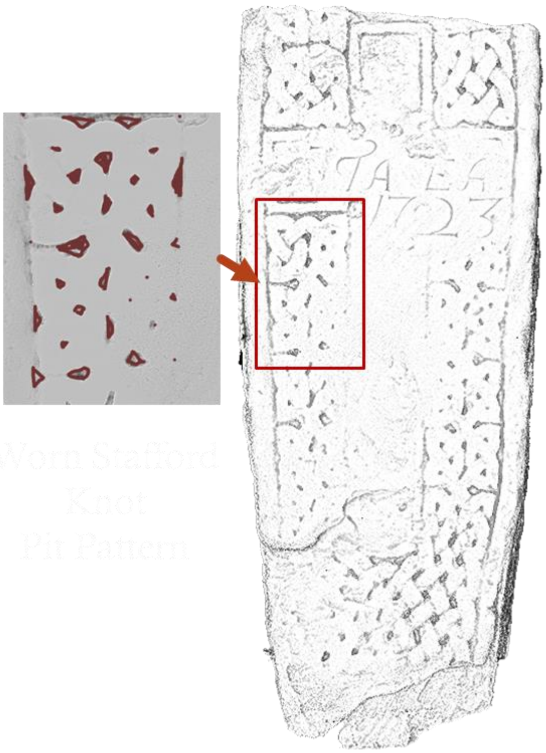


Figure 6.13. Govan 28 and the digitally worn 3D section of Stafford knot pattern.

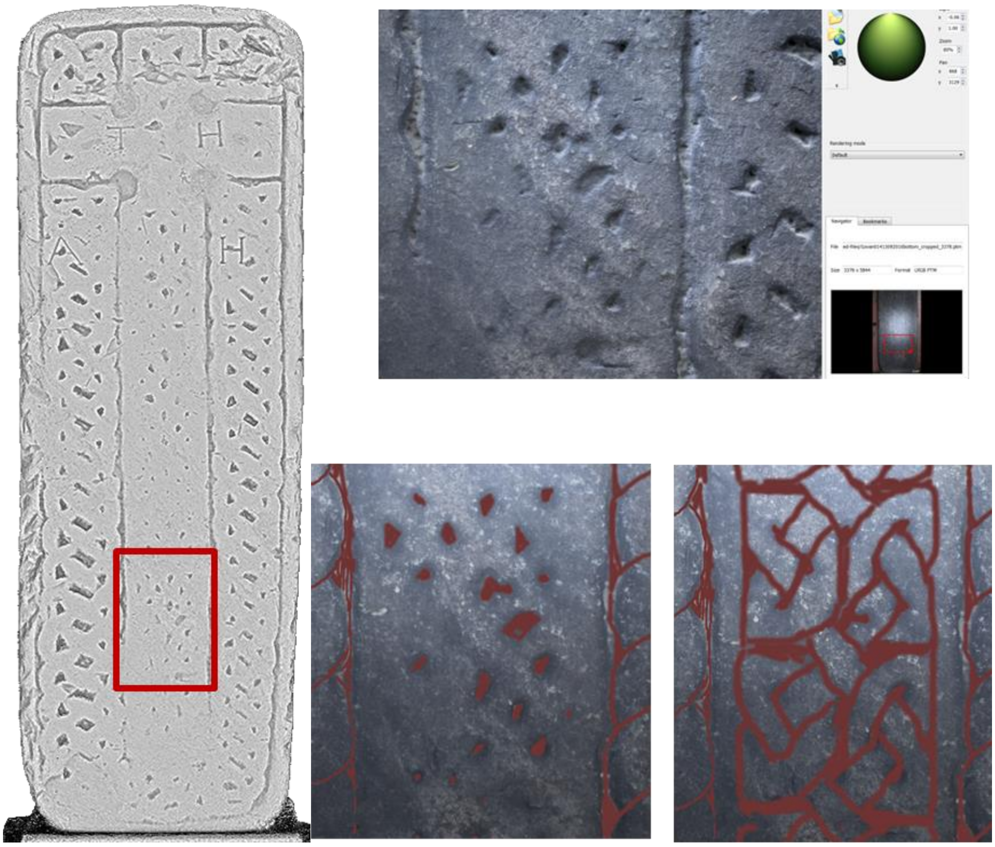


Figure 6.14. Section of Govan 14 where enough decoration exists to provide over-under order. Shown on 3D model, in RTI, and pattern recovery process.

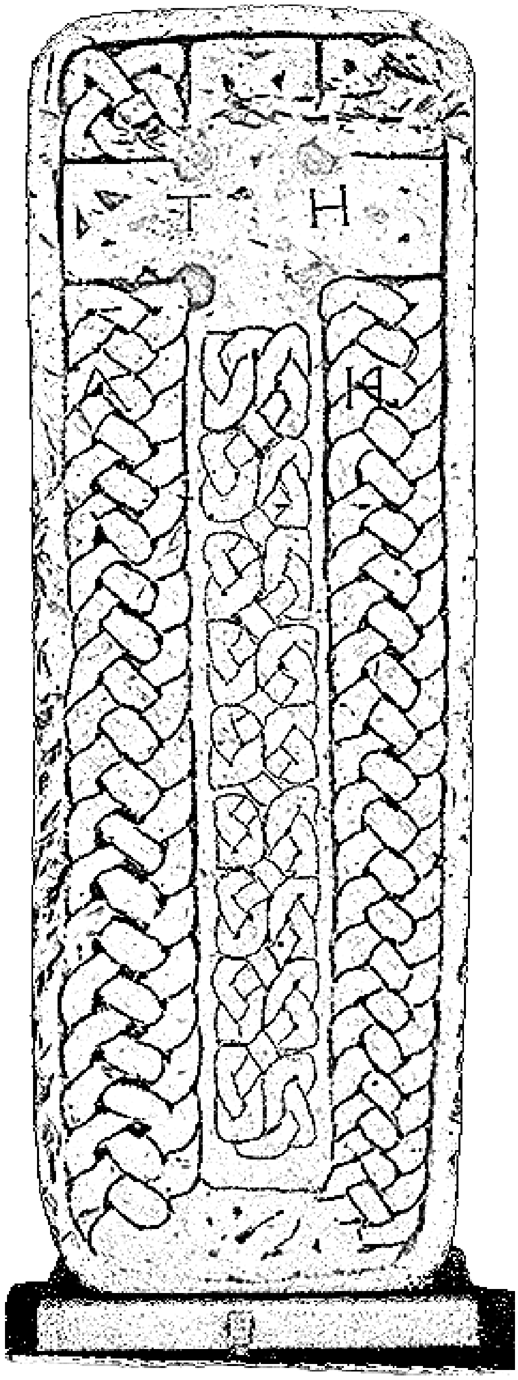


Figure 6.15. Recovered patterns digitally 'recarved' onto the Govan 14 3D model.

6.8 Govan 15

Govan 15 is one of only two recumbent cross-slabs exhibiting a form of key pattern in the Govan collection, a point which will become more significant in the full consideration of the recumbent cross-slabs in Section 8.4. The two panels adjacent to the cross-shaft are filled with this ornament, while the two panels above the cross-arms are filled with plait as is the cross-head. The rest of the cross has been significantly worn, which could have been deliberate to allow for the addition of an inscription for its later reuse as a burial marker. The cross-shaft exhibits deeper pits indicative of its former ornament. Damage along the edge of the cross-shaft has made it difficult to definitively identify the pattern, but the layout and shape of the surviving remnants suggest that it was decorated with an inward-facing Stafford knot pattern (Figure 6.16).

Govan 15 is unique to the collection for having a double frame. The only other recumbent cross-slab with a similar treatment is Govan 26, though in this case it is only present around the two panels of interlace that form the 'base' (Figure 6.28).

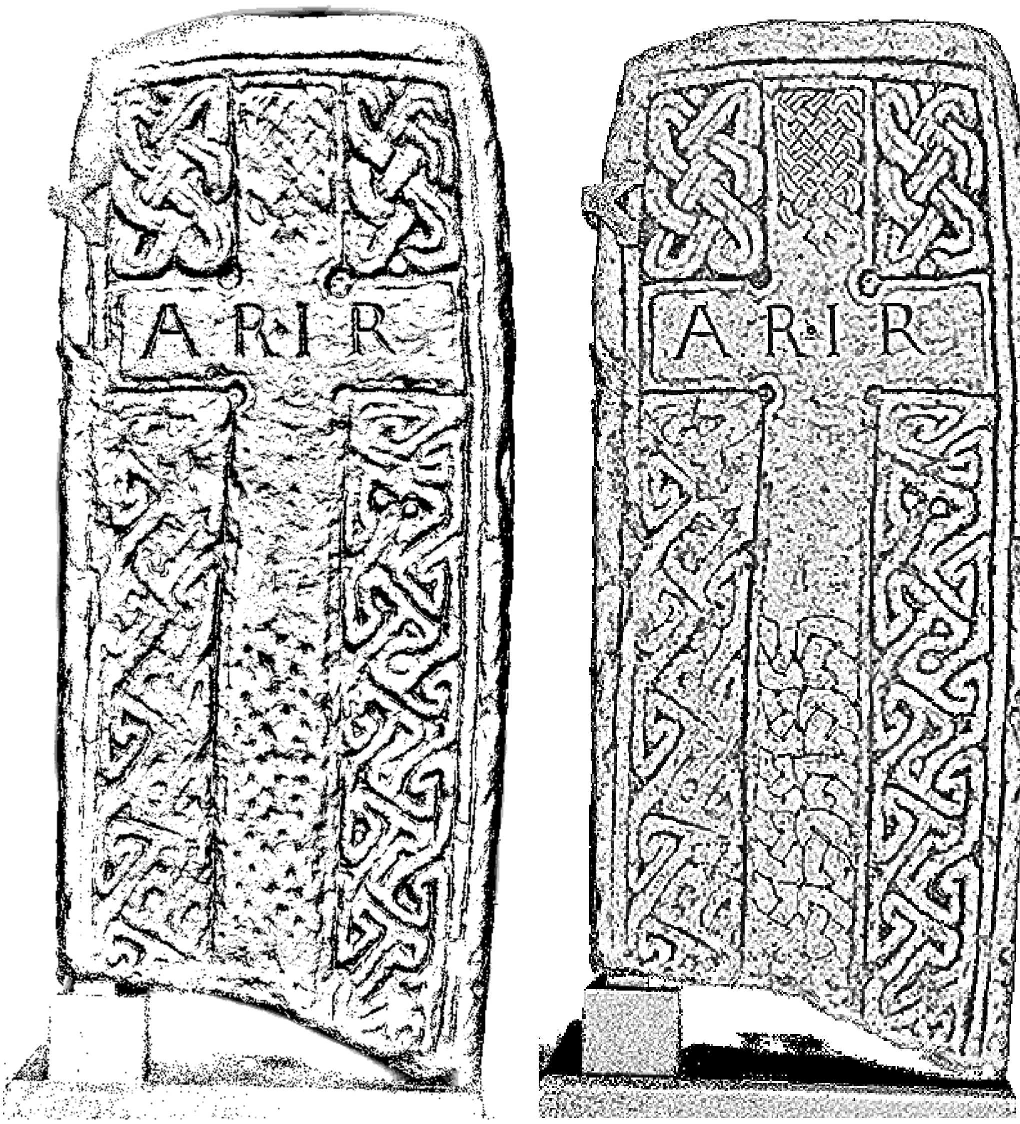


Figure 6.16. (Left) Black and white rendering of the unaltered 3D model of Govan 15. (Right) The above interpretation digitally 'carved' onto the 3D model.

6.9 Govan 16

Govan 16 is a recumbent cross-slab that has experienced a significant amount of wear and damage; the carving is more difficult to detect because of the present colour of the stone surface. After removing the texture of the 3D model, the outward-facing Stafford knots to the left of the cross-shaft and the inward-facing Stafford knots to the right of the cross-shaft first identified by Allen are more clearly defined (1903, 2, 468). However, the shaft of the cross is not decorated with 'irregular plaitwork,' as Allen and Anderson state, but is can be seen to be a series of free-rings and loops. The decoration of the left cross-arm was also identified. However, the cross-head and the pattern from the panel above the cross are far too damaged to be recovered (Figure 6.17).

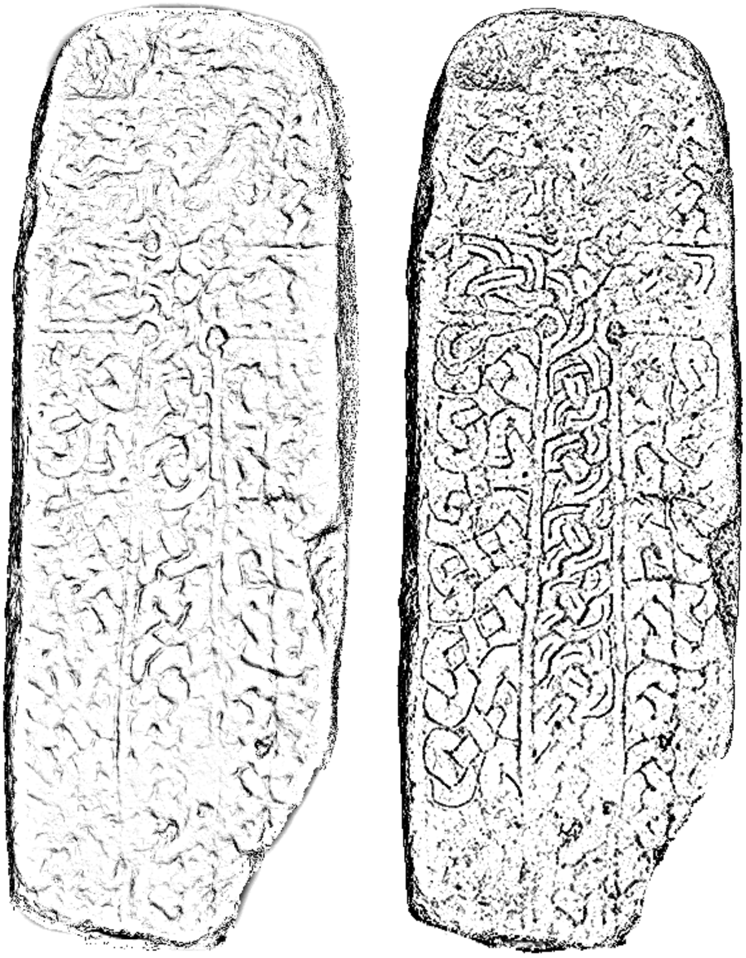


Figure 6.17. (Left) Black and white rendering of the 3D model of Govan 16; (Right) This interpretation digitally 'carved' into the 3D model of Govan 16.

6.10 Govan 17

Govan 17 is a recumbent cross-slab that has not suffered much wear in comparison to other slabs in the collection. However, digitally ‘recarving’ the 3D model assisted in the visualisation of the monument. All of the decoration consists of free-ring interlace and loops (Figure 6.18).

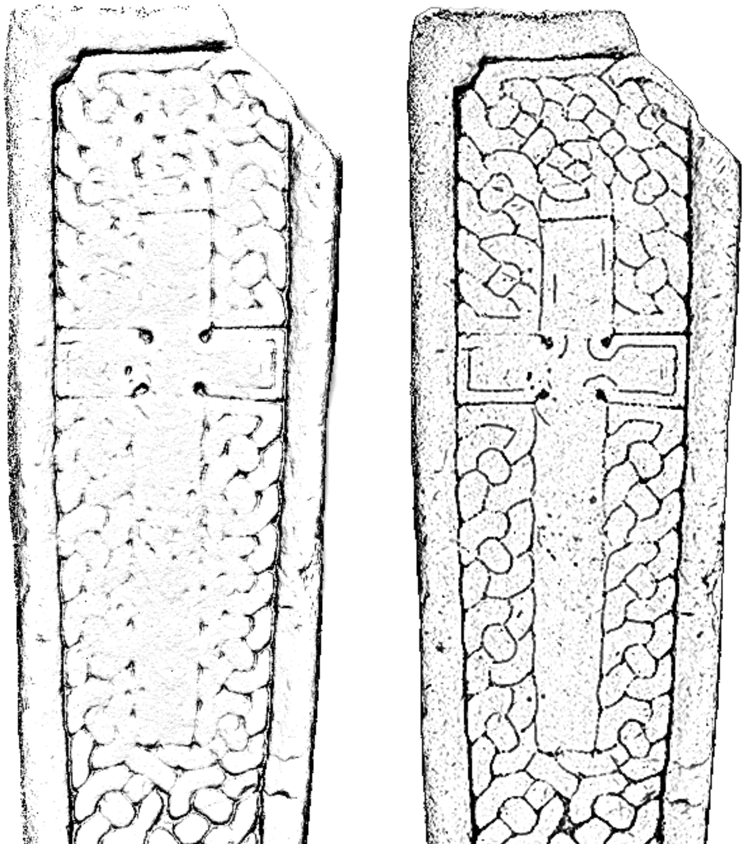


Figure 6.18. (Left) Untextured 3D model of Govan 17; (Right) Digitally 'recarved' 3D model of Govan 17 to clarify patterns.

6.11 Govan 18

Govan 18 is one of the most intact recumbent cross-slabs; however, it has experienced a certain degree of differential wear and some deliberate effacing that has complicated previous interpretations. Unfortunately, the top right panel is too obscured by the later addition of the initial ‘D’ to reconstruct. While Allen had previously identified the plaits adjacent to the cross-shaft as four-grain plaits (1903, 2, 466), this analysis has subsequently identified these as five-grain plaits with the loose ends tucked into the end of the plaits. At the bottom-right corner of the panel to the right of the shaft, it appears that this loose end is acting as a connection to the free-ring knot panel at the base of the monument (Figure 6.19). This is similar to the arrangement found on Govan 13, as described above. It is also worth mentioning that Govan 18’s free-ring knot panel is not as regimented as it first appears – several of the outermost ‘rings’ are simply strands that have been added to complicate the pattern. Only the two innermost free-rings are whole.

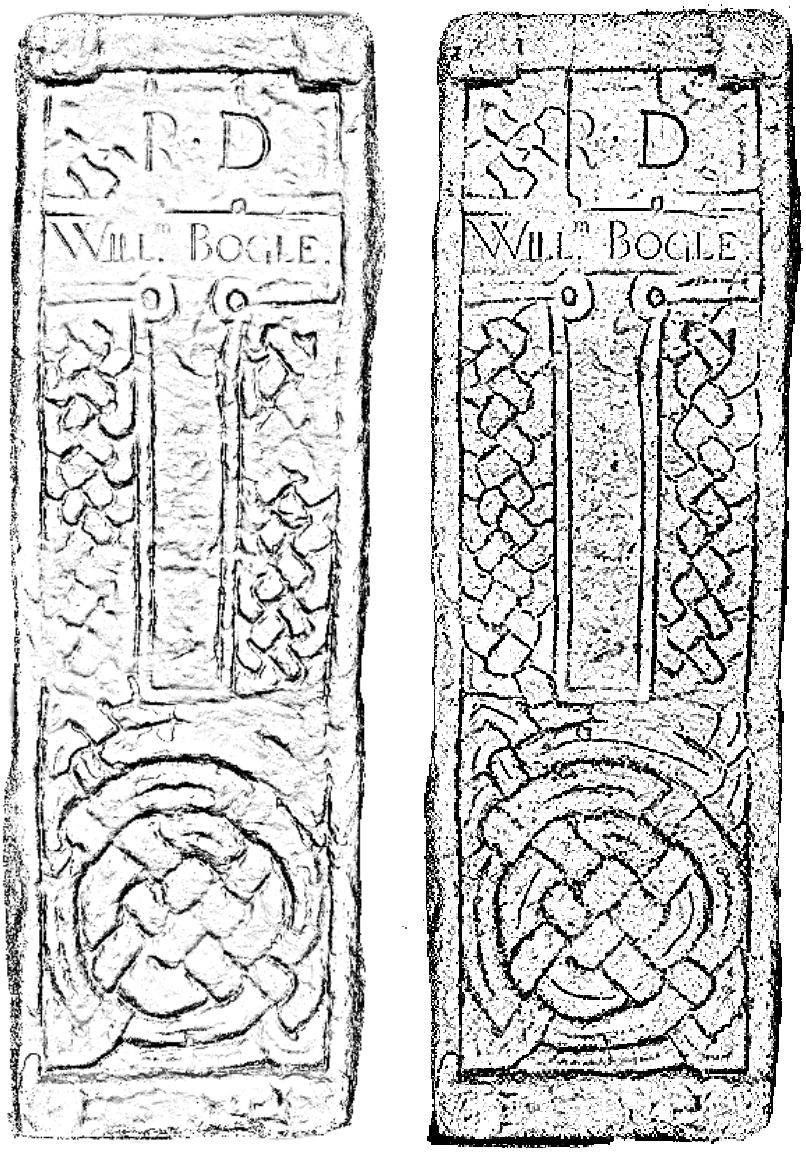


Figure 6.19. (Left) Black and white rendered image of the 3D model of Govan 18; (Right) Interpretation digitally 'recarved' into the 3D model of Govan 18.

6.12 Govan 19

In the case of Govan 19, the panels of loops, S-bends, and free-ring interlace are clear even without the 3D model. Unfortunately, the pattern above the cross-arms were nearly obliterated to facilitate the later inscription; however, the two terminals of the pattern adjacent to the cross-arms appear to be free-rings (Figure 6.20).

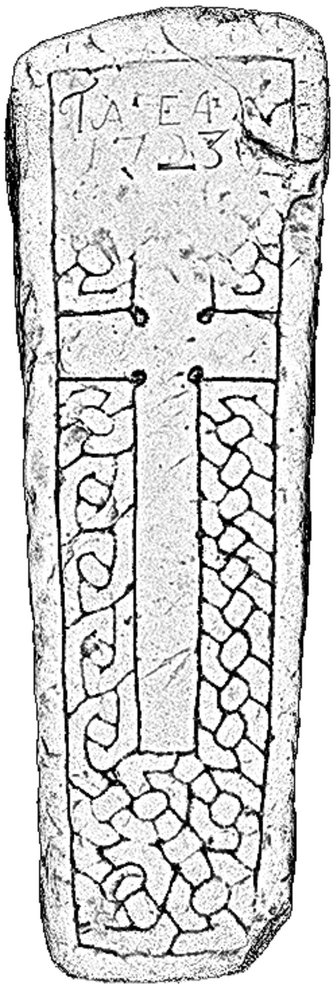


Figure 6.20. Black and white rendered image of the 3D model of Govan 19.

6.13 Govan 20

Govan 20 is a recumbent cross-slab that has experienced differential wear – the top left corner of the monument and the base have both experienced more weathering than the rest of the stone. This stone only required the removal of the texture from the 3D model to analyse. The carver, much like the carver of

Govan 13 and those of other stones in the collection, had no qualms about leaving loose strands in the corners of the monument. While the uppermost portion of the monument does adhere to one unit of Allen's pattern number 509 (1903, 1, 205), the patterns adjacent to the cross-head would most accurately be described as interlocking loops, though the left pattern is far less regular than that on the right. The patterns adjacent to the cross-shaft are also interlocking loops, which transition into free-ring interlace at the base of the monument. These were also identified correctly by Allen, though the possibility for other patterns (like loops used in the ornamentation of Govan 13) along the bottom row were ruled out during this process (Figure 6.21).

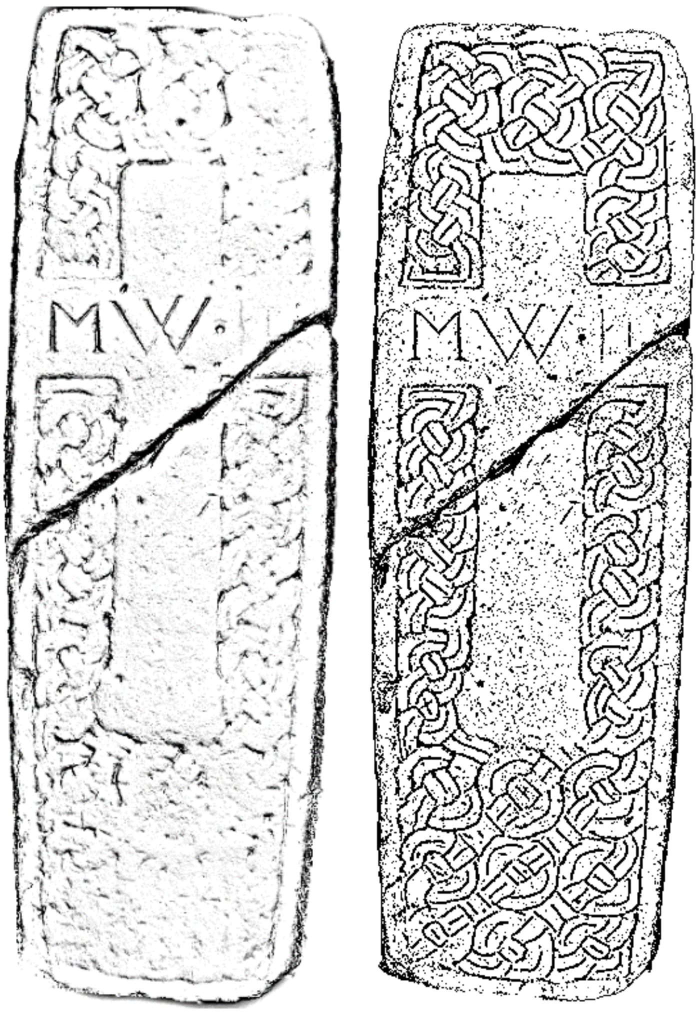


Figure 6.21. (Left) A black and white rendering of the unaltered 3D model of Govan 20; (Right) A digitally 'recarved' version of the Govan 20 3D model.

6.14 Govan 21

Govan 21 is a recumbent cross-slab that has experienced more than the usual amount of damage and wear; not only is the pattern severely worn around the area of the cross, but it has also had an approximately 5cm wide band from around the edge of the monument removed quite violently in some places. This characteristic raised the question as to whether Govan 21 had been altered to act as a sarcophagus lid; the flexibility of 3D allowed for this hypothesis to be tested. It was determined that Govan 21 is not long enough to have functioned as the lid to Govan 1 (Figure 6.23; Figure 6.24). The application of RTI was only able aid in interpreting the bottom panel, in highlighting a few trace elements of pattern in the panel on the left adjacent to the cross shaft and in the identification of the probable outline of the cross itself, aided by Stirling Maxwell's photographic record of the stone (1899, Pl. XVI; Figure 6.22).

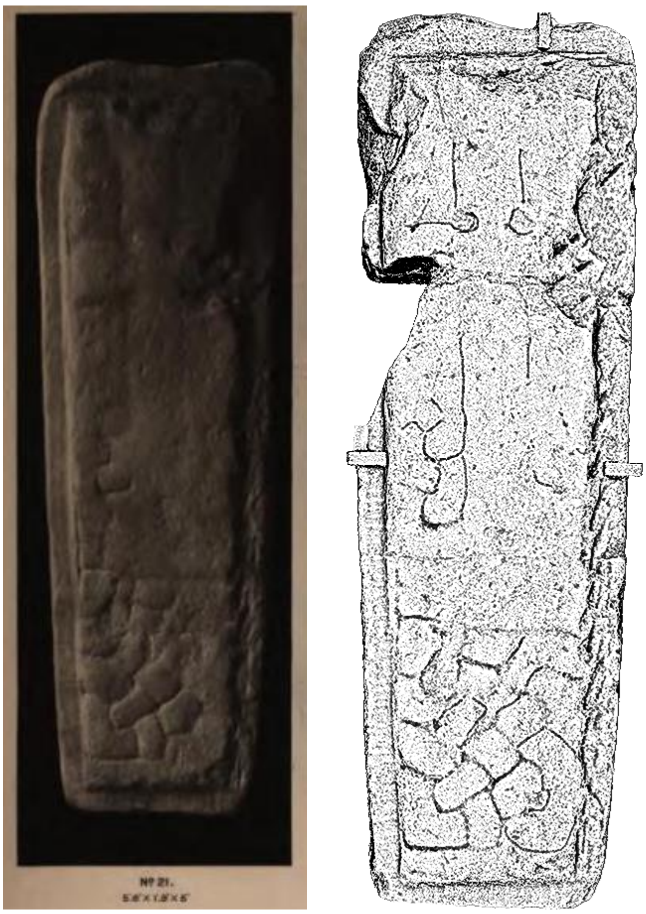


Figure 6.22. (Left) Image of Govan 21 from Stirling Maxwell's publication (1899, Pl. XVI) compared to (right) image from the 3D model that has been 'recarved' to highlight several features.

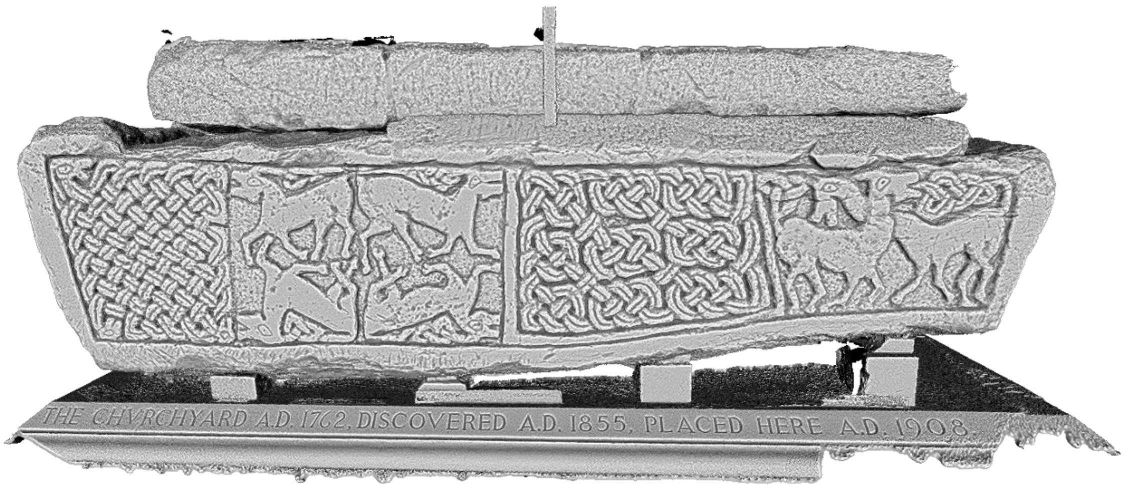


Figure 6.23. 3D model of Govan 21 tested as a potential 'sarcophagus lid', but Govan 21 is too short to securely close Govan 1.

Figure 6.24. 3D model of Govan 21 digitally tested as a potential 'sarcophagus lid'.

6.15 Govan 23

Govan 23 is another recumbent cross-slab which is severely worn and has lost both the top and bottom portions of the original slab. From Stirling Maxwell's photographic record of Govan 23, it is apparent that the slab originally exhibited subtle angle-knobs, and the cross appears to have had a splayed base not found anywhere else in the collection (Figure 6.25). While the use of free-ring interlace had been identified previously by Allen (1903, 2, 466), RTI was employed to identify the remnants and illustrate where they would have been situated on the monument. Clearly the photograph of this cast recorded many of the features that are also now apparent with RTI.

Figure 6.25. (Left) Photograph of the cast of Govan 23 created for Stirling Maxwell's publication (1899, Pl. XVII); (Centre) RTI image of Govan 23, illustrating the remnants of the decoration; (Right) Free-ring interlace patterns digitally 'recarved' onto the 3D model of Govan 23.

6.16 Govan 24

Govan 24 is a recumbent cross-slab that has been clearly impacted by reuse and weathering. The top and right side of the slab seem to have been the most severely affected. As Allen had originally identified, the cross-shaft is ornamented with a three-grain plait; the pattern adjacent to the cross-shaft on the left side is a median-incised ring-chain, connected by a central band; as mentioned above in the description of Govan 2, these two monuments are the only monuments in the Govan collection which exhibit this variant of ring-chain. The pattern on the right side appears to have been some sort of plait, but it is too badly damaged to be fully recovered. The pattern on the base, however, was revealed through careful examination of the RTI and the 3D mode. It became clear that there was no visual evidence to support Allen’s identification of

Pattern No. 732 (1903, 2, 465; Figure 6.26). Significantly, the most central strands lack the subdivision required to interlace these strands together, so it appears that this design should be identified as Pattern No. 731 (1903, 1, 287).

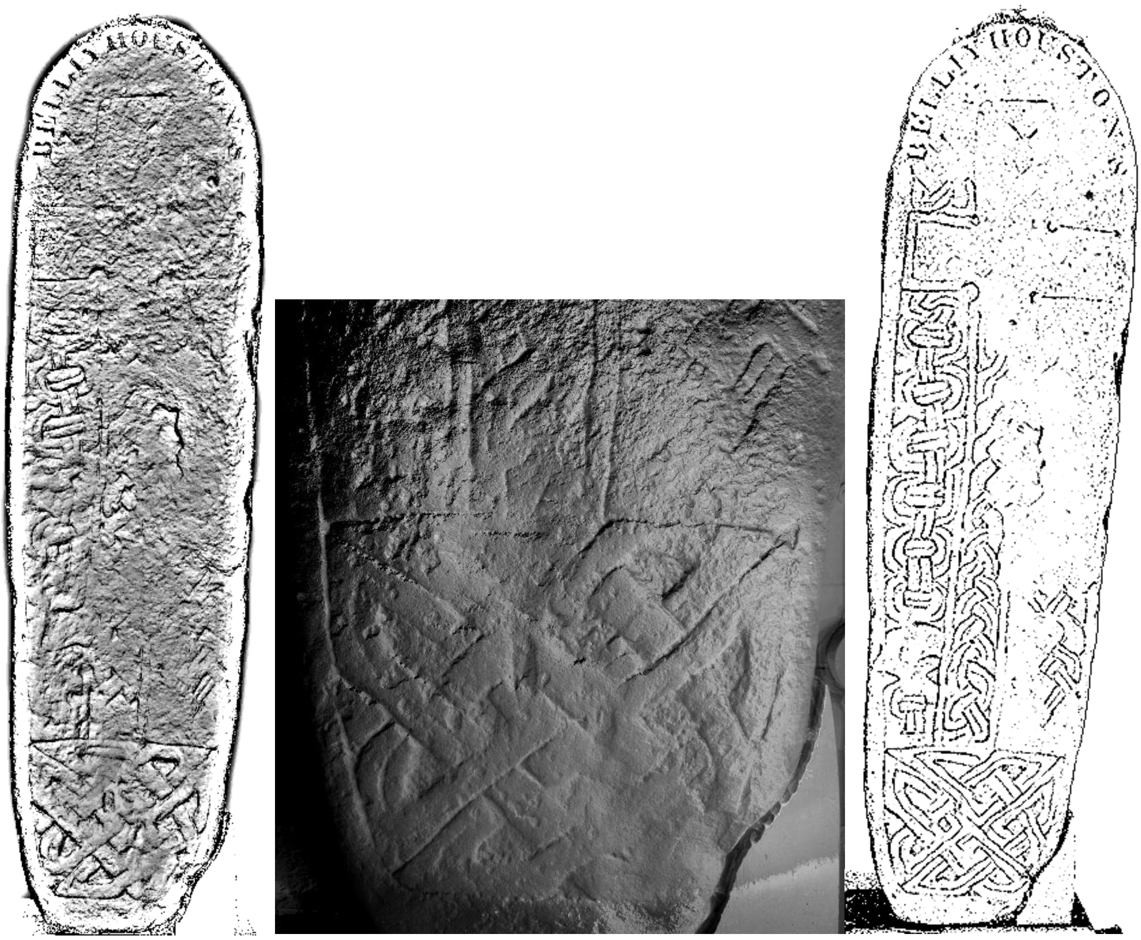


Figure 6.26. (Left) Unaltered 3D model of Govan 24; (Centre) Specular Enhancement of the RTI file depicting the base of Govan 24; (Right) Identified patterns digitally ‘recarved’ onto the 3D model of Govan 24.

6.17 Govan 25

Govan 25 is one of the most irregularly-carved stones in the Govan collection. While at first glance both panels adjacent to the cross-shaft seem to conform readily to what one has come to expect of Govan’s free-ring interlace, upon closer inspection it is revealed that the terminals of these panels are peculiar. It could be that the loose ends were left untucked in the corners. The base also appeared quite similar to the other triangular knot bases in the collection; however, the clearest unit of decoration, the bottom triangle, appears to have two loose ends – one which is tucked into the lower right gap, and another tucked into the central gap (Figure 6.27). It is possible that the application of RTI could clarify the interpretation of this monument.

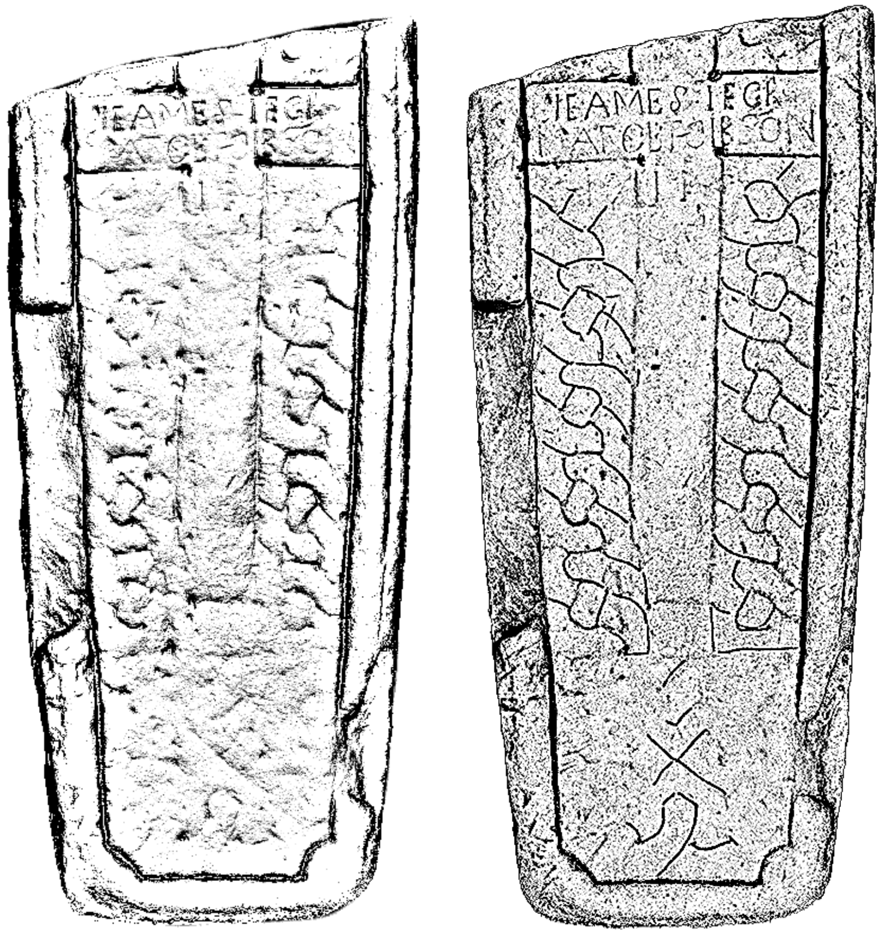


Figure 6.27. (Left) Unaltered 3D model of Govan 25; (Right) Digitally 'recarved' 3D model of Govan 25.

6.18 Govan 26

The recovery of patterns from Govan 26 required a combination of methodological approaches to complete. Removal of the texture from the 3D model revealed the six-grain plaits adjacent to the shaft and some elements of the two patterns forming the base. What is intriguing about the pattern just below the cross is that it appears to be a five-grain plait, but with an extra loose strand incorporated in the centre to create a slight peak in the pattern. The two right quadrants of the lower pattern mostly adhere to Allen's original assessment, Pattern No. 611 (1903, 2, 469; though one could argue that it is arranged more like his Pattern No. 607), but the left half of the pattern incorporates a single Stafford knot into an irregular plait. While RTI was not employed in the analysis of this stone, the deepest portions of the carving were already quite evident in the 3D model. After the shape of each of these remnants were highlighted, they were compared to the worn comparative collection of known patterns. The patterns above the cross are a combination of Stafford knots and Stafford knot-related patterns; the cross-head and cross-arms were decorated with plait, but the shaft of the cross was decorated with outward-facing Stafford knots. The ‘recarved’ patterns can be seen below in Figure 6.28. As stated above, this stone is unique for the complete separation of the ‘base’ from the rest of the decoration with an additional border. RTI may be able to clarify the patterns in the upper part of the cross, though the top half of the cross-shaft is less likely to be recovered because it has been significantly more weathered.

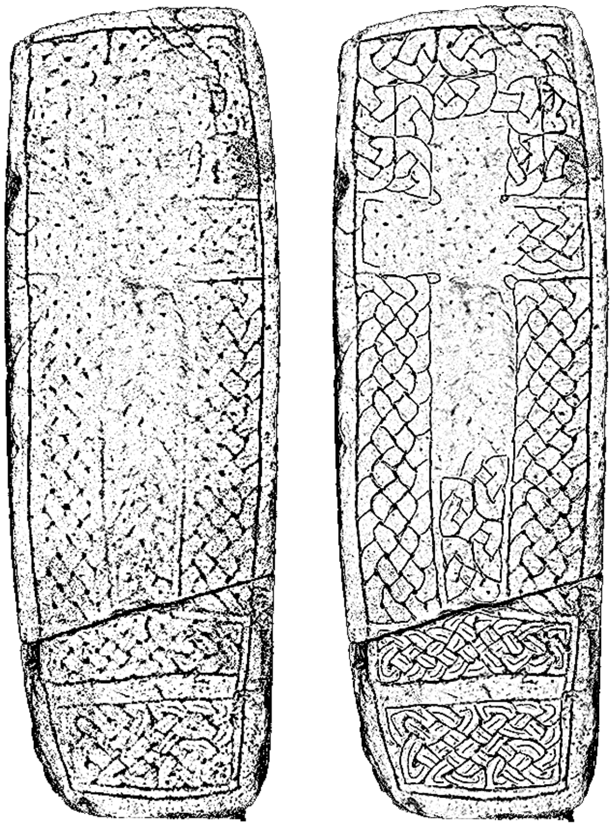


Figure 6.28. (Left) Unaltered black and white image of the 3D model of Govan 26; (Right) Digitally ‘recarved’ image of the 3D model of Govan 26.

6.19 Govan 27

Like many of the other recumbent cross-slabs, Govan 27 has experienced differential wear and weathering. Allen did not attempt to identify the patterns adjacent to the cross-shaft. While analysis of the RTI files and the 3D models revealed little of the pattern on the left side, the pattern on the right side appears to be a series of connected patterns derived from what Allen would describe as a broken three-grain plait (Figure 6.29). This is quite similar to what is found on narrow faces of the Old Kilpatrick cross-shaft (Allen & Anderson 1903, 2, 452–453; Macquarrie 2006, 9). The patterns above the cross are relatively intact and were correctly identified by Allen as double-ring knots. Allen had previously identified the base of the monument as Pattern No. 732 (1903, 2, 468); however, the 3D and RTI have revealed that there is no evidence for the subdivision of strands or interlacing in the centre of the pattern (Figure 6.30). This base conforms more closely to Pattern No. 731 (1903, 1, 287).

Figure 6.29. (Left) Unaltered black and white image of Govan 27's 3D model; (Centre) Snapshot from the Default Rendering mode of the RTI file of Govan 27; (Right) Digitally 'recarved' image of the 3D model of Govan 27.

Figure 6.30. Image from the Default render from the RTI of the base of Govan 27, showing no indication of interlacing of the strands in the centre of the pattern.

6.20 Govan 31

Govan 31 has been heavily eroded, leaving most of its surface completely smooth. The only surviving evidence for patterns are a series of pits on the left side of the stone. Govan 31 was used to pilot the development of the technique of using digitally worn 3D models to recognise heavily worn patterns. As can be seen in the image below, the vestiges of a plait remain on the left side of the monument (which survive as a series of large, pecked indentations), a section of carving on the top left corner of the stone, and sporadic pecked segments on the bottom third of the monument. The rest of the stone has been more severely worn, although small peck marks in almost discernible patterns are apparent (Figure 6.31).

Figure 6.31. (Left) Unaltered black and white image of Govan 31's 3D model; (Right) Digitally 'recarved' image of the 3D model of Govan 31.

While the panel of five-grain plait was tentatively reconstructed based on the results of the Reflectance Transformation Imaging, with some uncertainties as to the very top and very bottom of the panel, another pattern on Govan 31 was identifiable. In the top left corner of the monument, the use of RTI revealed a series of carved long, parallel lines adjacent to angular, triangular pits. The other better-preserved patterns consisting of angular and linear elements in the Govan collection were removed from their context and worn using the methods outlined in Section 5.4.2. After comparing the worn pattern from Govan 31 to these other newly-worn patterns, it became apparent that this was a mitre pattern (Thickpenny 2019). At least two of these are identifiable from this analysis, although it is possible that if the design of the stone follows the structure of others in the collection, a series of mitres might have flanked the cross-head (Figure 6.31).

6.21 Govan 36

Govan 36 is a heavily eroded and damaged recumbent cross-slab, so damaged that it is difficult to identify which end is the top and which end is the bottom. Apart from the top-left corner (as it is oriented in Figure 6.32), the surface of the monument was too eroded to positively identify any other areas of carving, even with the application of RTI. After removing the texture of the monument, it became apparent that there were some remnants of carving in this corner. After highlighting these features, they were compared to the comparative collection and identified as inward-facing Stafford knots. Just below these newly recovered patterns are the traces of a cross-arm and possibly its adjacent hollow; there is not enough detail to positively identify the cross form. The regular pecked surface inside this probable cross-arm indicates that the cross would have been decorated with some sort of pattern.

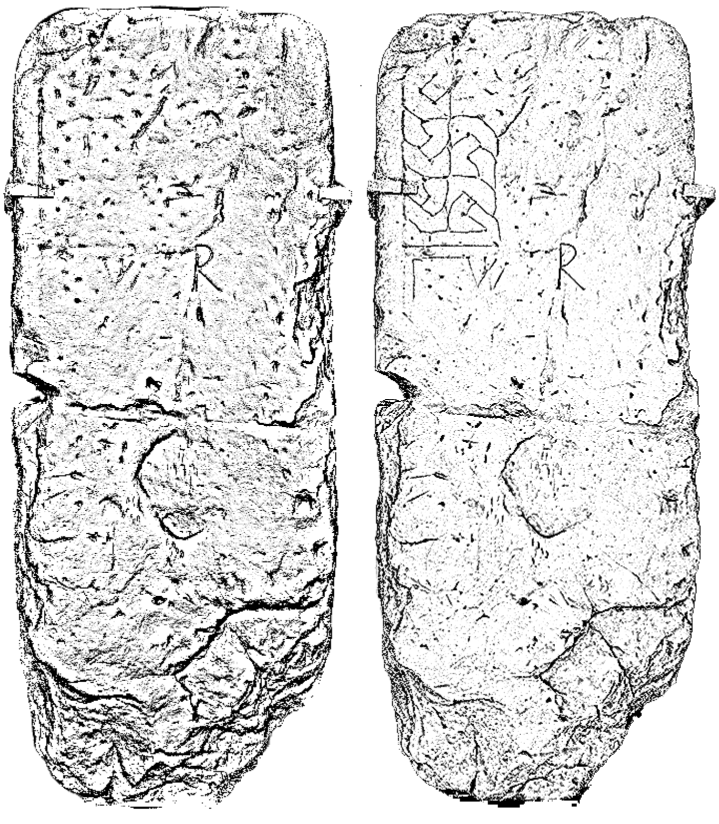


Figure 6.32. (Left) Unaltered black and white rendering of the 3D model of Govan 36; (Right) Digitally ‘carved’ 3D model of Govan 36 to reflect the recovered pattern.

6.22 Not able to recover them all – Govan 10 and 42

While this process has led to some significant discoveries and has broadened our knowledge of the patterns adorning the Govan collection, not all of the worn stones retain enough of their pattern to permit reconstruction. Govan 10 is a good example of this; while RTI has identified some areas that likely represent original decoration, it appears that this side of the cross has been shorn away completely; the scars of this action are a series of parallel ridges stretching across the monument (Figure 6.33). There is also a great deal of damage that took place after this event, evidenced by the linear gouges visible in Figure 6.33.

Figure 6.33. RTI Screenshot showing the parallel ridges stretching across this face of Govan 10. It is likely that this face was deliberately removed.

Govan 42, still located in the churchyard, is another stone where the original carving has been completely worn away (Figure 6.34). There are a few regularly spaced peck-marks that may be the remnants of some sort of decoration, but this is too damaged to reconstruct.

Figure 6.34. 3D model of Govan 42 – very little detail survives on the surface.

This does not mean that these significantly worn monuments are lost causes and should not be imaged. After playing a part in the recent discovery of the early medieval carved stone labelled as "Inchinnan 5," which had been previously identified as a later medieval monument, this process of pattern recovery was applied to the significantly worn stone using the RTI files and three-dimensional models produced by Spectrum Heritage (Spectrum Heritage 2017; Kasten In press b). While some of the individual panels were more difficult to recover, the comparison with known worn patterns from Govan was especially successful; four panels were identified and at least partially reconstructed. The significance of this is that the process is applicable to other stones in the Govan-Inchinnan School, and this process of pattern recovery might be applicable to stones outside of this school of carving.

6.23 Potential for Machine-Learning

While the above pattern recovery is the result of a keen familiarity with the style of the Govan carvers and a significant amount of time spent working with RTI files and 3D models, it is currently unclear to what degree machine learning could contribute to the automation of the process. Machine learning is the use of artificial intelligence to identify patterns in data, so it is possible that it could be trained to recognise different elements of decoration. In the case of Govan, this could be complicated because these stones have experienced varying degrees of wear, so the remnants of the same worn patterns are not necessarily the same shape or depth. The Govan carvers were also particularly creative in their design of some of the patterns; they often left loose ends or incorporated loose strands to amplify the perceived complexity of the pattern. Supervised machine learning also requires a significant number of samples to act as a learning dataset before it can be trained to identify a pattern (Schreck 2017) – it may not be feasible to build up a library of patterns from one collection of carved stone alone. While future advances in machine learning may make things easier for carved stone scholars, for now we must untangle these worn specimens ourselves.

6.24 Conclusion

The digital imaging techniques applied to the Govan stones have demonstrated their value for revealing many previously unidentified patterns and enhancing those which were poorly or erroneously interpreted. By creating three-dimensional models of the monuments, the removal of the texture enables a clearer view of the geometric structure of the carvings. In cases where the removal of the texture is not enough to identify the pattern, RTI can be applied to provide a different, but detailed, perspective on worn carved surfaces. By using RTI to identify the shape and location of carved sections, these can be highlighted in a still image and compared to a comparative collection of known digitally 'worn' patterns to identify what pattern most likely ornamented the eroded surface.

The application of the different levels of this process has expanded our knowledge of the decorative motifs employed by the carvers of the monuments at Govan. For example, Stafford knot patterns and their variants are far more prevalent in the Govan collection than was previously realised. Other patterns that had been classified by Allen have been reassessed to reflect the irregular creativity of the carvers. This analysis has led to a better understanding of the Govan carvers' repertoire, which has enabled more informed comparisons within and without the collection. As will be discussed in Sections 7.2 and 8.3.2, the irregularity of these patterns suggest that this could be intrinsic to a protective interpretation of the interlace. The method of comparing known worn patterns from Govan can be applied to other stones around Strathclyde, like in the case of Inchinnan 5, but the methodology itself could be repurposed for any number of monuments or artefacts with worn and unworn examples.

There are limitations to this approach, especially in cases where the shapes of the worn remnants are no longer identifiable (see Section 6.22). It would also be difficult to compare significantly worn patterns to a 'digitally worn comparative collection' if it does not have any intact parallels to compare to, though this has not been attempted. Finally, museum displays which obscure entire surfaces of a stone restrict the information that can be obtained through digital imaging techniques. While the basic form of the carving from the back of Govan 10 has been recorded, RTI could reveal subtle carved features to help determine whether the panel highlighted above does depict a house-shaped shrine.

While it is not possible for this to provide a comprehensive biography of each monument, several features highlighted by the digital imaging techniques are discussed. This process of pattern recovery has offered the most insight into one subsection of the Govan monuments in particular: the recumbent cross-slabs. As discussed in Chapter 3.4, these stones have experienced by far the most weathering and damage of the monument types found at Govan. We will always be working with a fragmented view of the past. However, by recovering these patterns, the most severely worn monuments, previously excluded from analysis, can now be brought into the discussion. As will be discussed more thoroughly in Chapter 8, by considering these newly classified patterns with other elements of their design, a typology can be constructed to highlight different phases of standardization that were previously unrecognised. Before these various features can be considered together, the different methods of construction that could have been employed by the carvers must first be explored. The possible use of templates for the creation of some of the beasts on the sarcophagus has been suggested and discounted for the Govan horsemen in the past (Craig 1994b, 79). These potential construction methods, among others, will be explored in the following chapter, as will the plausibility of their application and their pertinence to addressing the concept of a 'Govan school of carving.'

7 Templates

As discussed more thoroughly in Chapter 4, the use of templates in the design of stone monuments has sometimes been considered as evidence for the work of the same individual sculptor (itinerant or otherwise) or for sharing of a template between members of the same workshop (Bailey 1980, 249). In past research on the Govan stones, the plausibility (or implausibility) of the use of templates has often been discussed in the context of the horsemen and beasts rather than the interlace itself (Craig 1994b, 79). The creation of three-dimensional models expedites the process of directly comparing these features, as was discussed in more detail in Section 5.5, but will be briefly recounted below. This was in part inspired by Kitzler Åhfeldt's work with the Gotland picture stones, where she has used 3D imagery to identify the replication of several figures via templates. However, she uses tools available through a bespoke ATOS software package to apply this analysis (2009b, 137–139); the methods used in this thesis utilise software that is more widely available. The following analysis will compare the horsemen of the Govan collection via this method, identify any potential for the application of templates, and discuss these patterns in the context of the wider Govan school. This will be followed by a comparison of the beasts found on the sarcophagus and consideration of the role templates may have played in ensuring symmetry in the design of individual panels. The chapter will conclude with a discussion of whether templates were used in the design of the Govan stones and if this supports the idea of a centralised workshop of stone carvers.

7.1 Govan's horsemen

The investigation of the potential use of templates began with the riders as it is one of the few recurring figures in the Govan School. Horsemen appear on four of the stones within the Govan collection: the sarcophagus (Govan 1), the Jordanhill Cross (Govan 7), the Sun Stone (Govan 8) and the Cuddy Stone (Govan 9). The template comparison process outlined in Section 5.5 was followed. Notably, three of the four figures were roughly the same size when the meshes were imported into and aligned in Meshlab (Figure 7.1). A screenshot of this was brought into Photoshop, and each horseman was outlined on a separate layer. This allowed for the scaled outline of each stone to be compared to each of the others. Although there are other ways to undertake this sort of comparison

(Kitzler Åhfeldt 2009b, 137–139; Kitzler Åhfeldt 2015, 410), this workflow makes use of standard or easily accessible software (MeshLab is free, while Adobe Photoshop is an industry standard).

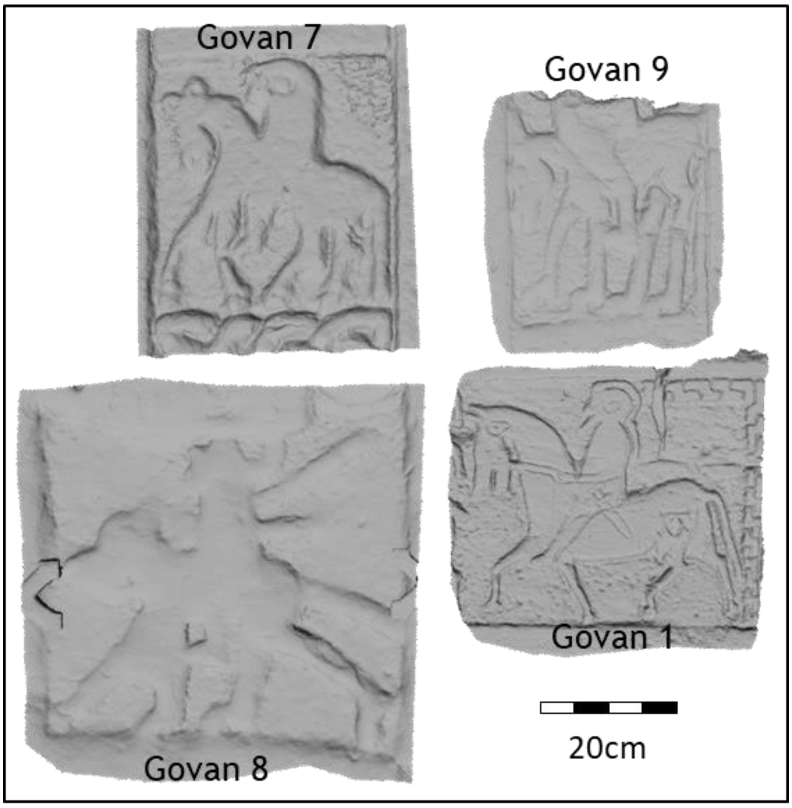


Figure 7.1. The four horsemen from Govan 7 (top left), Govan 9 (top right), Govan 8 (bottom left), and Govan 1 (bottom right), aligned and scaled relative to each other.

Comparison quickly revealed that the figures on Govan 8 and Govan 9 were unrelated to the others. As has been pointed out by Derek Craig, the horse found on the "Sun Stone" (Govan 8) resembles "a monkey running on its hands" (Craig 1994b, 79). However, comparison between the true-to-life scale outlines of the horsemen on Govan 1 and Govan 7 showed a high level of similarity. The interior curve of the horse's neck and the positioning and depth of the horse's mouth in the first position appear to correlate quite well, as does the location of the horse's distinctive eye (although on Govan 7 it is slightly smaller). In the second position, the horse's front foreleg appears to be positioned in a similar fashion. In the third position, the rider's silhouette on Govan 7 has much less detail than that on Govan 1 (which could have been supplemented with painted details in antiquity) but appears to be a simplified version with the same shape and posture. Rotating the outline of Govan 1 by ten degrees counter clockwise offers a more exact fit. In the fourth position, Govan 1's horse's front hindleg fits within the confines of Govan 7's. Finally, in the fifth position, there is not much similarity in the back hindlegs and tails, nor in the curvature of the horse's rump (Figure 7.2).

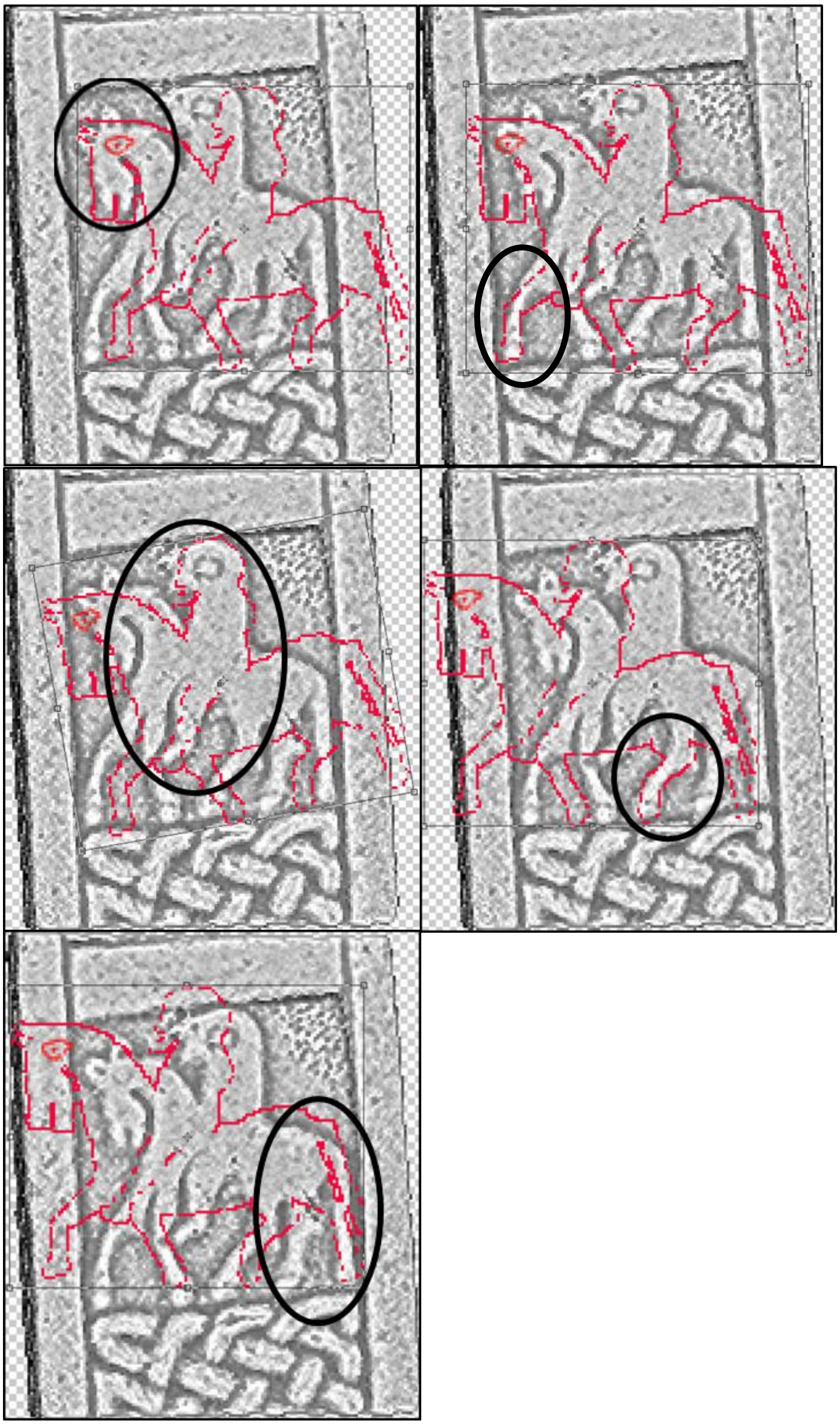


Figure 7.2. Exploration of Potential Template use between the Horsemen of Govan 1 (red outline) and Govan 7 (3D model) via translation and rotation. Both the model and outline in each image are to scale, position 3 involved the rotation of the Govan 1 outline by 10 degrees counter clockwise.

While the details of Govan 7's horseman do not align exactly with those of Govan 1, the sharing of some characteristics and not others might indicate the skilful use of a flexible template. If a leather or fabric template of the Govan 1 horseman was used in the design of Govan 7, the sculptor might have considered that the Jordanhill cross is naturally narrower in width than the sarcophagus. The difference in positioning of the limbs, but the similarity in form might indicate that a fabric or leather template could have been folded to transfer the basic form of the figure. The designer could have then improvised the rest of the design to produce a similar, but simplified, horseman that fit within the space allotted.

Even if the carver of Govan 7's horseman was referring directly the horseman on the sarcophagus, this does not necessarily indicate that it was the same person or even someone in the same workshop working from the same template. If the sarcophagus was carved first, Govan 7's carver could have created their own template by placing a piece of fabric or leather over the sarcophagus horseman and tracing around it or creating a rubbing. This could have been done to make a clear connection with the rider on the sarcophagus, either indicating that this is meant to represent the same person or that the person depicted on Govan 7 is related to that found on the sarcophagus (Bailey 1994, 114). If these figures were painted, potentially in similar colours, this might have made the reference even clearer. While this offers insight into how subsequent carvers might have gotten the underlying messages and devotions across without the use of inscriptions, the exploration of templates alone does not indicate the presence or absence of a cohesive carving workshop.

While Govan 8 and Govan 9's horsemen do not appear to have been created using templates, their form is still worth comment, especially when considered among the other horsemen in the wider 'Govan school'. If one considers St Blane's No. 2 (Figure 7.3; Allen & Anderson 1903, 2, 407), the arrangement of the horse's legs (with the left foreleg and hindleg positioned behind the right foreleg and hindleg) and the horseman's leg, which hangs between the horse's forelegs and hindlegs, is quite similar to that found on Govan 8 and 9 (and to some extent 7, though the arrangement of the horse's legs is far less clear). This also appears to be similar to that found on Mountblow cross and possibly

Lochwinnoch (Macquarrie 2006, 8 and 17); it could be that the positioning of the horseman's leg in particular signals a shift in riding style or the gear used (Cynthia Thickpenny pers comm), or at the very least a distinct change in how the sculptor(s) perceived and portrayed these horsemen. This is in contrast to the position of the horseman's leg on the Govan sarcophagus, and possibly those of the riders on the Kilwinning fragment, which is situated between the horse's forelegs much in the same way as the horsemen are often depicted in Pictish sculpture. The stirrup is thought to have been introduced to Britain by the Vikings sometime during the late 9th or 10th centuries AD (Seaby & Woodfield 1980, 98–104), so it could be that this shift in representation is related to the adoption of the stirrup by Strathclyde's elite. However, additional regional comparison is required before this can be taken further.

Unfortunately, the position of the rider's foot is not always identifiable, as is the case with Rothesay 2 (Allen et al. 1903, 2, p 416; although Ian Scott's drawing available through Canmore suggests that this horseman has adopted the 'Pictish' stance) and the Barochan cross (Allen & Anderson 1903, 2, p 457), though these may yet become apparent after renewed, close inspection with RTI or 3D imaging. There are additional art historical similarities between Govan 8 and St Blane's 2 in particular, specifically the shared panel of triangular interlace, which will be more thoroughly discussed in the final discussion in Chapter 10.

From this analysis, while the sharing and use of templates by members of a workshop in the production of the four Govan horsemen is an intriguing concept that seems unlikely at best, there are still valuable insights to be gained by comparing the individual forms of the horsemen. There seems to be at least two different leg positions of the horsemen in the Govan school: those with their leg between the horse's forelegs in a 'Pictish' fashion, like that of the Govan sarcophagus, and those with their leg situated between the horse's forelegs and hindlegs, like that found on Govan 8 and 9. Whether this has more to do with the identity of the individual that was commemorated by these pieces of sculpture or the type of horse riding that was prevalent at the time of carving, this division can be found elsewhere in the sculpture of Strathclyde and warrants further investigation.

Figure 7.3. Photo of St Blane's No. 2 in the Bute Museum, where the horseman's leg is clearly situated between the horse's forelegs and hindlegs.

7.2 Sarcophagus Templates

In the case of the sarcophagus, it appeared to the author and others that there was the potential for the use of templates in the case of the quadruped "beasts" on the side face opposite from the horseman in his hunting scene (Craig 1994, 79; Figure 7.5). However, upon direct comparison of the outline of each of the four beasts to each other, it became apparent that these animal forms differed significantly in the positioning of the eyes, the forms of the heads, and the arrangement of each leg. The bodies were not the same length and they were oriented at different angles. The interlacing tails and ears formed different patterns (Figure 7.6). While this would suggest the lack of template use at first glance by Laila Kitzler Åhfeldt's criterion that the 'outer contours and starting and crossing points of extremities coincide' (2009a, 501), the exploration of this panel was taken one step further. The following comparison considers the four beasts in Panel B and the pair of beasts on Panel D (schematic highlighting these two panels is provided in Figure 7.4 below).

As discussed in Section 5.5 and above, the lack of correlation between the complete outlines of the four “beasts” but the overall similarity in look led the researcher to compare the individual components of the figures. Much like Richard Bailey’s explorations of the Durham cross-heads (Bailey 1980, 247–254; Bailey 1996, 114), it appeared that several components of each “beast” might have shared a template, but were placed in different positions to fit the space allocated for the scene.

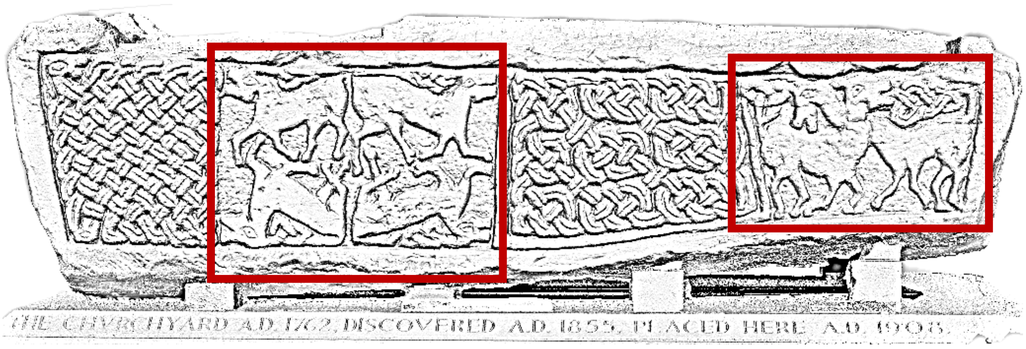


Figure 7.4. Schematic highlighting the two panels explored in this section: (left) Panel B and (right) Panel D.

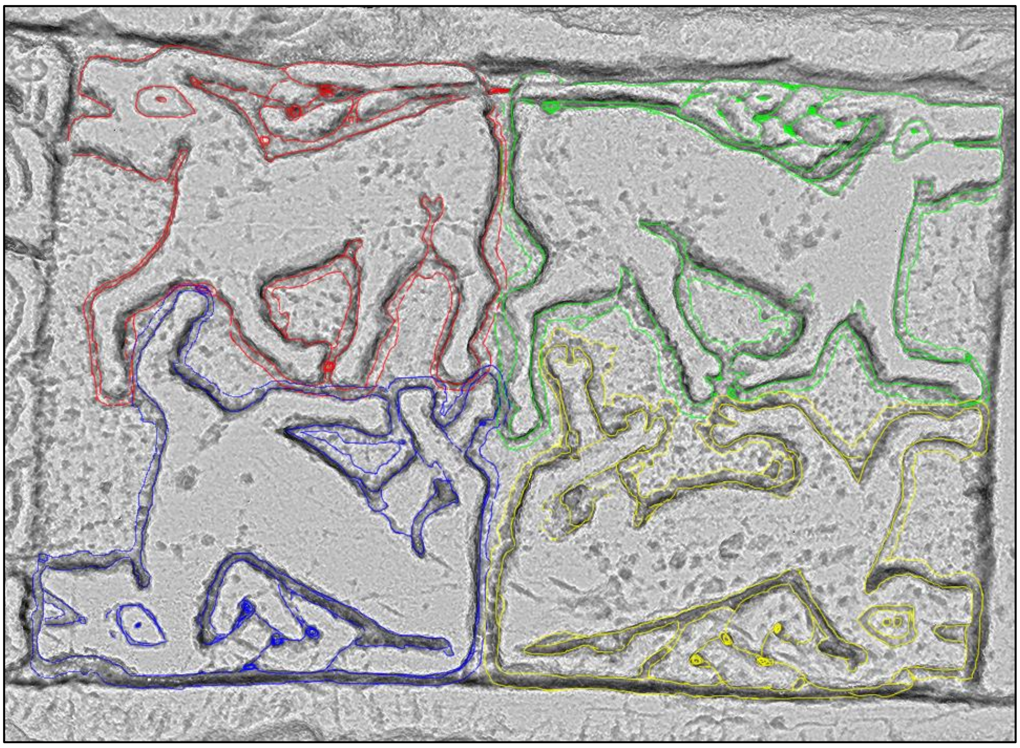


Figure 7.5. Outlines of each of the beasts from the sarcophagus Panel B.

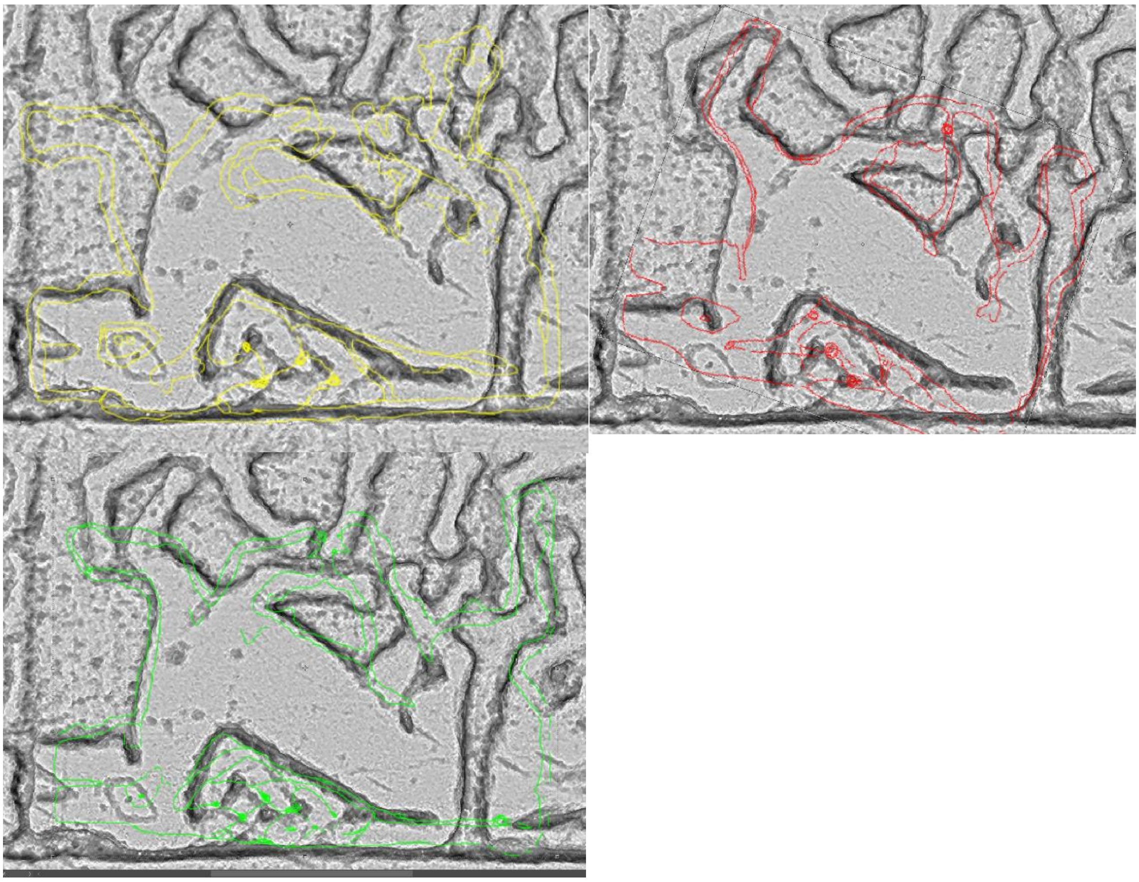


Figure 7.6. Outlines from three beasts imposed on the bottom-left beast - revealing no exact matches.

To explore this possibility, the foreleg of the bottom right beast was considered (Figure 7.7). This outline was sectioned off from the rest of the template, moved and rotated using Adobe Photoshop in order to compare its form with each of the legs found on the four individual “beasts”. It quickly became apparent that some, if not all, of the bent legs found within the panel might be related to the form of this one foreleg (Figure 7.8). While some of the legs fit within the carved boundary of the comparative leg, other legs matched the angle but were of differing lengths.

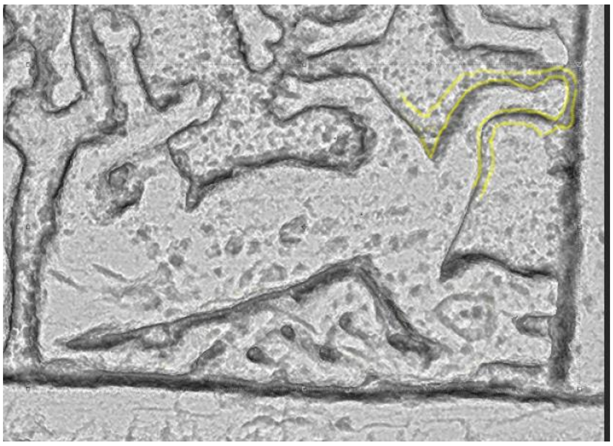


Figure 7.7. Original outline of the Bottom Right Beast's foreleg tested against other bent limbs on the panel.

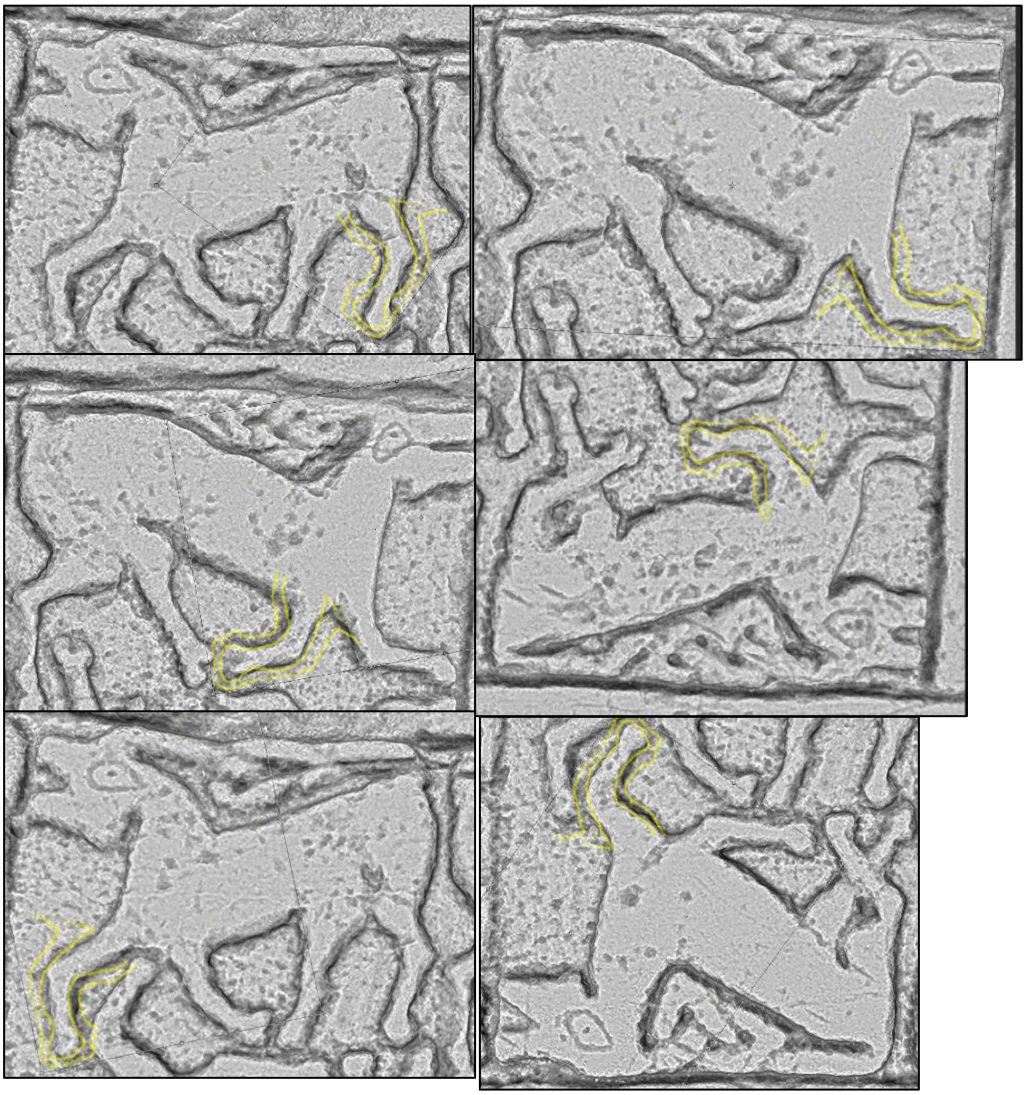


Figure 7.8. Original Outline featured in Figure 7.7 imposed on other bent legs on the panel: (top left) Flipped across both axes, rotated 54 degrees counter-clockwise; (top right) Flipped vertically and rotated 3 degrees clockwise; (centre left) Flipped vertically and rotated 10 degrees counter-clockwise; (centre right) Flipped horizontally and rotated 5 degrees counter clockwise; (bottom left) Flipped vertically and rotated 78 degrees clockwise; (bottom right) Rotated 54 degrees counter-clockwise.

From this initial comparison, it became apparent that each of the legs appeared to be consistent in terms of width, and the legs are bent at a recurring angle. It also seems that each front foreleg of each beast falls within the inner-most outline for the bottom-right beast's front foreleg, although this template would have been flipped and rotated to a variety of different positions. What is interesting is that in some cases, the upper and lower segments of two crossed legs fit the outline of the bent leg better than a single leg outline (Figure 7.9). If a single template was used to create these overlapping legs, it is likely that these crossed legs are planned deviations in the symmetry of the design. The significance of this will be discussed below.

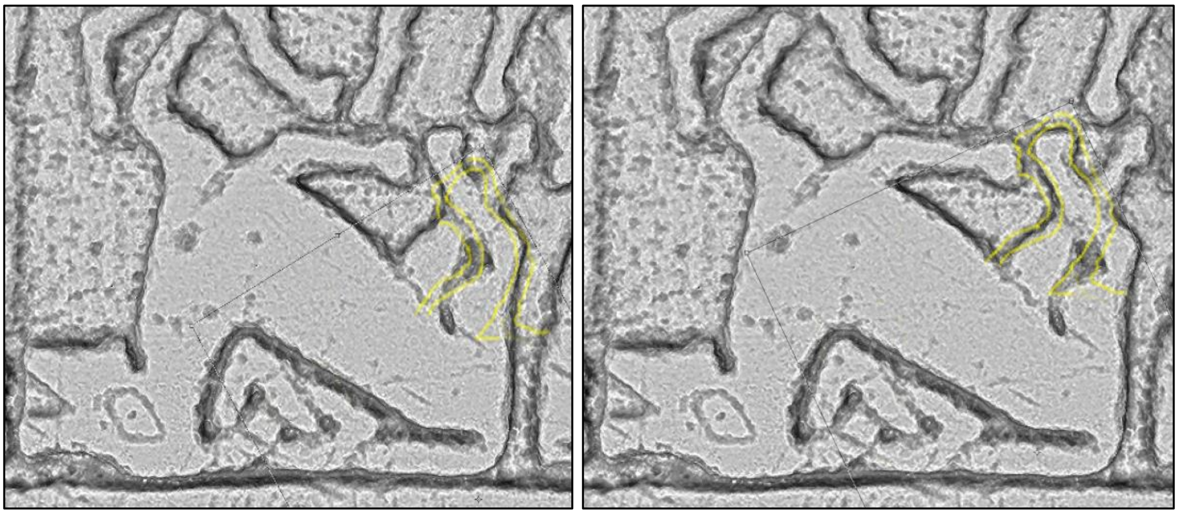


Figure 7.9. Imposing the outline of the bottom right beast's front foreleg onto the hindlegs of the bottom left beast. (Left) Flipped horizontally and rotated 60 degrees clockwise; (Right) Flipped horizontally and rotated 65 degrees clockwise.

After comparing the outlines of the bent legs in this panel, the consistently straight, front hindlegs of the beasts were compared to the outline of the lower right beast's front hindleg (Figure 7.10). From this analysis, it appeared that these legs too were quite similar in length, width and form. The only deviation from this was the top left beast, where the segment comprising of the crossed leg (highlighted in Figure 7.10 in green) had to be removed in order for the 'best fit'. The proximity of this leg in particular to the back foreleg of the bottom left beast may have forced the sculptor to make this minor truncation. From this analysis, while the implementation of templates is still in question, it is apparent that the carver(s) of this panel utilised a mostly consistent length, width and angle for each of the beasts' legs. To determine whether this was the case for other individual components of the beasts, the shape of the space allocated to the ear and tail knots and the shape of the bodies were also compared between the four beasts.

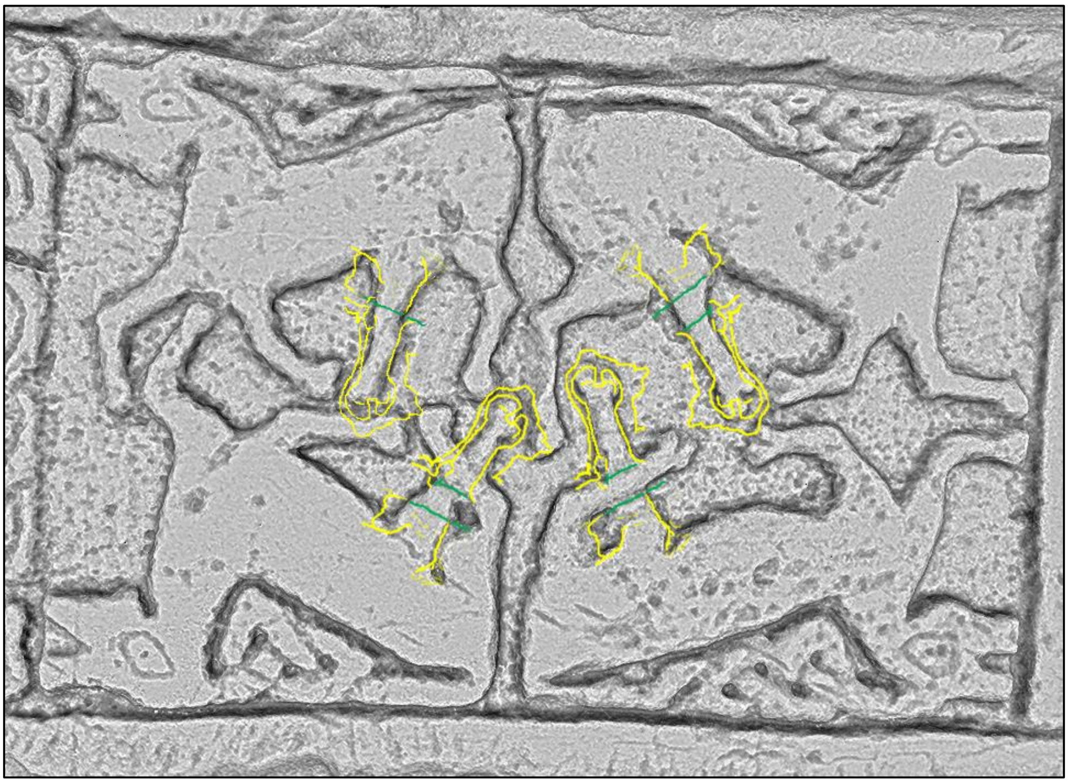


Figure 7.10. After creating an outline of the bottom right beast's front hindleg, this was translated and rotated to determine how similar the legs of the other beasts were. In the case of the top left beast, the section of the crossed leg (outlined in green) had to be removed for the outline to fit.

The knotted ears and tails of each of the beasts vary in size and complexity. However, if the interior details are ignored, these sections can be considered as triangular areas that were 'blocked out' by the sculptor(s), dedicating the space for these elements; these generalised shapes can be more easily compared. In Figure 7.11 below, the outline of the triangular space for comparison has been defined by the top left beast's tail and ears. This has been rotated and translated to find the 'best fit' over this element of the other beasts in the panel. From this comparison, it is apparent that the space allocated to the ears and tail is most similar in the cases of the top left, bottom left, and bottom right beasts, though the carvers have taken creative liberties in the shape of the beasts' necks and different areas of elongation, the latter especially in the case of the two right beasts. To complete the analysis of this panel, the shape of the bodies of the beasts were considered.

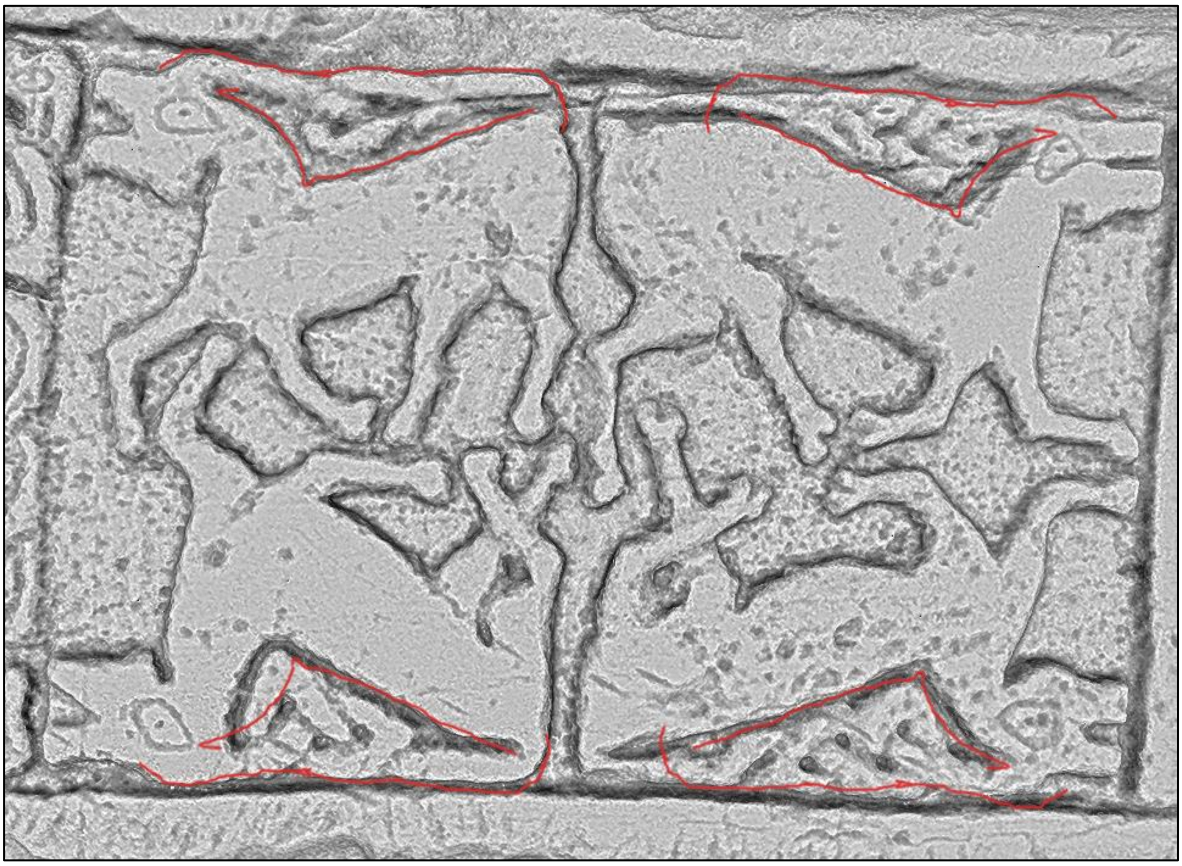


Figure 7.11. Top left beast's triangular outline imposed on all beasts in the panel – this fits quite well over the space dedicated to the ear-tail knots of the bottom left and bottom right beasts, although this is less coherent in the case of the top right beast.

The largest discrete element of these beasts are the bodies themselves, and so would have required the most consideration when the carvers were planning the layout of the panel. To compare these, the outermost boundaries of the top left beast's body were outlined. As above, this outline was then translated and rotated to determine the 'best fit' to the bodies of the other beasts in the panel, which can be seen in Figure 7.12. The most similarity in body-shape can be seen between the left-most beasts. On the right, elongation of both beasts is clear; however, the construction of the lower right beast is most intriguing, mostly due to its apparent strict adherence to the top left beast's body-shape before being stretched to the right. Undoubtedly the filling of the panel was more important to the carvers than was the assurance of symmetricity between the left and right beasts.

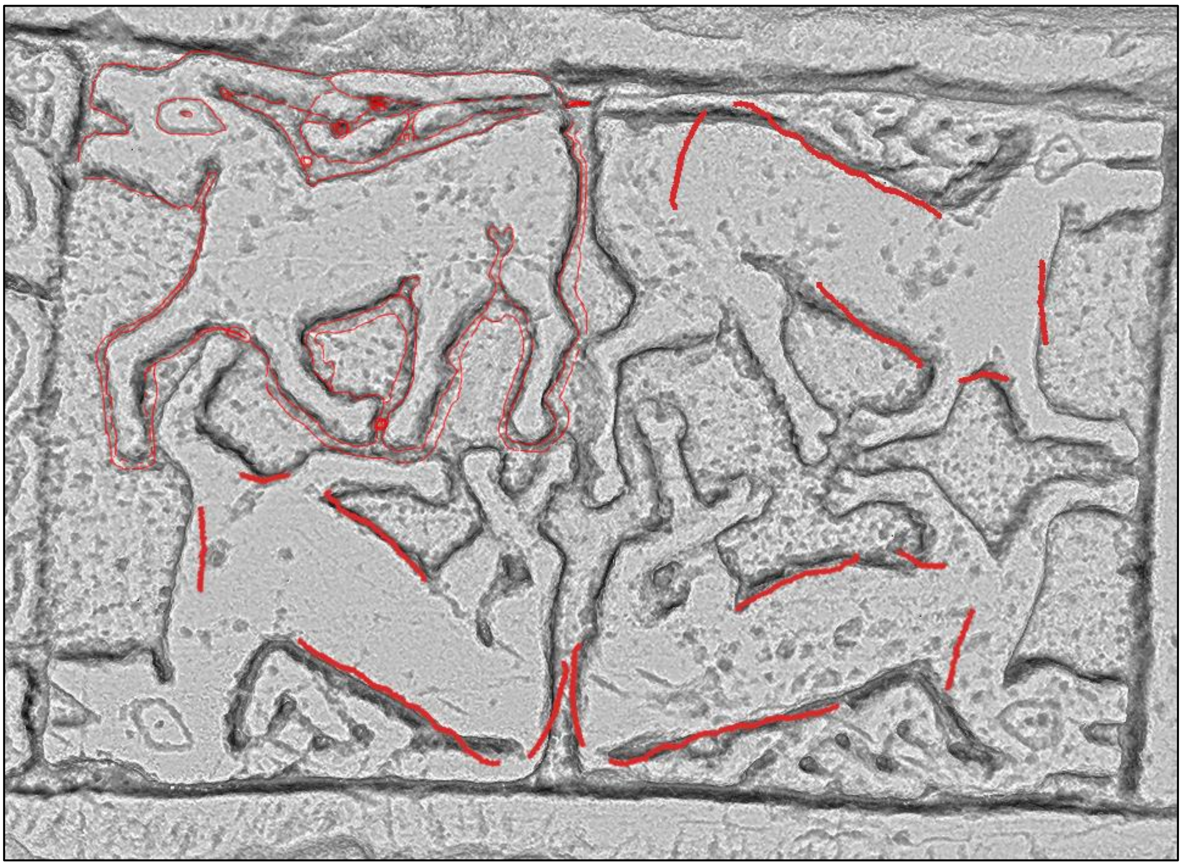


Figure 7.12. Comparison of the shape and extent of the bodies of the beasts.

The segmentation of these figures into discrete elements is an entirely subjective process, but at the very least this has been a useful exercise in considering and contrasting the different elements of the overall design of this panel. By looking at these comparisons altogether, not only has this highlighted several areas where the sculptors have striven for symmetry, but it has also brought attention to areas of blatant asymmetry.

While the proportions and angles of the legs are fairly consistent in their replication between the four beasts, as described above, it is clear from comparing the other elements that the pair of left beasts are more similar to each other, as are the right beasts to each other. In addition to the consistent amount of space dedicated to the ear-tail knots and the body-shapes, the left beasts' forelegs are arranged in a similar manner, both have un-cloven hooves and the knot formed by their ears and tails is simple (while the lower left beast's knot is clearly a Stafford knot, it is not immediately clear what form the top left beast's knot took). Based on these elements, it appears that the carvers were intent on the left beasts appearing symmetrical. However, this symmetry is broken by the deliberate crossing of the bottom left beast's hindlegs (and the positioning of its front foreleg, though this could be argued as an issue of space allocation).

A similar comparison could be made between the beasts on the right half of the panel. Both have had their bodies and ear-tail knots elongated by the carver, possibly to ensure the complete filling of the panel. The ear-tail knots appear to be similar to each other, but these are more complex than those of the left beasts. The forelegs of these two beasts mirror each other, splayed outward in a manner very different from those on the left. Finally, the pair of beasts on the right differs from the left pair in that some of their hooves are cloven, though this is not consistently applied. Again, however, the carvers have complicated this apparently symmetrical picture by crossing the hindlegs of the lower right beast.

If these four beasts were in fact pieced together through the use of templates, these may have been integral to the planning process, and the creation of a perceived, though altered, 'symmetry', which appears to be essential to the design of the panel and its underlying meaning. If this were the case, this would differ from the application of templates identified in Gotland by Kitzler Åhfeldt (2009a, 503). In her exploration of the Gotland picture stones, she found that portions of the motif would be cut off by the boundary of the stone, suggesting that there was little forethought or skill in the adaptation of the template in each subsequent use. This would not be the case in the design of the sarcophagus; if templates were employed, the carvers elongated and rotated these elements to fully fit the panel.

If the creation of apparent symmetry was one of the goals in this design, why were the legs of the two upside-down beasts crossed? Janet Backhouse (1981, 55) has suggested that the introduction of errors in the decoration of the Lindisfarne Gospels was an act of humility, based on the belief that only God can create perfection. But should asymmetry be considered an 'error' in the design? In Michelle Brown's analysis of the Lindisfarne Gospels, she states that the artist incorporated principles of divine geometry in his design; elements of asymmetry were incorporated in portrayals of the 'natural order', especially in the zoomorphic interlace (2003, 297–298). The creation of purposeful asymmetry in the design of the beasts by the sarcophagus's carver(s) could then be reference to these concepts. Brown also argues that minor asymmetry was also used in the design of other carpet pages of the Lindisfarne Gospels to emphasise instances where the artist applied 'perfect' symmetry, in this case the cross-carpet page of St John, which was considered the gospel most directly given from God (Brown 2003, 298). The use of asymmetry to emphasise other elements of symmetry, as suggested above, then may have been an established method by artists that worked in other media in the early medieval period.

In his discussion of the apotropaic qualities of complex interlace, James Trilling suggests that interlace that is confusing, or otherwise difficult to follow or solve, is imbued with more protective power (1995, 71). While not directly relevant to the figures discussed here, confusion is a theme that is found throughout the Govan interlace patterns and will be discussed more thoroughly in Section 8.3.2. Perhaps the insertion of 'errors' or purposeful asymmetric elements was considered introducing an element of confusion and so acted as a form of protection for the individual buried in the sarcophagus. There are several other elements in the design of the sarcophagus that seem to exude protective intent, like the panel of the 'lamb of God' trampling the beast, the 'confusion' of the snakes forming panels of plait, and the positioning of the 'step' pattern behind the horseman, which is paralleled in its depiction at Meigle, which will also be discussed more thoroughly in Section 8.3.2.

What makes the above analysis of Panel B even more interesting is its comparison to Panel D, which depicts a pair of beasts on the same side of the sarcophagus – both of which have their hindlegs crossed. While the knots formed by these beasts differ slightly in the form of interlace employed, there is still a less-complicated knot on the left in contrast the one on the right. Finally, the positioning of the forelegs of these beasts mirrors the two foreleg positions found in the panel described above. One significant difference is that neither of these beasts exhibit cloven hooves, so it is unclear if this is meant to 'continue the story' from the four-beast panel or not. On a final note, there is an apparent lack of symmetry between the two beasts; the application of the left beast's body outline to the body of the right beast was similar but did not match to the extent evident in the previous panel's pair of left beasts (Figure 7.13). After applying the outline of the left beast's front foreleg to the other seven legs in the panel, it became apparent that similar angles and widths were again used for the legs (apart from the front forelegs of the right beast); however the lengths of the legs were more widely variable than in the previous panel (Figure 7.14). In the case of this panel, it seems the carvers were less concerned about ensuring symmetry and might have been more intent on referencing the forms of the beasts in the other panel.

Figure 7.13. Panel D: the imposition of the left beast's body outline over the right beast; while there is a bit of similarity, there are clear differences.

Figure 7.14. Panel D: Imposition of the outline of the left beast's front foreleg on the others in the panel.

Whether or not templates were employed in the construction of the sarcophagus, it is clear from this analysis that, at the very least, consistent angles and measurements were used in the design of the sarcophagus panel containing four beasts to evoke symmetrical attributes. This was employed to a lesser extent in the case of the panel with two beasts, possibly to make the reference to the previous panel clear. While this exploration of symmetry and asymmetry on a single stone does not contribute to discussions concerning whether the use of templates indicates the existence of a centralised workshop at Govan, this does offer insights into the sculptor(s) approach to carving and the underlying meaning that they imbued into the design. It seems unlikely that these four beasts have anything to do with the Book of Revelations, as previously suggested by MacGregor Chalmers (1902, 12), and instead appear to be rooted in themes of protection and possibly evoking themes of divine geometry, as seen elsewhere at the time of the sarcophagus's carving.

7.3 Templates at Govan?

From the above analysis, it seems unlikely that templates were used in the replication of the horsemen at Govan, with only a slight possibility that the figure on Govan 7 was copied from or inspired by the form of the rider on the sarcophagus. However, this would not necessarily need to have been done by someone within the same school as the sarcophagus carver(s); they could have easily used charcoal and some pliable material to create a replica from which to work. The slight discrepancy in the positioning of Govan 7's horseman's foot, closer to between the forelegs and hindlegs of the horse than the positioning of the sarcophagus's rider, suggests that indeed the sculptor(s) was more readily influenced by the riding style evident on Govan 8 and 9 rather than the 'Pictish' one. The apparent division between these depictions of horsemen and their different riding styles requires further analysis in the wider context of the stones of the Strathclyde region before any clear patterns can be identified.

It is possible that templates were used by the carver(s) of the sarcophagus to aid in replicating figures to produce a symmetrical effect to emphasise the incorporated elements of asymmetry. If templates were used, they were employed piecemeal, in a way similar to the method Bailey has proposed for the carvers of the Durham cross-heads (1980, 249–252), and were adapted to better fit the panel, in a less strict adherence to the template than their application on the Gotland picture stones (Kitzler Åhfeldt 2009a, 205). While this cannot be used as evidence for the presence nor absence of a centralised workshop of carving, it does offer insight into the early medieval carving process and the possible meanings behind these panels.

Overall, the use of templates to replicate figures between different stones or the sharing of templates between members of a centralised workshop appears less well-supported in the Govan sculpture than has been suggested elsewhere in the Viking Age (Bailey 1980, 253; Kitzler Åhfeldt 2009a). However, this method of importing multiple three-dimensional models into the same Meshlab space side-by-side and outlining features for comparison in Adobe Photoshop has offered insight into other areas of analysis for the carved stones at Govan. This approach is less direct than that employed by Kitzler Åhfeldt using the bespoke ATOS software, but it uses software that is more accessible and cost-effective. In the future, it would be beneficial to test both approaches on the same material to compare the results. Not only does this approach offer a less damaging method to identify the potential use of templates than the creation of rubbings from the stone, but it has also been invaluable in evaluating standardization of the layout of the recumbent monuments and potentially identifying the replication and resizing of decorative elements, as will be discussed in the next chapter.

8 A new typology

As discussed in 3.4, the previous typologies of the recumbent cross-slabs from Govan have offered limited insight into the internal phasing of the collection. In the case of the most comprehensive typology developed by Rosemary Cramp, this was largely because of the difficulties posed by the worn and broken condition of these monuments, as discussed below. After taking this into account, her criteria were reapplied to the Govan collection; applying her criteria consistently resulted in new groups defined almost entirely by the presence or absence of decoration on the cross. This is one possible interpretation, but there are many features that could be utilised in the creation of a typology. Only a few of these are consistently identifiable for most of the extant monuments in the collection.

The typology developed in this chapter sought to 'identify points at which choices were made' (Lucas 2001, 91) in the monument's design process to identify any elements of standardisation that might have been missed due to the previous focus on the angle-knob feature. This approach complements many long-standing typological approaches because it operates at the assemblage level (Lucas 2001, 85) and combines both intuitive attributes based on art historical designations and attributes defined computer analyses (Hurcombe 2007, 58). However, the typology defined here goes against one of Adams and Adams' main points of 'mutual exclusiveness' (1991, 77), their assertion that each artefact must fall within a single group. However, this point of group 'fuzziness' is gaining some acceptance in archaeological typology (Lucas 2001, 98). While it would have been possible to add further definitions to assign the 'transitional' monuments to a single group, the acceptance of this fuzziness was particularly useful in this typology. This internal stratification may or may not have chronological significance, but the resulting overlap clearly demonstrates the continuity of the stylistic tradition over a relatively short time span and identifies the subtle underlying phases of standardisation.

The new typology developed here adopts a multivariate approach that considers the form of the cross, the nature of the decorative treatment, and the layout of those ornamental motifs. This approach identified several distinct groups which highlight different phases of carving that were previously unrecognised. These groups have implications for interpretations of the Govan collection and carved stones in the wider Strathclyde region.

8.1 Rosemary Cramp's Recumbent Cross-slab Typology

While Rosemary Cramp's typology represents the most comprehensive attempt to understand Govan's recumbent cross-slabs to date, there are three weaknesses to her approach. First, not all of the extant recumbent monuments were included in her typology. While this is understandable to some extent when considering severely worn monuments like Govan 31 and 36, four other monuments in the collection were not considered. Govan 13 and 24 are almost entirely intact and retain a great deal of their decoration but were excluded from discussion. Photographs of these stones were included, but were never referenced within the text (1994, 60–61). It is unclear why these two stones in particular were not included in the discussion.

Secondly, Cramp made several assumptions about cross-slabs which were 'misplaced' and for which we only had Stirling Maxwell's photographs to inform us. For example, when Cramp included Govan 32 (ECMS 20) in her group A, she cited that it is similar to Govan 11 and 16, "round headed and, the interlace, both on the crosses and surrounding the stem, is more like that of group A" (1994, 56). While the free-ring interlace does appear on the left side of the cross of Govan 20, one could hardly describe the damaged head of the monument as deliberately rounded like that of 11 and 16. In addition, she allocated Govan 42, 44, and 46 to Group C and described them as "plain slabs with chamfered edges" (Cramp 1994, 56). While Govan 42, a severely worn recumbent monument located in the churchyard, might fit this description, Govan 44 and 46 do not appear to exhibit these traits in the extant photographs. Since the latter two slabs have not yet been unearthed, it is not yet possible to verify, but in Stirling Maxwell's photograph of Govan 44, the incised boundary around the edge of the monument found on the other recumbent cross-slabs is clearly visible. In fact, this stone is described in Allen and Anderson as retaining hints of interlace, with no mention of chamfered edges (1903, 2, 470).

Finally, she did not take the worn or damaged condition of the monuments into account before classifying them. For example, Cramp included Govan 28 in her

Group B because the crosshead reaches the top of the stone. She cited this trait as significant in the classification of similar recumbent monuments from York Minster and other areas of late Saxon England (1994, 59–60). However, the interlace patterns on either side of the crosshead on Govan 28 have been clearly interrupted and the border across the top of the stone is missing, which indicates that the top of the slab has been broken. Because the interlace pattern would have continued above the crosshead and there is no evidence for decoration on the cross, this slab would not have fit within her Group B. When considering the rest of the collection, the position of the crosshead cannot be reliably identified in the case of at least seven of the recumbent monuments due to damage or wear. While this trait might be useful in the analysis of sculpture from elsewhere, it is not as informative at Govan. The differences in wear could also affect the classification of the carving techniques Cramp assigned to each group, but this will be addressed below.

8.1.1 Reapplying Rosemary Cramp's Classification

If we were to take Rosemary Cramp's classification and reapply her criteria to the extant collection, ensuring that the condition of the stone and the recovered patterns are fully taken into account, Groups A and B essentially become defined by the 'stones with plain crosses' and 'those with decorated crosses' traits respectively (Figure 8.1; Figure 8.2; and Figure 8.3). Due to the worn condition of some of the monuments, it is difficult to tell if some of the crosses were originally decorated or not (especially for Govan 13, 20, 31, and 36), but an informed guess was made based in each case. Only three of the recumbent cross-slabs can be definitively identified as exhibiting a cross that reaches the top of the frame (Govan 14, Govan 15 and Govan 18). While two of these feature decorated crosses and belong firmly in 'Group B' on that basis, Govan 18 on the other hand has angle-knobs and its cross is undecorated, which would suggest that it should be allocated to 'Group A'. If one includes Inchinnan 1, another example of the cross reaching the top of the frame, this would be in conflict between the two groups as it also exhibits a plain cross. For this reason, the cross reaching the top of the frame, while an interesting variation in Govan recumbent cross-slab design, is not a consistent trait to pair with decorated crosses in the definition of a typological group.

The other traits cited by Cramp in her definition of Groups A and B relate to the possible differences in carving techniques employed, specifically referring to a deeper carving style and the use of grids to plan the decorative motifs of Group B. It is argued here that definitively assigning stones based on this characteristic is difficult to qualify on sight, especially with the amount of wear most of the stones have experienced, but the interlace of certain stones is ‘gappier’ than others (see Govan 14, Govan 28 and Govan 31). The use of a grid could potentially be argued for Govan 26, but its carving is much shallower and ‘tightly-knit’ than that of others in Group B, which makes its inclusion within the group less coherent on this basis. The use of a grid is less apparent for the rest of the stones in this group, although their decoration is well executed. The ‘grid-like’ effect on Govan 28 (now in Group A), Govan 14, and Govan 36 (and possibly Govan 15) is likely due to the significant wear on Stafford knot patterns (see Section 5.4.2 on the results of simulated wear of different patterns) and does not necessarily require the use of a formal grid. These differences could reflect underlying properties of the stone used or a stylistic preference of the carver. Overall, the differential condition of the stones and the inconsistent application of these traits prevented these characteristics from defining a consistent classification. While these traits do not form a coherent typology together, there are many reliable traits on which a localised typology might be based, which will be discussed in below.

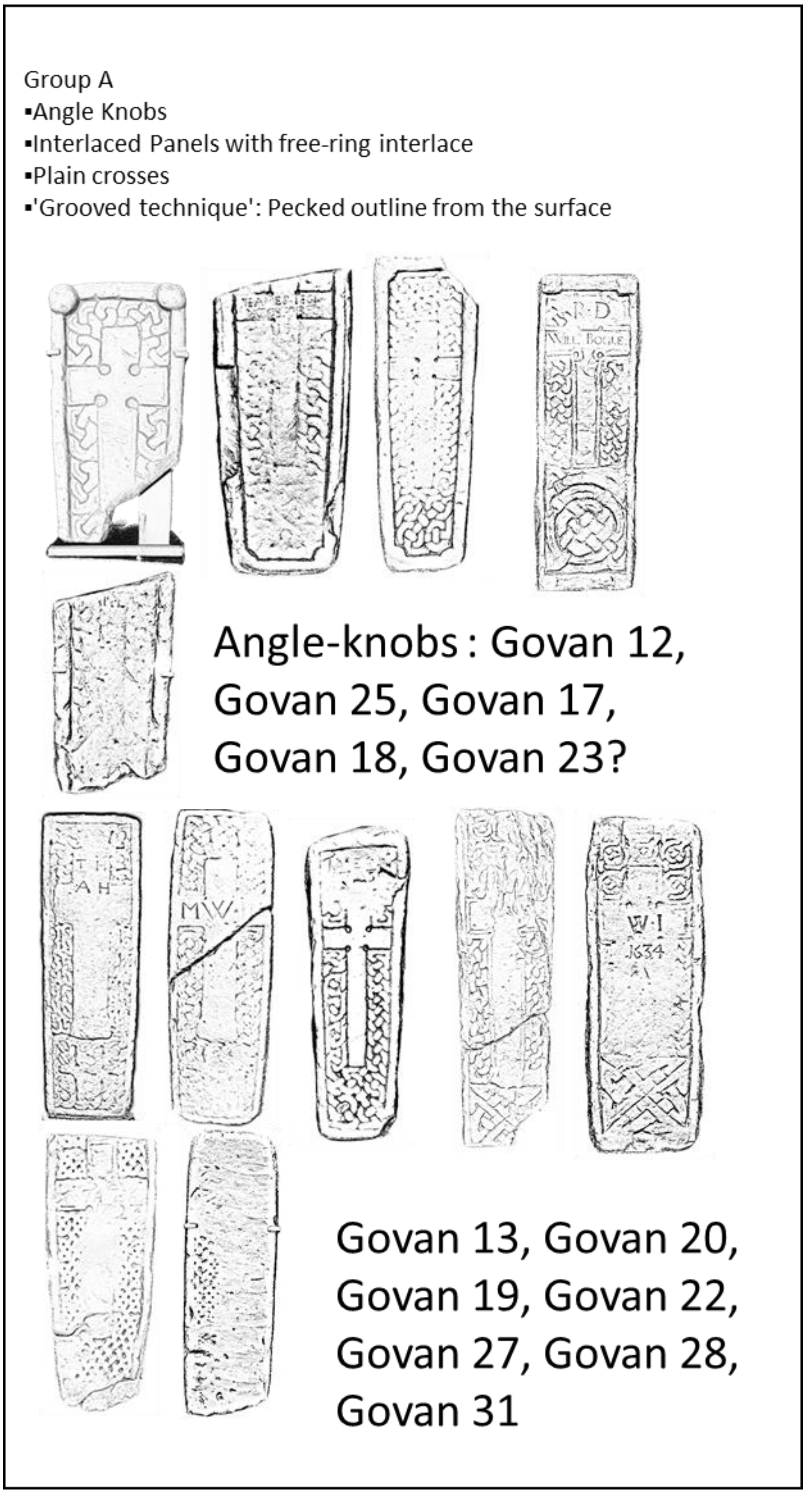


Figure 8.1. Visualisation of Rosemary Cramp's typological traits for Group A reapplied to the extant collection at Govan, taking into account their current condition.

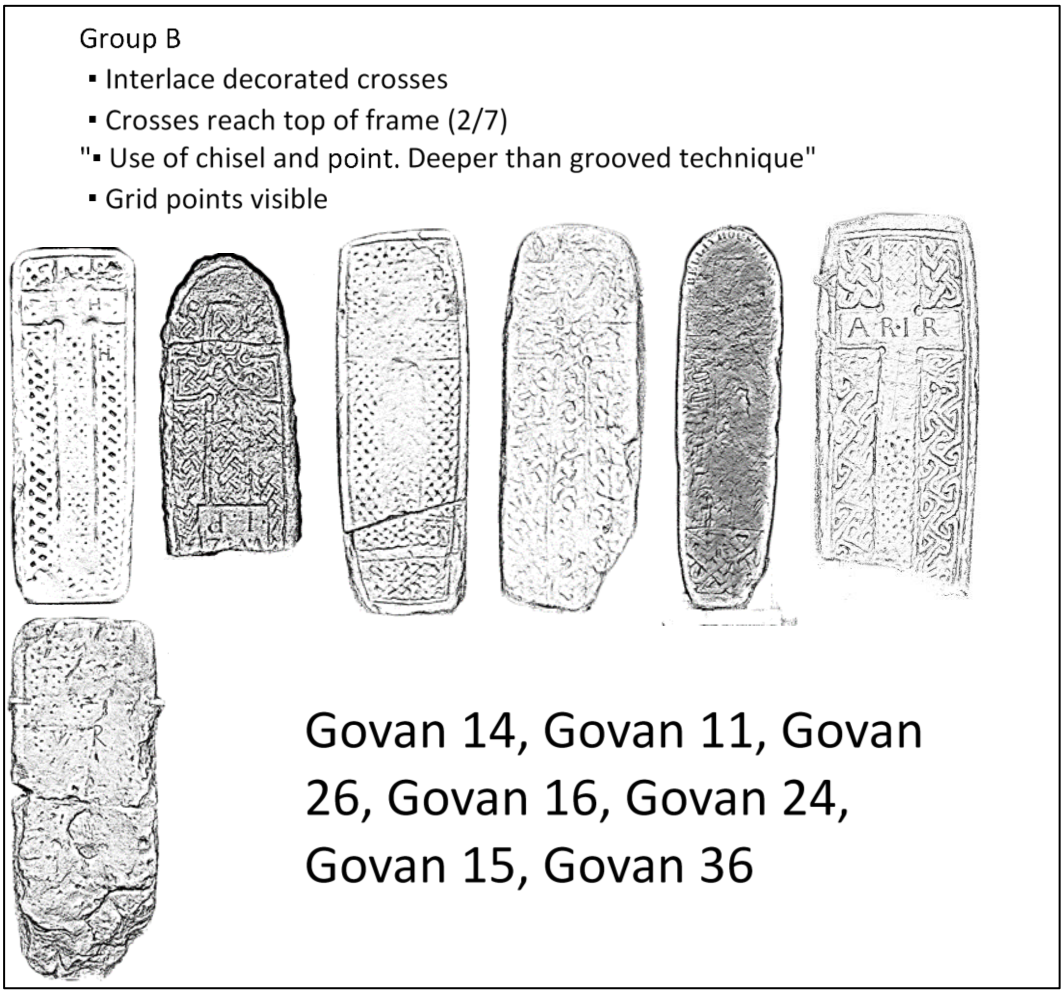


Figure 8.2. Visualisation of Rosemary Cramp's typological traits for Group B reapplied to the extant collection at Govan, taking into account their current condition.

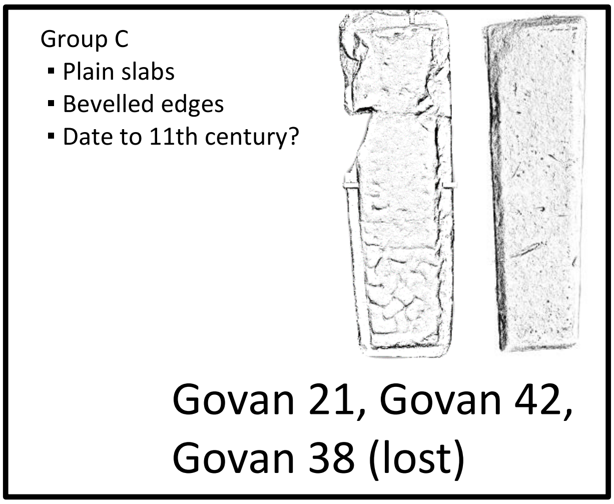


Figure 8.3. Visualisation of Rosemary Cramp's typological traits for Group C reapplied to the extant collection at Govan, taking into account their current condition.

8.2 Potential traits

This analysis has been limited to the extant recumbent cross-slabs from the Govan collection because, while the photographs from Stirling Maxwell's publication have been an invaluable resource, they do not provide enough information about the 'misplaced' slabs to include them in this typology. When deciding which traits should define this new typology for the twenty-one recumbent cross-slabs currently visible at Govan, it was important to take into consideration all of the physical attributes that could possibly be significant to forming classifications. These traits included:

- the dimensions of the monument,
- the geology of the stone,
- the shape of the monument,
- the presence or absence of angle-knobs,
- the type of cross,
- the proportional relationships between different features of the cross,
- the type of ornament used in decorating the monument, and
- the structure of the ornamentation.

A typology that can be applied to most of the monuments based on a combination of these characteristics was created. However, in many cases the condition of each monument affected the reliability of the observation of each these individual features. Below, the considered traits, the insights they could provide into the collection, and their applicability are discussed.

8.2.1 Dimensions of Finished Slab

The overall dimensions of the Govan grave-slabs, specifically the width, length, and thickness of the stone, may offer certain insights into their early medieval construction and use. Standardized measurements might have been used by the individuals responsible for quarrying the stone for these monuments or could have been dictated by the geological bedding in the quarries. Differences in these dimensions may be indicative of shifts in quarrying preferences or locations. The length of a monument might also signal the size of the grave and, consequently, the individual that was buried underneath it. However, nearly half of these stones have been damaged in ways that affect their overall length. Of those that appear to be whole, the stones range in length from 1.4 metres to 1.8 metres. While Stuart's *Sculptured Stones of Scotland* gives us some idea of how long Govan 11 was originally (Figure 8.4), we have no record for how long the others might have been originally as most of the other damaged stones have been fragmented for some time. The thickness of the slab is also difficult to determine, in large part due to the way in which the slabs are displayed against the wall of the church. The thinnest slab, Govan 11, has a thickness of approximately 8cm, while the thickest, Govan 19, measures approximately 24cm at its thickest point. In some cases, where visible, the back surface is quite roughly hewn and is not exactly finished, so it is not quantifiable as a single, simple dimension. As such, it would be difficult to identify a reliable and reproducible way to consistently measure this dimension.

Figure 8.4. Illustration of Govan 11 before lower half was lost (Stuart 1856, pl. CXXXVII).

Overall, it is easier to determine the original width of each monument because it appears to have sustained less damage than the length. Generally, the sides of the stones are roughly parallel, although several of these carved stones tend to taper at the ends. The widest part of each monument varies in width between approximately 46.7 centimetres and 68.4 centimetres (Table 8.1). These values were incorporated into a stem-and-leaf plot to identify clusters of monuments sharing similar widths, which is provided in Table 8.2. While a difference of 21.7 centimetres might suggest different quarrying practices, the differences between these five clusters range from 1.3 – 4.3 centimetres in width. A more compact second stem-and-leaf plot of the same data was then produced (Table 8.3), which resulted in one large group (Group 1) and two smaller ones (Group 2 and 3). Groups 2 and 3 consist of the widest of the monuments, including three of the four recumbent monuments display prominent, almost cylindrical edges. However, the fourth example with these edges (Govan 17) is firmly within Group 1, and the other members of Groups 2 and 3 have flatter edges. Solely based on this set of measurements, it is difficult to say if the differences between these groups has any significance in terms of shifting quarrying practices or other preferences of the carver. Therefore, while comparisons between the length, width and thickness of the recumbent cross-slabs might have offered insights into early medieval quarrying practices, the recumbent cross-slabs are too fragmentary to be reliable in these measurements except for width.

Table 8.1. List of recumbent cross-slabs at Govan (and one from Inchinnan), and the length and width of each cross-slab (in cm). For those with /? following the measurement, the monument has been damaged and was originally longer.

Monument (SM#)	Cross-slab length	Cross-slab width
Govan 11	111/?	49.5
Govan 12	131/?	66.9
Govan 13	178	58.1
Govan 14	183	63.6
Govan 15	118/?	54.1
Govan 16	136/?	46.7
Govan 17	170	55.3
Govan 18	166	51.2
Govan 19	157	50.9
Govan 20	166	52.2
Govan 21	166/?	50.8
Govan 22	178	52.5
Govan 23	98.3/?	62.4
Govan 24	176	47.9
Govan 25	148/?	68.4
Govan 26	168	56.6
Govan 27	143	49.2
Govan 28	145/?	57.4
Govan 31	169	54.7
Govan 36	170	67.4
Inchinnan 1	151.6	49.7

Table 8.2. Stem and Leaf plot demonstrating the differences in width between recumbent cross-slabs at Govan. Interval between stems: 1 cm. This results in five disparate groups, though it is doubtful a difference of 2cm can be qualified as a difference in quarrying practices.

Stem (cm)	Leaf
46	7
47	9
48	
49	2, 5, 7
50	8, 9
51	2
52	2, 5
53	
54	1, 7
55	3
56	6
57	4
58	1
59	
60	
61	
62	4
63	6
64	
65	
66	9
67	4
68	4

Table 8.3. Stem and Leaf plot clustering the widths of the recumbent cross-slabs to more accurately reflect potential differences in quarrying practices. Interval between stems: 2 cm. This results in one large grouping of slabs ranging in width from 46.7cm to 58.1cm and two smaller clusters including slabs that are more than 62.4cm in width.

Stem (every 2cm)	Leaf
4 (6-7)	67, 79
4 (8-9)	92, 95, 97
5 (0-1)	08, 09, 12
5 (2-3)	22, 25
5 (4-5)	41, 47, 53
5 (6-7)	66, 74
5 (8-9)	81
6 (0-1)	
6 (2-3)	24, 36
6 (4-5)	
6 (6-7)	69, 74
68	84

8.2.2 Geology

In the same vein, the geological analysis of the recumbent monuments requires further work. Ray Chadburn's note on the geology of the stones provided a general statement indicating that, overall, the stones were made of locally derived sandstone. He noted that there was some variation in the types of stone used for the recumbent cross-slabs (1994, 146), but he did not indicate which individual slabs were made of siltstone or sandstone and stated that these would need additional study. Understanding the geological composition of these monuments might offer insight into early medieval quarrying locations and practices, though changes in the landscape would undoubtedly make it difficult to identify specific quarry locations. Specialist study, possibly including non-destructive petrological analysis and magnetic susceptibility, is required before this characteristic can be incorporated into future typologies (Miller & Ruckley 2005, 289–290).

8.2.3 Monument Shape

Some previous discussion of the recumbent monuments, especially Allen, gave priority to the overall shape of the monument, distinguishing between the monuments with rounded ends and those that were rectangular in shape. Apart from the antiquarian image of Govan 11 which confirms that both ends were rounded before the bottom half was lost (Stuart 1856, CXXXVII), we cannot be certain of the complete shape of any of the other round-ended monuments. Wear and reuse of monuments can make it difficult to identify a stone's original shape. For example, Govan 24's inscription "BELLIYHOUSTON'S" was carved in an arch across the top (which appears to be referring to 'Bellahouston,' which is currently the name of a nearby district and park but referred to the name of an estate; it is likely that this stone was reused by the Rowan family, a prominent Govan family who were the original owners of the Bellahouston Estate (Cutmore 1997)). Unfortunately, all decoration, including the incised boundary around the border of the stone, was obliterated on this section of the stone, so it is unclear if this rounded shape is its original form or if it was modified. Because the bottom end is rounded, it seems likely that both ends were rounded as with Govan 11.

When one considers the records of the ‘misplaced’ in Stirling Maxwell’s publication in 1899, it becomes apparent that even if a stone has one rounded end, both ends need not have been. In the case of Govan 34 (and possibly Govan 33), it appears that the stone was rounded on one end and squared-off on the other (Stirling Maxwell 1899, Pl. XXII). However, even classifying a stone as “rectangular in shape” has its problems. Some stones, like Govan 18, appear to be truly rectangular, while others, like Govan 13, appear to taper slightly at both ends. Carved stones like Govan 17 taper towards the bottom, but its widest point is at the top of the slab. The question becomes then, do these “rectangular” slabs belong together, or do these slight variations in overall width reflect several different groups? In some cases, it is impossible to tell what shape it was originally due to the wear and damage along the edges, like Govan 16; even the incised boundary found around the edge of the monument, a characteristic shared with all the other cross-slabs, cannot be definitively identified (Figure 8.5). So, while something as seemingly simple as “monument shape” might be used as a starting point in building a typology, it is, in Govan’s case, quite complex.

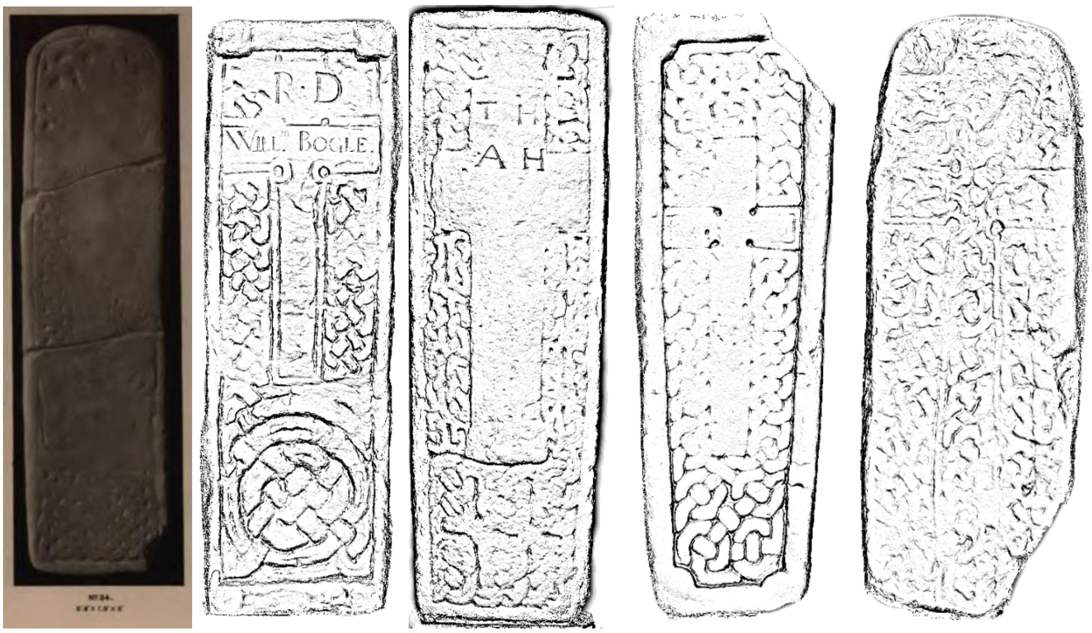


Figure 8.5. Highlighting the difficulty in characterising the shape of the Govan recumbent monuments: (left to right) Govan 34, 18, 13, 17 and 16.

8.2.3.1 Angle-knobs

Determining the overall shape of the monument becomes more complicated as one considers whether the presence of angle-knobs should be considered part of a monument's "shape". This feature has been seen as a defining characteristic in all considerations of the Govan school because it has a restricted geographical distribution, one that is shared by at least five of the recumbent slabs at Govan, one at Inchinnan, and one lost cross-slab from St Blane's on Bute (Allen & Anderson 1903, 2, 465; Cramp 1994, 56). However, the comparative rarity of the feature in the Govan collection (see the reapplication of Cramp's criteria above in Section 8.1.1) and the wide variation in angle-knob form (seen in Figure 8.6 below) makes this an unreliable feature to quantify.

Figure 8.6. Image of the recumbent cross-slabs from the Strathclyde region which are known to have exhibited angle-knobs: (Top Left to Right) Inchinnan 3 (Spectrum Heritage 2017), Govan 12, Govan 18 and St Blane's (Anderson 1900); (Bottom Right to left) Govan 25, Govan 23 (Stirling Maxwell 1899) and Govan 17. Not pictured: ECMS 24 (only described in Allen & Anderson 1903; we have no visual record for this stone, and it has since gone missing).

It is unclear what significance these structures had, but some have postulated that angle-knobs are a reference to an original angle-knobbed monument, potentially the “shrine cover” from Inchinnan depicted above (Spearman 1994, 39; Bailey 1994, 114–5). The significance of these features will be considered later in Section 8.4, but its rarity in the collection and the inconsistency of its form makes the presence of angle-knobs an unreliable trait to define this typology.

8.2.4Cross shape

The type and overall shape of the cross found on these recumbent cross-slabs has been included in both J. Romilly Allen and Rosemary Cramp's cross-slab typologies. Allen classifies the crosses based on his cross-shape categories, which were defined by all of the cross-shapes observed in Scotland, and all of the recumbent cross-slabs at Govan fall within his type 101A which is defined as a "Cross with Round Hollow Angles (with shaft)" (the upright cross-slab Govan 8's cross is different, and is described as type 96A due to the lack of circular armpits) (Allen & Anderson 1903, 1, 51; Allen & Anderson 1903, 2, 463–471). While this is useful for inter-regional comparisons, this does little for comparisons within the collection itself.

Figure 8.7. Govan 8's cross clearly lacking rounded armpits.

Cramp takes this one step further and defines her cross categories by whether the cross was treated with interlace and whether it reached the top of the slab, or if it was left plain with only an incised border and did not reach the top of the slab (Cramp 1994, 56–58). Unfortunately, this pairing of features is problematic because only three crosses clearly reach the top of the frame, and one of these is clearly a plain cross; this is more fully discussed in above in Section 8.1.1.

Additionally, the current condition of the stones makes it difficult to determine if some crosses were originally plain or if they have simply been worn beyond recognition. Govan 13 and Govan 20 are good examples of this – the incised boundary surrounding these crosses have been worn away and, apart from telling punctate marks visible occasionally along the edge of the cross, the interior surfaces of these crosses seem to exhibit additional punctate marks (especially visible on Govan 20), they are too sparse to be positively identified as original to the design (Figure 8.8). Again, while initially the presence or absence of decoration on the cross appears to be a straightforward trait for categorization, the condition of the stones creates a strong bias in the identification of this trait.

In an attempt to avoid the issues brought on by differential wear, this study will instead focus on the proportional relationships between the length of different cross features. This will include comparisons between the width of the cross-arms (measured across the top edge from top-left corner to top-right corner), the length of the shaft, and the length of the cross-head (both the length of the shaft and the length of the cross-head were measured along the left side of the cross unless it was unavailable due to wear or damage; these measurements terminate in the armpits where the approximate extension of the cross-arms and shaft/crosshead would intersect, so that crosses with wider armpits could be measured in a more comparable way with those with armpits seemingly composed of a single punctate). A diagram of the location of these measurements is provided below (Figure 8.9). By looking at these proportions, we may find that these stones that share similar proportions were carved by one or more sculptors operating under the same impression of what a cross “should” look like – either by referring to examples from existing monuments, metalwork, manuscripts, or other media – and fitting that ideal to stones of different dimensions.

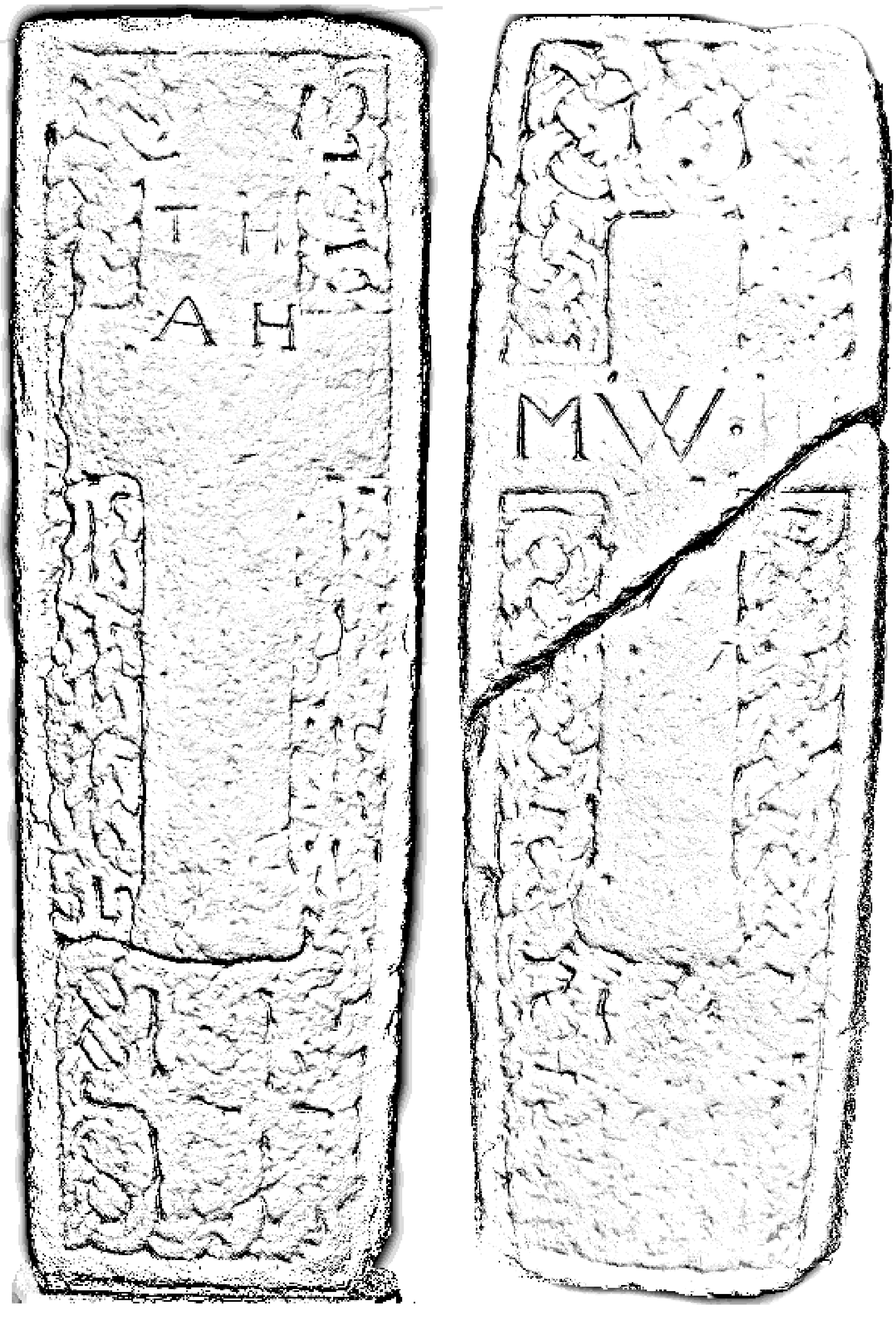


Figure 8.8. Black and white images of the 3D models of Govan 13 and 20.

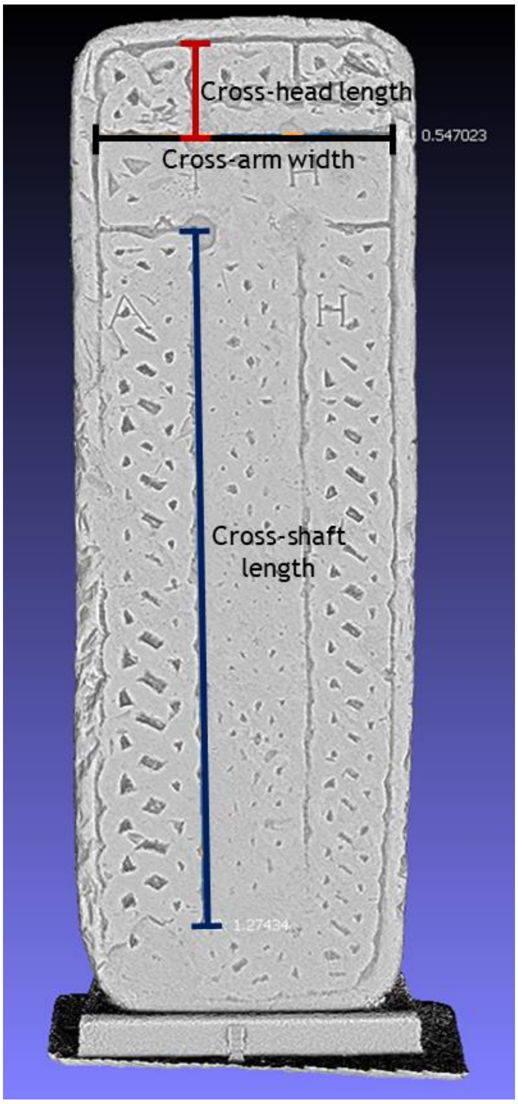


Figure 8.9. Diagram showing the location of measurements for the length of the cross-head, the width of the cross-arms, and the length of the cross-shaft on Govan 14.

8.2.5 Decorative Motifs

Another means of categorising these monuments is by differentiating between the decorative motifs utilised in ornamenting the carved stones. While Allen made the first real attempt to understand and categorise Govan's ornamental patterns, this did not play a role in his groups, which were based primarily on the shape of the monument. While Cramp highlighted the significance of free-ring interlace in her Group A (1994, 56), she does not apply this trait consistently, as Govan 16, Govan 13 and Govan 24 (which exhibits a form of ring-chain) are either relegated to Group B or are unclassified (as is the case in Govan 13), despite their carvers' use of free-ring interlace (Cramp 1994, 55–61).

Since Allen's initial description of the Govan interlace, there have been a few recent attempts to reassess the decorative motifs found at Govan (Katherine Forsyth, pers comm). If one consolidates Allen's very specific numbered patterns into generalised groups, the decoration at Govan can be classified into roughly eleven pattern families:

- Twists and Plaits (Nos. 501-506, (Allen & Anderson 1903, 1, 202–203)),
- Figure-8s (Nos. 568-572, (Allen & Anderson 1903, 1, 220–221)),
- Free-ring interlace (Nos. 574, 577-579, (Allen & Anderson 1903, 1, 222, 224)),
- Double Ring Knots (Nos. 575-576, (Allen & Anderson 1903, 1, 223)),
- Ring-chain (No number, pictured below in Figure 8.10),
- S-shaped Bends (Nos. 544-545, (Allen & Anderson 1903, 1, 213)),
- Stafford Knots (Nos. 595-618 and 623-625, (Allen & Anderson 1903, 1, 231–238, 241)),
- Triangular Knots (Nos. 731-732, (Allen & Anderson 1903, 1, 287)),
- Straight-Line interlace (No. 730, (Allen & Anderson 1903, 1, 287))
- Key pattern (Nos. 983-1012, (Allen & Anderson 1903, 1, 355–360)) and
- Irregular pattern.

These are based on Katherine Forsyth's reassessment which has not yet been published, and I am indebted to her for her assistance. In some cases, this project has allowed for a more confident identification and the recovery of less obvious examples of pattern, as described in Chapter 6. Diagrams of these patterns are provided in Section 6.1 and reproduced below (Figure 8.10).

The question then becomes what significance these different decorative motifs might have had to the carvers and those who viewed the monuments after completion. Certain traits have been identified as being temporally significant, including the prevalence of median-incised interlace, 'stopped plait' and free-ring interlace, which together indicate that the sculpture belongs to the Viking period (Bailey 1994, 117–119; Driscoll et al. 2005, 144–145). In general, it is likely that some patterns were more aesthetically popular than others during different phases of use. Much of the underlying meaning, however, was likely connected to the person or persons that decided to incorporate these individual patterns into the design. Would these motifs have been chosen by the family of the deceased, the master of the workshop, or the carvers themselves, who might have excelled in the creation of one pattern over the other? If designs were dictated by members of the family, it is possible that the burial markers created for members of the same family share decorative motifs. These patterns could then offer some insight into the lineage of the deceased. If these decisions were made by one or more master craftsmen, they might restrict the motifs used. Finally, the carvers themselves might make design choices to suit their own repertoire of motifs.

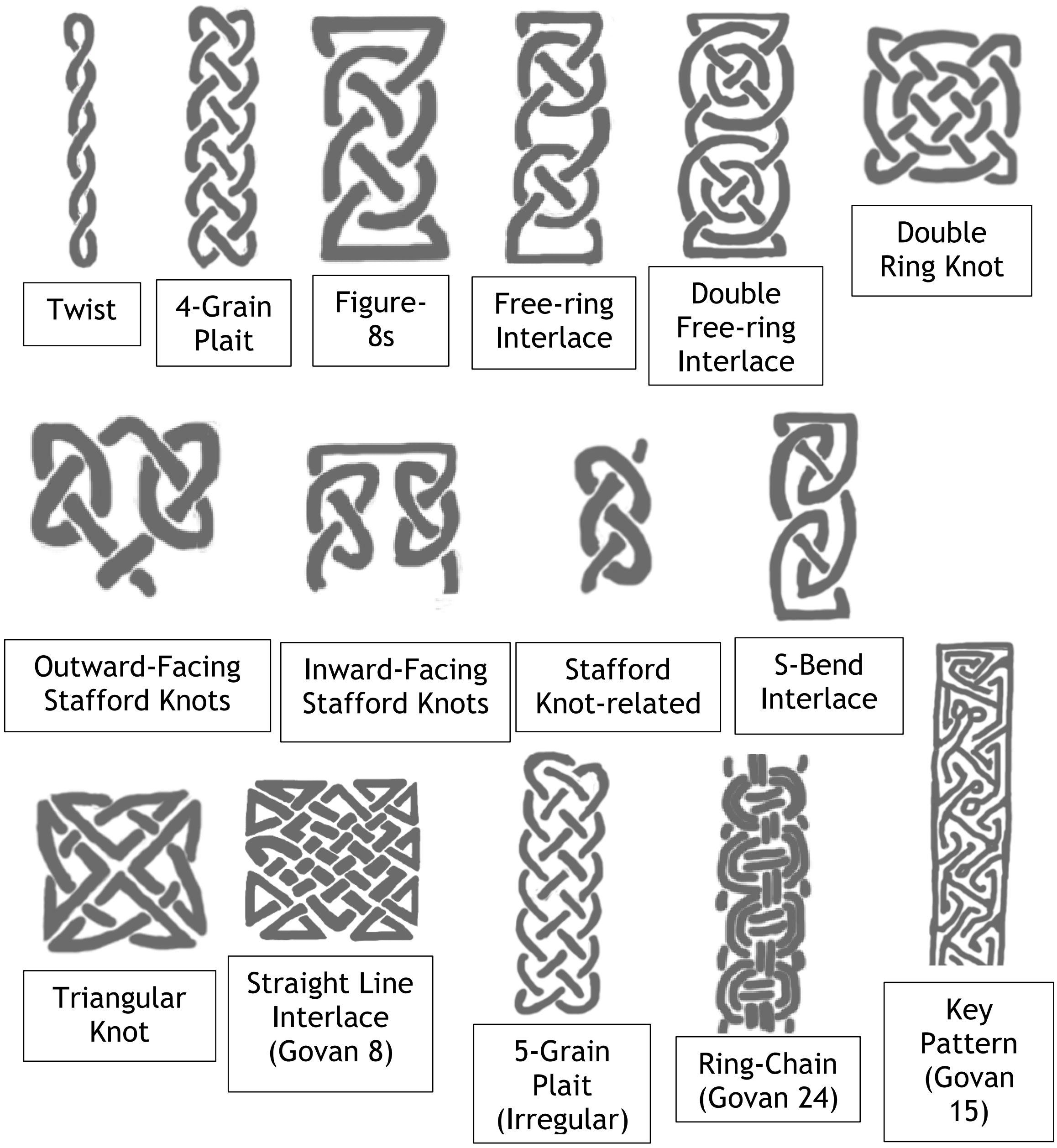


Figure 8.10. Diagrams of the various decorative motifs employed in the decoration of the Govan school; many adapted from Allen and Anderson 1903, Volume 1 (No. 501, 503, 568, 574, 575, DRK, 601, 598, 215, 544, 731, (Govan 8), 504, (Govan 24) and (Govan 15).

8.2.6 Layout of the Decoration

While there is a great deal of variety in the decoration of the monuments, some of the recumbent cross-slabs at Govan seem to follow an almost formulaic approach to the layout of the ornament. As Rosemary Cramp has pointed out, some of the crosses reach the top of the border, creating two distinct panels on either side of the cross-head, while others do not, resulting in one large panel arching over the cross-head (1994, 56). Some exhibit what Cramp describes as a pedestal, where the bottom section of the stone abruptly changes decorative motif in a section directly under the cross. This element of the structure of the stone might represent an abstract socket stone. Some types of interlace are restricted to this portion and appear nowhere else in the collection, like the triangular Stafford knots. Other motifs have been liberally applied to any area of the stone, including the free-ring interlace. By looking at how ornament has been restricted or unrestrained in its application, we might find the influence of a master craftsman exerting control over the designs of the carvers, or possibly the work of a lone craftsman who feels no need to adhere to these workshop conventions.

For the reasons listed above, the present typology for the recumbent cross-slabs will revolve primarily around the carved cross proportions, the decorative motifs used, and the structure or layout of that ornamentation. While the condition of the carved stone will affect almost all the traits listed above, these three features are available for observation to some degree on most of the twenty-one stones. The presence or absence of angle-knobs will also be taken into consideration as a secondary trait to some extent, as determining whether they were part of the design only requires one end of the monument to remain intact.

8.3 Building A Typology

8.3.1 Cross Proportions

Based on the measurements as described above in Section 8.2.4 and illustrated in Figure 8.9 above, proportions of the different dimensions can be quantified to find relationships between carved stones. While an infinite number of proportions can be identified, this study will simply focus on how the length of each of the elements of the cross compare to each other because these features were the most consistently identifiable on the majority of the recumbent cross-slabs. These proportions consist of the length of the cross-arms: the length of the shaft; the length of the cross-head: the length of the cross-arms, and the length of the cross-arms: total length of the cross (measured from the top left corner of the crosshead to the bottom left corner of the shaft). There was sufficient evidence to allow for these proportions to be determined for fourteen of the twenty-one extant recumbent cross-slabs from Govan and Inchinnan 1. A table of these proportions can be found below (Table 8.4). These were plotted on a 3D scatterplot using SPSS, and each proportion formed one of the three axes. In these plots, clusters of similar cross-shapes were identified; these separate clusters of data might represent different individuals or groups of sculptors with differing concepts of the "ideal" cross to carve, perhaps based on a pre-existing cross made from another material.

Table 8.4. Three sets of cross proportions for fourteen Govan recumbent cross-slabs and Inchinnan 1 used in the k-means analysis (k=7) depicted below.

Monument (SM#)	Length of Crossarms: Total Length	Length of Cross-arms: Length of Shaft	Length of Cross-head: Length of Crossarms
Govan 11	0.43	0.69	0.50
Govan 12	0.56	0.94	0.38
Govan 13	0.45	0.76	0.41
Govan 14	0.34	0.43	0.32
Govan 15	0.38	0.57	0.57
Govan 17	0.43	0.65	0.52
Govan 18	0.47	0.74	0.43
Govan 19	0.40	0.60	0.54
Govan 20	0.48	0.77	0.42
Govan 22	0.37	0.53	0.45
Govan 24	0.33	0.45	0.52
Govan 26	0.47	0.69	0.33
Govan 27	0.50	0.82	0.41
Govan 28	0.47	0.72	0.42
Inchinnan 1	0.54	0.92	0.41

After these were plotted, it became apparent that there were at least two larger clusters, one closely related pair, and four outliers. After using k-means clustering to validate these groups based on all three proportions, the following three-dimensional scatter plot was produced (Table 8.5; Figure 8.11; Figure 8.12; Figure 8.13; Figure 8.14). Govan 14, 22, 24, and 26 were outliers. The crosses of Inchinnan 1 and Govan 12, as one might guess from visual inspection, are virtually identical in terms of proportions. Similarly, Govan 13 and Govan 20 are almost exactly alike, although their proportions clustered them with a larger group consisting of Govan 18, Govan 27, and Govan 28. Govan 17 and 19 are also quite comparable at first glance; however, these are loosely grouped with Govan 15 and 11, which appear quite different from 17 and 19 (and are both damaged at the base of the cross, so their clustering within this group is tentative). To test the legitimacy of these comparisons, it is helpful to take a digital approach.

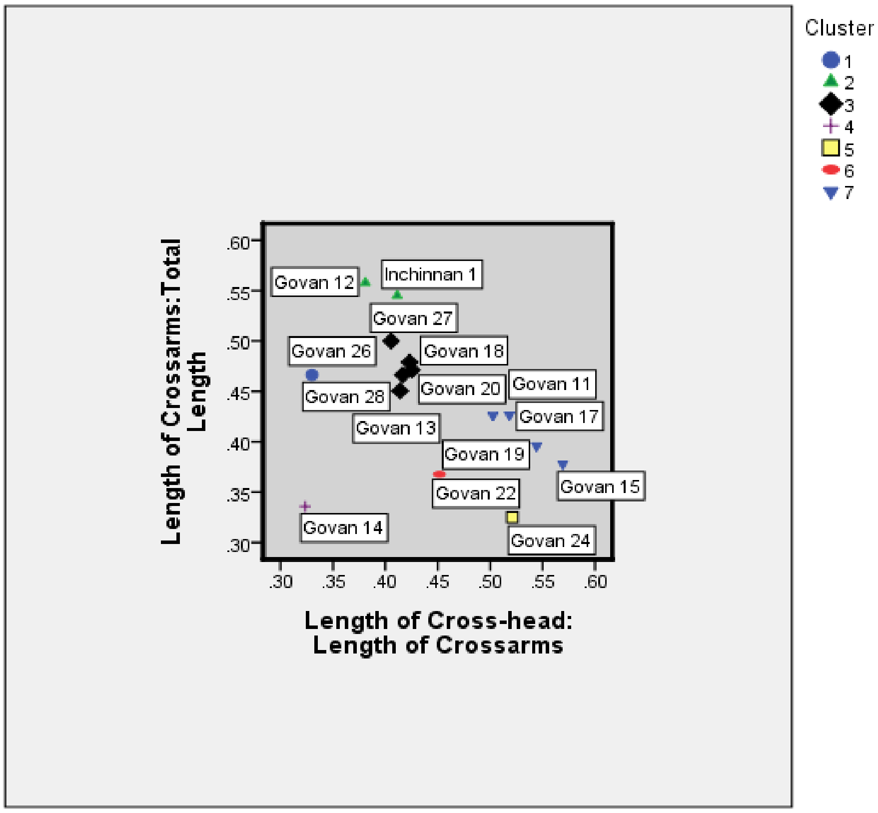


Figure 8.11. K-means cluster analysis (k=7) based on the ratio between the length of the cross-arms: the total length of the cross and the ratio between the length of the cross-head: the length of the cross-arms. Two large clusters (k:3, 7) and one pair of samples (k:2) are evident with multiple outliers (Refer to Section D.2 for how to read the results from a k-means clustering analysis).

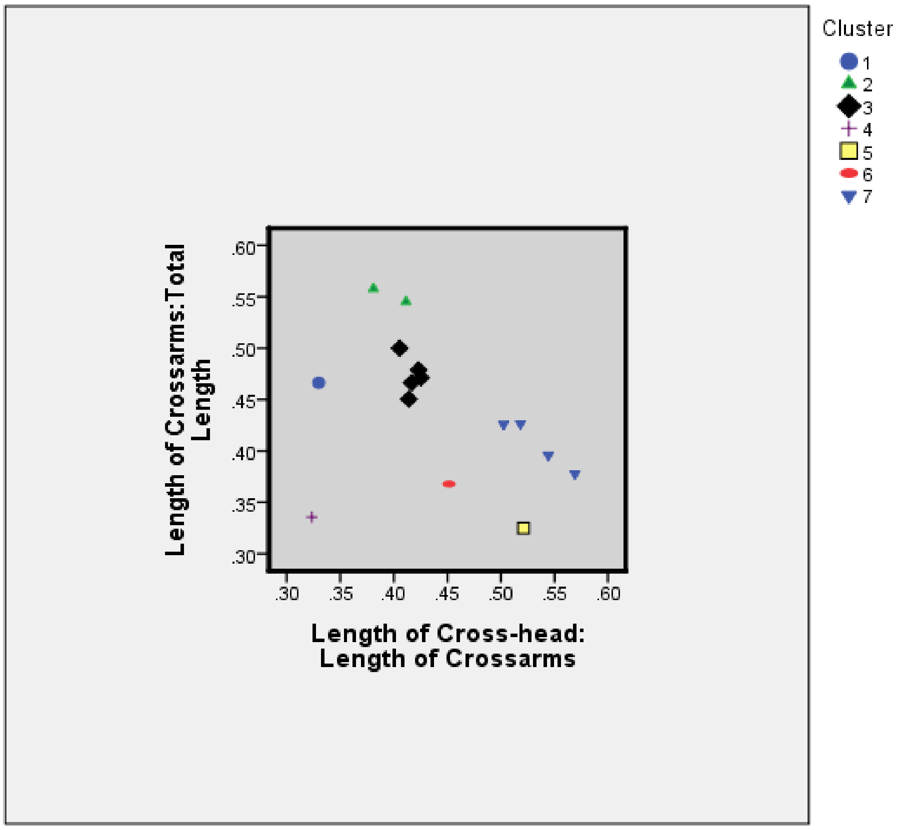


Figure 8.12. Same perspective as Figure 8.11, but without individual stone number labels.

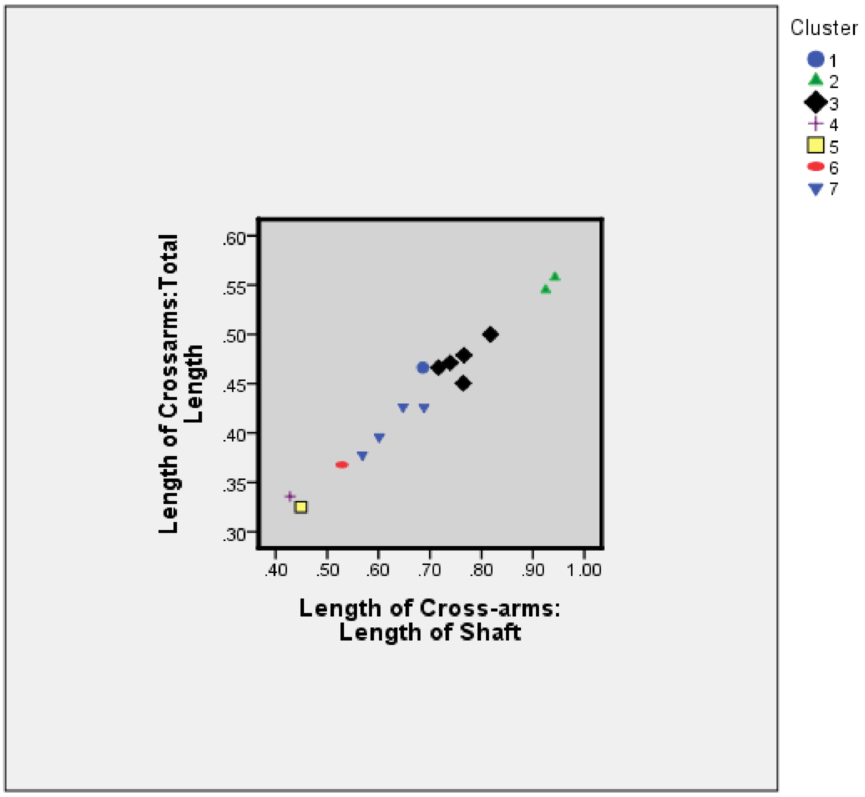


Figure 8.13. A k-means cluster analysis (k=7) using the ratio between the length of cross-arms: total length of the cross and the ratio between the length of the cross-arms: length of

the cross-shaft as variables show a linear correlation. The clusters identified in the previous graph are still visible, but the two large clusters are poorly separated.

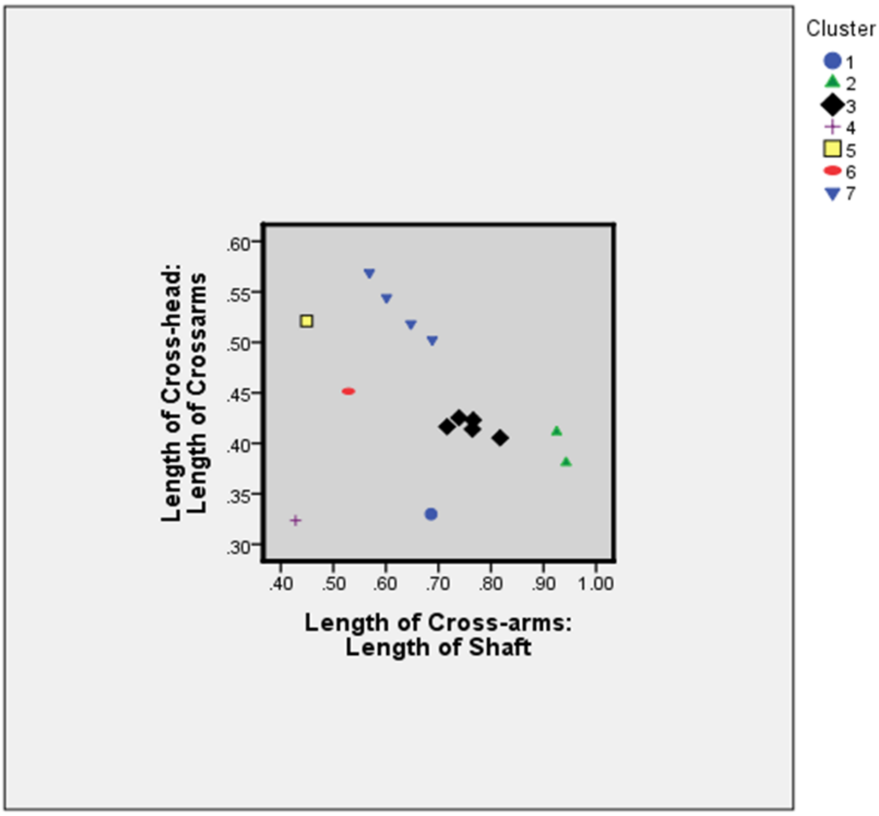


Figure 8.14. A k-means cluster analysis (k=7) using the ratio between the length of the cross-head: length of the cross-arms and the ratio between the length of the cross-arms: length of the cross-shaft show the best separation between clusters and outliers identified in Figure 8.11, Figure 8.12, and Figure 8.13

Table 8.5. Clusters that were identified using k-means analysis (k=7) on the three sets of cross proportions listed in Table 8.4 above. Corresponding graphical representations are provided above.

Cluster Membership

Monument (SM#)	Cluster
Govan 11	7
Govan 12	2
Govan 13	3
Govan 14	4
Govan 15	7
Govan 17	7
Govan 18	3
Govan 19	7
Govan 20	3
Govan 22	6
Govan 24	5
Govan 26	1
Govan 27	3
Govan 28	3
Inchinnan 1	2

Taking the paired Inchinnan 1 and Govan 12 as an example, to directly compare these crosses, both scaled three-dimensional models were imported into Meshlab and oriented so that their carvings laid on roughly the same plane. A snapshot of the two 3D models side-by-side was taken and imported into Adobe Photoshop. An outline of the Govan 12 cross was then drawn and superimposed onto the adjacent image of Inchinnan 1, essentially using the same approach used to identify template use described in Section 5.5 and applied in Chapter 7. While the outline needed to be scaled down, it quickly became clear how similar these two crosses are (Figure 8.15). The proportions of their crosses are virtually identical, but Govan 12's is 1.2 times larger than Inchinnan 1's cross. This suggests that, while a physical template was not used, model was used or referred to by the carver to consciously fit an almost identical cross on a different sized cross-slab. This may have involved a grid and implies a consistent unit of measurement. This might have been done to replicate a known cross in a different medium, to represent a social connection between those commemorated, or because they are made by the same carver. This last option will be explored more thoroughly in the results of the Groove Measure analysis (Chapter 9).

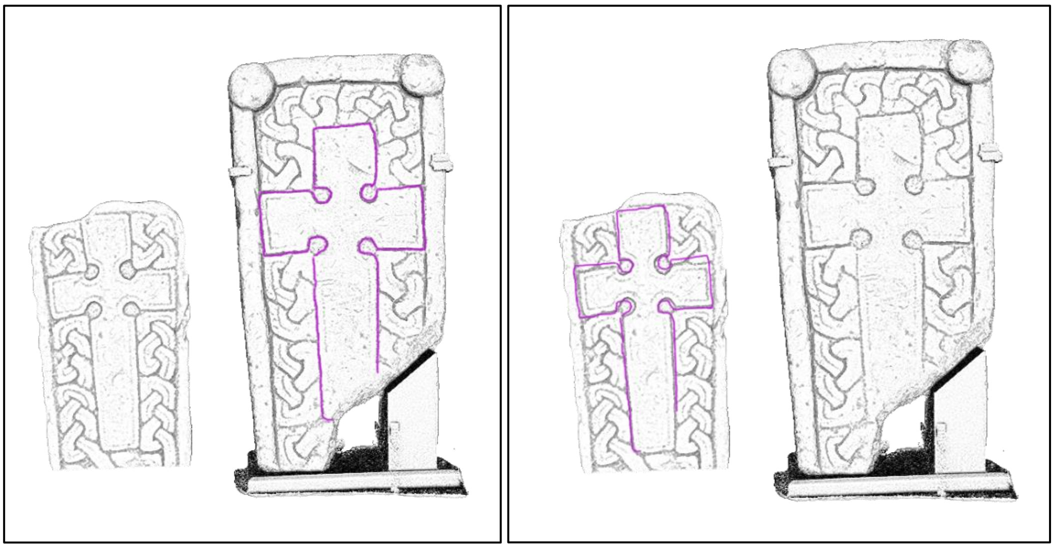


Figure 8.15. Outline of Govan 12 (left) imposed on Inchinnan 1 (right) (truncated 3D model; 3D model created by Spectrum Heritage).

In cases where these cross proportions have clustered together but do not appear to be similar at first glance, it is useful to test these clusters by superimposing the outline of one cross over another as demonstrated above.

After comparison, there is clearly a connection between the incised cross of Govan 13 and Govan 20, as the scaled-down outline of Govan 13's cross nearly matches that of Govan 20, including the slightly expanded terminal at the base of the cross (Figure 8.16). After creating an outline of the cross on Govan 13 and superimposing and scaling it to an image of Govan 18 (Figure 8.17), another cross that was grouped with 13 and 20, it became apparent that this did not match exactly and that it might be useful to take the width of the elements of the cross into account. However, after attempting to work this data into the analysis, it quickly became obvious that this would be a more problematic measurement to take. While the length of each segment of the cross is relatively consistent whether you take the measurement from the left edge, the centre, or the right edge of the cross, the width is more variable. The width of the shaft nearest the armpits of the cross is often much wider than the bottom; sometimes the reverse is true for the cross-head and cross-arms, with the elements nearest the centre of the cross being narrow and expanding out towards the edge of the stone. It is also worth pointing out that, in the case of Inchinnan 1 and Govan 12, the outline comparison indicates that the proportional width of each element is not as easily matched, especially the width of the cross-arms. It is possible that the placement and overall extent of the cross was decided early at the outset, but that the width of each element was altered to fit snugly within the surrounding decorative motifs.

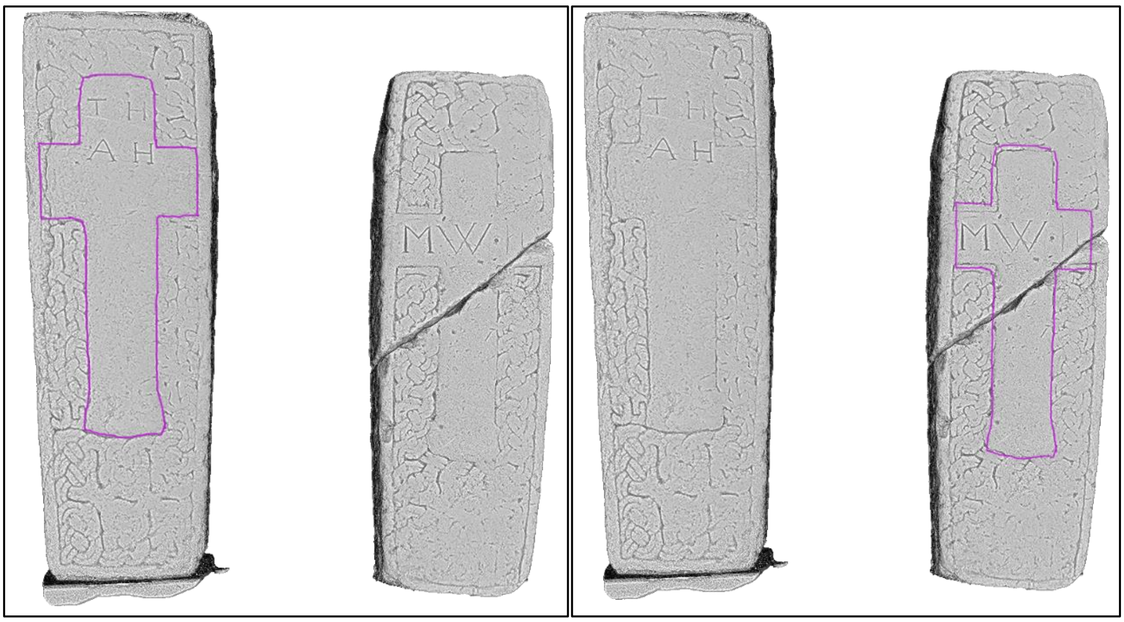


Figure 8.16. Govan 13 cross outline (left) imposed on Govan 20 (right), demonstrating the similarity not only in proportions, but also in the expanded terminal of the shaft.

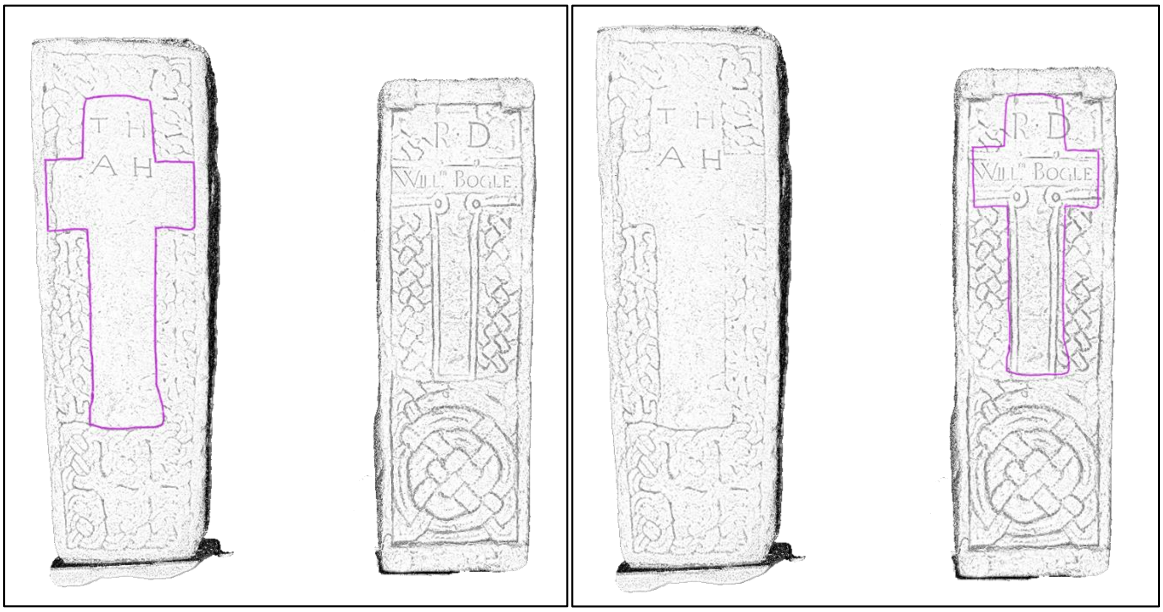


Figure 8.17. Govan 13 Cross outline (left), imposed on Govan 18 (right), which shows significantly more deviation from the outline than was seen in Figure 8.16.

This approach was also applied to crosses in the second-largest cluster, which is slightly more disparate than the largest. Although Govan 17 and 19 appear to be quite similar in appearance, this outline test reveals that, while all other elements, including the four cross armpits, align quite well, the shaft on Govan 19 is longer proportionally than that on Govan 17 (Figure 8.18). Because everything else matches, it may be the case that the intended design of the cross was laid out first, then the ornament, but the shaft was subsequently shortened by the carver of Govan 17, or elongated by the carver of Govan 19, to fit the rest of the design. Because the pattern underneath the cross of Govan 19 appears compacted and off-centre, while that of Govan 17 is spaced more evenly. It could be that the carver of Govan 17 wanted to replicate the cross of Govan 19 but took steps to avoid this potential issue.

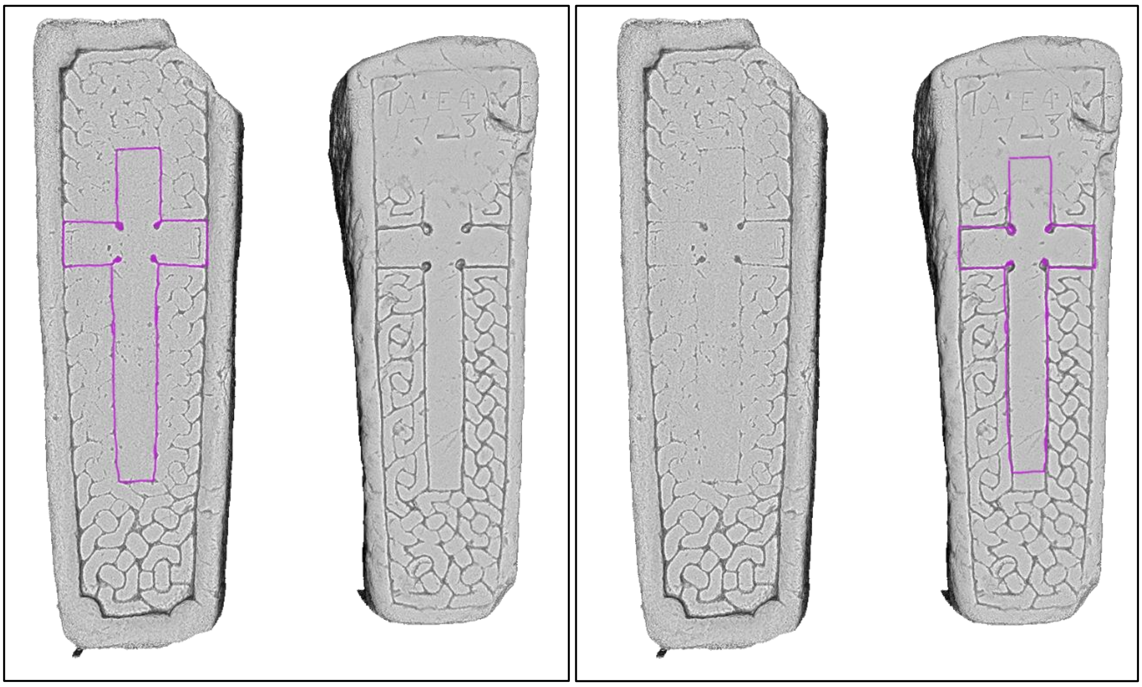


Figure 8.18. Govan 17 outline (left) imposed on Govan 19 (right).

In some cases, the outlines of the crosses belonging to the same cluster do not match as exactly as those pictured above (See Figure 8.15, Figure 8.16, and Figure 8.18), but they do appear to be more closely related than others (Figure 8.17). In the case of Govan 18, 27 and 28, their cross outlines can be scaled to appear quite similar, though it is difficult to be certain of how accurate this is due to the damaged and worn nature of Govan 27 and 28 (Figure 8.19). A similar argument could be made for Govan 11 and 15 (and 17 and 19 by extension, as all four belong to the same broad cluster) though the shape of the cross arms is not exact and the damage to the base of these monuments also complicates this interpretation (Figure 8.20). These stones have been conservatively defined and relationships between groups could exist (for example, Groups C and D could belong to the same group, although the decoration of the cross in Group D makes this unlikely). In summary, this statistical approach helps in identifying groups based on the initial cross-proportion groups which can be further investigated through this comparison of outlines. The final groups are listed below (Table 8.6).

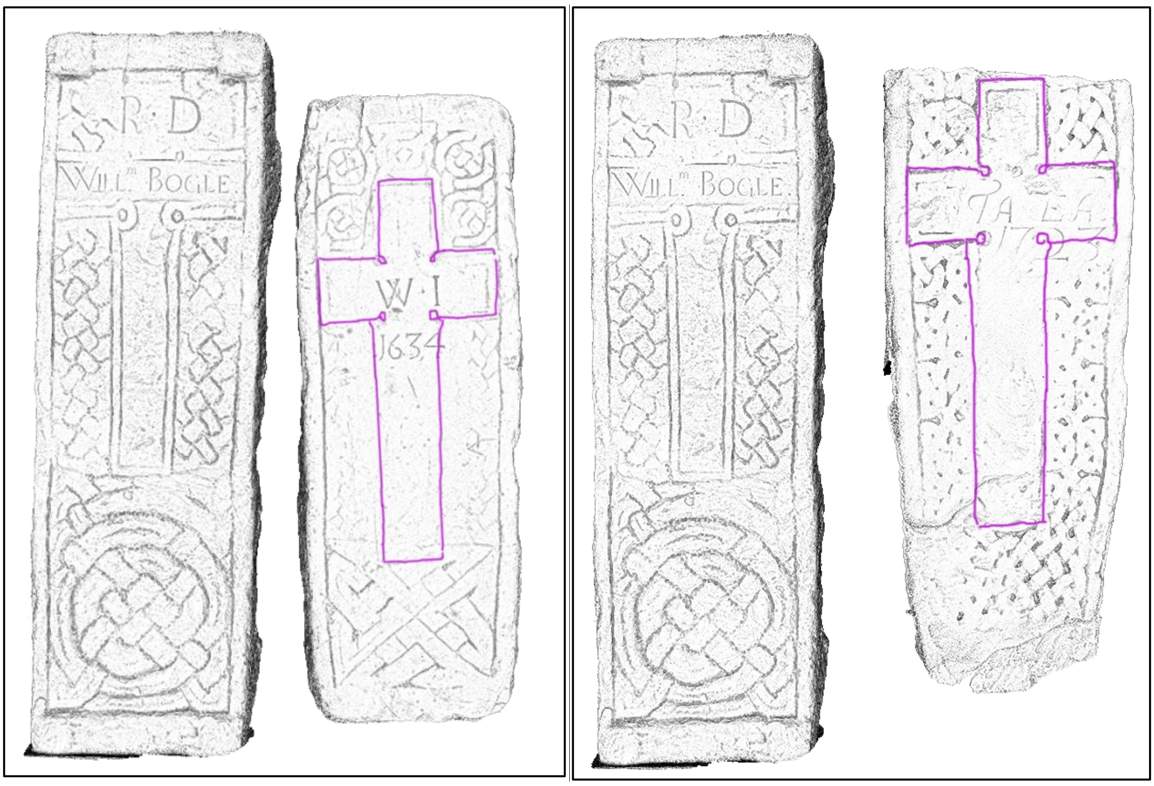


Figure 8.19. Govan 18's outline imposed on both Govan 27 (left) and Govan 28 (right).

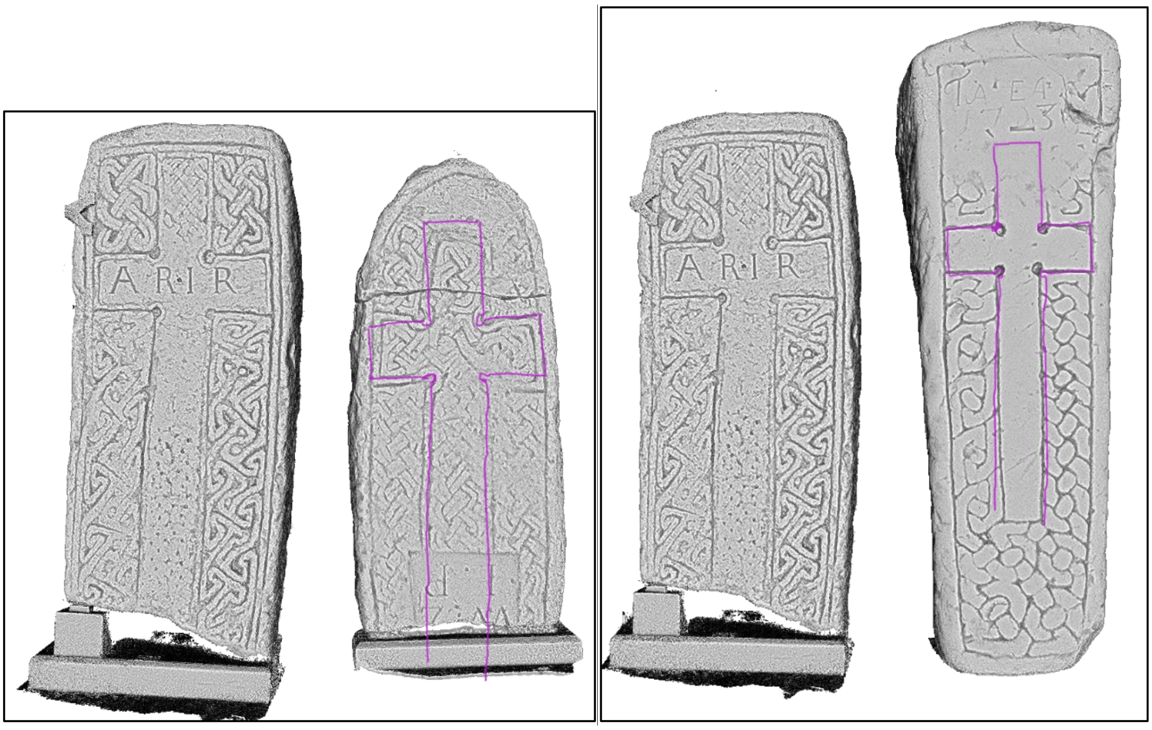
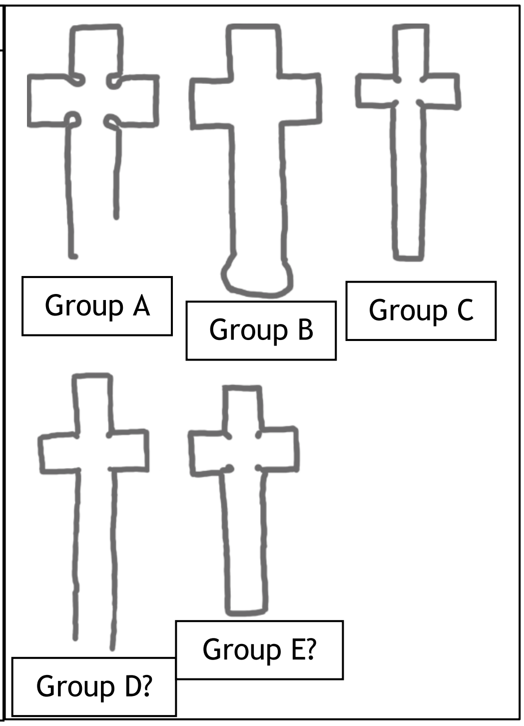


Figure 8.20. The cross outline of Govan 15 imposed on Govan 11 (left) and Govan 19 (right).

A thorough comparison reveals that cross comparisons are clearly a useful feature to include in a typology. This digital approach has allowed for the identification of crosses that seem to have been made to look identical, even when carved at different sizes. As mentioned above, it is unclear how this would have been done. It is also uncertain why skilled carvers would do this: is it the same carver reproducing the same cross, or emulating a cross crafted from a different material, or does this reflect part of the identity of the deceased? This process has also suggested that the cross may have been the first planned element, though the formation of the ornament could have altered the length of the shaft or the width of the cross-arms.

Table 8.6. Recumbent Monument Groups Based on Cross Outline Proportions with Ideal Cross-forms.

Monument	Cross Proportion Group
Govan 12	Group A
Inchinnan 1	Group A
Govan 13	Group B
Govan 20	Group B
Govan 17	Group C
Govan 19	Group C
Govan 11	Group D?
Govan 15	Group D?
Govan 18	Group E?
Govan 27	Group E?
Govan 28	Group E?
Govan 14	Outlier
Govan 22	Outlier
Govan 24	Outlier
Govan 26	Outlier



8.3.2 Decorative Motifs

As discussed in section 4.1.4.6, there are two main decorative traits that many of the carved stones in the Govan school have in common that have led to their assignment to the 9th-11th centuries AD: median-incised interlace and free-ring interlace. The question then becomes whether trends are visible in the different types of decorative motifs used, and whether these correlate to the groups created in the previous section based on cross proportions. This section will begin with a description of the families of patterns used in the Govan collection, followed by a discussion of the different groupings that emerge based on these classifications. This will in part be based on the designations in the *ECMS* and the information from Katherine Forsyth’s 2008 Govan Lecture, but the creation and analysis of three-dimensional models has enabled the reclassification of several worn decorative motifs. Diagrams for each of these patterns are given in Figure 8.10 above, but these are reproduced below before each motif is discussed.

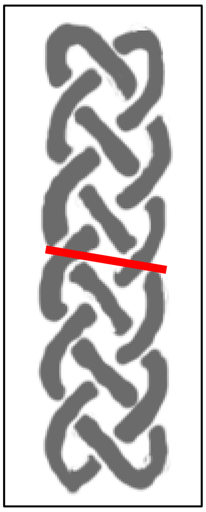


Figure 8.21. Example of a four-grain plait (reproduced from Allen et al. 1903, volume 1, Pattern No. 503) with a red line indicating where Brennan would cut through to calculate the grain of the plait.

Plaits are the most prevalent patterns in the Govan collection and are formed by a series of strands consistently weaving over and under themselves or another (see Figure 8.21 above). When Allen referred to different variants of plaitwork, he did so by counting the number of crossings made by these strands when drawing a horizontal line across the pattern and multiplying this number by two. If this process resulted in two strand crossings, he referred to the pattern as a four-cord plait (1903, 1, pp. 144–145). While this has been the standard terminology used to describe plaits since Allen's publication, it is counter-intuitive to the usual usage of the word 'cord', which is often synonymous with 'strand'. In a four-cord plait, only two 'cords' are required to form the pattern. For this reason, Michael Brennan has advocated for the replacement of 'cord' with 'grain' (2011, 37). Brennan has also illustrated a more flexible method of calculating the grain of a plait when dealing with 'irregular' interlace, which requires making 'a cut through a crossing on the side of the plaitwork and then aim for the crossing that is "diagonally" (even if distorted) opposite…continue like this until an exit is made from the plait via a crossing or over a single strand. The grain-count is… two when cutting a crossing, and one for a single strand' (Brennan 2011, 38). Brennan's method and terminology will be used for describing the plaitwork found at Govan.

Figure 8.22. Example of a twist, reproduced from Allen et al. 1903, volume 1, Pattern No. 501, a pair of figure-eights, reproduced from Allen's Pattern No. 572, and free-ring interlace, reproduced from Allen's Pattern No. 574.

Twists are relatively self-explanatory, as they are formed by two strands twisting together. They are also defined as two-cord plaits by Allen (1903, 1, p. 202) and are often employed by the Govan carvers to simulate free-ring interlace (see Figure 8.22 above) by interlocking pairs of twists together (as can be seen especially with Govan 20, 22, and 19). Figures-of-eight, twists consisting only of two loops, also appear in the Govan collection, and seem to function interchangeably as twists (see left panel adjacent to cross-shaft on Govan 22) or as free-rings (Govan 17, top of right panel adjacent to cross-shaft).

Free-ring interlace can be defined as discrete strands that form rings, which are then woven into the pattern by 'diagonalling strands' (Cramp 1984b, xxx). Rosemary Cramp designated these free-ring patterns as a type of 'closed circuit pattern' (1984b, 24). The reconstructed Govan 17 above is a clear example of this, as its decoration is formed entirely of free rings and the diagonalling strands, which form twists (Figure 6.18).

Figure 8.23. Examples of Stafford knots and related patterns, reproduced from Allen et al. 1903, volume 1, Pattern Nos. 601, 598, 215, and 731.

As demonstrated in Chapter 6, there are considerably more instances of the use of Stafford knots than were previously identified in the decoration of the recumbent monuments at Govan (see Figure 8.23 above). Stafford knots are defined by Allen as patterns constructed from 'two unsymmetrical loops, both facing upwards, but one right-handed' (1903, 1, p. 172) and is also referred to as 'simple pattern E' by Rosemary Cramp (1984b, xxxii) and Gwenda Adcock (1974, 54). As Allen points out, the triangular knots (ECMS pattern 731/732) forming 'pedestals' on five of the recumbent monuments are constructed in the same way as Stafford knots (1903, 1, p 196), but are not rounded and are repeated through a series of 90-degree rotations to form a knot. Some patterns assigned different numbers appear to be closely related to Stafford knots, including Allen's patterns related to number 215, like pattern 623 and 645 (1903, 1, pp. 148, 240–241, 249), which appear as different variants on Govan 12 (with a loose end tucked behind the pattern), Govan 26, and Govan 28. These patterns will be classified on the table below as part of the Stafford knot family.

Some patterns may not be useful in defining groups as they occur infrequently and are only found on one or two of the recumbent cross-slabs (although they are found on other monument types in the Govan collection). One of these is called an 'S-bend' (ECMS pattern 544), which is constructed of two U-bends (Allen & Anderson 1903, 1, pp. 165, 213; Cramp 1984b, xxx, xxxix) and only occurs on the left side of the cross-shaft on Govan 19 (Figure 6.20). The second of these infrequent patterns is key pattern, which can be found on Govan 15 and the remnants of which has been identified on Govan 31 (Figure 6.31). While Allen defines key pattern as 'geometrical designs composed of straight lines, or…narrow straight bars, but leaving a space or background between the bars, thus resembling the L and T shaped slots cut in an ordinary key...' (1903, 1, p. 308), his approach and definition has been criticised and comprehensively redressed by Cynthia Thickpenny recently in her doctoral thesis (2019, 38–69), so this will not be discussed in great detail here. A more accurate description would be non-alternating geometric pattern composed of straight lines and based on spirals. These infrequent patterns will not be integral to the recumbent cross-slab groups discussed below but may assist when making comparisons to monuments of other types.

Finally, several patterns are described as 'irregular' interlace, which Allen uses as a catch-all category for patterns that do not follow his rules for interlace. In some cases, this irregularity was a result of the damage to the stones. For example, Allen had originally classified the interlace decorating the cross of Govan 16 as irregular, but the three-dimensional model has clarified that these two patterns consist of regular free-ring interlace and loops. In other cases, irregularity seems to be caused by the experimentation of the carver; Govan 12 is decorated above the cross with an 'irregular' pattern, but this appears to have been caused by the carver or designer attempting true mirror symmetry.

In most cases, even when interlace is 'irregular', the main goal of the Govan artists seems to be to give an illusion of consistent alternation of the strands. While the three examples of five-grain plaits in the Govan assemblage 'cannot be joined up properly' (Allen & Anderson 1903, 1, p. 203) due to the nature of uneven-grained plaits, the artists are content to tuck any loose strands 'behind' the pattern in a way that maintains the over-under relationship between strands. With the, admittedly odd, broken three-grain plait above the cross on Govan 12, the nonsensical segments of strand are still carved in a way that simulates a strict adherence to alternation. At least two examples (Govan 26 and 31) incorporate an additional strand mid-way through the pattern so these are occasionally confused as six-grain plaits (see Figure 8.24 below). This complication of an otherwise simplistic pattern, a sort of 'theme of confusion,' seems prevalent throughout the collection. If one attempts to follow the traces of plaitwork and interlaced strands on any of the recumbent monuments, many will not lead back to the origin and incorporate what Michael Brennan has termed 'open strands' (Brennan 2011, 35). While some of these could be interpreted as errors, in the above examples these errors appear to be deliberate.

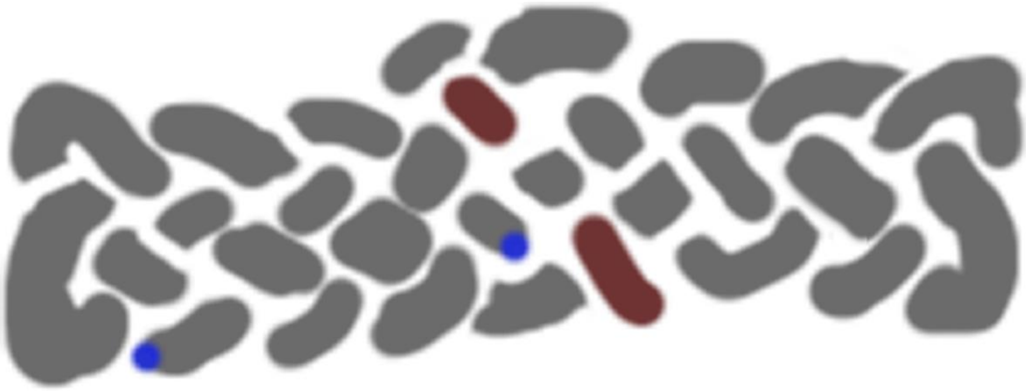


Figure 8.24. Irregular Plait from Govan 26. The vast majority of the plait is composed of one 'strand' in grey (with the end points indicated with a blue dot); the red indicates where an additional strand has been worked into the design halfway through.

Many art historians and archaeologists are of the belief that interlace had an apotropaic meaning in Insular art. James Trilling (1995) discussed several lines of evidence, including folklore traditions brought together by Karl-Heinz Clasen (1943), discussions of the evil eye in Greco-Roman antiquity by Katherine Dunbabin and M. W. Dickie (1983), and various archaeological examples from different time periods in different parts of Eurasia. Trilling argued that the protective quality of knots in the western middle ages came from their un-solvability, or the difficulty of untying the knot. The more difficult it was to understand or trace the strands in a panel of interlace, even by resorting to the concealment of the end of a strand, the more protective power the ornament would have. The further addition of alternating pigments that do not necessarily follow one strand consistently could potentially add to the confusion (Trilling 1995, 70–71).

This theme of protection can be inferred from the figural scenes found elsewhere in Scotland, but it is overt in the sculpture at Meigle. This can be found in several instances within the Meigle collection, but it is best illustrated by the figure of the griffin. The griffin can be found on three of the Meigle stones: Meigle 4, 9, and 26. In the case of both Meigle 4 and 9, the griffin has been described as carrying off various farm animals, with the animal in its beak (Allen & Anderson 1903, 2, pp. 299–300, 330; Henderson 1996, 26). However, in the case of Meigle 26, the griffin and another beast are without their quarry; the beasts are seemingly halted by a panel of ornament which stands between them and their apparent prey, a hunting party (Figure 8.25). This scene appears to demonstrate the protective power of these decorative motifs, while many of the other stones within the Meigle provide a stark contrast. Several stones show triumphant beasts devouring human figures, including the face opposite from the protected party on Meigle 26 (Thompson 2017).

Figure 8.25. Hunting party from Meigle 26 protected from beasts with ornament (Allen & Anderson 1903, 2, 305).

The hunting scene found on the Govan Sarcophagus provides a parallel to the scene found on Meigle 26; the rider is protected from behind by a prominent step pattern. This step pattern does not continue around the entire frame of the panel, which seems to emphasize that its purpose is to form a barrier behind the rider. This step pattern does resume on the other side of the plait panel behind the rider; the panel which shares this step pattern depicts a beast trampling another beast and what appears to be a snake. This triumphant beast has been interpreted by past researchers to be a lamb, potentially the lamb of God, due to the pattern decorating its body (Spearman 1994, 43; MacGregor Chalmers 1902, 16). Because these sets of step pattern frame the panel of interlace between these two illustrative panels, the lamb could be interpreted as the source of the protective force surrounding the rider (Figure 8.26). Other snakes, specifically those forming the panel on the opposite side of the sarcophagus from the 'lamb panel', appear to have become so 'confused' that they have become interlaced. While in some contexts the snake has been thought to be a symbol of death and resurrection (Mac Lean 1993, 251), in this case it seems to be emphasizing the apotropaic function of the patterns.

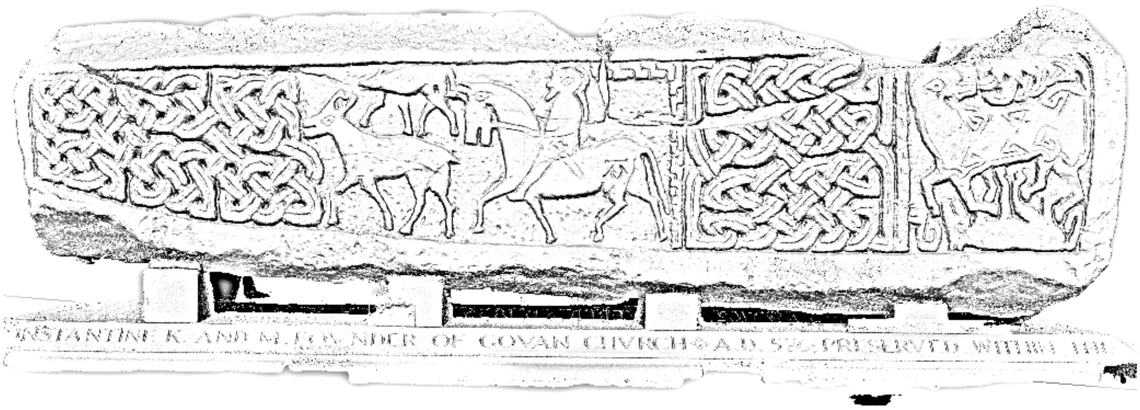


Figure 8.26. Govan's hunter protected by the panel of interlace and 'Lamb of God'.

The interlace patterns found on the Govan sculpture are often dismissed as unskilled carving by researchers. However, it seems likely that its sculptors had a similar apotropaic meaning in mind in the initial design. These issues will be considered in more detail in Section 10.3.

While the discussion above offers a possible interpretation of the artist's mindset and goal, the table below tabulates the types of patterns that have been identified on the extant recumbent monuments from Govan (Table 8.7**Error! Reference source not found.**). At first, there are no clear divisions based on pattern preference on the stones. Plaits and twists are prevalent throughout the collection, followed by rings. However, if Stafford knots are considered together with the triangular Stafford knots (ECMS patterns 731/732), three tentative groups can be identified. The first of these groups includes Stafford knots, but not free-ring patterns, in its design. The second uses both Stafford knots and free-ring patterns, while the third does not use Stafford knots and instead relies on free-ring patterns. Three extant recumbent cross-slabs cannot be reliably assigned to any of these due to wear or damage; all of these are decorated by at least one panel of plaitwork, and two exhibit variants of key pattern (Govan 15 and 31). The pattern on the cross-shaft of Govan 15 has been identified as a Stafford knot pattern, which suggests that both recumbent cross-slabs exhibiting key pattern could be more closely related to the Stafford knot group. The group allocations are illustrated in Table 8.8.

Table 8.7. Patterns identified from the recumbent cross-slabs allocated to 'Families' of pattern.

Maxwell	ECMS	Twists and Plaits	Rings	Figure - 8s	Stafford knots	S-shaped	Knot angle, Triangular	Key Pattern	Irregular	Notes
11	9	x					x			
12	13	x							x	Irregular due to mirror symmetry attempt
13	38	x	x	x						Side-panels are more like 590-594 groups - triple loop entangled in strand
14	32	x			x					5-grain knot above crossarms, unclear transition under cross between 4-grain plaits
15	34	x			x			x		Pattern on shaft is unclear, largely due to damage along edge of cross shaft
16	14	x	x		x					Unclear pattern above cross due to damage
17	35		x	x						
18	7	x	x							Unclear patterns above cross
19	15	x	x			x				
20	8	x	x	x						
21	33	x								Too worn to identify more patterns
22	27	x	x	x			x			
23	31		x							Broken, cannot identify pattern above or below cross
24	6	x	x		x		x			Unclear pattern above cross
25	23		x				x			
26	21	x		x	x					
27	17	x	x	x			x			
28	28	x			x					
31	16	x						x		Right half of stone too worn
36	25				x					Most of stone's decoration is unclear due to damage

Table 8.8. Recumbent Monument simplified pattern groups.

Interlace Group	Maxwell	ECMS	Twists and Plaits	Rings	Stafford knot	Key Pattern
Stafford knot Group	11	9	x		x	
	12	13	x		x	
	14	32	x		x	
	15	34	x		x	x
	26	21	x		x	
	28	28	x		x	
	36	25			x	
Free Ring and Stafford Knot Group	16	14	x	x	x	
	22	27	x	x	x	
	24	6	x	x	x	
	25	23		x	x	
	27	17	x	x	x	
Free Ring Group	13	38	x	x		
	17	35		x		
	18	7	x	x		
	19	15	x	x		
	20	8	x	x		
	23	31		x		
Unclassified	21	33	x			
	31	16	x			x
	42	-	-	-	-	-

This initial grouping appears promising, as several stones that were paired together through analysis of the cross-arm proportions share similar ornament styles (Govan 13 and 20, Govan 17 and 19, and Govan 12 and Inchinnan 1). The distinction between the above groups may indicate a shift in popularity or preference for these patterns through time, although it is difficult to say in which direction this shift would occur. While it seems more likely that the examples with both free-ring and Stafford knot patterns would occur between the shift in preference, it is also important to consider whether there is a correlation between the ornament used and where it is located on the stone.

8.3.3 Layout of the Decoration

The recumbent monuments all share certain traits, including a thin, plain boundary that outlines each cross, and the cross-arms consistently reach to the edge of the frame to create a minimum of two separate panels for decoration. However, several variations in the layout of the cross and ornament occur in the collection: some crosses reach the top boundary of the slab, creating three discrete panels of interlace, some crosses are decorated with ornament within their plain outline, and the space below the cross on some of the cross-slabs has been subdivided into one or more separate panels of decoration. By analysing these different layouts in conjunction with the patterns identified above, it may be possible to identify groups differing levels of standardization or even gain insight into the motivations behind the carver's actions. A table of these traits and whether they are present, absent, or uncertain on each of the recumbent cross-slabs is provided below (Table 8.9).

Out of the fourteen cross-slabs from Govan for which this trait could be determined with any certainty, only three are carved with a cross that reaches the top of the slab. The cross on Inchinnan 1 similarly reaches the top. These four stones do not consistently share any of the other characteristics listed in Table 8.9. It seems unlikely, then, that the positioning of the cross on the stone would be suitable for use in this typology.

The crosses of six of the recumbent cross-slabs have been decorated with one or more types of pattern. An additional six have clearly been worn but show some pecking; it is uncertain whether their crosses were ornamented with something other than the incised boundary or if these marks are the result of later damage despite the application of RTI. Eight recumbent cross-slabs have an undecorated cross. Those with ornamented crosses do not have angle-knobs, nor a protruding frame (three of the four recumbent cross-slabs exhibiting angle knobs also have an exaggerated, projecting frame).

Identifying the presence or absence of a pedestal element to the design was more complicated than initially thought. In the Govan collection, there are some recumbent cross-slabs that exhibit clear definition between the pedestal and the panels of interlace above them. Most of the clearest divisions occur with the pedestals formed of triangular Stafford knot interlace. With these, the pedestal pattern is completely separated from the panels flanking the cross-shaft by a simple incised line. In one case, that of Govan 26, the pedestal is formed by two distinct panels that are each framed with a plain boundary. For the other stones where the transition from cross to the bottom portion of the stone remains intact, the distinction is less clear-cut.

Table 8.9. Features relating to the layout of decoration in the Govan recumbent cross-slabs.

Maxwell	ECMS	Cross to top? Yes/No/Uncertain	Cross decorated? Yes/No/Uncertain	Frame: Angle-Knobs? Yes/No	Frame: Extra boundary? Yes/No/Uncertain	Frame: Prominent/raised? Yes/No/Uncertain	Pedestal? Y: Clear-cut/ U: Change in Pattern/ N: Continuation of pattern	Pedestal? Y: Clear-cut Pedestal / P: Partial Integration of Pedestal / N: Complete Continuation of Pattern / -: Missing base, or otherwise uncertain
11	9	N	Y	N	N	N	Y (John Stuart)	Y
12	13	N	N	Y	N	Y	Y?	-
13	38	N	U	N	N	N	U	P
14	32	Y	Y	N	N	N	N	N
15	34	Y	Y	N	Y	N	-	-
16	14	U	Y	N/U	N/U	U	-	-
17	35	N	N	Y	N	Y	N	N
18	7	Y	N	Y	N	N	Y	P
19	15	N	N	N	N	N	U/N	PN
20	8	N	U	N	N	N	U/N	N
21	33	U	N	U	U	U	-	-
22	27	N	U	N	N	N	Y	Y
23	31	U	N	Y	N/U	U/Y?	-	-
24	6	N	Y	N	N	N	Y	Y
25	23	U	N	Y	Y/U	Y	Y	YP - RTI required
26	21	N	Y	N	Y	N	Y	Y
27	17	N	U	N	N	N	Y	Y
28	28	N	N	N	N	N	U/N	N
31	16	U	U	N/U	N/U	U/N	-	-
36	25	U	U	N/U	U	U/N	-	-

As suggested above, the identification of a pedestal element is not always straightforward. If a pedestal is defined by a clear delineation between the patterns flanking the cross to the pattern forming the base, one might argue that Govan 13 and 18 would qualify. Upon closer inspection, however, it appears that the carvers of these stones made a subtle attempt to connect the lower patterns to the panel of interlace to the right of the cross-shaft with a single strand (see Figure 8.17 above). A similar process can be seen in the case of Inchinnan 1, where the strand forming the left pattern forms only four crossings with the lower strand (which forms nearly the entire lower pattern, see Figure 8.27) before forming the pattern to the right of the cross shaft. These examples are less fully integrated with the lower pattern than those that fill the entire lower portion with the same coherent ornament (Govan 17 using free-ring interlace, see Figure 8.18), or those that transition between two patterns (like Govan 20 from twists simulating free-rings to actual free-ring interlace (see Figure 8.16) or Govan 28 from Stafford knots to a likely 14-grain plait (see Figure 8.19)). For this reason, the table collating the traits used in the typology below will make the distinction as to whether the decoration of the lower portion of the slab is separate from the adjacent panels (like Govan 26 or 22), if the pedestal is connected to the patterns above it (like Govan 18), or if the transition between the patterns is seamless and integrates the lower portion of the slab with the top (like Govan 28; see Table 8.10 below).

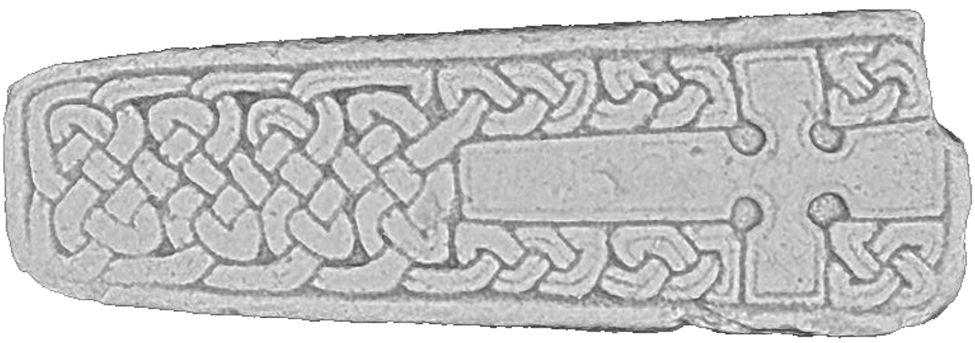


Figure 8.27. Inchinnan 1 from 3D model produced by Spectrum Heritage 2017.

Unfortunately, seven of the recumbent cross-slabs are missing most or all of the pattern below the cross, so this cannot be determined for each of them. From what can be analysed, however, it appears that those carvers that insisted on creating some sort of connection between the panels, whether well-executed or not, did not use both Stafford knots and free-ring Interlace; they opted for one pattern or the other. From what we currently know of the recumbent cross-slabs, as mentioned above, only those stones that use the triangular Stafford knot pattern and Govan 26 exhibit a complete separation of the ‘pedestal’. Govan 25 is the only instance where there appears to be an attempt on the part of the carver to connect free-ring interlace with the triangular Stafford knot pattern (though this still needs to be confirmed; Figure 8.28).

Figure 8.28. Govan 25, where the left panel of free-ring interlace attempts to connect to the 'cross base'.

8.4 Recumbent Cross-slab Typology

If the cross proportions, decorative motifs, and layout of the decoration are all considered together, several trends can be identified. The most variation in the layout of decoration is found in the Stafford knot pattern group. The free-ring interlace group is consistent in terms of cross proportions and how the base of the monument is treated, either incorporated or at least connected to another panel of interlace. Finally, the pattern group that uses both Stafford knots and free-ring interlace is the least consistent in cross proportions, but the most consistent in how the base is decorated and separated from the other patterns. This analysis also revealed smaller sub-groups, including pairs of stones that exhibit virtually identical crosses and are decorated with similar patterns. These six stones in particular, spanning Groups I and II, offer a new perspective on the potential meaning for the identity of the deceased imbued in the design choices made by the carvers.

Table 8.10. Classification of the recumbent cross-slabs from Govan and one from Inchinnan based on the types of patterns used, the treatment of the base of the monument, and the cross proportions. Grey cells indicate these belong to the transitional groups.

	Maxwell	ECMS	Patterns: Stafford Knot (SK), Free-ring (FR) or Both (SKFR)	Pedestal: Separated, Connected, or Integrated	Cross Proportions
Group I	14	32	SK	I	Outlier
	28	28	SK	I	E?
	-	Inchinnan 1	SK	C	A
	12	13	SK	-	A
	36	25	SK	-	-
	11	9	SK	S	D?
	26	21	SK	S	Outlier
Group II	13	38	FR	C	B
	19	15	FR	C/I	C
	17	35	FR	I	C
	20	8	FR	I	B
	23	31	FR	-	-
	18	7	FR	C/S	E?
Group III	22	27	SKFR	S	Outlier
	24	6	SKFR	S	Outlier
	25	23	SKFR	S	-
	27	17	SKFR	S	E?
	16	14	SKFR	-	-
Group Ia	15	34	SK+Key Pattern	-	D?
	31	16	Key Pattern	-	-
Unclassified	21	33	-	-	-
	42	-	-	-	-

If the shift in pattern usage is seen as a temporal indicator for the Govan school, it can be helpful to consider other monument types in the collection. The sarcophagus is thought to be the earliest monument in the Govan collection, largely due to the ‘Pictish-style’ animals and hunting scene it depicts (Spearman 1994, 42). If this were the case, it is notable that the patterns covering the sarcophagus consist primarily of plaits, loops, and Stafford knot-related patterns, and does not incorporate free-ring interlace. This would suggest that the first recumbent cross-slabs carved may have exhibited primarily Stafford knots, like Govan 28 or Govan 14. However, this group is disparate enough that other stones in this group might have been carved concurrently with other groups.

It is possible that the two recumbent cross-slabs exhibiting key pattern represent a slightly later off-shoot of the Stafford knot group. For both Govan 15 and 31, the only other patterns identified with the key pattern are plaits, patterns which do not occur with any of the stones in the free-ring group. It is unclear whether a separated pedestal was a part of their design, as that part of the stone is either severely worn or missing from these stones (though as indicated in the interpretation in Section 6.20 for Govan 31 it is a distinct possibility). The only other examples of key pattern that occur in the Govan collection can be found on the two cross-shafts, Govan 7 and 10, of which both incorporate all four pattern types (Stafford knots, free-ring interlace, Key pattern and plait) into their design. In Macquarrie's analysis of the crosses from the area surrounding Glasgow, he suggested that Govan 7 (Jordanhill) is likely the earliest of Govan's crosses, with Govan 10 in the middle of the sequence, by placing the monuments with the most diversified decoration earlier in the sequence (2006, 23).

A shift towards standardisation may have occurred after the first slabs were carved, along with the adoption of free-ring interlace. The only firmly-identified cross proportion groups, Groups A, B, and C, represent pairs of monuments decorated with nearly identical crosses, the same pattern groups and either connected or integrated decorative motifs at the base of the cross. The two stones in Group A exhibit Stafford knot-related patterns, while Groups B and C are decorated with free-ring interlace. These pairs of stones are intriguing for many reasons. These strong similarities may indicate that the same carver worked on the pair of stones (which will be discussed in Chapter 9, focusing on Group A), or the choice in ornament may be an attempt by the carver to express a connection between the deceased.

It is also worth noting at this point that in the case of Group A and Group C, each pair contains one stone with angle-knobs and one without. While angle-knobs do not appear to be a strong temporal indicator, it is possible that these features reflect the enhanced status of the individual – considering the shrine-like appearance these angle-knobs confer (Bailey 1994, 114–115; Radford 1967a, 182–183), the deceased could have been a high-ranking ecclesiastic official. It is unclear how many more pairs of recumbent cross-slabs there might have been in antiquity. With the fifteen (possibly sixteen) 'misplaced' recumbent cross-slabs from Govan, the damaged condition of others, and the physical distance between Group A's paired stones (Inchinnan 1 and Govan 12), it is possible that other sets of identical crosses were present at Govan or other sites in the Strathclyde region.

Finally, a third group consists of cross-slabs which exhibit both Stafford knot and free-ring interlace patterns, the separation of a pedestal from the panels above it with an incised line, and which are either outliers or only tentatively linked to other stones via cross proportions. Govan 18, which is not decorated with Stafford knots, and Govan 11, which does not have free-ring interlace, may have been carved just before this transition as they both have been carved with distinctive pedestals (although the pedestal of Govan 18 is not quite separate from the rest). Two of these monuments, Govan 22 and 27, are more similar than the others, with double free-rings above the cross and the triangular Stafford knot pattern forming the base, although with different types of pattern on either side of the cross-shaft. However, their cross proportions are completely different (See Figure 8.11 - Figure 8.14 and Table 8.6 above). It seems as though the carvers of these monuments were primarily concerned with the standardised layout of the patterns, specifically with an angular Stafford knot pattern forming the pedestal. This specific layout could be a reference to the end stones situated with the recumbent cross-slabs seen at York Minster (Lang 1995, 455–457), though it seems more likely that these are symbolising cross socket stones. Angular interlace is found elsewhere in the Govan collection, specifically on the Govan 8, also known as the Sun Stone, which, along with the Cuddy Stane (Govan 9), has been thought to belong to a later phase of carving at Govan due to the amount of blank space employed in the design (Macquarrie 2006, 23). A graphical interpretation of the above potential phasing is provided below in Figure 8.29 **Error! Reference source not found.**.

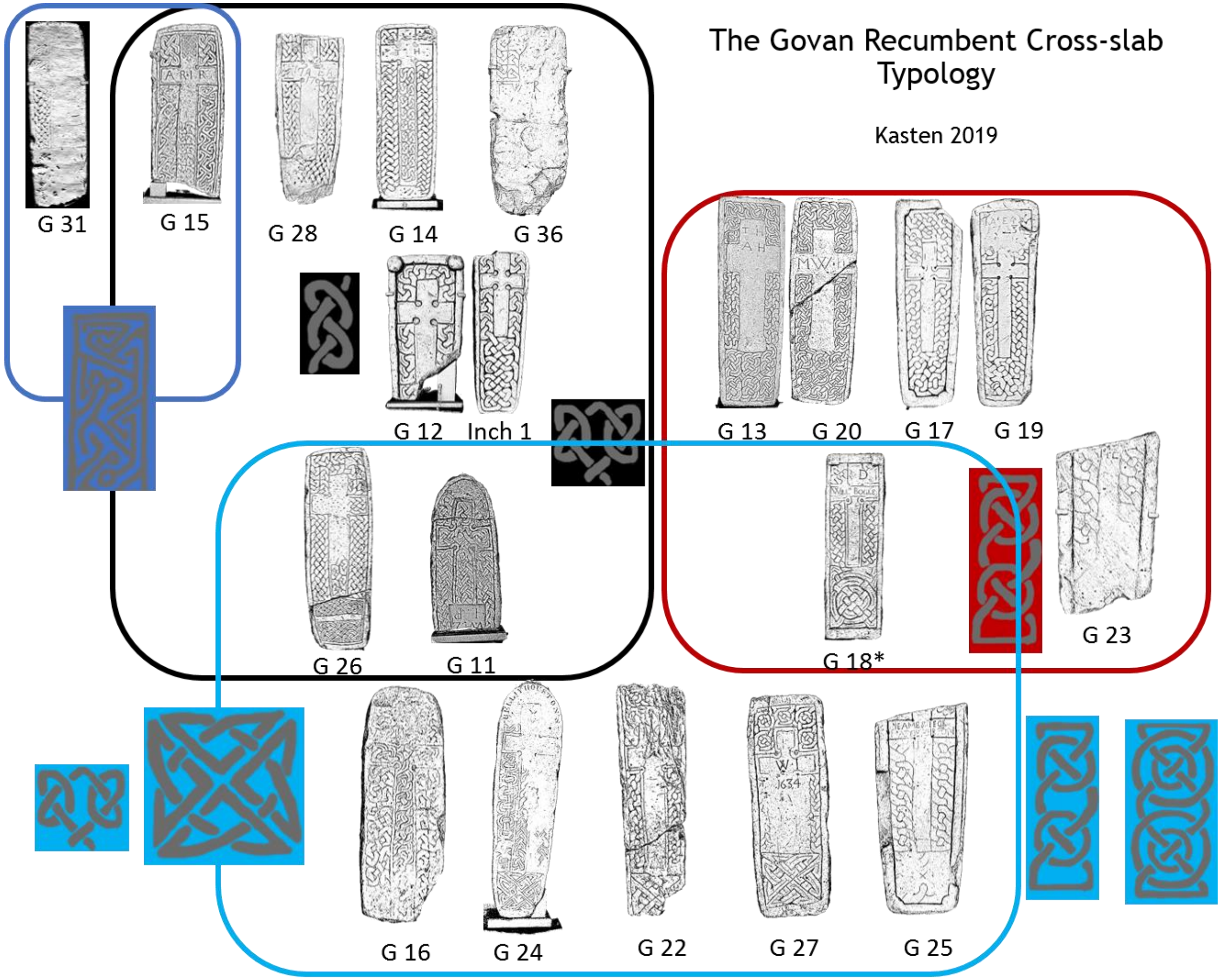


Figure 8.29. Graphical representation of Govan's recumbent cross-slab typology.

While the temporal phasing of this is purely hypothetical because it cannot take into account that other less well-preserved media might have impacted these design choices and is based on previous observations of other monument types in the Govan collection, the overall trends do seem to hold. The stones in Group I seem less standardized than those belonging to other groups, and at least three (Govan 11, Govan 12 and Inchinnan 1) seem to be transitional monuments or are related to other internal phases standardisation that have been identified. The free-ring patterned stones in Group II are more standardised in layout and cross-proportions and were likely carved around the same time as Govan 12 and Inchinnan 1, which have identical cross forms. The final group suggests that the carvers were less concerned with ensuring similarities in cross proportions and more intent in the standardisation of the layout of the decoration, specifically in the clear delineation of the bottom panel to form a cross base, where angular Stafford knot patterns were frequently used, and free-ring interlace in other panels.

If we were to compare this newly developed typology with the reassessed typology based on Rosemary Cramp's criteria, as defined in Section 8.1.1, several similarities and differences are highlighted. Overall, the strict application of the criteria cited for Groups A and B in Rosemary Cramp's typology results in a division between 'cross-slabs with plain crosses' and 'cross-slabs with decorated crosses' respectively. While the reapplication of Rosemary Cramp's criteria places some of the stones, specifically Govan 14, Govan 26, and Govan 36, into the same group, as my typology does here, hers does not identify the additional internal phases of standardization evident in the construction of the Govan cross-slabs, especially in the shift towards incorporating a 'pedestal' beneath the cross, and a phase where pairs of proportionally-identical crosses were purposefully used in the design. This newly developed typology implements consistent principles that highlight these aspects and enables the inclusion of many of the worn monuments in the collection. It also reflects some of the groupings initially identified by Rosemary Cramp; Govan 28, Govan 14, and Govan 26, classified into her earliest Group B (1994, 57), were identified in this typology as coming from the same general period of carving and are the most likely to date to the earliest phases of Govan's recumbent cross-slab sequence.

8.5 Conclusion

In conclusion, there are three clear groups with two transitional blurred groups. Group I includes the cross-slabs that have Stafford knots are the primary decorative motif (Figure 8.30). Group II consists of the stones where free-ring interlace predominates the designs (Figure 8.31). Slabs which are designated under Group III are those with both Stafford knot and free-ring patterns; almost all of these also exhibit a cross-base/pedestal element to the structural layout of the stone (Figure 8.32). The two transitional groups lay between Groups I and III and Groups II and III, where a cross-base section is present, but only one of the two defining pattern types is employed in the design. The two slabs which incorporate different variants of key pattern seem to be most closely related to Group I. The newly developed classification may not offer a definitive timeline for the Govan sculpture, but these three traits have highlighted several phases of development in Govan's recumbent cross-slab monuments that can contribute to new interpretations of how the carvers were organised and who the monuments were commemorating. While the overarching groups are largely defined by the trends in decorative motifs employed in the design, two internal phases of standardization are evident from the above analysis: a phase where cross proportions were purposefully replicated in the construction of two slabs from Group I and of four slabs from Group II, and the transition towards separating the decoration underneath the cross into a different pattern, potentially emulating a decorated socket stone.

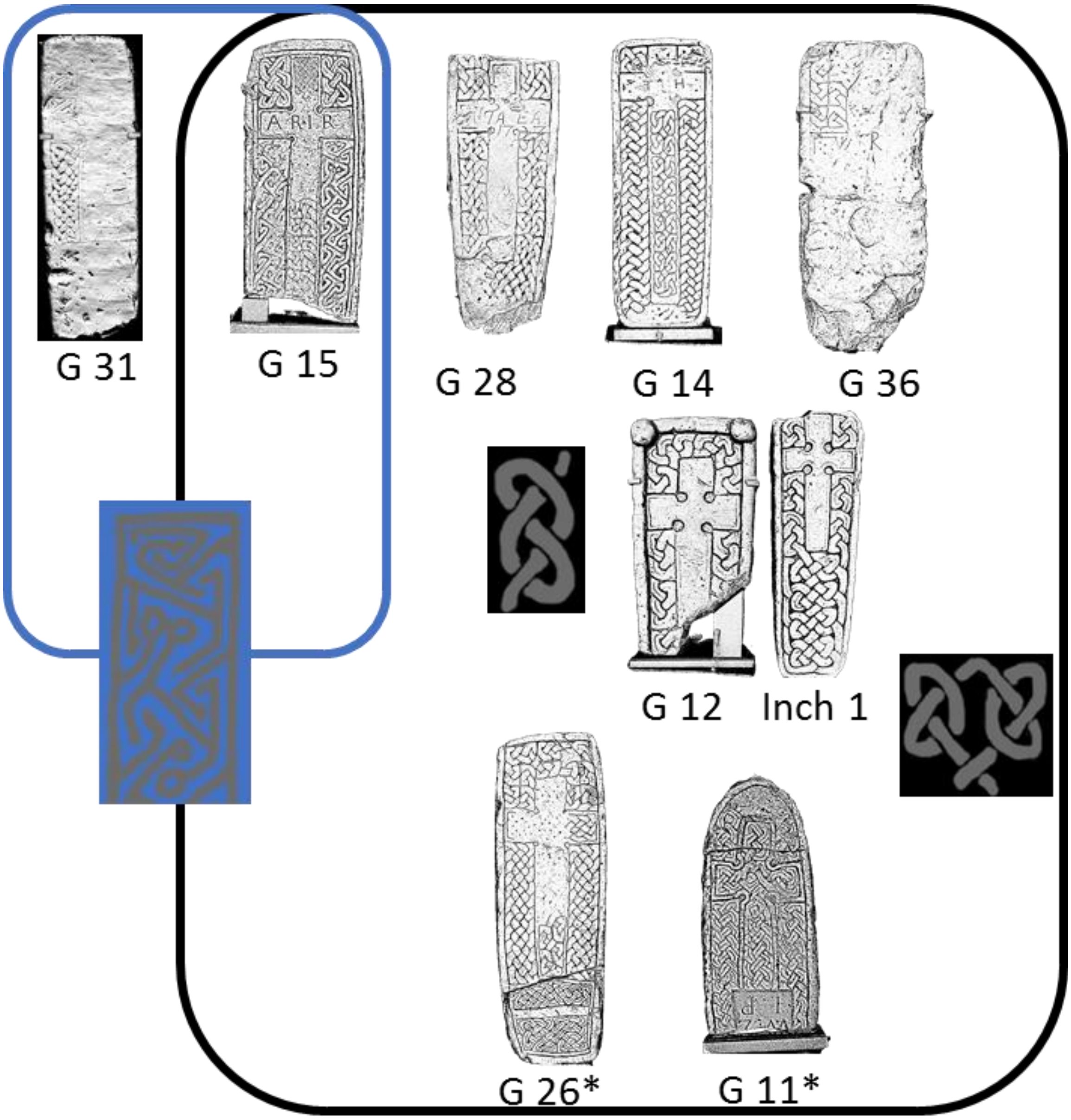


Figure 8.30. Groups I and Ia; Transitional monuments marked with an asterisk.

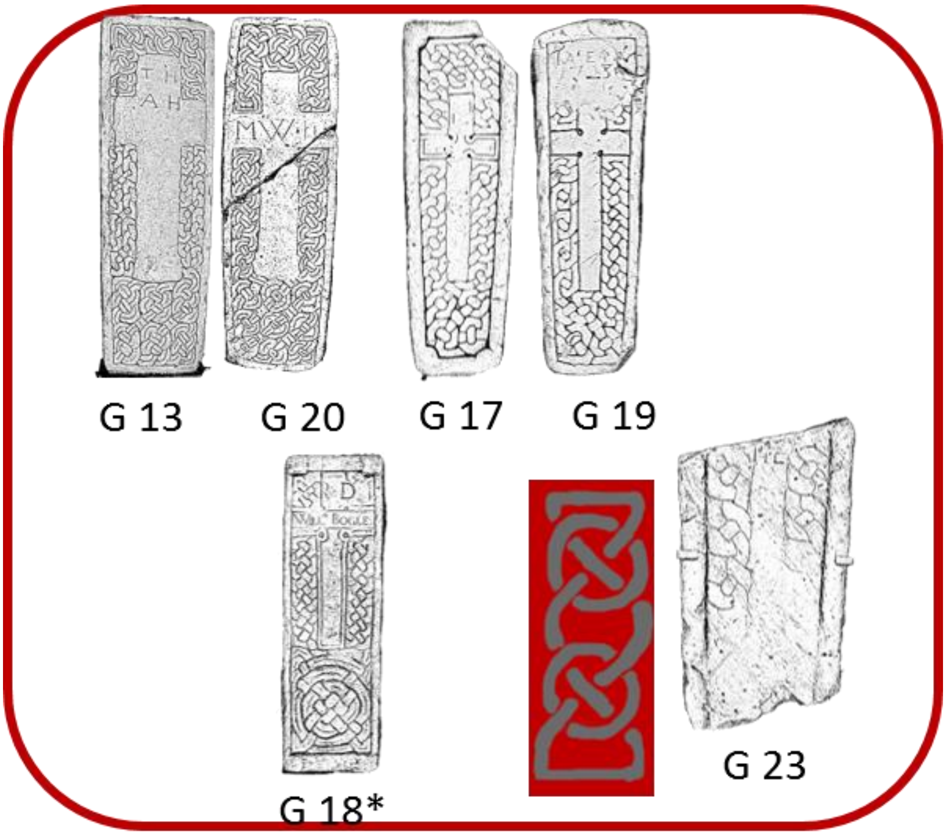


Figure 8.31. Group II; Transitional monument is marked with an asterisk.

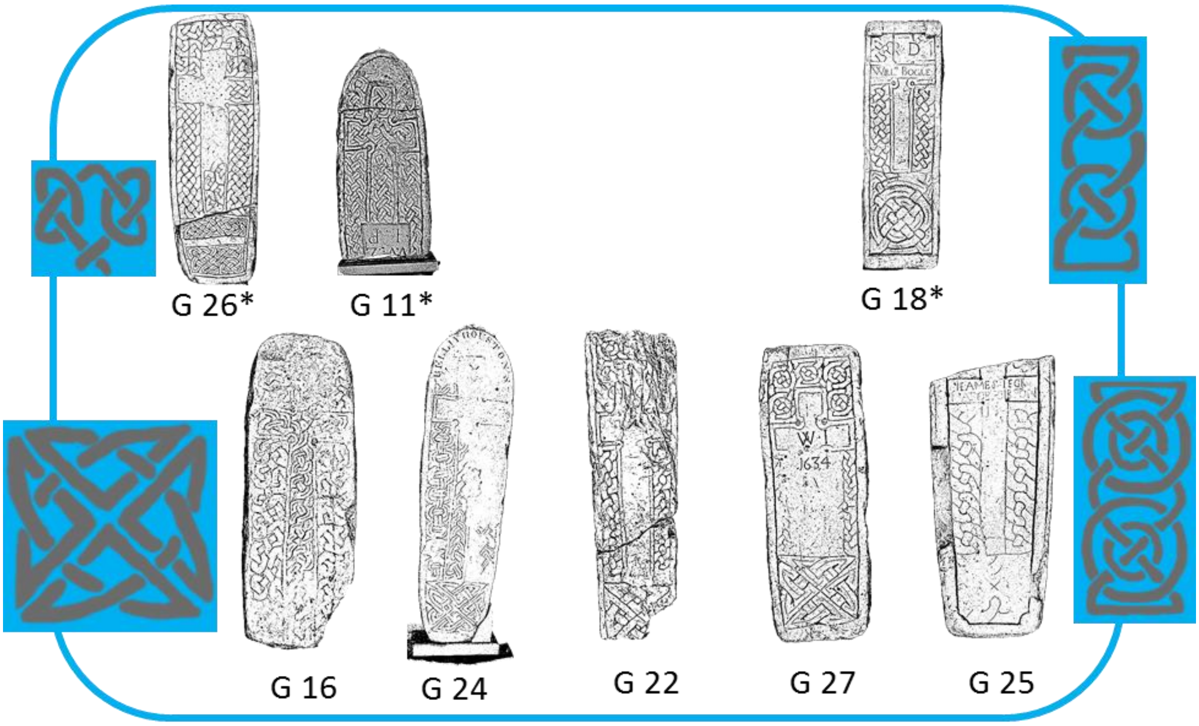


Figure 8.32. Group III; Transitional monuments are marked with an asterisk.

The proportional similarities between pairs of crosses on the recumbent cross-slabs raise some intriguing questions about the carving process and the role of a centralised workshop or school of carving in the production of the Govan and Inchinnan carved stones (Figure 8.33). As mentioned above in Section 8.3.1, it is unclear how these crosses would have been replicated – would a common unit of measurement be necessary to scale the outline down so exactly, or would grids or models have been sufficient? If it were the same skilled carver executing the design of both stones, perhaps they would not require aids to replicate them. If two different carvers were responsible for each stone, were the two stones carved around the same time, as the consistency in the decorative motifs trends suggest, would the carvers been working side-by-side in the same location and so copied the cross-outline by eye, or would a sketch or motif of the original cross be copied to some medium by a later sculptor? In the case of Inchinnan 1 and Govan 12, stones which were erected roughly ten kilometres away from each other, this reinforces the notion of a single workshop or 'Govan school'.

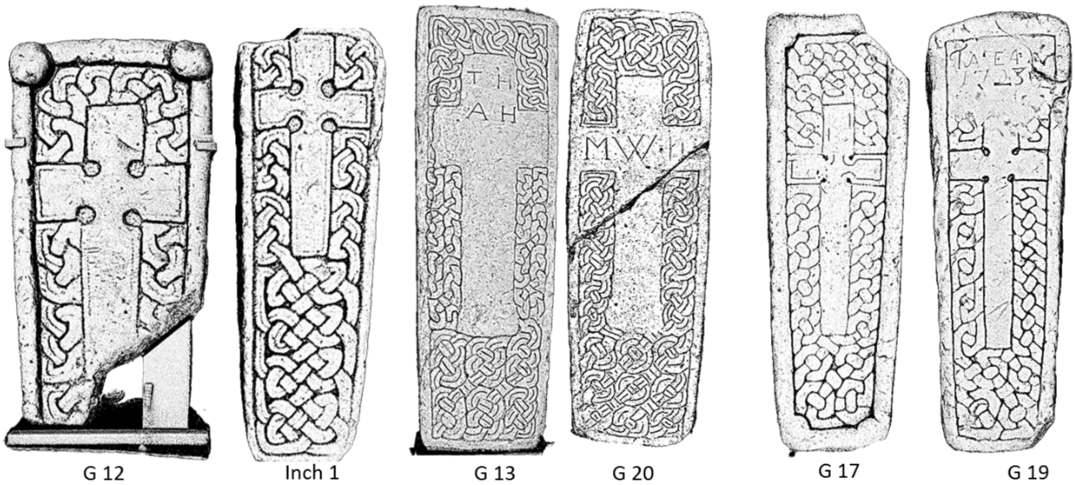


Figure 8.33. Pairs of identical crosses; G12 and Inch 1 belong to Group I, the rest belong to Group II.

If we assume that these were skilled artists creating these monuments, then why did they feel the need to duplicate the cross-outlines between each pair of these monuments? The fact that, according to our current knowledge, these occur in pairs, seems to suggest that the carvers were evoking a social relationship between the individuals commemorated by the cross-slabs. What the nature of these potential relationships is unclear – because the stones have been reused since the early medieval period, we have lost the context as to which burials they likely would have been marking. They might have been indicative of familial relationships, which is particularly evocative if one considers the later medieval trends of paired burial monuments situated side-by-side for the wedded elite. However, the distance separating Govan 12 and Inchinnan 1 cautions against making this assumption; there were undoubtedly other significant relationships that were worthy of commemoration at this time, like those between craftsmen and their proteges.

The prominence of these cross pedestals/bases in the design of Group III and the transitional groups is striking, particularly because of the lack of decorated cross bases known in the Strathclyde region. While the Stanely cross, Capelrig cross, and Barochan cross have all been documented with their original stone base (Macquarrie 2006), none of these bases currently exhibit any decoration. While there are quite a few undecorated stone cross bases in Scotland, there are very few examples of those that are decorated, apart from Culross (Douglas 1926, 68), Dupplin Cross/Constantine's Cross (Ewart et al. 2007, 320, 324), and some which are occasionally decorated with an incised cross. There are many intricately decorated examples supporting the high crosses of Ireland; these are often covered with figural decoration, though some also incorporate abstract decoration like Muiredach's cross at Monasterboice, Co Louth (Stalley 1996, 8–9). It is possible that the carvers of these recumbent cross-slabs were familiar with these Irish examples, they may be alluding to more local decorated cross bases that are missing, or they could be referring to a cross in another medium.

Throughout this typology, the feature that once so defined the Govan recumbent cross-slabs has been seemingly neglected: the angle-knobs. These protrusions span all three defined groups in the typology laid out above; intriguingly, when looking at the pairs of proportional crosses, in two of the three pairs, one of the slabs exhibits angle-knobs (Govan 12 and Govan 17), while the other does not (Inchinnan 1 and Govan 19). If these pairs of proportional crosses are indicative of a social relationship between the deceased, it is possible that the angle-knobs highlight the individual's elevated status. It could be that, as suggested by Radford and others, the angle-knobs are intended to emulate composite shrines (Radford 1967a, 182–183; Spearman 1994, 39; Bailey 1994, 114–115) and could mark the burial of high-ranking ecclesiastical figures. Without additional context, of course, this is all speculation. But if the trends highlighted in the typology above can ever be substantiated as representative of different temporal phases of carving, then clearly the angle-knobs served as indicators of the deceased’s special status over a significant period of time.

This is only the first step in achieving a better understanding of the recumbent cross-slabs at Govan. A comprehensive geological study of the recumbent cross-slabs would be of great benefit and would likely shed new light any shifts between different early medieval stone sources that might have occurred. For now, this classification has given a new stratification to the recumbent cross-slabs and will be discussed further when the results of the Groove Analysis undertaken in Chapter 9 are considered. While only two recumbent cross-slabs are compared via Groove Analysis in this thesis, this typology will form a framework for the interpretation of the application of Groove Analysis to the other stones in the collection and the wider ‘Govan school of sculpture’ in the future.

9 Groove Analysis

Groove Analysis was applied to three three-dimensional models of carved stones in the 'Govan school of carving' to attempt to identify variation in the physical characteristics of the carvings. These features can reflect the development of an individualized motor performance in an artisan's technique for their craft, as introduced in Section 4.1.3 and discussed more thoroughly in Section 5.6. The approach of taking measurements from three-dimensional models of carved grooves was developed by Laila Kitzler Åhfeldt in her research addressing Swedish runestones. These sub-millimetre measurements were then converted into ten variables that characterise different elements of the shape and rhythm of the carved groove, which, after a series of multivariate statistical analyses, can reveal the 'signature' of different sculptors (2002b, 8–9). This chapter will discuss why these stones were chosen for analysis, what the difficulties of adapting and applying this process to these stones were and how they were overcome, and how these results can reveal the number of carving signatures present on the stone. The interpretation of these carving signatures and their relevance to addressing the presence or absence of a Govan school or workshop will be discussed. The chapter will conclude with a critique of the method and avenues for future applications of the research.

9.1 The Stones

The three stones analysed here include Govan 1 (the sarcophagus), Govan 12 and Inchinnan 1 (recumbent cross-slabs). These stones were chosen for several reasons: in the case of the sarcophagus, it is thought to be the earliest monument in the collection, so the identification of several different carving signatures could indicate the early existence of a 'Govan school of carving'; in addition, questions have been raised as to whether the Alpha symbol on the horseman was added at a later date than the rest of the decoration (Spearman 1994, 43). The final 3D model of the sarcophagus (saved as an OBJ file) consists of 32,616,110 faces, 16,318,744 points, and is 2.69 GB in size. This model was divided into individual panels because of its size and for ease of alignment in Deskartes Design Expert, of which eight were chosen. A total of thirty-seven samples were taken from these eight panels; the samples were chosen from areas that provide over 50mm of uninterrupted groove (avoiding junctions between strands of interlace), appeared undamaged and unworn, and provided a variety of types of carving (including grooves that made up the exterior frame of the panel, bisected strands of interlace, and formed animal decoration). The locations of each of the samples are available in Figure 9.23 - Figure 9.30 below in Section 9.8.1.

Govan 12 and Inchinnan 1 were chosen for comparison with Groove Analysis because they visually appear as though they could have been carved by the same person: they share strong art historical and structural parallels, with a few differences, as highlighted in the new typology developed in Chapter 8. Importantly, they also seem to have experienced similar levels of wear. These two stones also offer the opportunity to compare samples taken from 3D models created by two different researchers, which is key to the development of a digital equivalent of *ECMS*, as proposed by the first 'Carved Stone Workshop' organised as a part of creating the Scottish Archaeological Framework (ScARF 2015). The three-dimensional model of Inchinnan 1 used in this analysis was not produced by the author. The data came from Spectrum Heritage, a conservation company that specialises in digital approaches and its uses in the preservation of cultural heritage based in Edinburgh at the time of writing, who created three-dimensional models of the early medieval and 'Templar Stones' from Inchinnan as a part of a community project led by the Inchinnan Historical Interest Group and Dr Heather James of Calluna Archaeology (Spectrum Heritage 2017; Inchinnan Historical Interest Group 2018). This stone was included to test whether three-dimensional models produced by different researchers (both used photogrammetry and Agisoft Photoscan Professional but did not necessarily approach data capture in precisely the same way) could both be examined using Groove Analysis and whether those results could be compared in a meaningful way. If so, this could argue for a centralised repository of three-dimensional models so that researchers could apply this analysis but would not necessarily need to create their own models if they have already been created to a standardized and sufficient resolution (ScARF 2015). While Spectrum Heritage has made the models available for download on Sketchfab (2017), this does impose a size limit on the downloadable model. To ensure that the highest-resolution model was used in the analysis, the original dataset was requested, which Spectrum Heritage kindly provided. This model consists of 627,469 vertices, 1,252,224 faces, and is 85MB in size. In comparison, my 3D model of Govan 12 is made of 1,918,657 vertices, 3,830,665 faces, and is 301 MB in size. From the perspective of those who study early medieval sculpture, this could help identify the work of individuals at different locations, although this would need to be done with caution as will be discussed more thoroughly in the Discussion (Section 10.8).

Twelve samples were taken from each of these two stones, adhering to the number of samples suggested by Laila Kitzler Åhfeldt as an adequate sample size to identify the workmanship of more than one carver on a single stone (2002b, 27). However, this is considered a low number of samples in multivariate statistics, which can affect the strength of power of the statistical tests (Stevens 2009, 4–5); for many of these multivariate statistical analyses there are several conditions under which the results are considered significant no matter how small the sample size, which will be addressed further below (see Section 9.4). As in the case of Govan 1 above, samples were taken where possible from uninterrupted, relatively unworn groove segments that were at least 50 mm in length and avoided areas of intersection between strands of interlace. Unfortunately, the extreme protruding, rounded frame of Govan 12 prevented samples from being taken from adjacent grooves. The maps showing the locations of each sample are given below in Figure 9.39 - Figure 9.42.

Samples from seventeen other stones from the Govan collection were also taken while the specialised software from DeskArtes was available for this project. The following statistical analyses took a great deal of time for each stone, so it was decided that only three stones would be analysed and addressed here in detail as a proof of concept. The samples not included in this analysis are available for future work.

9.2 The Process

While a description of each step of the sampling process is given in detail in Section 5.6, a brief summary of the process will be given here. The sampling strategy is mentioned above. Each of these samples were measured from the three-dimensional model of the stone by the Deskartes software, which exported the set of measurements for each groove. These measurements were then copied into an Excel template designed and generously provided by Laila Kitzler Åhfeldt to calculate ten variables for each groove sample (2017; see Appendix B). Five of these variables relate to the profile shape of the groove (AvgX, AvgY, AvgZ, v and D) and five describe the longitudinal cutting rhythm of the carver (w, k, mindiff, plusdiff, and meddiff) (Kitzler Åhfeldt 2002b, 28–33). More complete definitions of the variables, both how they are calculated and what they represent in the analysis, are provided in Section 5.6.1. Each groove sample produced values for these ten variables; these samples comprised the datasets for each stone to which multivariate statistical analyses were applied, as described below.

9.3 Different 'Types of carving' and Wear

One of the main issues that arose in the application of this analysis to the Govan collection was addressing stones that exhibit different 'types of carving' and those that have been influenced by differing degrees of wear. In Kitzler Åhfeldt's analysis, she noted that the same carver often developed different carving techniques for runes and ornament; from her modern examples, the sculptors frequently carved runes deeper and with fewer hits of the tool than they carved ornament (2001, 146; 2002b, 35). If the samples from the runes and decoration were all considered together in the multivariate statistics, the work of one sculptor would likely be attributed to two separate clusters, or two different individuals. To counteract this in her analyses, she separated the samples into two 'types of carving': runes and decoration. She essentially performed the statistical analyses twice for each runestone, once to analyse the samples taken from runes, and again to consider the ornament samples. Once different individual carving signatures were identified from these two types of carving, she standardized the signatures separately, compared them, and matched the carvers' runic technique with their ornamental signature. This concept of separating samples into different 'types of carving' was indispensable in applying Groove Analysis to the Govan stones.

In the case of the Govan sarcophagus, samples were taken from a variety of carved sections, including deeper grooves that form the outlines of the interlace panels and shallower grooves that bisect each strand of interlace. To avoid the allocation of all the shallow grooves to a single carver group simply because of a significant difference in depth defined by the nature of the design, the samples from the Govan sarcophagus were also divided into two types of carving. One group consisted of samples that could be considered ‘shallow types of carving,’ including the grooves bisecting the interlace strands and the detailed carving on the Govan horseman. The ‘deep carving group’ included all other types of carving, including those that outlined the panels, interlace and some features of the beasts. After these ‘types of carving’ were treated separately, like Kitzler Åhfeldt’s rune and ornament groups, the resultant ‘carving signatures’ for each can be matched based on the relationship between the variables, as will be more thoroughly explained in Section 9.8.

While the three stones chosen for this analysis are relatively unworn, much of the Govan collection has been affected by weathering and wear (see Section 5.6.4). This process of separating the samples into different groups for additional analysis could also be applicable when dealing with stones that appear by visual inspection to be differentially worn. While this has little bearing on the current analysis, this will likely affect future applications of this analysis to the Govan collection.

9.4 Identifying Clusters

After defining the groups of samples to be analysed, the next step was the most crucial – the dividing of samples into initial clusters. In her analyses, Kitzler Åhfeldt used what she calls a ‘mean profile diagram’, a 3D scatter plot of the AvgX, AvgY, and AvgZ values of the samples from a single stone (the variables characterising the average profile of the groove), to visually identify clusters that hypothetically represent the work of individual carvers. In her analysis of the work of modern runestone carvers, where the author of each groove is known, the use of this diagram resulted in a 70% accuracy of attribution; subsequent steps outlined below improve the accuracy of the assigned grooves (Kitzler 2000, 91–92; see Sections 9.6 - 9.7). Because many of the samples taken from the Govan stones seemed to have a more diffuse distribution when looking at the ‘mean profile diagram’ than Kitzler Åhfeldt’s examples (Figure 9.1; Figure 9.2), it was decided that instead of a visual inspection, this analysis would use statistical methods to divide the samples into clusters. The software utilised in this analysis is IBM SPSS Statistics, Version 24.0.0.1 (IBM Corporation 2016).

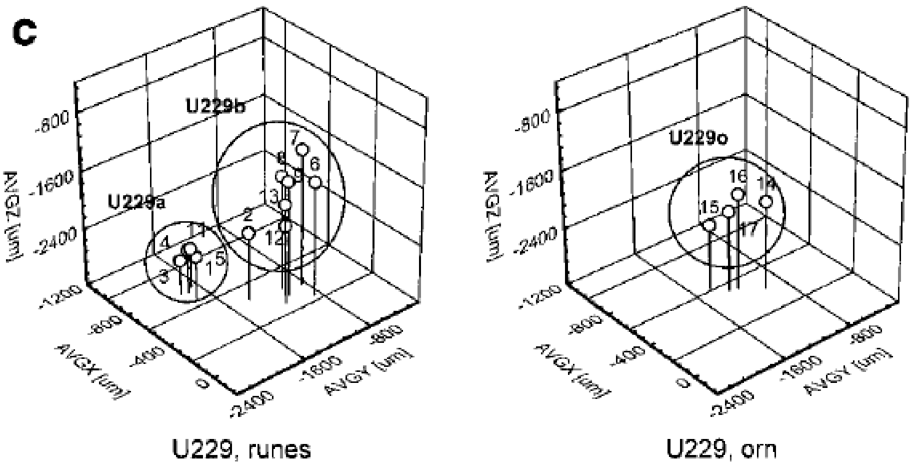


Figure 9.1. Diagram demonstrating how Kitzler Åhfeldt visually identifies clusters through 'mean profile diagrams' (from 2001, 3c).

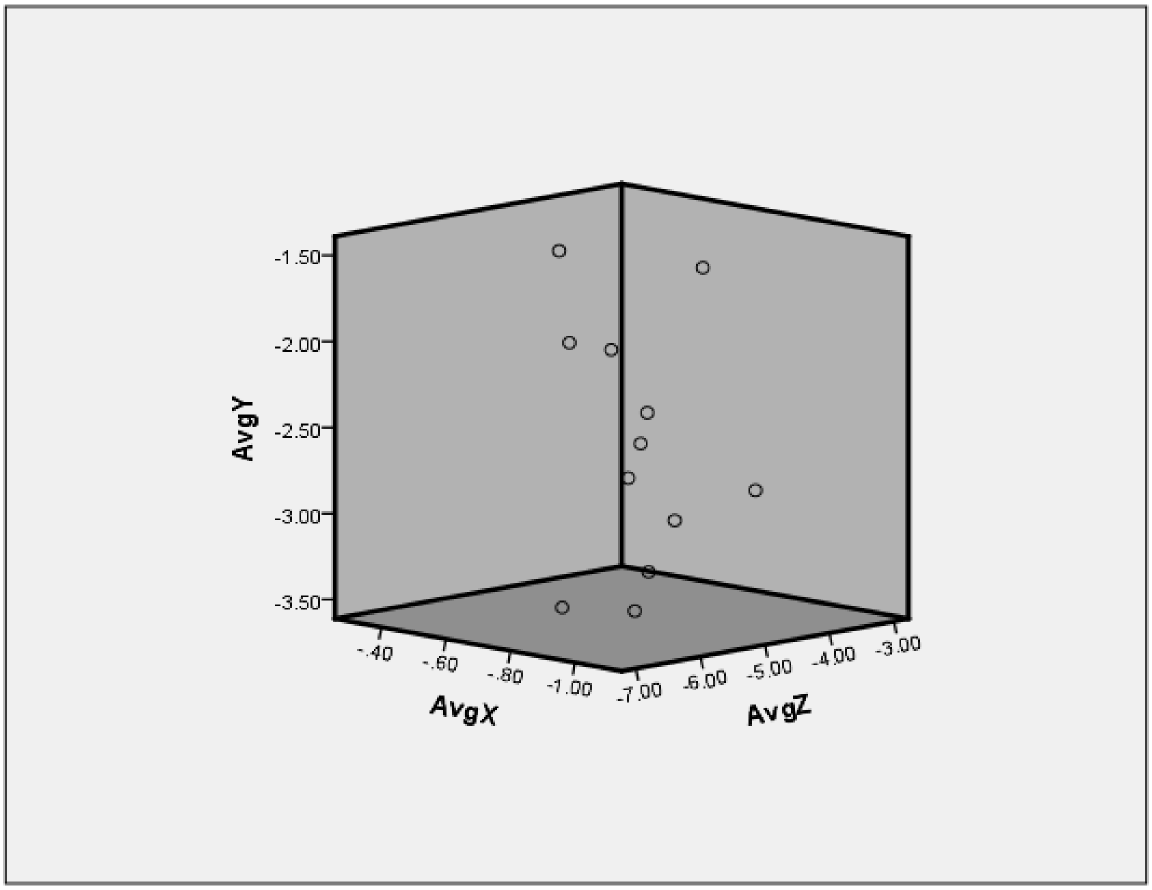


Figure 9.2. Govan 12's samples plotted in a 'mean profile diagram'; no clear clusters are immediately apparent.

Hierarchical Cluster Analysis (HCA) offered the best approach to identify clusters in this data (for other options offered by SPSS and the reasoning behind this decision, see Appendix B). This method produces a dendrogram that illustrates each case's relationship to other samples, step by step, in a transparent way, so this approach is well suited to small sample sizes. It includes seven different statistical approaches to assess how similar or different individual cases are from one another and clusters them. The approach most often used here is 'Ward's Method' (for statistical definition see Ward 1963; Kitzler Åhfeldt 2002b, 34), although in some cases 'Nearest Neighbour,' otherwise known as 'Single-Linkage, (George et al. 2016, 273; see Drennan 2010, 310–312 for a complete definition)) was more appropriate (see the clustering of Inchinnan 1's samples below).

Once HCA had been chosen, it was necessary to decide which variable(s) would define the initial clusters. Because the aim of the analysis is to identify individual carving signatures, the best variable(s) to use would be those that account for the most variability between clusters in the sample, which could indicate different carving techniques. To identify which variable(s) would satisfy this criterion, Principal Components Analysis (PCA) was used. PCA is an abstract mathematical approach, which is "a way of reducing a large number of variables to a much smaller number of variables that still reflects reasonably accurately…the major patterns in the original dataset…a set of variables that all show strong correlations with each other are all responding to the same underlying thing" (Drennan 2010, 300). The results of this analysis are the Principal Components and their component loadings, which indicate how strongly each of the original variables correlate to the underlying Principal Components. These Principal Components, and the variables that contribute most to them, can then be demonstrated to best illustrate a certain proportion of variance in the dataset.

Because the total number of samples taken for each stone was considerably fewer than what most statisticians consider 'ideal' for Principal Component Analysis, several rules of thumb were used to enhance the reliability of the interpretation of the analysis. According to James Stevens, "components with four or more loadings above .60 in absolute value are reliable, regardless of sample size…any component with at least three loadings above .80 will be reliable…Velicer also indicated that when the average of the first four largest loadings is >.60 or the average of the three largest loadings is >.80, then the factors will be reliable (2009, 333)." (Loadings are the values indicating how much a variable contributes to an underlying Principal Component.) For this reason, in the tables resulting from PCA referred to in the following sections and provided in Appendix C, any loadings above .60 were highlighted, and only the variables that meet these prerequisites were considered in the analysis (except in the comparison between Inchinnan 1 and Govan 12's carvers, see Section 9.8.2). AvgZ, the variable reflecting the average depth of the groove 1.5mm from the base of the groove, was consistently strongly correlated with an underlying variable that made up a large proportion of the variation in the samples according to Principal Components Analysis, so this variable was usually sufficient when dealing with the Govan material to create the initial subdivisions into clusters (for guidance to reading the charts relating to Principal Components Analysis in Appendix C, refer to Appendix Section D.3).

Once AvgZ was chosen, it was important to determine whether this would cluster samples consistently whether the stone was worn or not, due to the condition of many of the stones in the collection. To test which variable provided the most reliable initial clustering, the following example datasets were used. These came from samples taken from the 3D model of Govan 7 (Table 9.1) and the samples taken from the corresponding locations on the digitally worn 3D model of Govan 7 utilised in Sections 5.4.2 and 5.6.4 (Table 9.2). These datasets were clustered using HCA by each of the ten variables to determine which was most reliable to consistently assign clusters between correlated well-preserved and worn samples. Through this process, it became apparent that AvgZ produced uniform results, where other variables did not; as can be seen in Figure 9.3, samples 3, 4, 5 and 8 are in one cluster, samples 2 and 6 in another, and 1 and 7 in a third. The clusters containing samples 2, 6, 1 and 7 are more closely related to each other by the variable AvgZ than to the larger cluster, illustrated by a 'branch' connecting the two small clusters. While the three initial clusters are the same for the corresponding Worn samples depicted in Figure 9.4, there is a slight difference in how the clusters were related. This diagram informs the researcher how each sample is related to the others, but it is up to the researcher to decide the significance of the cluster linkage revealed by the statistics; ultimately this is a subjective judgement.

Table 9.1. Groove Analysis Samples taken from the Unworn 3D model of Govan 7

	Sampl_nr	v	D	AvgX	AvgY	AvgZ	mindiff	plusdiff	meddiff	w	k	n
1	701	111.7	-6.5	-1.9	-4.5	-6.6	4.4	4.8	0.1	9.1	0.5	16
2	702	94.9	-7.7	-2.0	-5.1	-7.8	2.0	6.0	0.1	8.0	0.8	4
3	704	117.7	-5.2	-1.0	-3.0	-4.8	4.8	5.8	0.1	10.7	0.5	12
4	705	120.8	-5.0	-1.2	-3.1	-4.8	5.6	5.0	0.2	10.6	0.5	7
5	706	110.1	-4.7	-0.6	-2.1	-4.2	4.5	5.3	0.2	9.8	0.5	13
6	707	87.5	-8.8	-1.7	-4.8	-7.9	3.8	4.5	0.2	8.3	0.5	6
7	708	118.4	-6.4	-1.9	-4.4	-6.3	6.3	7.3	0.1	13.7	0.5	6
8	709	104.5	-4.9	-0.8	-2.6	-4.9	5.2	5.4	0.2	10.6	0.5	5

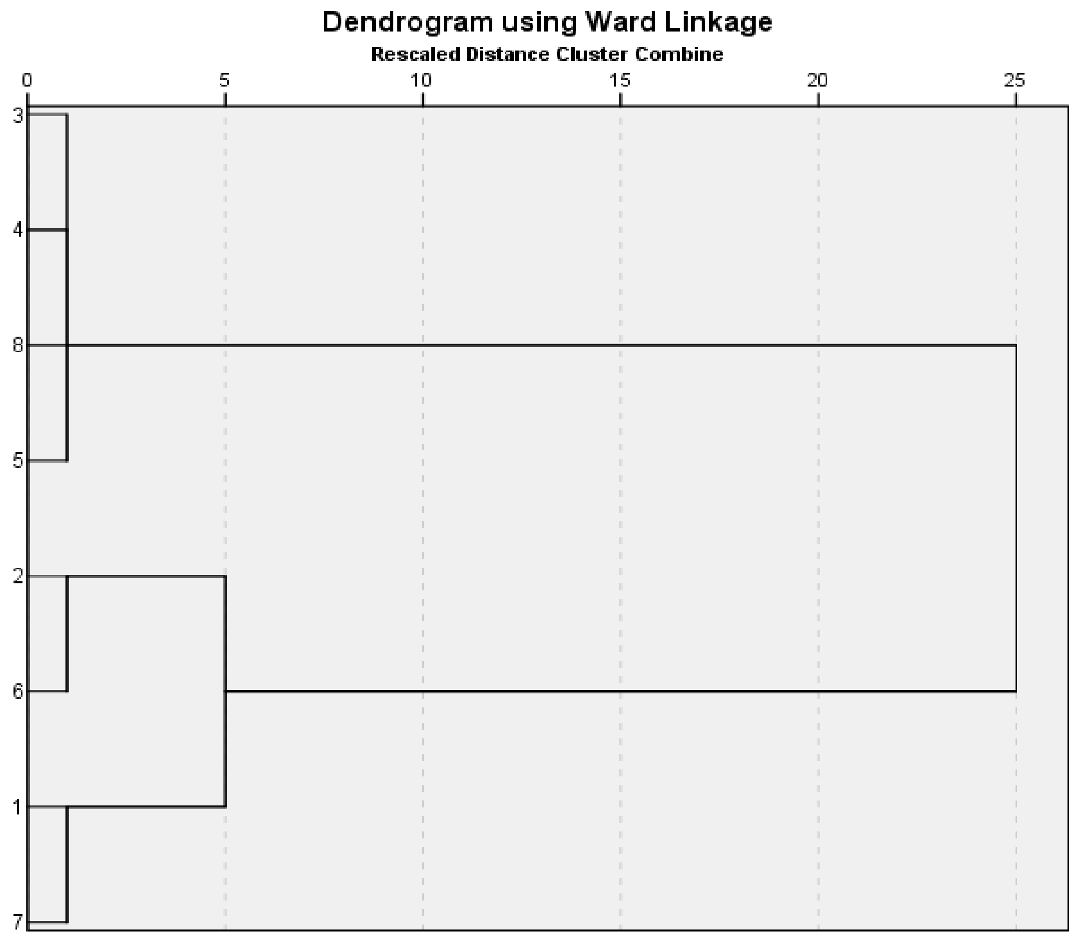


Figure 9.3. Dendrogram of Unworn Govan 7 samples clustered by Hierarchical Cluster Analysis using Ward's Method based on the variable AvgZ. Three clusters are immediately visible (refer to Section D.1 for guidance on interpreting Dendrograms).

Table 9.2. Corresponding Groove Analysis Samples taken from the Worn 3D model of Govan 7 (Numbers along the left side of this and Table 9.1 indicate pairs of samples that were taken from the same Groove, ie. Sample 1 in Unworn Table was taken from same groove as Sample 1 in Worn Table)

	Sampl_nr	v	D	AvgX	AvgY	AvgZ	mindiff	plusdiff	meddiff	w	k	n
1	710	131.7	-2.8	-0.2	-1.0	-2.4	3.6	4.6	0.2	8.1	0.6	18
2	711	106.1	-4.4	-0.4	-1.8	-4.1	2.8	5.3	0.1	8.0	0.7	4
3	713	163.7	-0.7	0.0	0.0	-0.4	3.5	5.5	0.1	9.1	0.6	15
4	714	161.1	-0.9	-0.1	-0.2	-0.7	4.4	6.7	0.1	11.1	0.6	7
5	715	167.1	-0.6	0.0	-0.1	-0.4	4.5	5.3	0.1	9.8	0.5	14
6	716	100.6	-5.0	-0.6	-2.4	-5.0	3.2	4.8	0.3	8.0	0.6	5
7	717	139.4	-2.5	-0.3	-1.0	-2.1	3.0	5.3	0.1	8.3	0.6	9
8	718	144.7	-1.7	0.0	-0.3	-1.2	3.7	5.2	0.2	8.8	0.6	6

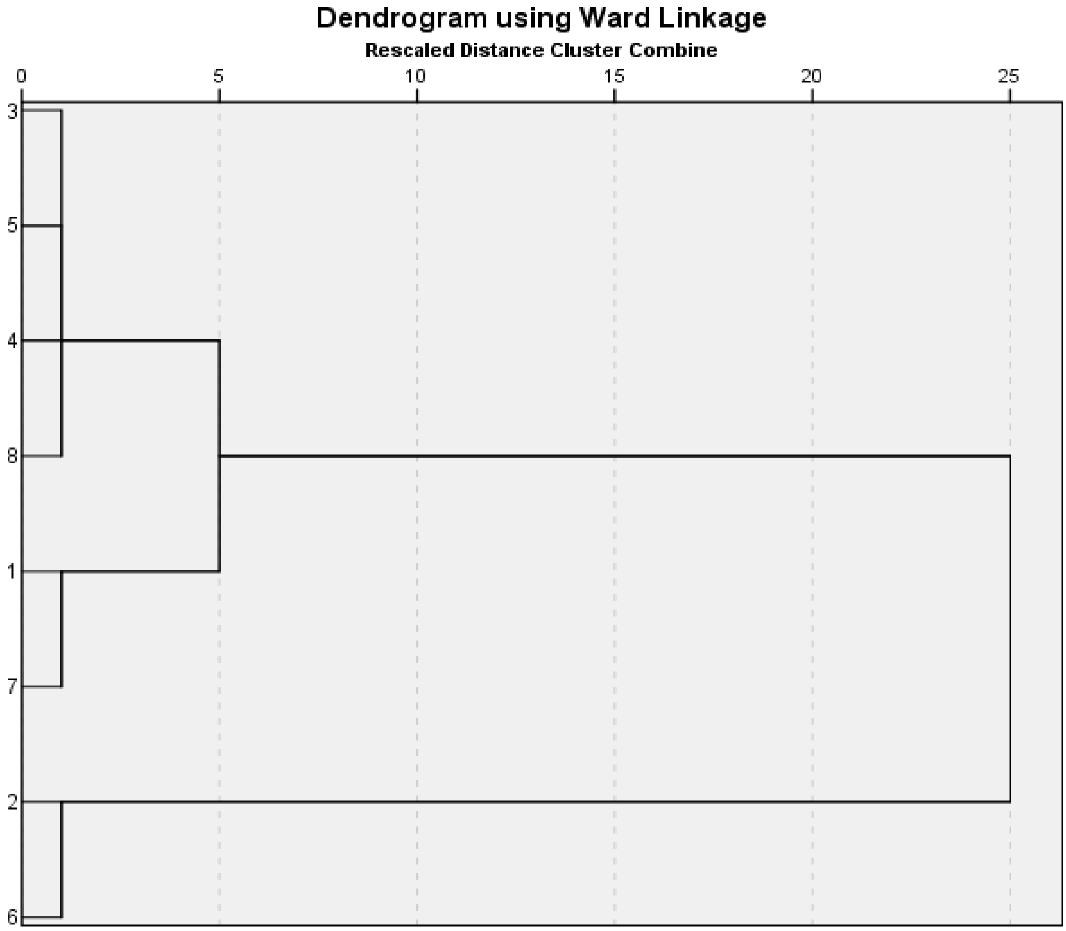


Figure 9.4. Dendrogram of corresponding Worn Govan 7 samples clustered by Hierarchical Cluster Analysis using Ward's Method based on the variable AvgZ (pairs of worn and unworn samples are given the same number, for example Unworn Sample 1 was measured from the same location as Sample 1 in the Worn population). The same groups as those in Figure 9.3 are defined if the researcher divides the samples into three groups.

While the above process validated the results of the PCA, it was discovered that Hierarchical Cluster Analysis using Ward's method with each of the variables measuring the depth of the groove at different points, AvgX, AvgY, and AvgZ, also succeeded in assigning the Govan 7's corresponding pairs of worn and unworn samples to the same clusters (Figure 9.5, Figure 9.6). As such, it was decided that it was important to examine these statistically assigned clusters in a three-dimensional scatter plot of the AvgX, AvgY, and AvgZ values; do the clusters defined by AvgZ remain clustered in the ‘mean profile diagram’? If not, is there a discernible reason why not, and does this justify using one set of variables over the other? In some instances, it was decided that including these three variables in the clustering process rather relying on one resulted in better-defined clusters (see Govan 12 and Inchinnan 1 below). In essence, the resultant clusters were still being decided visually, much like Laila Kitzler Åhfeldt’s clusters, but were guided by statistical methods.

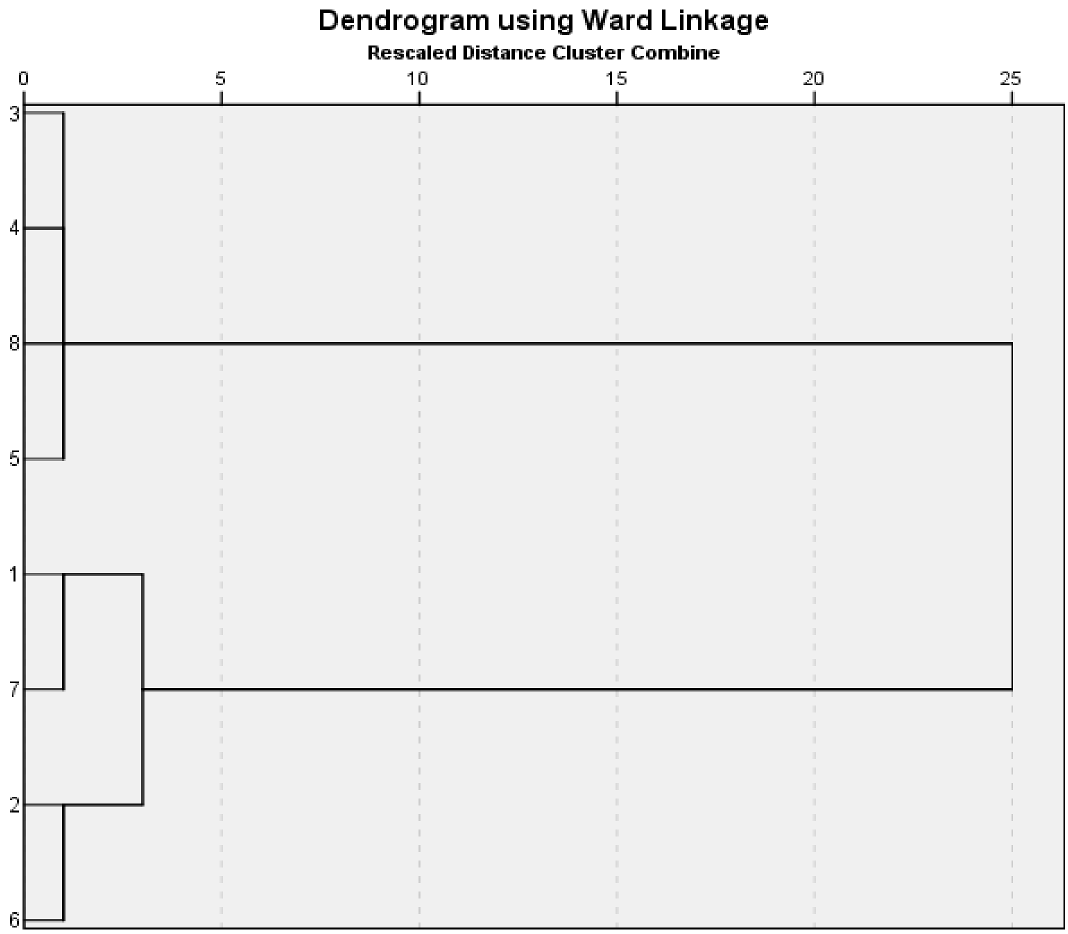


Figure 9.5. Dendrogram illustrating the resultant clusters using Hierarchical Cluster Analysis using Ward's method based on variables AvgX, AvgY and AvgZ on the Unworn Govan 7 samples. If one divides these samples into three clusters, the same groups are created as in Figure 9.3 and Figure 9.4.

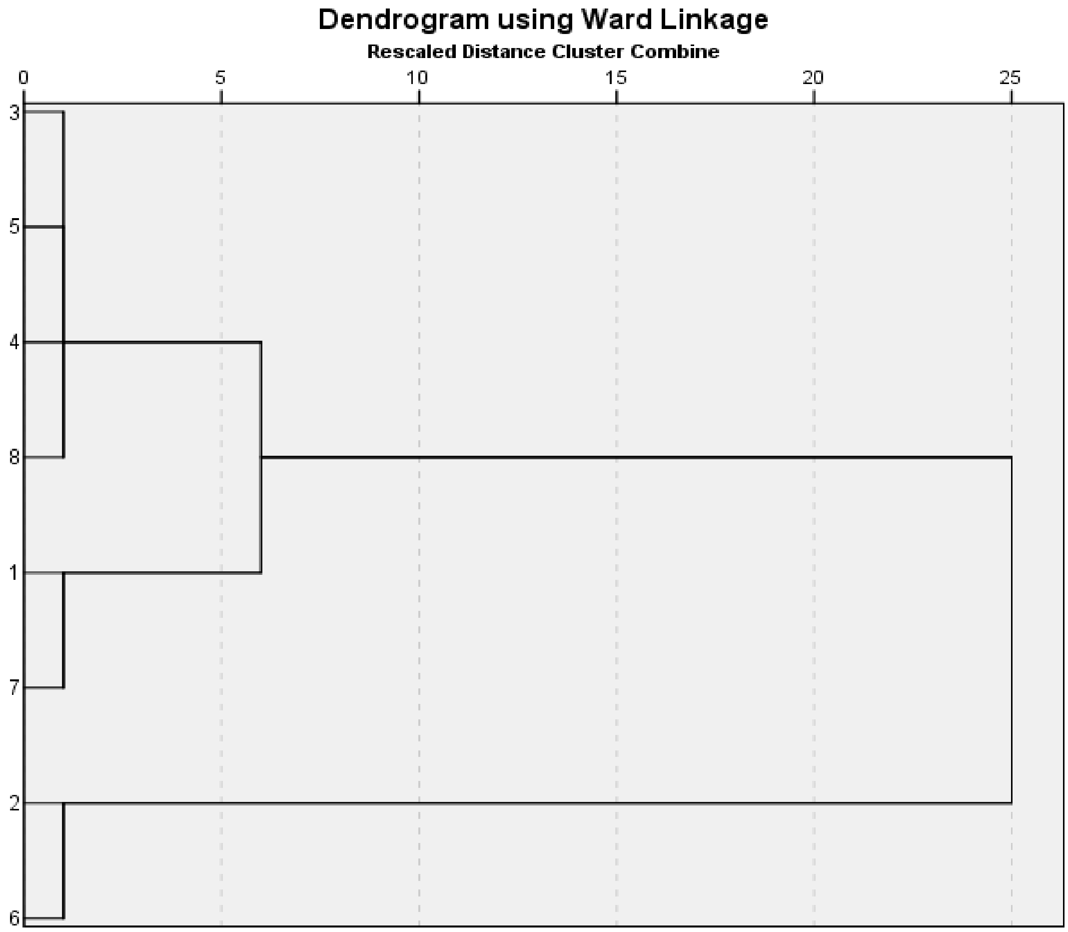


Figure 9.6. Dendrogram illustrating the use of Hierarchical Cluster Analysis using Ward's method based on variables AvgX, AvgY and AvgZ in the clustering of the Worn Govan 7 samples.

9.4.1 Defining the Govan 1 clusters

The decision on whether to use AvgZ alone or AvgX, AvgY and AvgZ in the clustering of the samples became crucial in the case of the ‘Shallow’ samples from the Govan sarcophagus – while using AvgZ to separate the separate the samples into clusters resulted in three relatively sparse clusters (Figure 9.7), the use of AvgX, AvgY and AvgZ classified the samples into two clusters that appear better-defined in the 3D Scatter plot (Figure 9.8). However, after re-examining the raw measurements from the calculation of the variables for each case, it became clear that AvgX and AvgY were not consistently accurate measurements for these samples. Some of these shallow grooves are much narrower than the vast majority of the samples taken from Govan 1, so the points used in the calculations of AvgX and AvgY fall outside of the actual groove onto the surrounding surface of the stone (Figure 9.9). AvgZ, then, provided more consistent groupings for the thinner grooves. This method of clustering was also applied to the 'Deep' samples from Govan 1 for consistency, the results of which are presented below (Figure 9.10).

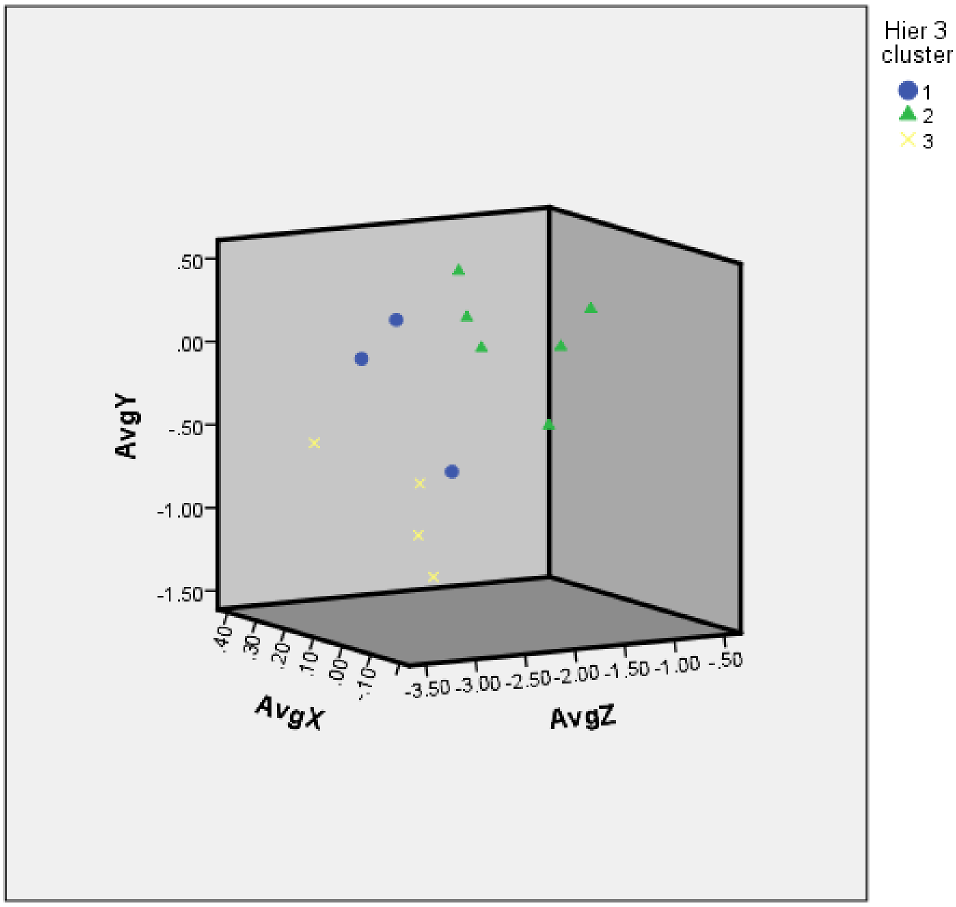


Figure 9.7. Mean Profile Diagram illustrating the three sparse 'Shallow' Govan 1 clusters defined by using Hierarchical Cluster Analysis with Ward's method based on the variable AvgZ. The clusters are sparse, likely because the measurements for AvgX and AvgY fell outside the groove and were not taken into account when defining the clusters.

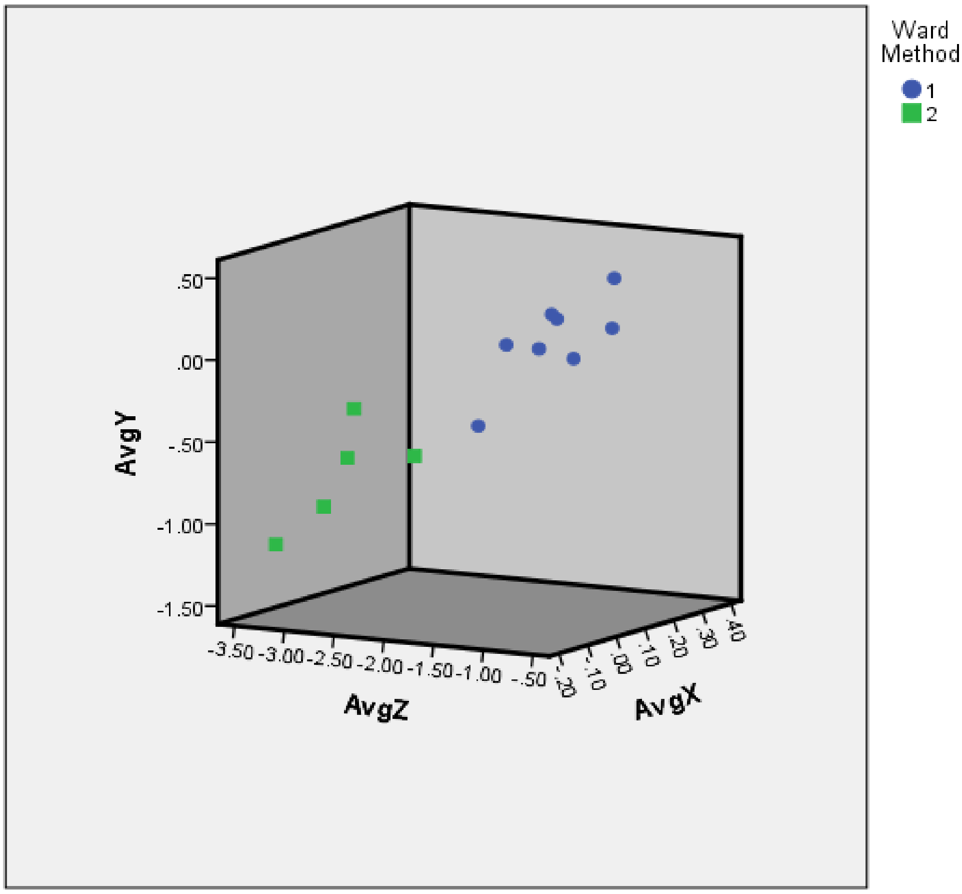


Figure 9.8. Mean Profile Diagram illustrating the two 'Shallow' Govan 1 clusters from using Hierarchical Cluster Analysis using Ward's method based on the variables AvgX, AvgY and AvgZ. Taking variables AvgX and AvgY into account when defining the clusters as resulted in better clustering.

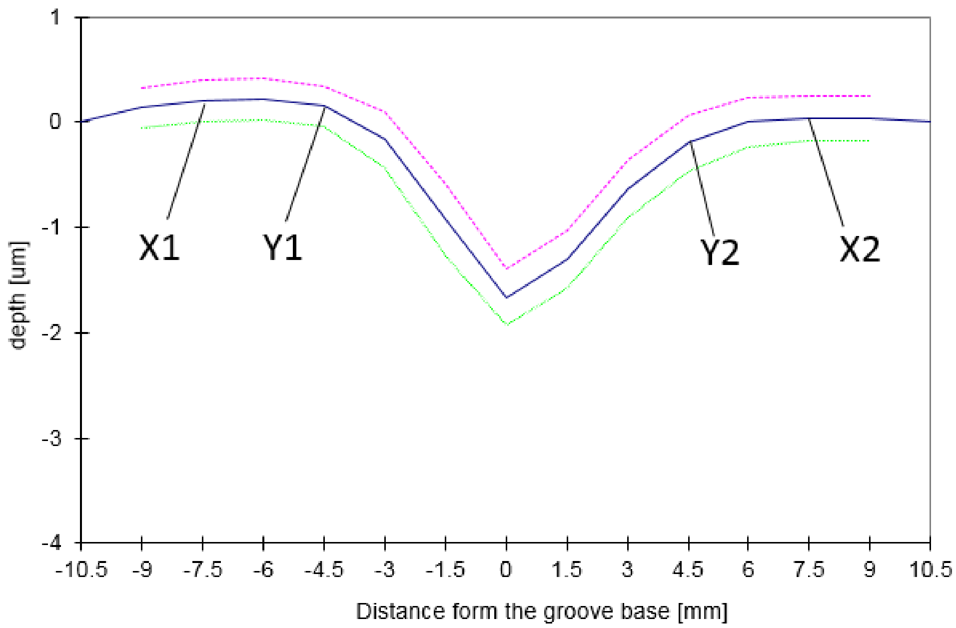


Figure 9.9. Groove Diagram of Sample 36 from the Govan 'Shallow' Group - X1, Y1 and X2 are clearly outside of the groove, causing the AvgX and AvgY variables to be less useful than AvgZ.

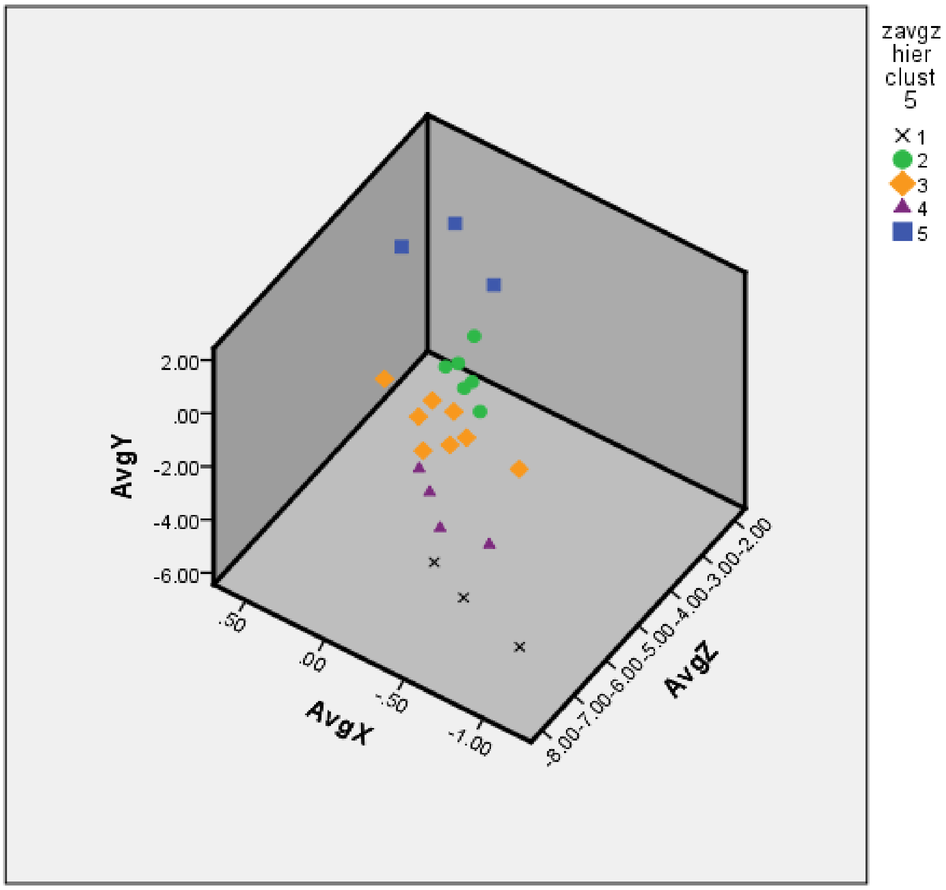


Figure 9.10. Mean Profile Diagram of the Hierarchical Cluster Analysis 'Deep' Govan 1 Groups. There is a clear linear trend in the data, and it is already clear that some of these clusters should be amalgamated.

9.4.2 Govan 12

Because the samples from Govan 12 were so diffuse, it was difficult to determine which method best clustered the samples. When Hierarchical Cluster Analysis using Ward's Method and Squared Euclidean Distance based on variable AvgZ was applied, the resultant mean profile diagram did not seem satisfactorily clustered (Figure 9.11). The Hierarchical Cluster Analysis using Ward’s method based on squared Euclidean Distance and the variables AvgX, AvgY and AvgZ was used to form the initial clusters used in the analysis, which resulted in the Mean profile diagram below (Figure 9.12).

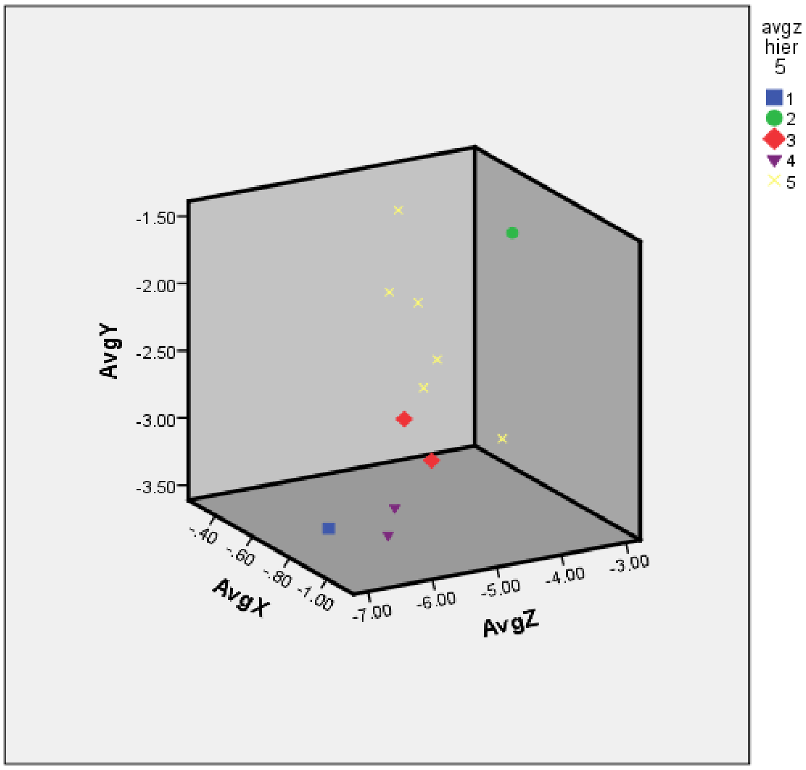


Figure 9.11. Mean Profile Diagram of Govan 12 clusters defined by Hierarchical Cluster Analysis using Ward's Method and Squared Euclidean Distance based on variable AvgZ. This was not the method used in the analysis, resulting in sparse clusters.

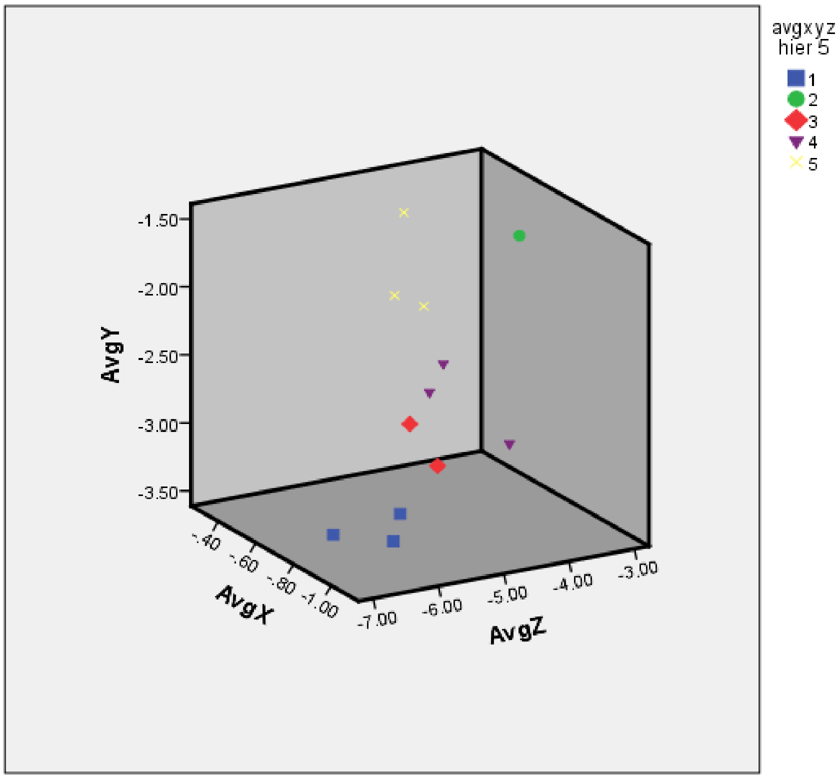


Figure 9.12. Mean Profile Diagram of Govan 12 Clusters defined by Hierarchical Cluster Analysis using Ward's Method and Squared Euclidean Distance based on variables AvgX, AvgY, and AvgZ. Four sparse clusters were identified with one outlier.

9.4.3 Inchinnan 1

In the case of Inchinnan 1, the use of AvgX, AvgY and AvgZ in Hierarchical Cluster Analysis with Ward's method resulted in two samples assigned to Cluster 1 that, as a visual inspection of the 3D Scatter Plot suggests, are not associated with the main Cluster 2 (Figure 9.13), unless Hierarchical Cluster Analysis is carried out with these three variables using 'Nearest Neighbour' instead of Ward's method (Figure 9.14). Using 'Nearest Neighbour' with AvgX, AvgY and AvgZ also succeeded in assigning the worn and unworn Govan 7 samples to their corresponding groups (Figure 9.15; Figure 9.16).

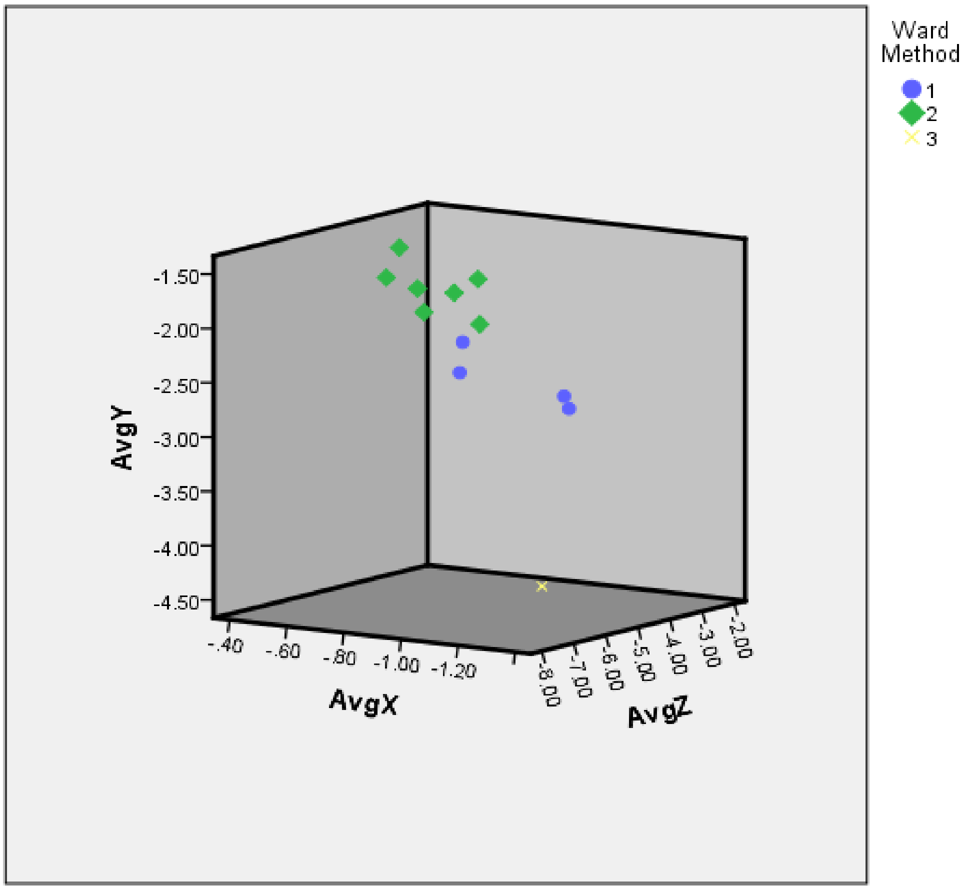


Figure 9.13. Mean profile diagram illustrating the three clusters identified in the Inchinnan 1 samples using Hierarchical Cluster Analysis with Ward's method based on the variables AvgX, AvgY and AvgZ. Two samples from Cluster 1 seem like they would belong in Cluster 2.

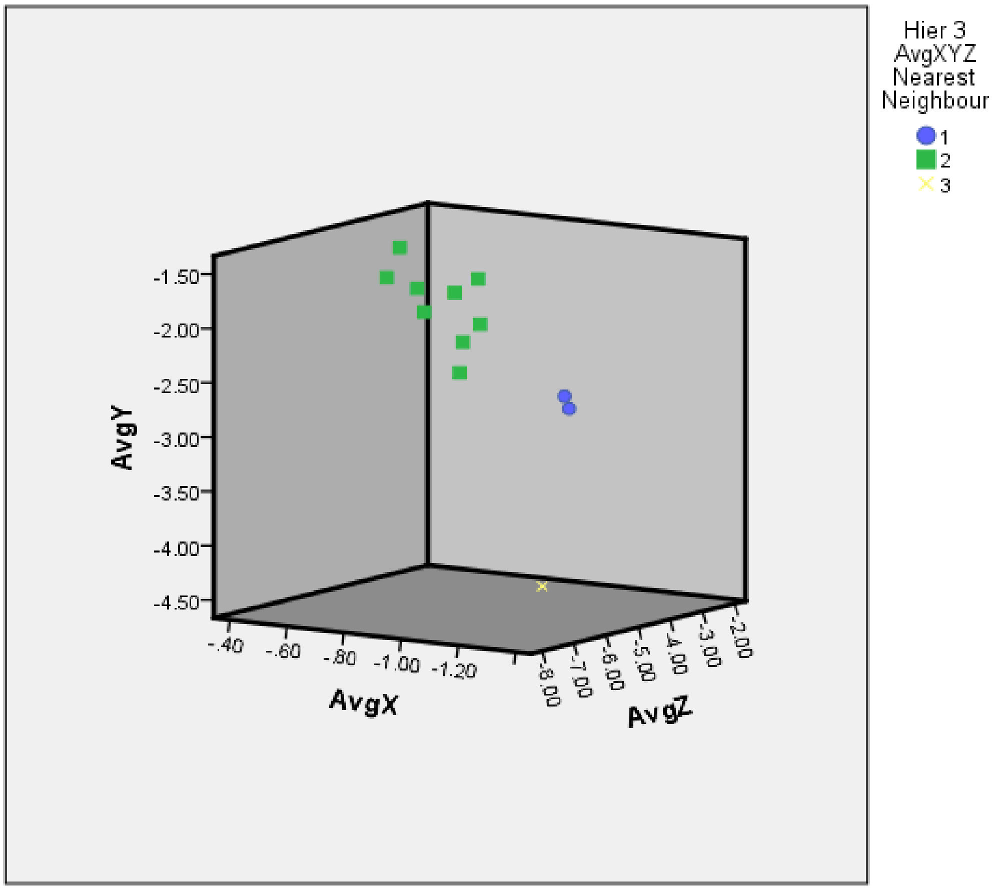


Figure 9.14. Mean profile diagram illustrating the three clusters identified in the Inchinnan 1 samples using Hierarchical Cluster Analysis using the 'Nearest Neighbour' method based on variables AvgX, AvgY and AvgZ. Using 'Nearest Neighbour' has resulted in clusters with better separation.

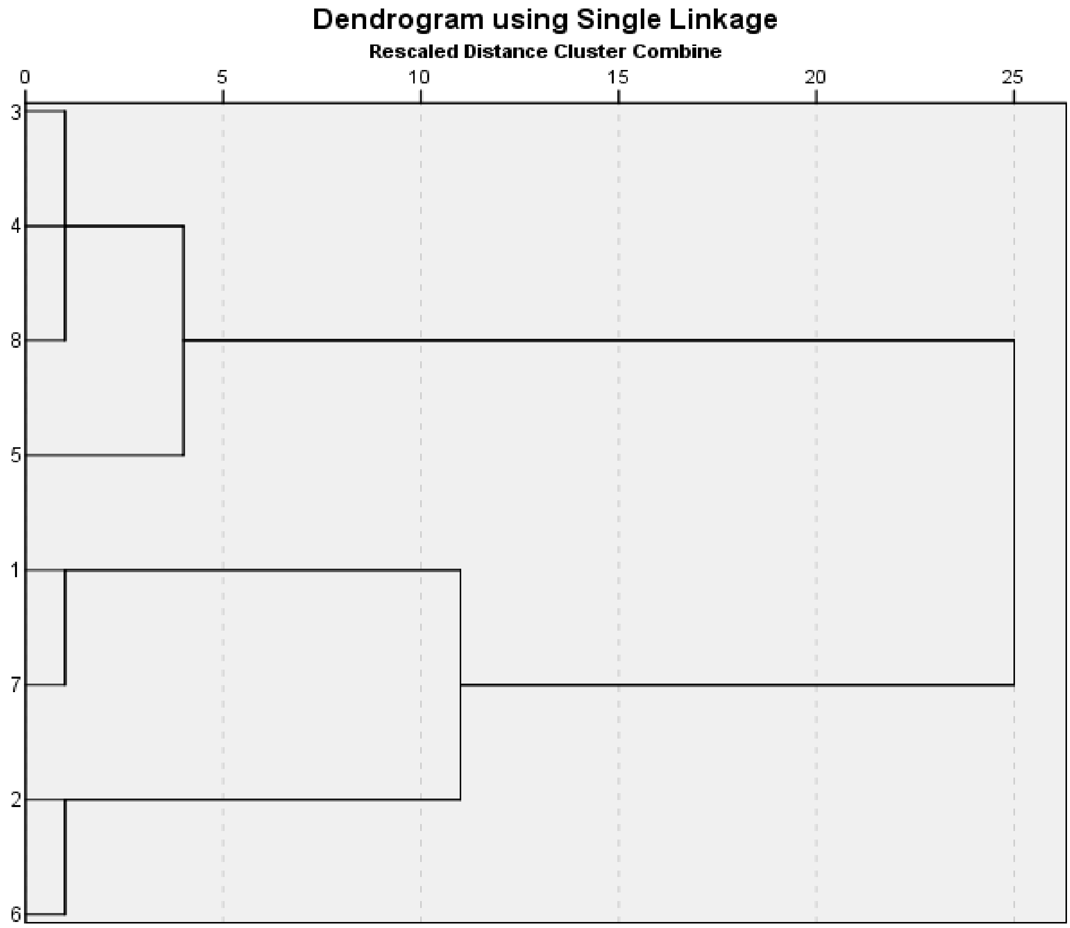


Figure 9.15. Dendrogram illustrating the results from the Hierarchical Cluster Analysis of the Govan 7 unworn samples using the 'Nearest Neighbour' method based on the variables AvgX, AvgY, and AvgZ. This has resulted in the same three clusters as the HCA that used other methods in Figure 9.3 and Figure 9.6

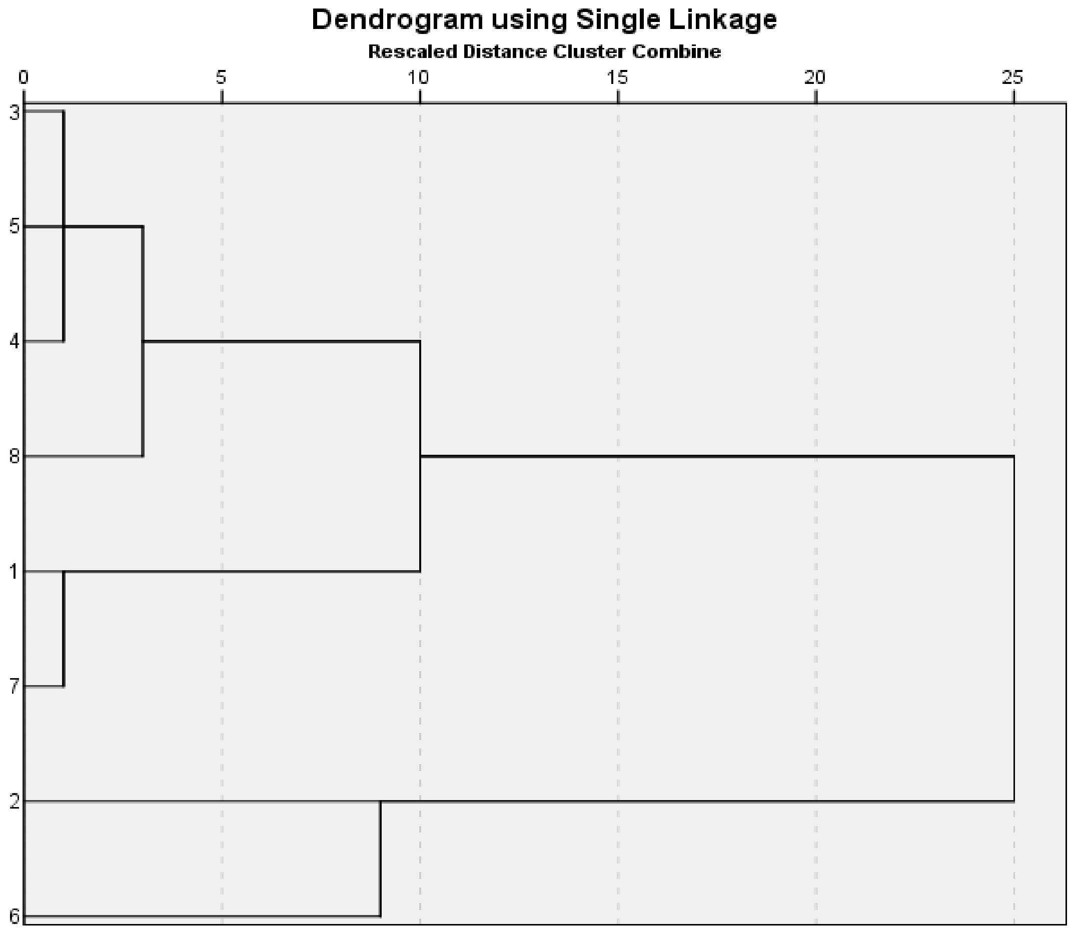


Figure 9.16. Dendrogram illustrating the results of Hierarchical Cluster Analysis of the worn Govan 7 samples using the 'Nearest Neighbour' method based on the variables AvgX, AvgY and AvgZ. As above, if this is divided into three clusters, the relationships between the samples are the same.

In summary, Hierarchical Cluster Analysis was chosen as the most suitable clustering method to identify initial clusters. The variable AvgZ and a combination of the variables AvgX, AvgY and AvgZ were determined to produce the most consistent clusters whether taken from unworn or digitally worn 3D models. While Ward's method based on squared Euclidean distances using the variable AvgZ was employed in the analysis of Govan 1's samples, Ward's method based on squared Euclidean distances using the variables AvgX, AvgY, and AvgZ was used in the case of Govan 12 and the Nearest Neighbour method using AvgX, AvgY and AvgZ was employed in the clustering of Inchinnan 1's samples. Different methods used in Hierarchical Cluster Analysis sometimes result in different clusters, varying perhaps in one or two samples each. Deciding where to create the divisions in samples was far from an objective process, but these provided the most interpretable results (Drennan 2010, 315–316). The most important part of this step was to treat these clusters as the work of 'hypothetical carvers', as the assignment of these cases to each cluster were tested for their statistical significance and amalgamated in later stages.

9.5 Outliers – under-sampled carvers?

One statistical aspect that needs to be addressed here is how outliers are treated in this analysis. As mentioned above in Section 8.4, outliers are samples which fall well outside the normal range of the other samples in a population; in multivariate statistics, they tend to form one-sample groups. Kitzler Åhfeldt has discussed thoroughly what outliers in Groove Analysis might represent from her analysis of the modern runestones. Outliers may represent a groove that has been carved from a different position (after a stone was erected, for example (Kitzler Åhfeldt 2002a, 82)), the tiring of the carver, or the carver being in a hurry (Kitzler Åhfeldt 2002a, 83, 85). However, these outliers also may represent the work of an under-sampled individual (Kitzler Åhfeldt 2001, 140). For this reason, outliers will be retained as one-sample clusters to avoid excluding potential individual carvers.

9.6 Combining Clusters

As mentioned above, the clusters identified during this first step began as hypotheticals. Discriminant Analysis is a statistical process that can use the variables in this study and predefined groups (in this case, these predefined groups are samples that were clustered into the work of 'hypothetical carvers' in the statistical methods outlined above (Section 9.4) and applied below (Section 9.7)) to calculate the maximum difference between these groups and the minimum distance between the samples within the groups to create rules or formulae to best separate the groups. These rules can be used to determine how consistently the samples fall within the 'hypothetical carver' groups (Tharwat et al. 2017; Teknomo 2015).

Two variants of Discriminant Analysis were considered here: the standard method and the forward stepwise method (the differences between these as relevant to this analysis are considered in more detail in Section C.1). The main outputs of the standard method that were considered are the 'Wilks' Lambda', the 'Structure Matrix', the 'Casewise Classification Statistics', and the plot of the 'Canonical Discriminant Functions' (the tables containing the raw results are provided in Appendix C; Section C.2 for Govan 1's 'Shallow' samples, C.3 for the 'Deep' samples, C.4 for Govan 12, and C.5 for Inchinnan 1; a more comprehensive guide to reading these charts are available in Appendix D). In Discriminant Analysis, Wilks' Lambda "tests how well each level of independent variable contributes to the model" (Statistics How To 2017). The closer the value of Wilks' Lambda is to 0, the more that variable contributes to the separation of clusters in the model, which is directly related to how statistically significant the results are. The structure matrix indicates how each variable correlates to the Discriminant Functions. The Casewise Classification Statistics table indicates which group a sample was assigned to by the researcher, how this compares to the group the sample was assigned based on the Discriminant Scores, and probabilities that the sample belongs to the group (George & Mallery 2016, 295). There is an additional option to 'cross-validate' the model these assignments are based on using the 'leave-one-out cross-validation.' The Canonical Discriminant Functions plot illustrates how these samples are best separated based on Function 1 and Function 2. Because there are fewer samples in these analyses than is preferable in statistical analyses, not all variables are included in the Discriminant Analysis (Stevens 2009, 246). Instead, a Principal Components Analysis is first carried out to identify which variables contribute most to the variation in the samples, then a selection of those variables is used in the analysis (see Section 9.4 above for a discussion on the rule of thumb used to decide these variables).

The outputs of the Stepwise Method that will be considered are the 'Variables Entered/Removed', the 'Test of Equality of Group Means', the 'Pairwise Group Comparisons', and the 'Casewise Statistics' (these can also be found in Appendix C according to stone). The Variables Entered/Removed table does as its title suggests- it lists the variables that passed the F value significance test and were incorporated into the analysis. The Test of Equality of Group Means table indicates the significance of each of the variables as they are added. The Pairwise Group Comparisons indicates the distance between each group based on the variables admitted into the analysis, the significance of each separation is given by a p value and an F-value. Finally, the Casewise Statistics table is useful in that it can be compared to the resultant table from the standard Discriminant Analysis described above. As fewer variables are admitted into the Stepwise Method (although these variables are responsible for the most separation between the groups), it is useful to see if any cases are assigned to different groups due to the inclusion of fewer variables (George & Mallery 2016, 286–295).

If, in the Casewise Statistics table derived from the standard Discriminant Analysis, the 'predicted group' column indicated that a case was misclassified, or if the Pairwise Group Comparisons table from the stepwise Discriminant Analysis indicated that clusters should be merged (with a p value >0.10 as suggested by Kitzler Åhfeldt (2002a, 96; 2001, 140–142; Kitzler 2000, 93)), individual cases were reassigned or entire groups were combined. However, in this case, all of the initial clusters identified in Section 9.4 above were determined to be statistically significant (see Appendix C and Appendix D for detailed explanations). These clusters then proceeded to the next step of the analysis.

9.7 Hypothetical Carver Signatures - Case profiles

After the clusters were identified and determined statistically significant, the results of the Principal Components Analysis required further consideration. As described above, the variables that contribute most to the Principal Components account for the most variation in the samples. The variables where these samples deviate most can point towards differences between the carving techniques of individuals; a few of the most influential variables that best reflect these differences were selected to define 'hypothetical case profiles' for each cluster.

In Kitzler Åhfeldt's research, she also used Principal Components Analysis to identify which variables account for the most variation in the samples from the modern reference material. However, she chose five variables from the first four Principal Components, including v, AvgZ, k, w and meddiff (Kitzler Åhfeldt 2002a, 88–89). In this analysis of the Govan school, the variables that were chosen to define the case profiles, as mentioned above in Section 9.4, were restricted to the Principal Components that met Stevens' rule of thumb, most often from the first and second Principal Components (see Section C.1). In most cases, an equal number of variables from each Principal Component were taken into consideration, although there were some instances where a variable contributed a great deal to both the first and second component. In those instances, another variable was chosen from the second component.

After these variables were decided, the average value for these variables was calculated for each cluster (Kitzler Åhfeldt 2002a, 96, 98; Kitzler Åhfeldt 2001, 143), which can be considered unstandardized ‘hypothetical case profiles’. These are not yet considered the final determination of an individual’s carving style. The following sections (9.7.1-3) outline the results of this process applied to Govan 1, Govan 12, and Inchinnan 1. After each of the hypothetical carvers’ signatures were identified (see Table 9.3; Table 9.4; Table 9.5; Table 9.6), these proceeded to the final phase of analysis, which will be discussed in Section 9.8.

9.7.1 Govan 1

As mentioned above in Section 9.3, Govan 1’s samples can be classified into two broad types of carving: grooves intended to be shallow, and those which were intended to be deep. The ‘shallow grooves’ included the samples taken from grooves bisecting strands of interlace and the detailed carving of the horseman. The ‘deep grooves’ consist of all other samples. This division was necessary, as groove depth plays a large part in the initial definition of the clusters. This difference in depth was not from an individual’s carving style, but a consequence of design choices. As such, this section will be broken up into two analyses, which will then be matched together much in the same way that runes and ornament were matched in Kitzler Åhfeldt’s analyses (2002a, 95, 98).

9.7.1.1 Shallow Group

The thirteen samples included in the ‘Shallow’ Group ranged in value of AvgZ from -0.77mm to -3.45mm. As discussed above, a Hierarchical Cluster Analysis using Ward’s method with squared Euclidean distance on the basis of variable AvgZ was used in the initial clustering of the ‘Shallow’ Govan 1 samples. This resulted in three clusters, as seen in Figure 9.7 above. These clusters were confirmed to be statistically significant through Discriminant Analyses, as can be surmised from Section C.2.

The variables chosen for the definition of the hypothetical case profiles were based on those that contributed most to the first and second Components of the Principal Components Analysis (see Section C.2.1). The variables chosen included v (groove angle), AvgZ (depth 1.5mm from the base of the groove), k (carving rhythm), mindiff (length of the peck formed by the carving tool), plusdiff (length of the space left between hits), and w (the total length of the wavelength formed by mindiff and plusdiff). The average for each of these variables was calculated for each cluster, which resulted in the three hypothetical carver profiles in the table below (Table 9.3). These values were then standardized in preparation for comparison with the case profiles from the 'Deep' samples (resulting in the 'z' variables in the table).

Table 9.3. Three hypothetical carver profiles from the 'Shallow' Govan 1 samples.

Case profiles	v	mindiff	AvgZ	plusdiff	k	w	zv	zmindiff	zavgz	zplusdiff	zk	zw
1	110.56	4.22	-2.33	4.14	0.50	8.37	-0.30	-0.81	-0.03	-0.80	-0.44	-0.99
2	129.95	4.27	-1.39	4.83	0.53	9.10	1.12	-0.31	1.01	1.12	1.14	1.01
3	103.54	4.41	-3.19	4.31	0.49	8.73	-0.81	1.12	-0.99	-0.33	-0.71	-0.01

9.7.1.2 Deep Group

Twenty-four samples taken from nine different panels of the sarcophagus were considered 'deep' samples (ranging -2.29mm to -7.84mm). The Hierarchical Cluster Analysis used Ward's method based on squared Euclidean distance and based on the variable AvgZ. This resulted in five clusters, which can be seen in the mean profile diagram above (Figure 9.10). The Discriminant Analyses provided in Sections C.3.2 and C.3.3 indicated that these were statistically significant clusters.

After taking the average of the five variables that contributed most to the first and second Principal Components (and variable k, so that this could be available for direct comparison to the 'Shallow' results), five 'hypothetical carver profiles' were calculated and standardized (Table 9.4) prior to comparison with the three 'Shallow' Govan 1 'hypothetical carver profiles'. The analysis of Govan 1's case profiles will be discussed further in Section 9.8.1.

Table 9.4. Five hypothetical carver profiles from the 'Deep' Govan 1 samples.

Case profiles	v	mindiff	AvgZ	plusdiff	k	w	zv	zmindiff	zavgz	zplusdiff	zk	zw
1	68.80	4.69	-7.78	4.47	0.49	9.16	-0.81	1.40	-1.18	0.08	-1.33	0.72
2	85.25	4.17	-4.49	4.56	0.52	8.73	0.42	0.14	0.49	0.25	0.20	0.23
3	75.60	4.00	-5.51	4.35	0.52	8.36	-0.30	-0.27	-0.03	-0.13	0.11	-0.21
4	68.25	3.54	-6.75	3.62	0.51	7.15	-0.85	-1.39	-0.66	-1.49	-0.39	-1.62
5	100.22	4.16	-2.75	5.13	0.55	9.29	1.54	0.12	1.38	1.30	1.42	0.88

9.7.2 Govan 12

Twelve samples were taken from the cross outline and between interlace strands on Govan 12. The Hierarchical Cluster Analysis used Ward's method on squared Euclidean distance and based on the variables AvgX, AvgY and AvgZ. This resulted in five clusters, which can be seen in the mean profile diagram above (Figure 9.12).

The Principal Components Analysis indicated that the first two components were the most reliable (Section C.4.1). Variables v (groove angle), AvgZ (depth 1.5mm from the base of the groove), and meddiff (the evenness of the base of the groove) were chosen from the first Component for further analysis, as were variables plusdiff (length of the space left between hits), w (the total length of the wavelength formed by mindiff and plusdiff) and k (carving rhythm) from the second component. The five initial 'hypothetical carver profiles' from the Govan 12 samples are listed below and were utilised in the final step of the analysis in Section 9.8.2 (Table 9.5).

Table 9.5. Five hypothetical carver profiles from the Govan 12 samples that went on to the final stage of the analysis.

Case profiles	v	AvgZ	meddiff	plusdiff	w	k
1	87.28	-6.47	0.21	5.22	11.07	0.47
2	130.73	-3.12	0.13	6.00	11.43	0.53
3	96.66	-5.50	0.21	3.80	8.47	0.45
4	108.14	-4.79	0.18	5.20	9.66	0.54
5	97.82	-4.57	0.16	4.74	9.62	0.49

9.7.3 Inchinnan 1

Twelve samples were taken from the three-dimensional model of Inchinnan 1. Hierarchical Cluster Analysis using the Nearest Neighbour method and the squared Euclidean distance based on the variables AvgX, AvgY and AvgZ was used in the clustering of the samples. The Mean profile diagram of the resultant three clusters can be found above in section 9.4.3 (Figure 9.14). The Principal

Components Analysis indicated once again that only the first two Principal components were reliable due to the small sample size (see Section C.5.1). For each of the three clusters, the average value of the variables v, AvgZ, meddiff, plusdiff, w, and k were calculated (Table 9.6). These hypothetical carver profiles were compared against the hypothetical carver profiles from Govan 12, as discussed in Section 9.7.2.

Table 9.6. The three hypothetical carver profiles from the Inchinnan 1 samples.

Case profiles	v	AvgZ	meddiff	plusdiff	w	k
1	135.36	-4.01	0.09	5.82	11.10	0.53
2	122.46	-3.69	0.09	5.55	10.66	0.52
3	88.34	-7.25	0.16	4.38	8.50	0.51

9.8 Comparing Case profiles

9.8.1 Govan 1

It is likely that some of the eight separate ‘Shallow’ and ‘Deep’ hypothetical carver profiles that were calculated for Govan 1 above in Section 9.7.1 were in fact carved by the same individual. To identify the profiles that were most similar, the ‘Shallow’ and ‘Deep’ profiles were standardized separately before comparison much in the same way that Kitzler Åhfeldt standardized and then matched the carver profiles of runographers and those who carved ornament (Table 9.7; 2001, 146; 2002b, 34). These standardized variables were compared using Hierarchical Cluster Analysis using Ward’s method based on the squared Euclidean distance, using the standardized values of v, mindiff, avgz, plusdiff, w and k, which resulted in the dendrogram below (Figure 9.17).

Table 9.7. All eight 'hypothetical carver profiles' identified in the above Groove Analysis for Govan 1. The first three profiles listed are those identified from the 'Shallow' samples, while the final five are identified from the 'Deep' samples.

Case profiles	v	mindiff	AvgZ	plusdiff	k	w	zv	zmindiff	zavgz	zplusdiff	zk	zw
1	110.56	4.22	-2.33	4.14	0.50	8.37	-0.30	-0.81	-0.03	-0.80	-0.44	-0.99
2	129.95	4.27	-1.39	4.83	0.53	9.10	1.12	-0.31	1.01	1.12	1.14	1.01
3	103.54	4.41	-3.19	4.31	0.49	8.73	-0.81	1.12	-0.99	-0.33	-0.71	-0.01
4	68.80	4.69	-7.78	4.47	0.49	9.16	-0.81	1.40	-1.18	0.08	-1.33	0.72
5	85.25	4.17	-4.49	4.56	0.52	8.73	0.42	0.14	0.49	0.25	0.20	0.23
6	75.60	4.00	-5.51	4.35	0.52	8.36	-0.30	-0.27	-0.03	-0.13	0.11	-0.21
7	68.25	3.54	-6.75	3.62	0.51	7.15	-0.85	-1.39	-0.66	-1.49	-0.39	-1.62
8	100.22	4.16	-2.75	5.13	0.55	9.29	1.54	0.12	1.38	1.30	1.42	0.88

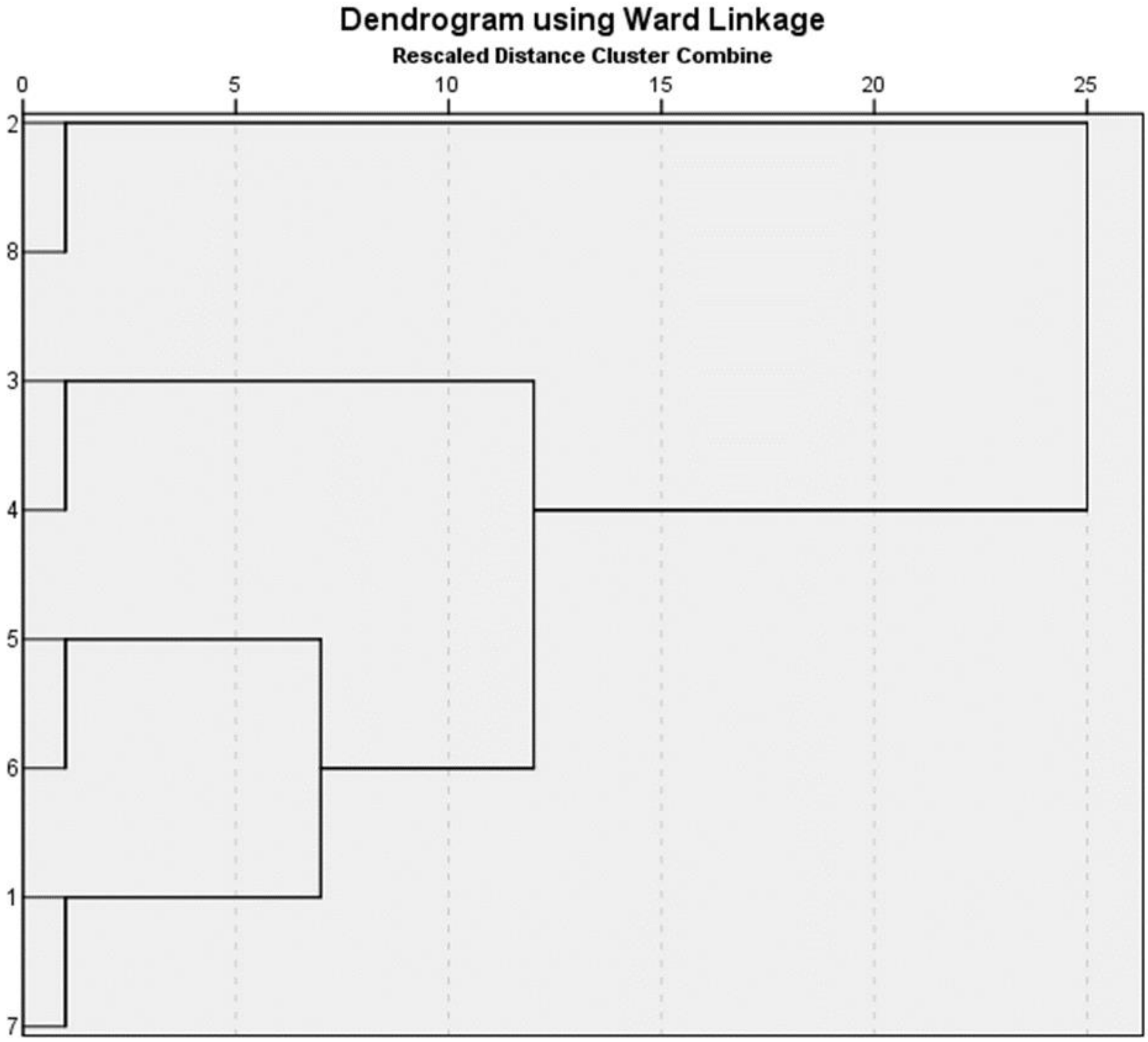


Figure 9.17. Dendrogram of the Hierarchical Cluster Analysis of the Govan 1 hypothetical carver profiles.

This Hierarchical Cluster Analysis suggests that Cluster 1 from the 'Shallow' and Cluster 4 from the 'Deep' samples were most likely carved by the same individual (Figure 9.18), Cluster 2 from the 'Shallow' and Cluster 5 from the 'Deep' samples were likely carved by the same individual (Figure 9.19), that Cluster 3 from the 'Shallow' and Cluster 1 from the 'Deep' Samples were most likely carved by the same individual (Figure 9.20), and that Clusters 2 and 3 from the 'Deep' samples should be clustered together (Figure 9.21). This dendrogram also suggests that, if only three carvers had been at work on the sarcophagus, that the samples belonging to Case Profiles 5, 6, 1, and 7 are the most likely to have been carved by a single individual (Figure 9.22), although this will be discussed further below. A comparison of the case profiles in the form of a line graph was the best way to illustrate how the Hierarchical Cluster Analysis identified and paired the most similar cluster profiles from the standardized variables in Table 9.7, as Kitzler Åhfeldt had demonstrated in her own analyses (2002a, 94).

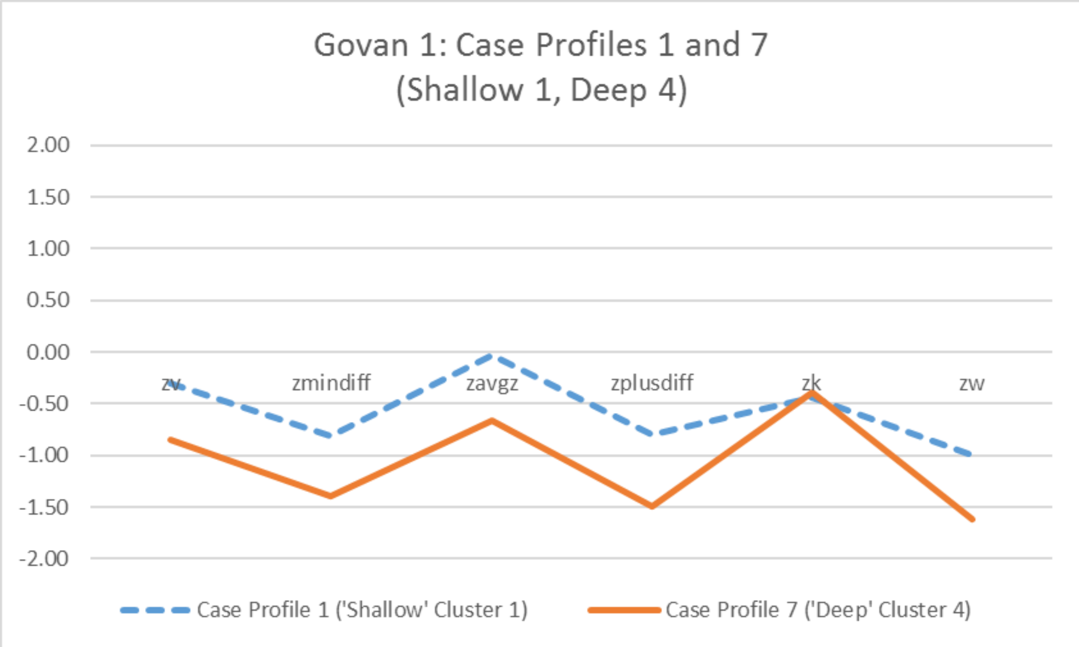


Figure 9.18. Hierarchical Cluster Analysis paired Case profiles 1 and 7 from Table 9.7; the samples included in these two clusters were probably carved by the same individual.

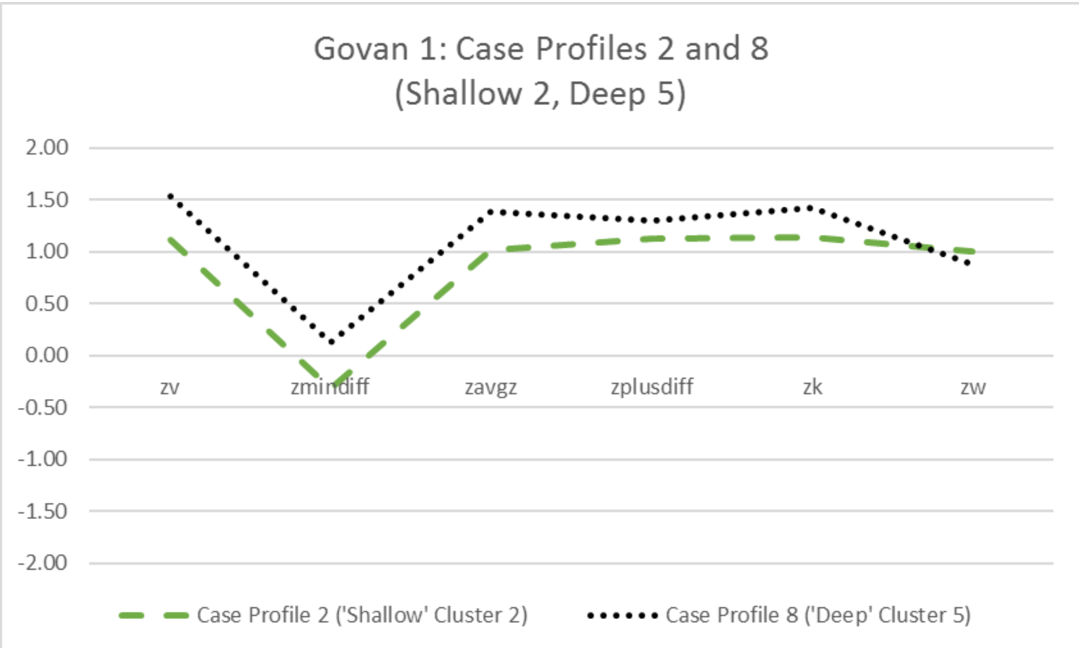


Figure 9.19. Hierarchical Cluster Analysis paired Case Profiles 2 and 8 from Table 9.7; the samples that are grouped in these clusters were very likely carved by the same individual.

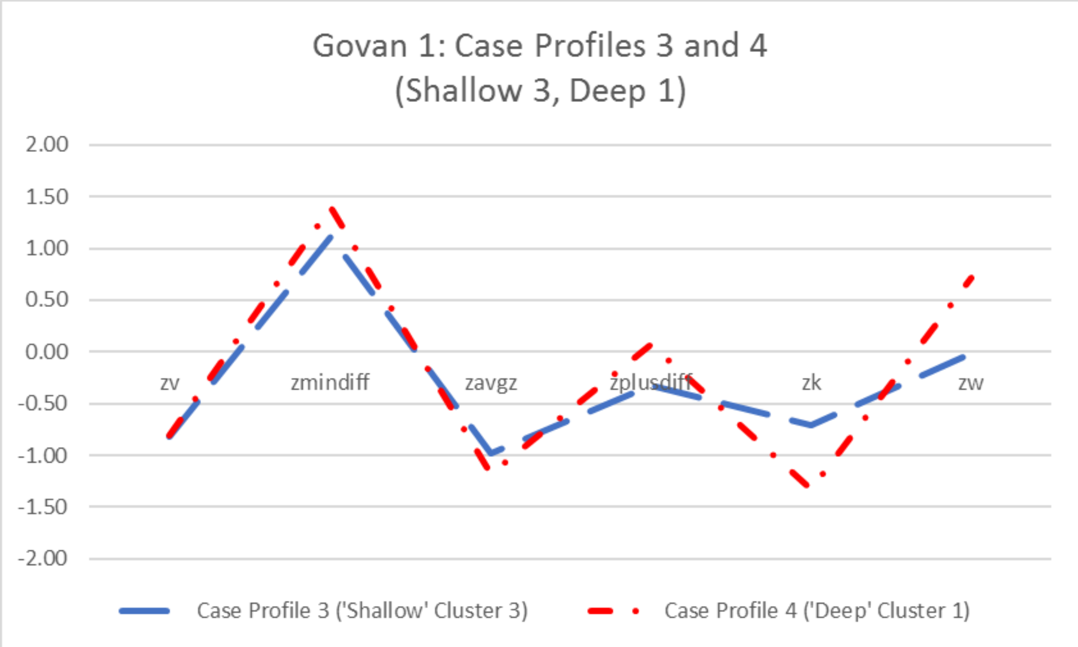


Figure 9.20. Hierarchical Cluster Analysis paired Case Profiles 3 and 4 from Table 9.7; the samples included in these two clusters were very likely carved by the same individual.

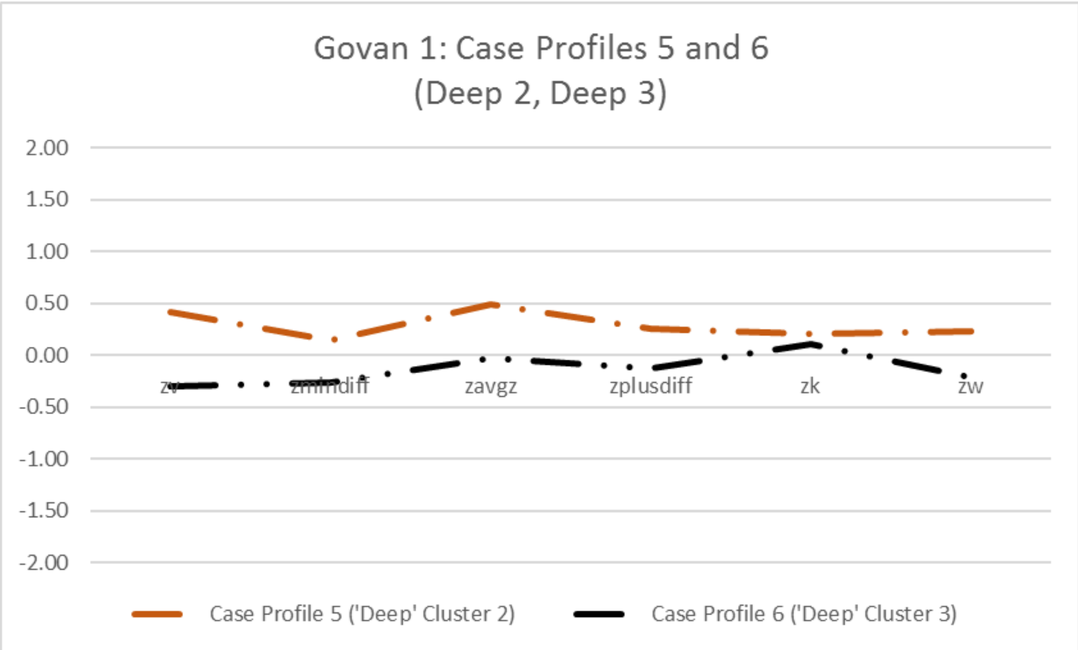


Figure 9.21. Hierarchical Cluster Analysis paired Case Profiles 5 and 6 from Table 9.7; the samples included in these two clusters were probably carved by the same individual.

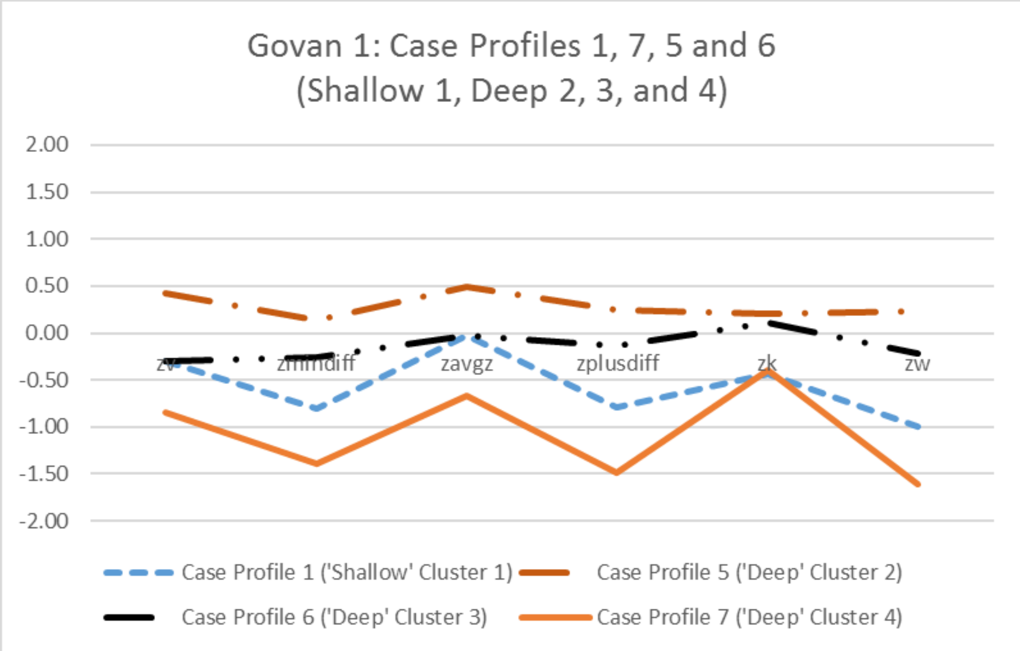


Figure 9.22. After the initial four pairings were made in Hierarchical Cluster Analysis, these four clusters could possibly represent the work of a single individual.

While it is interesting to suggest that the samples taken from the sarcophagus represent the work of no more than four carvers, it is significantly more informative to map these samples onto images of the sarcophagus panels and observe where the work of an individual lies in relation to the others. In the interest of avoiding unnecessary confusion, the four pairs of case profiles that likely represent the work of individual carvers will be labelled as follows: the carver of case profiles 1 and 7 will be referred to as Carver A (in red), case profiles 2 and 8 as Carver B (in yellow), case profiles 3 and 4 as Carver C (in green), and case profiles 5 and 6 as Carver D (in blue). The samples that have been allocated to clusters falling under these case profiles have been highlighted in a Carver specific colour and labelled as one of these Carvers below.

Through consideration of the mapped samples, a pattern begins to emerge. Carver D appears only along the panel edges and when it was possible to take samples from some of 'groovier' aspects of the 'beasts' (Figure 9.23, Figure 9.25, Figure 9.26, Figure 9.27, Figure 9.28, Figure 9.29, and Figure 9.30). Carver C seems to primarily appear in the interior of the interlace patterns (Figure 9.23, Figure 9.27, and Figure 9.29). Carver B is less prevalent, as is Carver A, but appears to work on more detailed areas (Figure 9.23, Figure 9.24, Figure 9.25, Figure 9.26, Figure 9.27, Figure 9.28, Figure 9.29, and Figure 9.30).

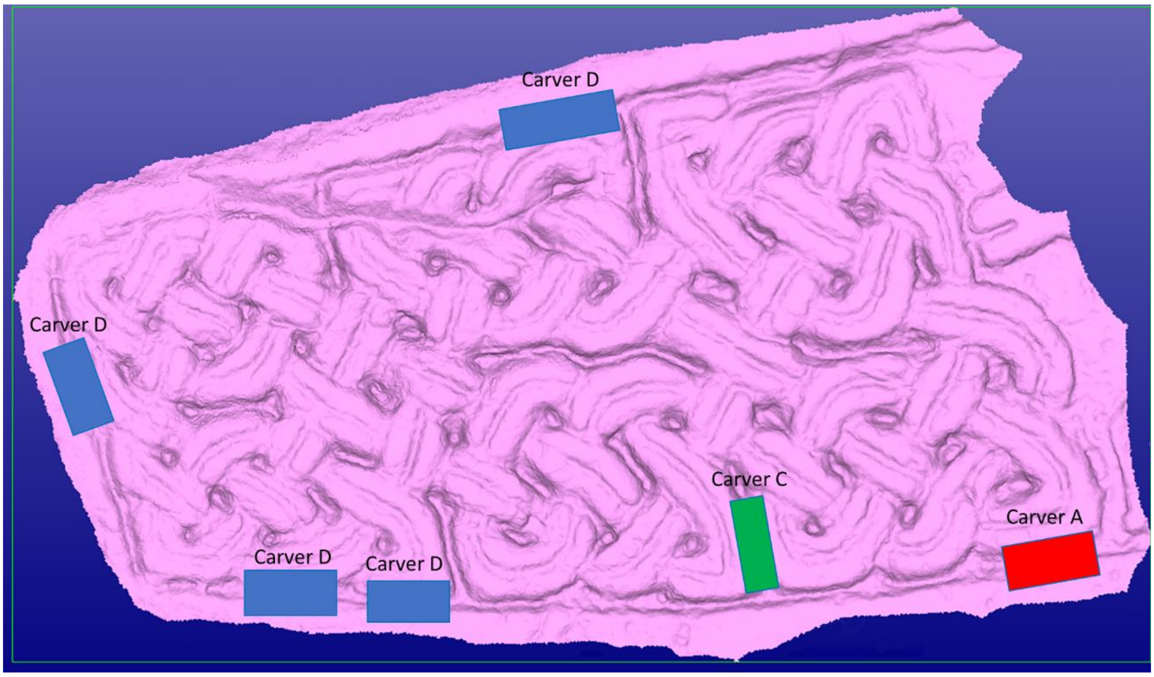


Figure 9.23. Front Panel A of Govan 1 with Groove Analysis samples highlighted and labelled as the carver it was assigned to in the analysis.

Figure 9.24. Front Panel B of Govan 1 with Groove Analysis samples highlighted and labelled as the carver it was assigned to in the analysis.

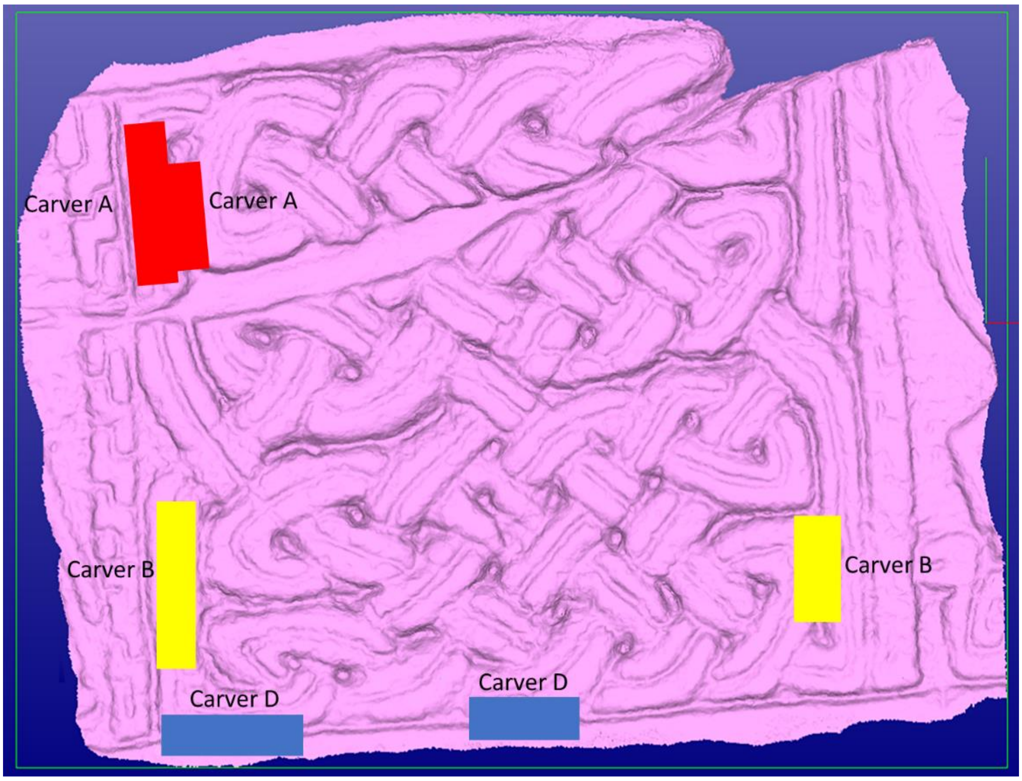


Figure 9.25. Front Panel C of Govan 1 with Groove Analysis samples highlighted and labelled as the carver it was assigned to in the analysis.

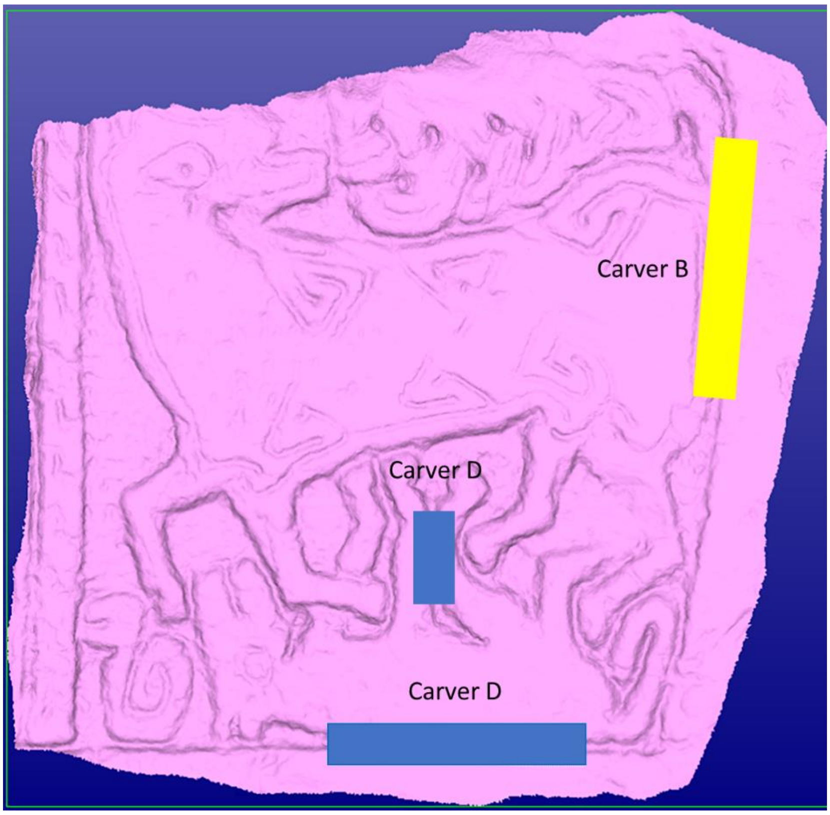


Figure 9.26. Front Panel D of Govan 1 with Groove Analysis Samples highlighted and labelled as the carver it was assigned to in the analysis.

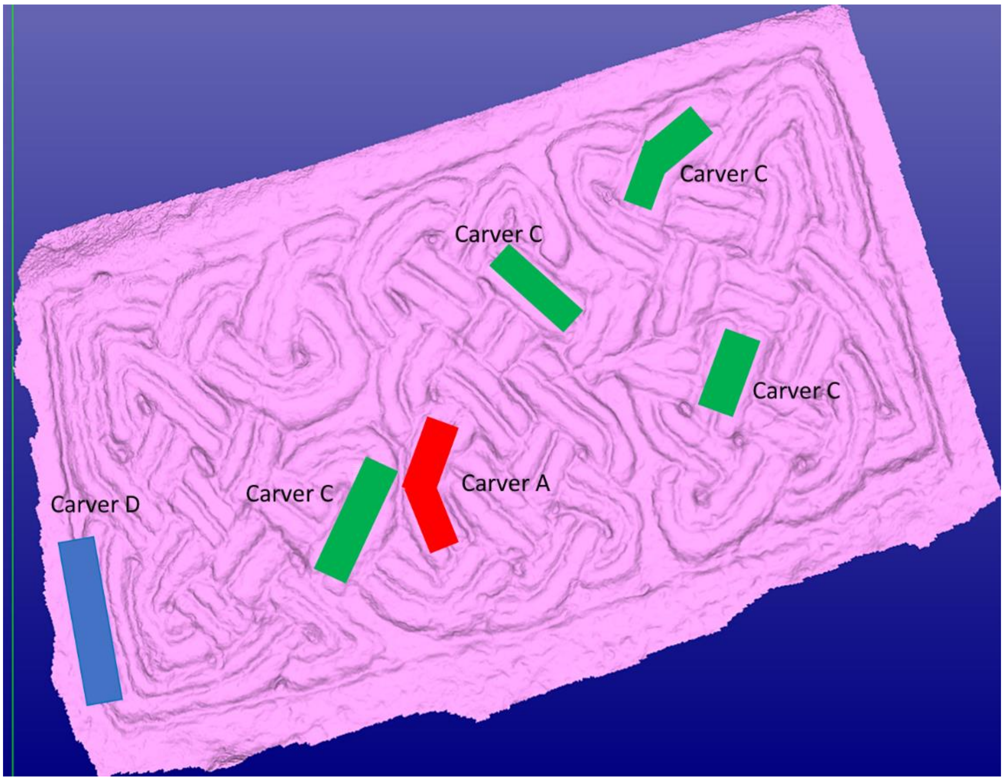


Figure 9.27. Side Panel (Head end) of Govan 1 with Groove Analysis Samples highlighted and labelled as the carver it was assigned to in the analysis.

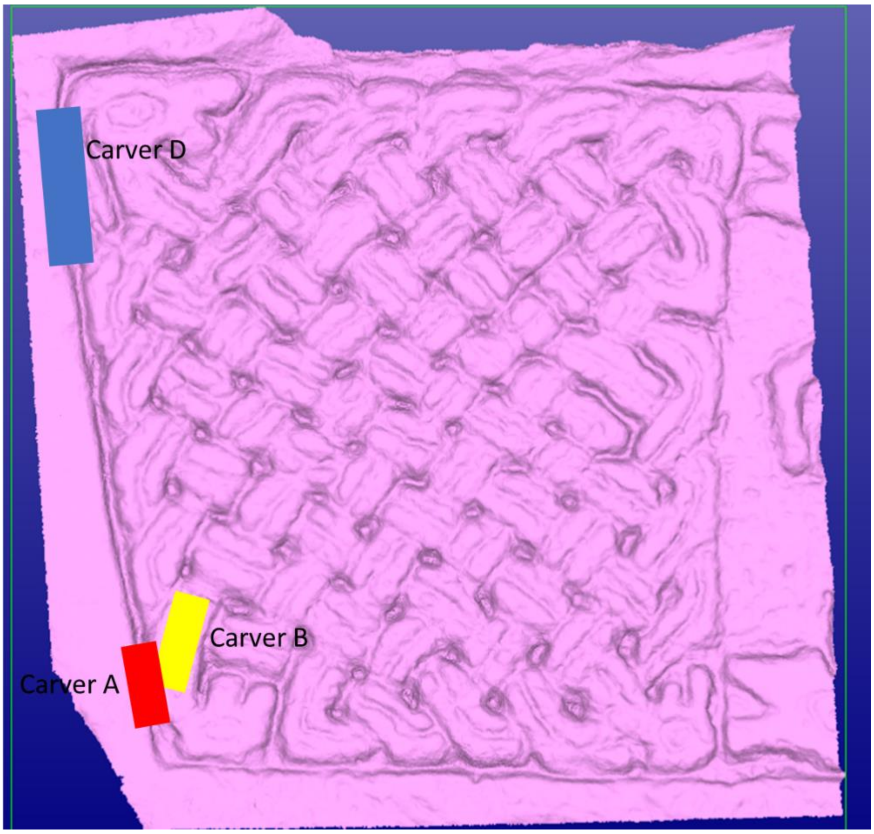


Figure 9.28. Back Panel A of Govan 1 with Groove Analysis Samples highlighted and labelled as the carver it was assigned to in the analysis.

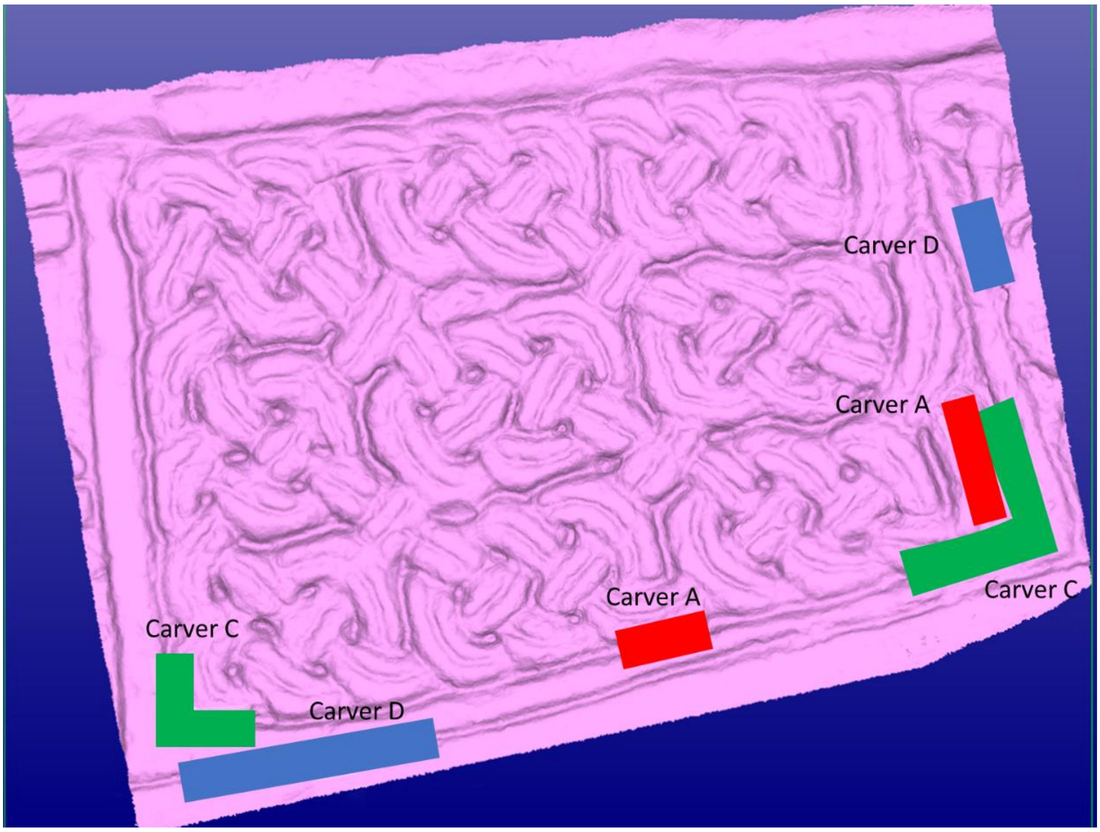


Figure 9.29. Back Panel C of Govan 1 with Groove Analysis Samples highlighted and labelled as the carver it was assigned to in the analysis.

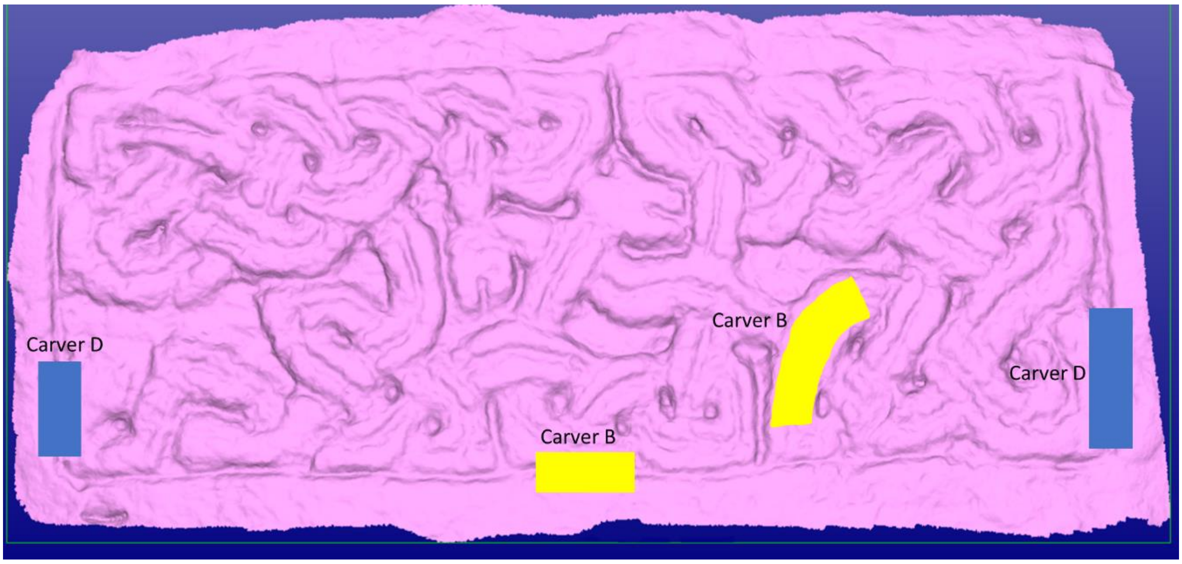


Figure 9.30. Side panel (foot end) of Govan 1 with Groove Analysis samples highlighted and labelled as the carver they were assigned to in the analysis.

It appears from the above maps that Carvers C and D are defined quite well by the ‘type’ of carving that is being done; Carver C only carves grooves that form interior elements of the design (forming the strands of interlace or, especially in the case of the head-end side panel, the grooves that bisect the strands), while

Carver D only appears along the edges of panels or in the exterior outlines of the beasts. This suggests that there is a division of labour – one individual lays out the panels of ornament, creating clearly defined boundaries, while a second individual works with those boundaries to create the patterns of interlace. The question then becomes, what of Carvers A and B?

As Kitzler Åhfeldt has discovered in her examination of the reference material, multiple 'carving signatures' can arise from a single individual in certain situations: if the carver increases in skill over time (usually more pronounced between different monuments), changes their tool-set, becomes fatigued, makes additional cuts after a monument has been erected, or is focused on carving a particularly difficult area of ornament; these can all result in a sparse cluster or outliers to the primary cluster (Kitzler 1998, 90–91; Kitzler Åhfeldt 2002a, 85, 92–93; 2002b, 30–31). With these possibilities in mind, we can address the samples attributed to Carver A and Carver B.

If one considers the locations of Carver A's samples, they frequently occur closest to samples allocated to Carver C (see Figure 9.23; Figure 9.27; Figure 9.29, although this is not necessarily the case with Figure 9.25 or Figure 9.28) and often appear to be areas that could require more caution in carving. One could argue that the Carver A sample in Figure 9.23 may have been more difficult if the adjacent hunting scene was already carved (the deep pits between the interlace and the deer's front leg may have been undesirable). The Carver A sample in Figure 9.27 is a curved bisecting line, which may have been more difficult to carve or required different kit to execute than the straight bisecting lines of Carver C on the same panel. Finally, in Figure 9.29, the lower of the two Carver A samples is approaching an area where the lower boundary presumably carved by Carver D is becoming much narrower than it is on the left side of the panel, potentially encouraging the sculptor to be more cautious. Although the dendrogram above suggests that, if any, Carver D's carving is most similar to Carver A (Figure 9.17; Figure 9.22), the location of these samples would suggest that the work of Carver A has more in common with Carver C.

When considering the work of Carver B, it is again useful to identify where these samples are located on the stone. Carver B predominates in the detailed decoration of the horseman on Govan 1 (Figure 9.24), occurs in close proximity to Carver D's work in Figure 9.25, Figure 9.26, and Figure 9.30. If Carver A does in fact represent the work of a carver being cautious with certain types of carving, Carver B worked in a similar way, which is best exemplified by Front Panel C (Figure 9.25). The difference is that the work of Carver B is most often adjacent to that of Carver D (see Figure 9.25, Figure 9.26, and Figure 9.30). It could be, then, that Carver B is the 'cautious signature' of Carver D, or the result of Carver D using a different chisel better suited to delicate carving. The dendrogram above does not support this interpretation, but the above analysis included the standardized variable v, which represents the angle of the groove, in the allocation of these groups. Kitzler Åhfeldt, in her earlier work, identified that the variable v was confusing the assignment of samples of more difficult ornament to the correct cluster in her reference material produced by modern carvers, although it was less of a problem in the analysis of runes (Kitzler 1998, 95–96). If the standardized variable v is left out of the Hierarchical Cluster Analysis of the eight initial case profiles, no matter which method is used, the closer relationship between Carver B and Carver D becomes overwhelmingly clear through the depth (AvgZ) and especially the rhythm of the carving (mindiff, plusdiff, k and w; the length of the peck, the length of the space left between pecks, the rhythm of that spacing, and the overall wavelength of the carving cycle respectively) (Figure 9.31; note that removing variable v had no discernible impact on the grouping of the Govan 12 and Inchinnan 1 case profiles).

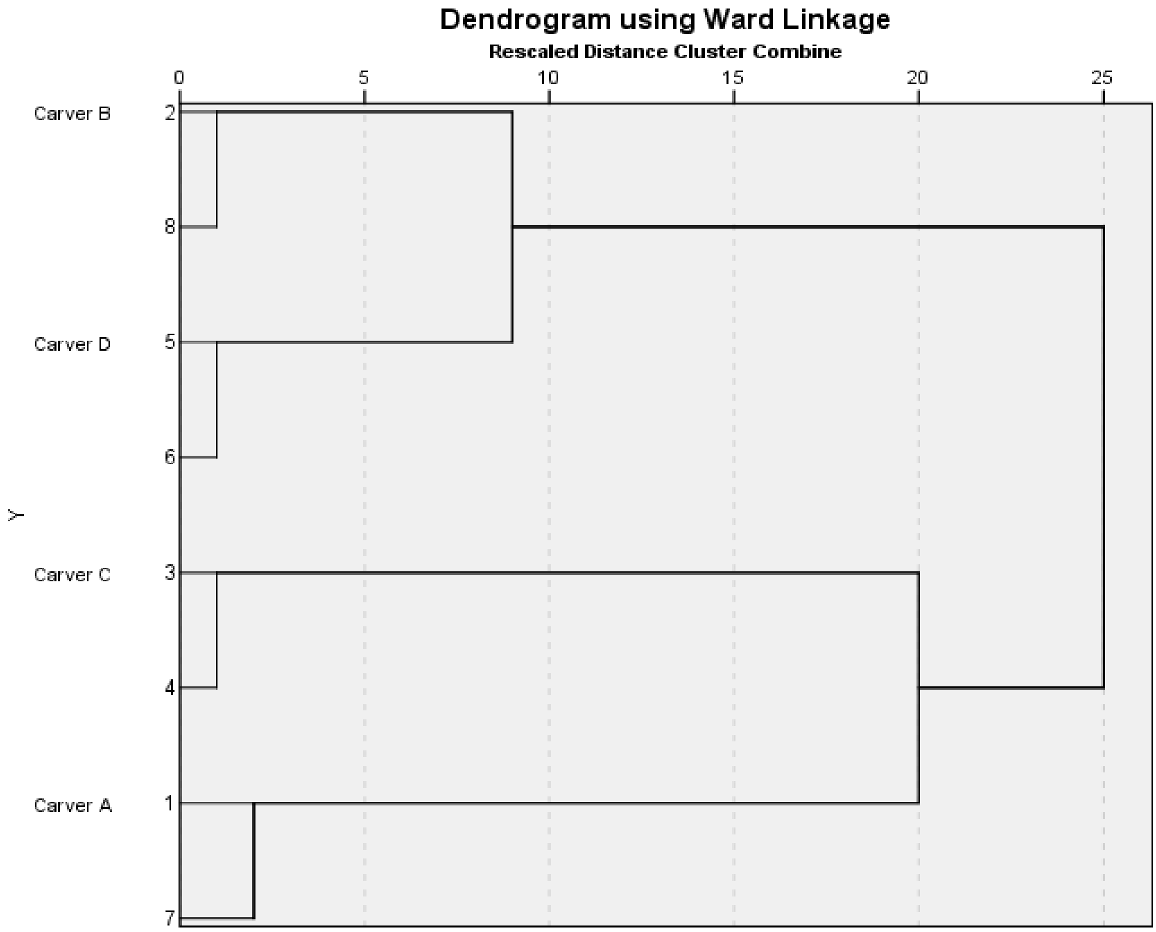


Figure 9.31. Dendrogram illustrating the results of the Hierarchical Cluster Analysis of Govan 1's hypothetical case profiles using Ward's method and squared Euclidean distances based on the standardized variables mindiff, AvgZ, plusdiff, k and w (excluding v). Carvers B and D are more likely to represent one carver, as are Carvers A and C, which corresponds more readily to the spatial distribution of the samples.

From the above, it seems most likely that two carvers, Carvers A+C and B+D, worked on the sarcophagus together, where Carver B+D created the basic outline of the panels, the outlines of the beasts and the detailed work on the horseman, and Carver A+C carved the bulk of the interlace. It is possible that there could be one carver with four different approaches to carving, or even three or four individual carvers represented by these samples, but the statistical analysis together with the mapping of the samples seems to strongly suggest the work of two carvers executing certain areas of carving differently. It is unclear if either could be considered a 'master' or an 'apprentice'; the 'Deep' samples assigned to Carver A+C are consistently deeper (AvgZ) and have a narrower groove angle (v), traits Kitzler Åhfeldt often attributes to a more skilled carver (Kitzler Åhfeldt 2002b, 32-33), but it could also be that these individuals were skilled at different aspects of carving (carving beasts and details versus carving interlace patterns). At the very least it seems that this monument was the result of at least two carvers cooperating in its production, not the work of a single carver.

9.8.1.1 The 'Alpha'

One final note from this analysis is concerned with the carved 'Alpha' on the haunch of the horse (Figure 9.24). Previous work has indicated that this letter may have been a later addition "to emphasize the royal connection" (Spearman 1994, 43). Spearman does not indicate why he thought it was carved later, though photographs often cause the letter to appear more shadowed and perhaps gives it a 'fresher' look than the other carved details of the horseman. A closer look at the three-dimensional model suggests that the haunch of the horse slopes downward, decreasing its height above the background, which could be causing the letter carving to appear deeper (Figure 9.32). Throughout the process of exploring the statistics of the shallow samples, the sample from the top bar of the letter was frequently clustered with one or the other of the samples forming the horseman's leg. While the wavelength and the unevenness of the base of the groove (variables w and meddiff) do seem quite high for the bar in comparison to the two leg samples from the rider, the variable w is heavily impacted by the short samples available from the symbol (34mm for the bar across the alpha symbol, 48mm for the upper part of the rider's leg, and 61mm for the bottom part of the rider's leg); meddiff, the evenness of the base of the groove, appears to have been impacted by this and the relatively few hits that the carver required to create the groove. From the present analysis it seems very likely that the Alpha symbol and the rider's leg were carved by the same individual, though a more detailed study of more samples from the horseman and the Alpha could offer a more definitive interpretation in the future.

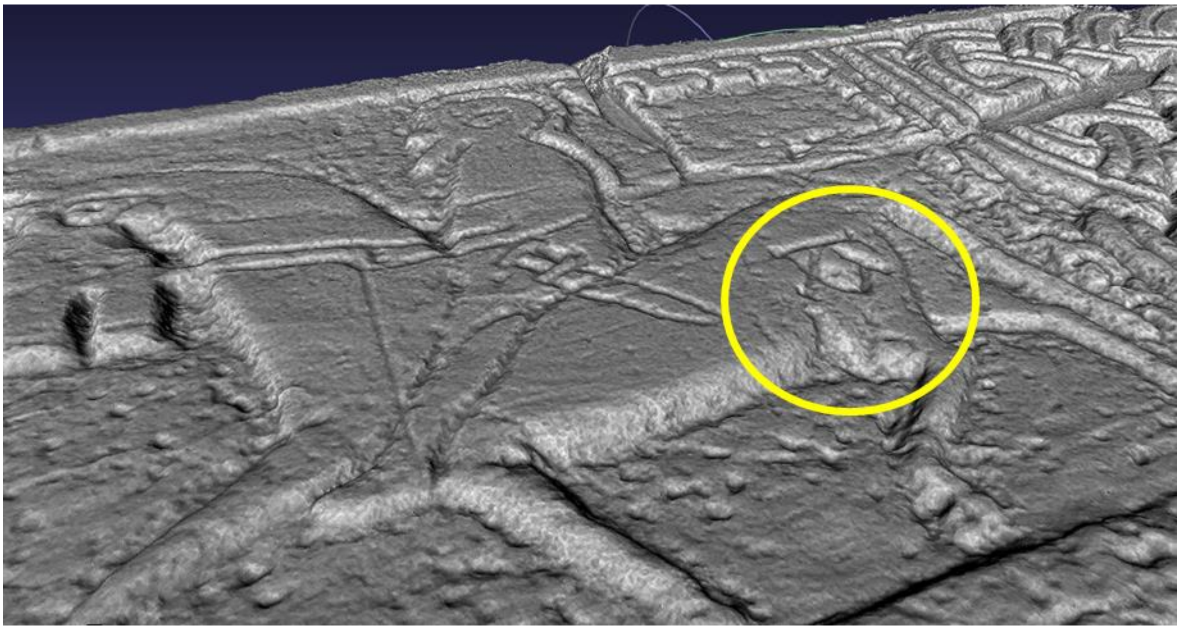


Figure 9.32. Govan 1 horseman showing where a change in depth occurs below the Alpha symbol.

9.8.2 Govan 12 vs Inchinnan 1

From the analyses above (Sections 9.7.2 and 9.7.3), five hypothetical carver profiles were identified from Govan 12 (Table 9.5) and three from Inchinnan 1 (Table 9.6). Given the similarity in cross form and types of interlace used in the decoration of these two monuments, as discussed in Chapter 8, it was suggested that these monuments might have shared at least one carver. As Kitzler Åhfeldt has done in her analyses comparing the Öpir and Fot workshops (2001; 2002a), the case profiles for Govan 12 and Inchinnan 1 were standardized altogether so that the magnitude of the variables would be retained, but the variables measured in different units would be more comparable (Table 9.8). These standardized case profiles were then compared using Hierarchical Cluster Analysis (the rhythm of the carving, variable k, was still included in the analysis because it contributed to the interpretation of Govan 12, despite the fact that it did not contribute to the first two Principal Components of Inchinnan 1). The dendrogram below indicates how similar each hypothetical profile was determined to be using Ward's method and the squared Euclidean distance based on the standardized variables v, avgz, meddiff, plusdiff, w and k (the groove angle, the depth of the groove, the evenness of the base of the groove, the length of the surface between hits, the wavelength of the groove, and the rhythm of the carving respectively; Figure 9.33). From this analysis, it seems that the work of two separate individuals are represented, and there is a slight possibility that they cooperated on both monuments. Carver A consisted of the case profiles Govan 12a, c, d, e and Inchinnan 1c (the latter of which consists of only one sample), while Carver B seems to have worked primarily on Inchinnan, as the process allocated Inchinnan 1a, 1b and Govan 12b (the latter of which was, again, an outlier). This would suggest that the vast majority of each monument was completed by separate individuals, with the possibility of a second under-represented carver. The line graphs below demonstrate how the Hierarchical Cluster Analysis identified the clusters of signatures (Figure 9.34; Figure 9.35). To test the statistical validity of these assignments, all of the samples were included in a Principal Components analysis, the results of which are presented below (Table 9.9). In the plots of the first three Principal Components Scores for each sample, it becomes clear how separate these two clusters of samples are in comparison to the original eight hypothetical case profiles (PC 1 and 2 are graphed in Figure 9.36; PC 1 and 3 are graphed in Figure 9.37; PC 1 and 2 are graphed in Figure 9.38).

Table 9.8. Hypothetical Carver Profiles from Govan 12 and Inchinnan 1, standardized together.

Case Profiles	v	AvgZ	meddiff	plusdiff	w	k	zv	zavgz	zmeddiff	zplusdiff	zw	zk
Govan 12a	87.28	-6.47	0.21	5.22	11.07	0.47	-1.11	-1.10	1.20	0.17	0.86	-1.12
Govan 12b	130.73	-3.12	0.13	6.00	11.43	0.53	1.18	1.28	-0.50	1.22	1.16	0.68
Govan 12c	96.66	-5.50	0.21	3.80	8.47	0.45	-0.62	-0.41	1.12	-1.73	-1.36	-1.72
Govan 12d	108.14	-4.79	0.18	5.20	9.66	0.54	-0.01	0.10	0.64	0.15	-0.34	1.09
Govan 12e	97.82	-4.57	0.16	4.74	9.62	0.49	-0.55	0.25	0.18	-0.47	-0.38	-0.49
Inchinnan 1a	135.36	-4.01	0.09	5.82	11.10	0.53	1.42	0.65	-1.34	0.98	0.88	0.72
Inchinnan 1b	122.46	-3.69	0.09	5.55	10.66	0.52	0.74	0.87	-1.35	0.62	0.51	0.49
Inchinnan 1c	88.34	-7.25	0.16	4.38	8.50	0.51	-1.05	-1.65	0.06	-0.95	-1.33	0.35

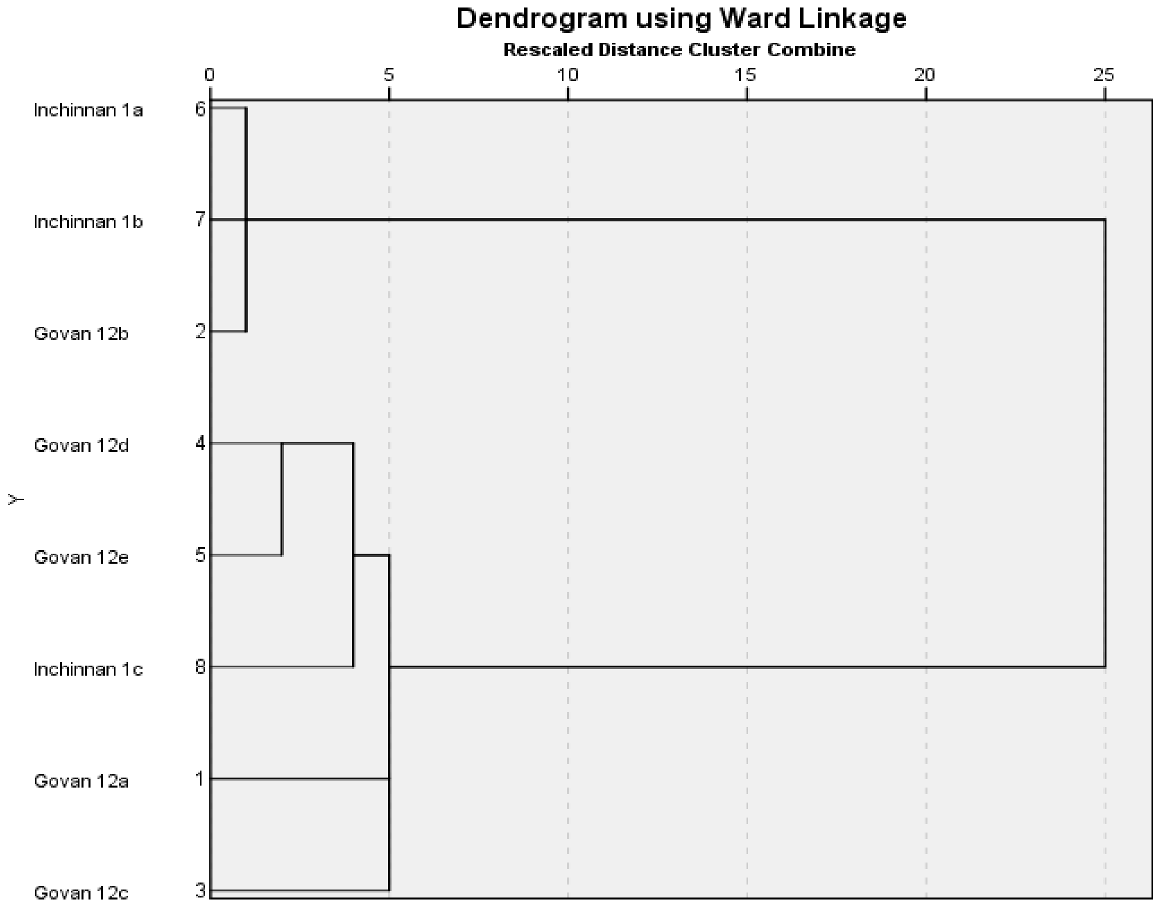


Figure 9.33. Dendrogram of the Hierarchical Cluster Analysis results using Ward's method and squared Euclidean distance based on the standardized variables v, AvgZ, meddiff, plusdiff, w and k.

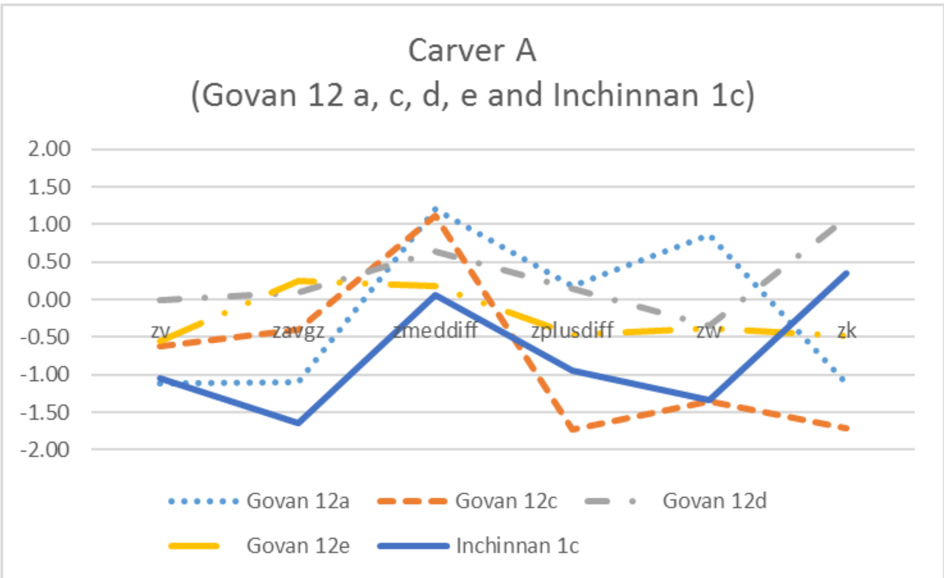


Figure 9.34. Line graph of hypothetical case profiles assigned to Carver A; this carver is less regular in their carving technique than Carver B. Most similarities occur in variables v (groove angle), meddiff (evenness of the base of the groove) and w (wavelength).

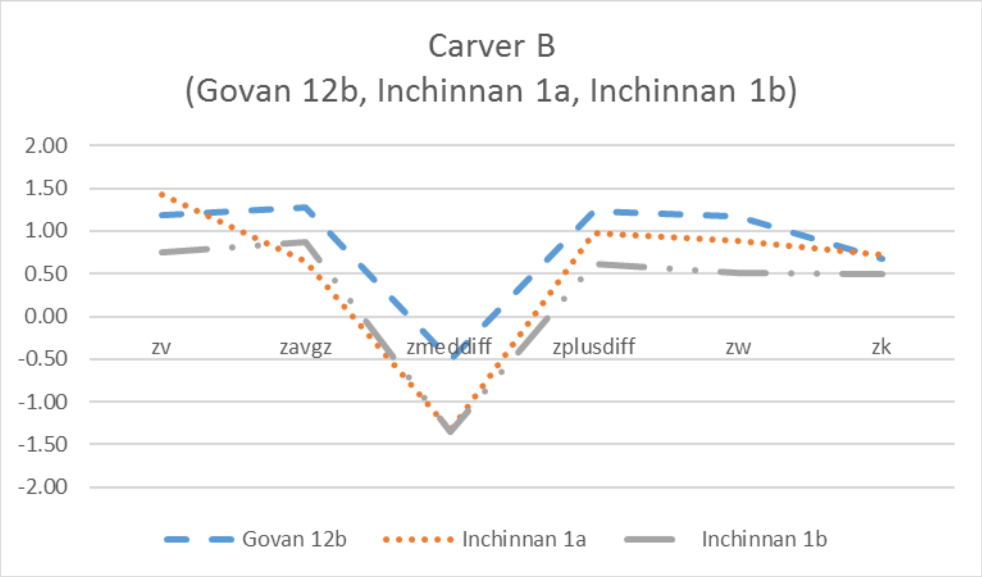


Figure 9.35. Line graph of hypothetical case profiles assigned to Carver B; this carver is more consistent in their technique than Carver A. The three profiles are virtually identical in each variable.

Table 9.9. Principal Components Analysis of the Govan 12 and Inchinnan 1 samples together.

Component Matrix[a]

	Component		
	1	2	3
v	0.890	0.034	-0.176
D	0.968	-0.136	-0.050
AvgX	0.527	-0.535	0.502
AvgY	0.775	-0.443	0.377
AvgZ	0.956	-0.236	0.095
mindiff	-0.026	0.615	0.764
plusdiff	0.541	0.790	-0.089
meddiff	-0.852	-0.057	0.151
w	0.366	0.866	0.326
k	0.543	0.322	-0.672

Extraction Method: Principal Component

a. 3 components extracted.

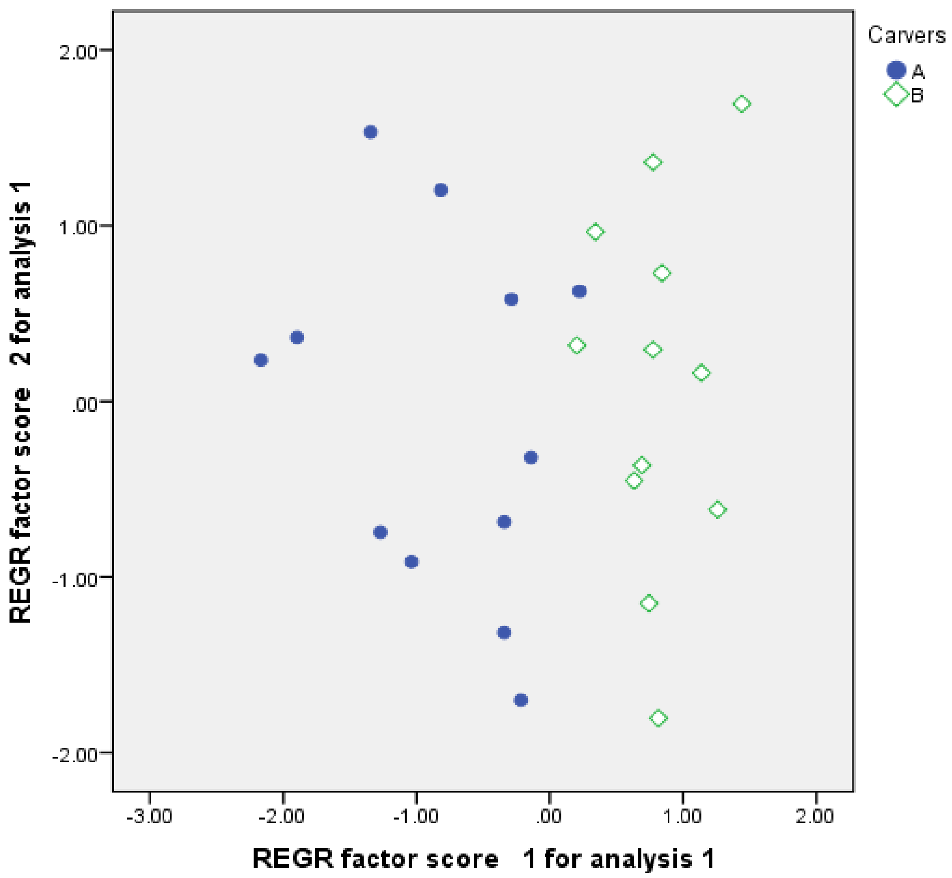


Figure 9.36. Plot of the first and second Principal Component Scores for the Govan 12 and Inchinnan 1 samples, labelled according to carver. While there is a small amount of overlap, there is good separation between the carvers.

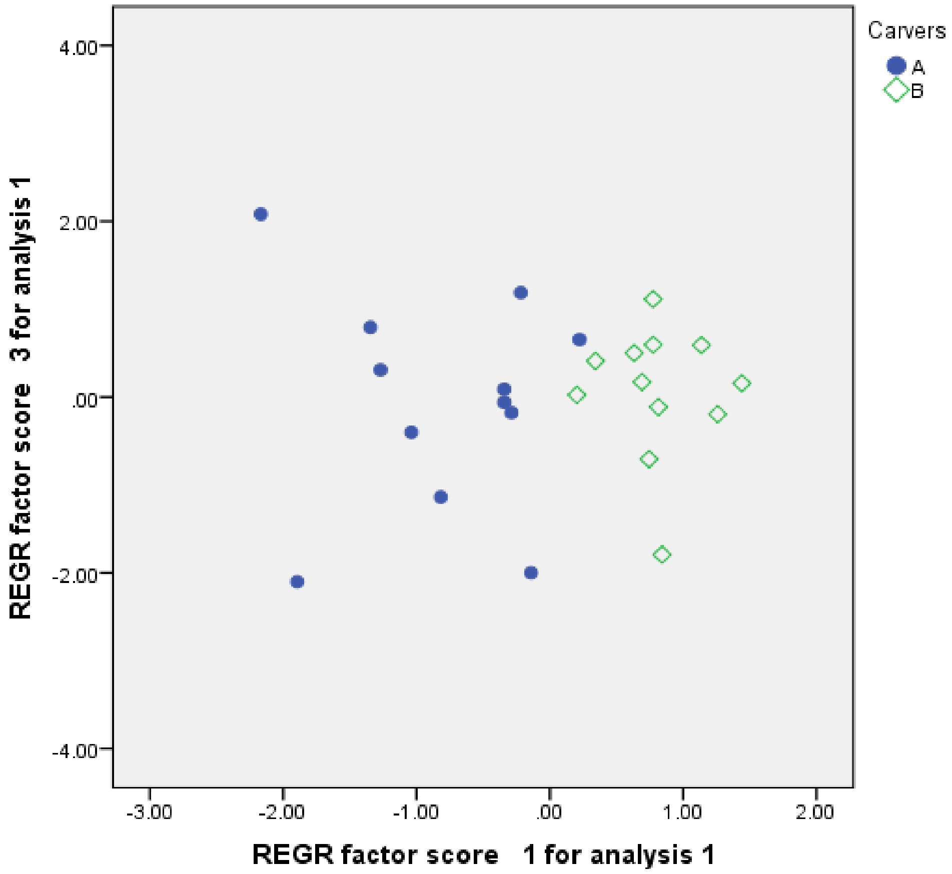


Figure 9.37. Plot of the first and third Principal Component Scores for the Govan 12 and Inchinnan 1 samples, labelled according to Carver. While PC3 was not utilised in the analysis because it did not quite pass the rule of thumb outlined by Stevens (see Section 9.4), it most clearly demonstrates how consistent Carver B is in their technique.

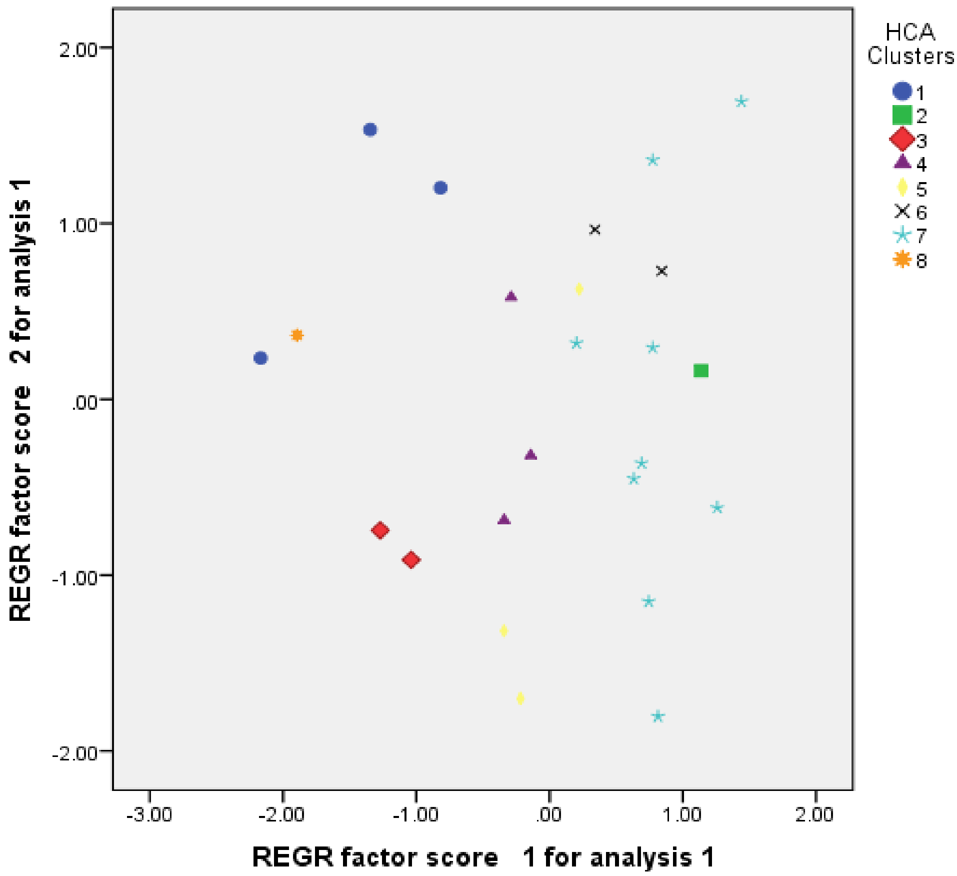


Figure 9.38. Plot of the first two Principal Component Scores for the eight initial Govan 12 and Inchinnan 1 hypothetical carver profiles. Note the positioning of Govan 12's outlier, Cluster 2, and Inchinnan 1's outlier, Cluster 8.

As in the case of Govan 1, it was essential to map where each of these samples originated from Govan 12 and Inchinnan 1 (See Govan 12 in Figure 9.39 and Figure 9.40; Inchinnan 1 in Figure 9.41 and Figure 9.42). As can be seen in Figure 9.40, the single Govan 12 sample that was allocated to Carver B appears to be situated in an area that is more worn than other areas. It is unclear, however, if wear is the deciding factor in its attribution to Carver B, as its case profile does adhere quite closely with that of Inchinnan 1a and Inchinnan 1b (Figure 9.35). This sample is not located in an area that would be considered difficult carving either, as the rest of the cross was carved with little issue. Additional samples would be required to identify if Carver B worked on other areas of decoration and is under-represented in this sample, or if this an outlier of Carver A.

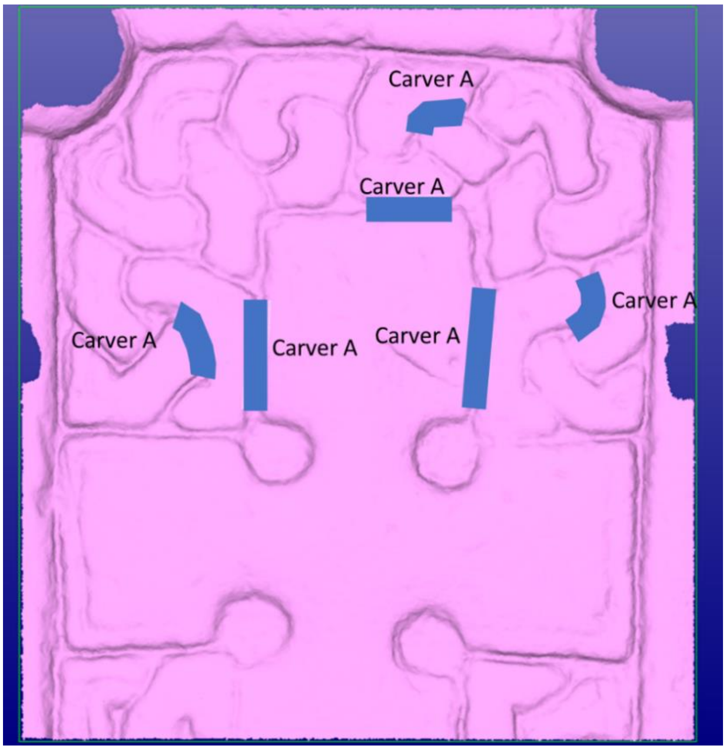


Figure 9.39. Top half of Govan 12 demonstrating where the Groove Analysis samples came from and to which Carver they were allocated.

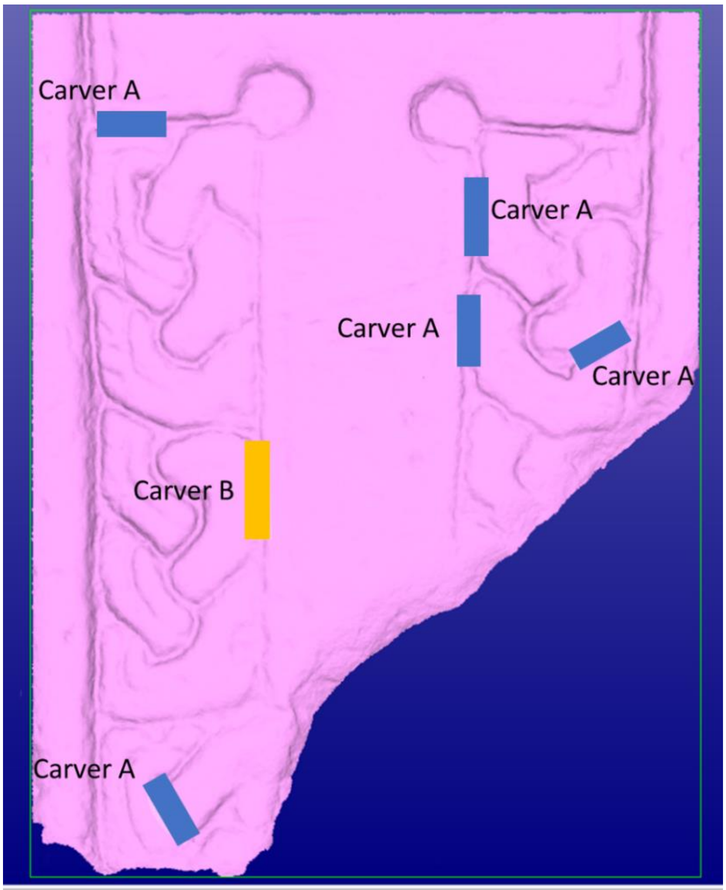


Figure 9.40. Bottom half of Govan 12 demonstrating where the Groove Analysis samples came from and to which Carver they were allocated.

In the case of Inchinnnan 1, the sample allocated to Carver A is visibly deeper than the other samples, which appears to be a consistent feature of most of similar turns in the interlace on the left side of the monument (Figure 9.42). One might infer that the increased depth of this sample was the result of recutting or correcting a difficult area of carving, but the groove angle is much narrower than the other samples, and one would expect recutting a groove to result in a wider groove angle (Table 9.8). If the outlying samples on each monument do represent co-authorship of the monuments, this could either represent two carvers from the same workshop or perhaps two itinerant carvers working together. However, if these monuments were each created by a different individual, these outliers could represent the tiring of the carver or a change in toolset. Here, the rarity of the outlying sample argues strongly for the latter, for a single carver of the monument who was mostly, but not always, consistent.

While Kitzler Åhfeldt has suggested that individuals that produce a narrower groove angle and a deeper groove likely represent the more experienced carvers (1998, 91; 2001, 136). This may not necessarily be the case here, possibly in part due to the difference in raw material between the granitic runestones and the predominantly sandstone monuments in this study. By looking at the case profiles for Carver A and Carver B (Figure 9.34; Figure 9.35), it is striking how consistent the three clusters that form Carver B’s profile are in comparison to Carver A’s; this consistency is reflected again in how well the samples attributed to Carver B cluster in Figure 9.37 above. When this is considered with a close, qualitative study of the stones, the Inchinnan 1 monument appears to have been carved by a more practised hand. In the top right-hand corner of the cross on Govan 12 (Figure 9.43), the carver seems to have had trouble keeping the boundary between interlace and cross coherent. In comparison, the Inchinnan 1 cross fits neatly between the panels of ornamentation (Figure 9.41). The Inchinnan 1 carver also ensures that the interlace panels on either side of the cross continue into the lower panel, while Govan 12’s carver truncates the left panel abruptly (and presumably did the same on the right side, but this has been lost). Overall, a subjective qualitative analysis of the carving supports the idea that two separate individuals created these two monuments.

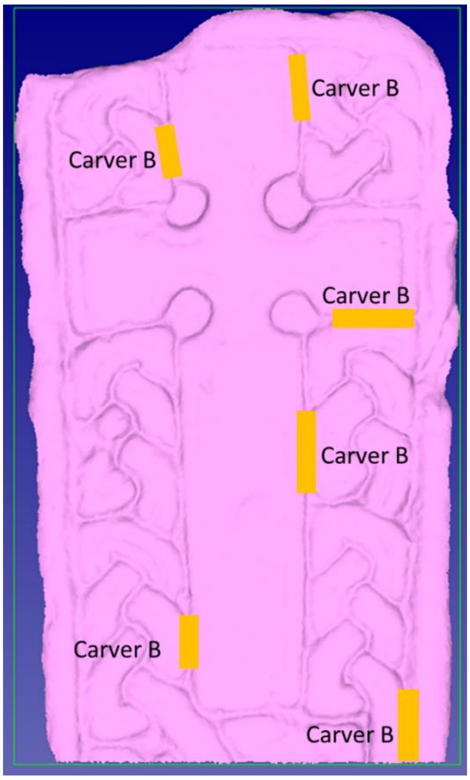


Figure 9.41. Top half of Inchinnan 1, demonstrating where each of the Groove Analysis samples came from and to which Carver they were allocated.

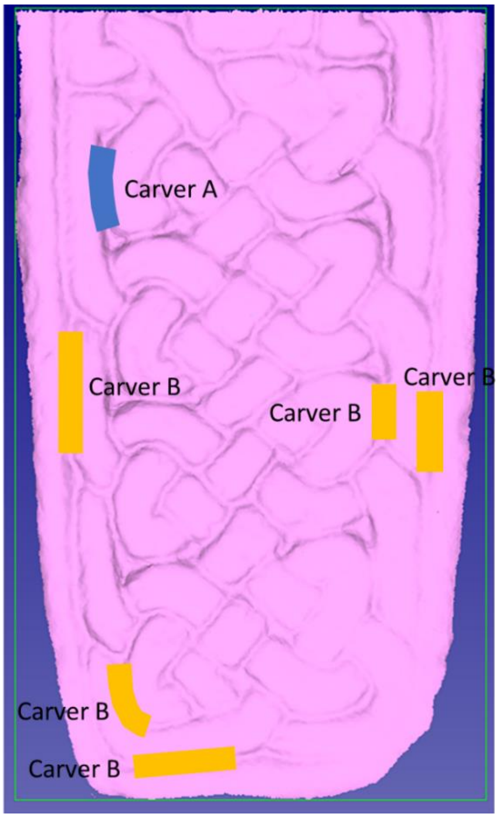


Figure 9.42. Bottom half of Inchinnan 1, demonstrating where each of the Groove Analysis samples came from and to which Carver they were allocated.

Figure 9.43. Top right corner of the cross on Govan 12, demonstrating the carver's inconsistent approach.

If Carver A was solely responsible for Govan 12 and Carver B for Inchinnan 1, this has implications for whether there was a Govan-Inchinnan school or centralised workshop. As discussed in the above recumbent cross-slab typology in Section 8.4, the outlines of the incised crosses of these two monuments, although of different size, are almost exactly proportional to each other (Figure 9.44). Scaling down the cross outline from Govan 12 allows it to be mapped neatly onto the cross of Inchinnan 1, apart from a slight discrepancy in the width of the cross-arms. If two different artisans created these two monuments, why did they choose to adopt nearly identical designs?

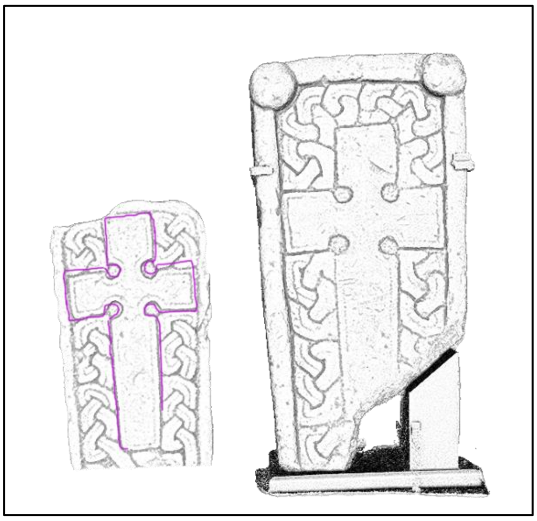


Figure 9.44. Comparison of cross-proportions; the outline of Govan 12's cross scaled down fits neatly over that of Inchinnan 1.

These two lines of analysis, Groove Analysis and typological comparison, strongly support the concept of a centralised workshop or school, where the individuals might have been trained to add this cross to their repertoire, quite likely in reference to an existing cross (either an upright stone cross, or one in a completely different medium like metal or wood). Two unassociated carvers could have been motivated in the same way, but it seems unlikely that the cross outlines would have been quite so exact, or the style of interlace so similar, if this were the case. Operating under the assumption that these two monuments are the result of two carvers from the same school, the question then becomes why differently proportioned crosses are also present in the Govan – Inchinnan school. As seen in Section 8.4, there are several “pairs” of matching cross proportions. It could be that these monuments were imbued with social significance. It is possible that these “pairs” may represent familial connections between the deceased, or, if imitating a known monument, could be used to reflect or construct a connection between the deceased and the individual to which the known monument was dedicated. Another possibility could be that these shifts in monument design reflect a change in the workshop or school’s leadership, but this is less likely as these occur mostly in pairs. Whatever the connection, there is clearly some meaning behind these similarities.

9.9 Discussion

While the above method clearly has a great deal to offer the study of early medieval sculpture, there are several complicating factors to consider. Firstly, it is important to note that this method, as is the case with many approaches to statistical cluster analysis, is better suited to identifying dissimilarities in data, rather than similarities (Kitzler Åhfeldt 2002b, 47). This makes it difficult to definitively identify a monument created by a single individual. Secondly, for samples to be comparable, consistent measurement intervals need to be used for all of the samples, which may cause complications for stones exhibiting radically different types of carving. Thirdly, several of the ten variables defined in Section 5.6.1 were left out of the analysis above either because they were either heavily impacted by weathering or the width of a groove, or because their inclusion might have overemphasised the importance of other predominant variables due to how they are calculated. It is also worth considering introducing a new variable, the consistency of carving, which is suggested here. Next, while statistical rules of thumb were adhered to in the above analysis, the impact of Principal Component 3 on the clustering of the Govan 12 and Inchinnan 1 samples above in Figure 9.37 suggests that this may not be necessary. Finally, and most importantly, it is not possible to identify one carver's signature, compare it across the collection, and identify that person's hand based on features of the grooves alone. Other elements of supporting evidence must be considered alongside the Groove Analysis data, like the design of the monument or any inscriptions that may survive. By comparing groove characteristics and design features across the collection, one can begin to come to some conclusions about the authorship of a stone.

The main issue with this approach is that it does not necessarily lend itself well to situations where a single carver is at work. If we were to isolate the samples taken from Inchinnan 1's 'Cross outline', we are left with five samples (Table 9.10). If we carry out the initial hierarchical cluster analysis, using Ward's method with squared Euclidean distance and based on AvgZ, the resultant graph does not indicate that these are very well clustered at all (Figure 9.45). However, after looking at the raw data for these samples, these separations do not make much sense: the mean value for AvgZ for all five of these samples is -3.76 mm with a standard deviation of 0.32 mm. When looking at the other variables, these are also quite consistent in their comparatively low standard deviations. When looking at the Agglomeration Schedule for the Hierarchical Cluster Analysis again, the coefficients are also very low, not exceeding 0.5 (Table 9.11). If we were to compare this Agglomeration Schedule with the same samples, but incorporating a single sample from Govan 12 (Table 9.12), this outlier's incorporation into the cluster causes the coefficient to increase to 5.761 (Table 9.13). This suggests that when using Hierarchical Cluster Analysis to identify initial clusters, it is important to consider these raw factors instead of relying solely on the 'tree'. For situations such as this, it is necessary to refer to the AvgXYZ plot for the samples – it quickly becomes apparent that there is a tight cluster of most of Inchinnan 1's samples, including those analysed here.

Table 9.10. Raw data measured from Inchinnan 1 Cross outline.

Sampl_nr	Stone_nr	v	D	AvgX	AvgY	AvgZ	mindiff	plusdiff	meddiff	w	k	n	Location
264	100	122.71	-4.16	-0.42	-1.60	-3.24	4.13	4.13	0.10	8.25	0.50	8	Cross outline
265	100	121.63	-4.61	-0.65	-1.93	-3.60	5.00	5.20	0.11	10.20	0.51	5	Cross outline
266	100	113.92	-4.91	-0.44	-1.84	-3.79	5.00	5.38	0.13	10.38	0.52	8	Cross outline
267	100	115.41	-4.85	-0.55	-1.90	-3.80	5.86	5.71	0.08	11.57	0.49	7	Cross outline
269	100	117.16	-5.10	-0.75	-2.31	-4.15	6.00	6.75	0.08	12.75	0.53	4	Cross outline

Table 9.11. Agglomeration schedule for Inchinnan 1's cross outline samples, illustrated in the dendrogram below.

Agglomeration Schedule

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	3	4	0.000	0	0	2
2	2	3	0.025	0	1	3
3	2	5	0.154	2	0	4
4	1	2	0.433	0	3	0

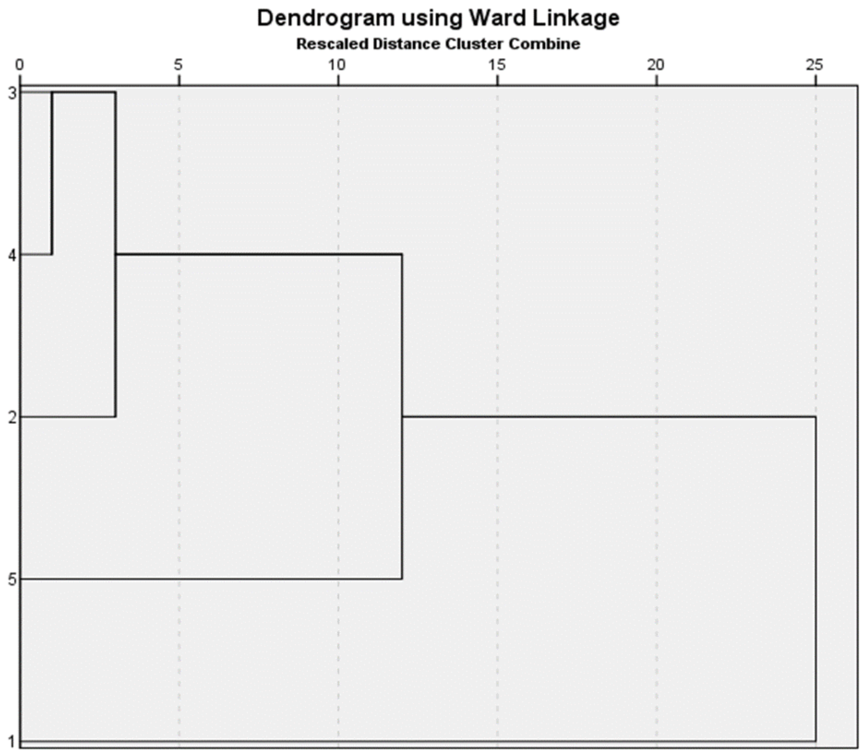


Figure 9.45. Dendrogram illustrating the relationships between the Inchinnan 1 Cross outline samples. While the Groove Analysis above has indicated that these samples were all carved by the same individual, the diagram does not reflect this very well because statistics tend to seek separation in datasets.

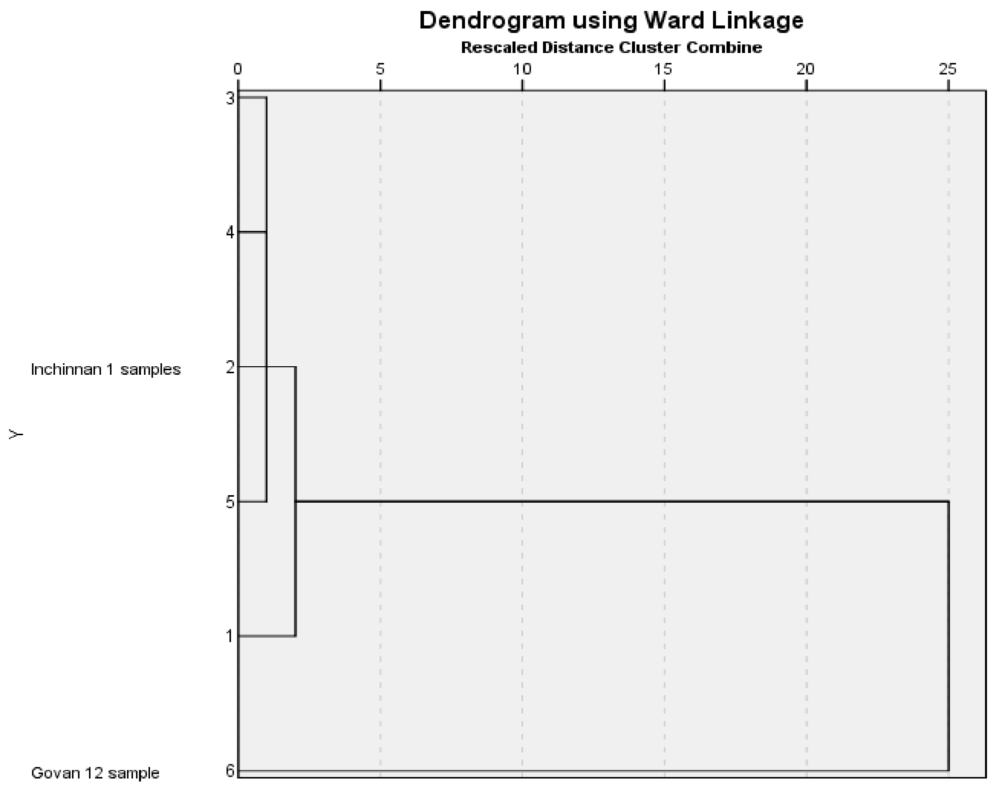


Figure 9.46. Hierarchical Cluster Analysis of the same samples as above with a sample from Govan 12's cross outline added – by adding something quite different, it becomes apparent that the five samples from Inchinnan 1 were likely to be created by the same individual.

Table 9.12. Inchinnan 1 cross outline samples with one sample from Govan 12's cross outline.

Sampl_nr	Stone_nr	v	D	AvgX	AvgY	AvgZ	mindiff	plusdiff	meddiff	w	k	n	Location
264	100	122.71	-4.16	-0.42	-1.60	-3.24	4.13	4.13	0.10	8.25	0.50	8	Cross outline
265	100	121.63	-4.61	-0.65	-1.93	-3.60	5.00	5.20	0.11	10.20	0.51	5	Cross outline
266	100	113.92	-4.91	-0.44	-1.84	-3.79	5.00	5.38	0.13	10.38	0.52	8	Cross outline
267	100	115.41	-4.85	-0.55	-1.90	-3.80	5.86	5.71	0.08	11.57	0.49	7	Cross outline
269	100	117.16	-5.10	-0.75	-2.31	-4.15	6.00	6.75	0.08	12.75	0.53	4	Cross outline
132	12	92.95	-7.57	-0.99	-3.38	-6.24	4.75	6.25	0.17	11.00	0.57	8	Cross outline

Table 9.13. Agglomeration Schedule for the Hierarchical Cluster Analysis of the Inchinnan 1 cross outline samples with one sample from Govan 12 included, illustrated in the dendrogram above.

Agglomeration Schedule

	Cluster Combined			Appears		
Stage	Cluster 1	Cluster 2	Coefficients	Cluster 1	Cluster 2	Next Stage
1	3	4	0.000	0	0	2
2	2	3	0.025	0	1	3
3	2	5	0.154	2	0	4
4	1	2	0.433	0	3	5
5	1	6	5.761	4	0	0

One of the major limitations to this approach is that the samples taken must be done at a consistent measurement interval so that the results can be comparable. In the case of Govan, most of the decoration found on the recumbent cross-slabs and crosses could be measured consistently using the 1.5mm interval between the fifteen measurements spanning the width of the groove. However, carving that is intended to be much thinner (like in the case of the shallow samples from Govan 1 above) or much wider, like the tegulated decoration found on most of the hogbacks, must be analysed separately. Upon reflection, in addition to the above analysis of the shallow grooves decorating Govan 1, it would have been even more productive to use a smaller measurement interval on the decoration of the Govan 1 horseman and compare these elements directly to identify whether its details were carved by a single individual. The carving on the Govan hogbacks (apart from Govan 2, where samples, using the same measurement intervals indicated above, were taken from various locations along the ornamental band along the bottom of the monument), is generally unsuitable for direct comparison with the 'flatter' designs of the recumbents and sarcophagus. While this approach can give us more insight into the individuals who created the cross-slabs, crosses and sarcophagus, limited connections will be possible between these monuments and the hogbacks.

In this study, while there were ten variables initially included in the analysis, there were several that were excluded from different stages of analysis for two main reasons. In the case mentioned above, the difference in groove width in the Govan 1 ‘Shallow’ samples led to AvgX and AvgY being less useful in the classification of the samples because the measurements largely fell outside the carved groove itself. These variables were also most likely to be affected by wear, as discussed more thoroughly in Section 5.6.4 and visualised in Figure 5.17. Other issues arose from variables v and D, though this may be because only decorative motifs were sampled in this analysis. As was referenced above in Section 9.8.1, Kitzler Åhfeldt has stated in her earlier research that variable v, the angle of the groove’s shape, interfered with assigning samples to their known carvers when working with decorative motifs (Kitzler 1998, 95–96), and it was discovered that removing v from the analysis had no discernible impact on the above analysis of the Govan material. Additionally, the variable D is calculated from v; while D was useful for discerning between carvers in Kitzler Åhfeldt’s analyses (Kitzler 1998, 87–89; Kitzler Åhfeldt 2002b, 31–33), the inclusion of D seemed to amplify the issues caused by v in the Govan material. While these issues would not necessarily present themselves in all cases, it is important to highlight these potential problems for the benefit of future applications of this approach.

One feature that is not currently quantified as a variable, but should be considered in future developments, is the consistency of the carving, which seems particularly well-captured in the standard deviation of the values of AvgZ. This feature has already been built-in to the Groove Profile diagrams developed by Kitzler Åhfeldt as the pink and green lines (one standard deviation above and one below the average; these can be seen in Figure 10.1 and Figure 10.2 below), and it seems particularly well-suited to identifying the work of a skilled carver as opposed to a novice carver.

One issue that is often struggled with in archaeology is how strongly we should adhere to certain statistical requirements. While tests of statistical confidence employed in other disciplines often require 95% significance to state that they are confident in a result, archaeologists are often happy with 80% confidence or more (Drennan 2010, 157–162). Small sample size is also a frequent issue, as it was in the analysis above. While the rule of thumb outlined in Section 9.4 indicated that only Principal Components 1 and 2 should be considered statistically significant, a scatterplot of PC 1 and PC 3 resulted in the most definitive separate clustering of the carving signatures for Govan 12 and Inchinnan 1. It is quite likely that adhering to this statistical rule was overly cautious.

After establishing the above two points, it is worth considering what causes might be underlying Principal Component 1. While it is most likely that the variables v, D, AvgX, AvgY and AvgZ are so consistently contributing to PC1 because of their description of the groove shape, it is possible that the preservation of the sample itself is a contributing underlying factor. In these analyses, variables AvgZ, v, and D are associated with the largest loadings for PC1 by far; because variable D is a hypothetical projection of a 'pristine' V-shaped groove, it is possible that this strong relationship between these variables is causing PC1 to reflect preservation as an underlying factor. This will need further consideration in the future to be certain.

Finally, it is not possible to identify a single carver's 'signature' and say for certain that a similar signature on a different stone represents the same individual's work without additional supporting evidence. While the ornamentation of the early medieval sculpture at Govan is relatively consistent in art historical terms, the specific period of these stones is uncertain. Two individuals, especially beginners, within a timespan of two centuries could easily demonstrate a similar carving style. Kitzler Åhfeldt has found in her reference material that if two beginners work on a single stone, it can be difficult to identify their individual carving technique (2002a, 83). If this analysis can be expanded upon in the future, these caveats will need to be considered along with the statistical results.

Overall, this analysis has been successful in that it has demonstrated that it is possible to apply this analysis to photogrammetric models created by different individuals, and to carving that is quite different from the Swedish runestones for which Kitzler Åhfeldt has developed the method. To date, samples have been taken from nineteen of the Govan stones and Inchinnan 1. From the above, it appears that at least two carvers had a hand in carving the sarcophagus, one or two carvers created Govan 12, and one or two carvers carved Inchinnan 1. The carver assignment and position of the samples of Govan 1 strongly suggest for a division of labour in its creation: Carver B+D outlined panel edges and detailed the horseman and beasts, while Carver A+C focused on the interior forms of interlace and their bisecting grooves. While it was previously thought that the Alpha symbol on the flank of the horse was a later addition, this analysis suggests that it most likely was carved concurrently with the horseman's other details. The comparison between Inchinnan 1 and Govan 12 suggested that, despite design similarities, these two stones were probably carved by different individuals inspired by a common source. This has interesting implications for the question of whether or not a centralised school or workshop existed. If two different carvers with distinguishable carving styles carve a nearly identical cross to different scales, it is suggested here that this is strong evidence for the presence of a common workshop and moreover could reflect social connections between the individuals being commemorated. While Govan 1, Govan 12, and Inchinnan 1 represent a small subset of the stones of the Strathclyde region, the quantitative and statistical analysis of their carvings has already offered a bit more insight into the expertise of their carvers. It is clear that this analysis has the potential to enhance our knowledge of the stones through this innovative digital perspective.

10 Discussion and Conclusions

10.1 Introduction

This final chapter summarises and draws together the individual strands of evidence from the digitally-based analyses addressed above into a new perspective on the Govan school of sculpture and its carvers. From the outset, the study presented here set out to:

- Identify the best method for recording the Govan stones in 3D. Photogrammetry was chosen primarily due to the technique's flexibility, but an added benefit was discovered during data capture. To create the ideal lighting environment for photogrammetry, additional engagement with the material is required. This process allowed for a more intimate familiarity with the carving than that necessitated by laser scanning or white-light scanning, while still producing a highly detailed and accurate dataset;

- Create a full digital corpus of the Govan collection and identify the best method of dissemination for these resources;

- Use both 3D and Reflectance Transformation Imaging to enable worn and previously unidentified patterns from the stones to be recognised. This led to the creation of a 'digitally-worn reference collection' which proved valuable in identifying significantly worn ornamentation;

- Adapt Laila Kitzler Åhfeldt's approach of comparing the outlines of carved figures with bespoke software to identify areas of potential template use into a step-by-step guide using comparatively affordable and accessible software (2009a); and

- Determine whether Groove Analysis can be applied to the Govan material to identify the work of individual sculptors.

The results of the digital analyses performed here now allow for wider issues to be discussed, including:

- The critical reappraisal and recovery of worn patterns from the recumbent cross-slabs, simultaneously considered alongside the proportions of the crosses and the structural layout of the decoration, led to the development of a new classification of Govan's recumbent cross-slabs;

- The potential for the use of templates in the replication of the horsemen and deer-like beasts in the Govan collection was considered;

- After Groove Analysis was applied to the photogrammetric models of the sarcophagus and two of the recumbent cross-slabs, it was determined that a minimum of two carvers worked to create the sarcophagus, and that two separate individuals carved Govan 12 and Inchinnan 1, despite their similarity in appearance and typological classification;

- The culmination of the results from digital analyses are discussed in the context of whether they support or contradict the existence of a Govan school or workshop.

Finally, this chapter concludes with a discussion of the several avenues for future research this work has highlighted. It considers the potential for further analysis of worn archaeological materials, future directions for investigation of the Govan School, and the immense research benefit that the creation of a centralised 3D digital corpus of the early medieval sculpture in Scotland would offer.

10.2 Digital Imaging in the Analysis of Early Medieval Sculpture

From the preceding chapters, it is clear that digital imaging has a great deal to offer future analyses of carved stone. In this case, Structure-from-motion photogrammetry was chosen as the best 3D imaging technique to record the Govan collection. This decision was influenced in part by the way in which the stones are mounted; the majority have at least one side that is partially or fully inaccessible. While each approach explored in Section 5.1 produced 3D models of comparable quality, photogrammetry is a more flexible technique than white-light scanning and laser scanning because photographs taken from almost any digital camera can be used. Indeed, a smartphone camera was used to capture the undersides of four of the hogbacks and an obscured surface of Govan 10, which would not have been accessible using white-light scanning or laser scanning.

Photogrammetry also allows for intrusive objects, like the metal brackets holding many of the Govan stones in place, to be ‘masked,’ or excluded from the final 3D model. Supplementary photographs were taken of the surface underneath the brackets as they were removed and returned one at a time; this allowed the stones to be sufficiently supported as these obscured surfaces were recorded. If white-light scanning or laser scanning were used to capture these surfaces, this would have required heavy lifting equipment, which would have been more inconvenient and much more expensive. This method had the additional conservation benefit of making it possible to identify the damage the brackets had done to the stones and enact protective measures.

An unappreciated intellectual benefit is that the process of photogrammetry necessitates a deeper engagement with the carving than the other approaches (see Chapter 5). For both laser scanning and white-light scanning, the operator’s attention is primarily focused on the imaging equipment rather than the object; in photogrammetry, during data capture, the operator must engage with the object by moving the light sources to minimise shadow in the photographs and scrutinize how the carving reacts to the lighting position. This close engagement revealed details in real time and drew attention to key elements of the stones. In this thesis, it was determined in both quantitative and qualitative terms that photogrammetry was the best 3D imaging technique to apply to the Govan collection.

The digital files have allowed for a closer inspection of the carved stones in the Govan collection. Even by simply removing the coloured texture from the 3D model and emphasizing the carved areas with freely available software, previously unidentified patterns have been observed, for instance, on the ridge of Govan 2, in the panel below the horseman of Govan 9 and the reverse of Govan 10 (See Sections 6.2, 6.3, and 6.4).

10.3 Pattern Recovery, 'Aura', and the Carver's Vision

As the results of Chapter 6 have shown, digital imaging techniques, like photogrammetry and Reflectance Transformation Imaging, have the potential to enrich our interpretation of the worn carved stone monuments. By analysing the remnants of pattern using these imaging techniques, either through examination of the RTI file, or comparison of these remnants with a 'digitally-worn reference collection', it was often possible to identify and reconstruct the ornament that had eroded from the stone's surface. These reconstructions aim to remain true to the carver's design; where Govan's patterns had previously been simplified in J. Romilly Allen's descriptions to fit his idealized mathematical interlace classification (1903), here the reconstructions preserve the imperfections, even where the patterns are confusing and disconnected. By embracing these authentic features, these newly identified patterns and their intended purpose can be more thoroughly discussed and understood.

As discussed in Chapter 6, a combination of approaches was often employed in recovering differentially worn patterns from a single stone; some patterns were more intact and only required close examination of the surface using RTI. However, the creation of a 'digitally-worn reference collection' was a key innovation of this thesis and has been instrumental in identifying patterns that previously have been considered too far gone. The application of this specific process (outlined in Section 5.4.2) has led to the recovery of at least eight previously unidentified patterns from seven different recumbent cross-slabs in the Govan collection. Sixteen copies of the 3D models of the recumbent cross-slabs at Govan have been digitally 'recarved' to outline and enhance their patterns so that they are clearly visible.

The digital restoration of an incomplete or damaged work of art is not simply a technical matter; it raises conceptual, philosophical, and ethical issues. Some have argued that the damage that an artefact or monument has sustained throughout its lifetime is intrinsic to its 'aura' (Douglas-Jones et al. 2016). Walter Benjamin had argued that the mechanical reproduction of an object interrupts or diminishes the viewer's experience of the 'Art' because it cannot replicate this 'aura,' or its authenticity (Benjamin [1936] 1999, 214–215). While Benjamin was largely referring to the photography of art, this became a particular concern of museum professionals with the increasing prevalence of 3D recording, as it was believed that these would be seen as adequate replacements for the physical objects themselves (Cameron 2007, 50–51). This position has since been challenged by many, especially in the past twenty years (Cameron 2007; Latour & Lowe 2011; Jeffrey 2015). A key point, emphasised by this study, is that 3D models from any method are not objective copies because the operator must make creative decisions in data capture and processing (Jeffrey 2018, 50). While some may argue that 3D models and reconstructions of the monument diminish the 'aura' of the object itself, the opposite is argued here, as long as the reconstructions are clearly and transparently labelled as such (Galeazzi 2018, 273).

When considering this concept of authenticity in the context of the recumbent cross-slabs at Govan, their prevalence in the collection and their accumulation of 'biography' (i.e. damage and wear) had led to an academic atmosphere of benign resignation that little more information could be recovered from the individual monuments. As a result, the sarcophagus, hogbacks, and crosses at Govan have largely received the most in-depth analysis. It is argued here that, through the creation of these digital files and their utilisation in the recovery of previously unidentified patterns from these monuments, these newly-informed 3D reconstructions can in fact enhance their 'auras,' especially if the interpretation can be situated adjacent to the object itself (or on the same webpage as the original 3D model), by offering newly informed interpretations of the damaged monument's appearance in the earliest stages of their biographies. This, in a way, complements the modern viewer's understanding of the monument and ties the physical object closer to those people in the past who carved the recumbent cross-slabs, or even those who were commemorated by them (Jeffrey 2018, 51). Despite the different approaches to data capture between this project and ACCORD ('professionals' vs co-production with voluntary members of the community), this echoes one of the findings of the ACCORD project: 'the creation of digital models can actively mediate the authenticity and status of their original counterparts' (Jones et al. 2017, 350).

This process of recovering and identifying ornament has also highlighted patterns that have been misidentified or oversimplified by J. Romilly Allen's interlace classification. Much of the ornament at Govan incorporates loose strands mid-way through the panel or completes a pattern with loose ends tucked into corners. As argued in Section 8.3.2, while this is occasionally attributed to the 'incompetence' of the carver, it is likely that this reflects an artistic decision by the carver to achieve a certain effect at the expense of 'perfection.' This purposefully confusing interlace may have had a non-aesthetic function in the sculptor's mind: an apotropaic function for the individual commemorated by the monument. This has been argued as a theme for the Pictish sculpture at Meigle, where Christian imagery and panels of interlace protect riders and other figures from various monsters and beasts (Thompson 2017). While imagery in the Govan collection is not as explicit in portraying this function as at Meigle, the rider on the sarcophagus at Govan is akin to that seen on Meigle 26 where the horseman is flanked and 'protected' by interlace panels.

This study has shown that digital imaging techniques can offer new insights into the decoration of the Govan stones and can be used to recover patterns from worn and damaged monuments in a critical way. Both 3D imagery and RTI have the potential to offer new perspectives on worn and damaged monuments; defining features can be identified and highlighted on still images to clearly illustrate the decision-making process behind the reconstruction. A key development of this thesis has been the development of a methodology for recovering significantly worn panels; 3D models of well-preserved stones can be digitally eroded to produce a comparative collection of known worn patterns. By highlighting the remnants of carving on a worn stone and comparing the shape and positioning of these remnants to the comparative collection, the basic form of the ornament can be reclaimed. While Allen's interlace classification scheme is useful for identifying trends on a national level, the inherent generalisation results in the loss of the idiosyncrasies and underlying meaning or function of the carving intended by the carver. Patterns that have been newly recovered or reinterpreted in this thesis have been portrayed in a representation faithful to the carver's design. This restores the recumbent cross-slab monuments, previously overshadowed by the sarcophagus, crosses, and hogbacks, to their approximate significance as the most numerous and most long-lived of the collection. This is synthesised in the new typology which reveals the rich evolution and the cross-fertilisation of distinct sub-groups within the assemblage.

10.4 Template use identification

Leading scholars in early medieval sculpture have postulated that the Govan carvers could have utilised templates in the reproduction of certain figures and beasts across different pieces of sculpture (Craig 1994b, 79). Traditionally, the exploration of template use relied on comparing rubbings taken directly from the stone, which can cause undue stress to the carved surface. Laila Kitzler Åhfeldt employed a digital approach to identify the use of templates in her analyses of the picture stones of Gotland; she used the bespoke ATOS software associated with the brand of laser scanner utilised in these projects. This software provides tools that can produce outlines of features that take into account the three-dimensionality of the surface for more accurate comparison (2009b, 138–140). A simple, but more accessible, combination of software was used here based on the same overall concept to explore the possibility of template use in the carving of the Govan stones. While this process, laid out in Section 5.5, involves transitioning the 3D model into a 2D image for comparison, the surfaces of the carved figures and animals on the Govan material are relatively flat and even; any undulations in the surface of the figures would have had minimal impact on the 2D outline. Template use is of relevance to the question of whether a ‘Govan school’ or centralised workshop existed; Richard Bailey has argued that the replication of motifs through templates is likely indicative of the presence of a workshop, where multiple individuals share tools and templates (1996, 114–115). However, Kitzler Åhfeldt was more conservative in her discussion of whether the replication of a feature between stones as indicative of a centralised workshop at work; she argued that pattern books containing reproduced motifs could have a long use-life (2009a, 499–500, 502–503). It is also worth noting that these early medieval carvers could have just as easily created their own templates from already existing sculptural details with charcoal and a pliable material, much in the same way rubbings of sculpture have been created in more recent times. Overall, it was unclear whether this analysis of template use would contribute much to the discussion of a Govan school, but it was necessary to explore and address the possibility.

The analysis and discussion outlined in Chapter 7 has confirmed that templates were unlikely to have been used to transfer and replicate the forms of the Govan horsemen between monuments in the collection. However, by undertaking a close comparison between the outlines of these figures, it became apparent that there a shift in the positioning of the horseman's leg within the Govan collection. While some insight was gained into the significance of the horsemen's different leg positions through this close comparison of horsemen on other pieces of Scottish sculpture, further analysis is required on a wider scale.

There is also some evidence to suggest that templates may have been used piecemeal to simulate symmetry and plan the positioning of different beast components on the sarcophagus. Some have previously argued that the use of templates might indicate a lack of skill on the part of the sculptor, but if templates were used in the composition of the beast panels on the sarcophagus, it seems most likely that they were utilised to ensure the viewer's perception of symmetry between beasts to emphasize the elements of asymmetry introduced between them. It could be that these panels reference biblical passages of salvation, like Psalm 42:1-5 where the 'reflection' of the deer-like beasts could represent water or 'streams' from which the deer wish to drink. The crossing of their hindlegs in the lower half of the panel seems to contradict this interpretation, though this could be emphasizing the apotropaic function of the crossed strands of interlace. This is purely conjecture, and while the exact meaning is lost to us now, this analysis offers some insight into the carver's process and necessitates a closer examination of sculptural details.

It is possible that the use of templates between pieces of sculpture could indicate the presence of a workshop, but there is little evidence for this in the Govan collection. Without the recovery of a physical template, it will be impossible to definitively prove that the carvers had 'expectations to have use for them' (Kitzler Åhfeldt 2009a, 502). While the results of this analysis do not contribute much to the discussion of whether a formal Govan school of carving existed, they do offer insight into changes in figural representations and the intent of the carvers. The methodology outlined in Section 5.5 provides step-by-step guidance for an accessible, non-contact digital alternative to the rubbings that are usually taken to compare elements of sculpture suspected to share a template. This approach also proved useful in the comparison of cross proportions between the recumbent cross-slabs, which was integral to the identification of internal phases within the collection and culminated in the development of a new typology.

10.5 Typology

The typology proposed in Chapter 8 offers a fresh model for understanding the complexity of the recumbents. It is of course provisional, but it is based on a more rigorous trait analysis than previous schemes. It highlights several trends of similarity in monument design that were overlooked in previous work. By incorporating the newly identified patterns from the recumbent cross-slabs, the classification of the ornament, and considering the proportionality of the cross-forms, three groups broadly defined by interlace-type were identified and further stratified by two prominent internal phases of standardization. By considering features that were identifiable on the most worn monuments, a more coherent vision of the carved stones at Govan was constructed.

The three groups that were identified by interlace type are those that utilised Stafford knots (Group I) (which includes an additional sub-group comprised of the recumbent cross-slabs exhibiting key pattern (Group Ia)), those that employed free-ring interlace (Group II), and finally a group where both Stafford knots and free-ring interlace were both used in the ornamentation of the monument (Group III). While different variants on plaits and twists (some made to resemble or simulate either Stafford knots or free-ring interlace, but fundamentally differ in construction) were also used throughout the collection, the definition of these large groups by the presence or absence of these two basic units of ornament highlighted further internal phases within the collection.

The two phases of standardization are evident across different primary groups. Across Groups I and II, it is evident that there was a phase where proportionally identical crosses were applied to pairs of recumbent monuments, of which there are three clear pairs extant between the collections at Govan and Inchinnan. Why this element was replicated so exactly albeit at different scales is unclear, though it seems likely that the carvers made these direct references for a reason. The second trend is most clearly visible in Group III, where the space directly below the cross is separated visually from the rest of the design, forming a visual 'cross base' for the cross. This element is present in almost all of the recumbent cross-slabs in Group III as an angular Stafford knot pattern, except for Govan 16, though the base of this monument is damaged. This feature found on some of the stones from Groups I and II is why they are considered 'transitional monuments,' because although they may not exhibit both Stafford knots and free-ring interlace, but they do have a separate 'cross base' segment in their layout.

Some of the transitional monuments suggest that these shifts in pattern preference were not sudden. The temporal relationship between Groups I and II is unclear, though there must be some overlap due to the presence of proportional cross pairs standardization occurring across both groups. It may be that individual carvers preferred the look of one family of patterns over the other, and that Group III represents what appears to be a later generation of carvers that embraced both. As discussed in Section 8.4, the other monument types in the Govan collection can be considered alongside the typology for a different perspective on the time-depth of the recumbent cross-slabs. If one accepts that the sarcophagus is amongst the earliest carved stone monuments at Govan, it is chronologically significant that it does not use free-rings, only Stafford knot-related patterns and plaits, like the recumbent cross-slabs in Group I. In the same way, if one agrees with many who have argued that Govan 8 is one of the latest monuments in the collection, the prominent angular interlace reflects the angular Stafford knot patterns forming the 'cross-base' element of the recumbent cross-slabs of Group III. The swastika-esque pattern on the hogback Govan 2 could also fall within this trend of angular ornamentation, and the only parallel for its ring-chain pattern in the collection is that found on Govan 24, one of the recumbent cross-slabs that here is proposed to be later in date.

Previous scholars were unable to identify a temporal sequence for the recumbent cross-slabs (Craig 1994b, 80), but the level of standardization apparent during the two internal phases strongly suggests that these correlate to temporal divisions within the collection. The dating and duration of these phases remains a matter of speculation (see above). These regimented features also indicate that there was some higher authority or, at the very least, guidance followed by the carvers. These standards clearly left ample opportunity for the carvers to apply their own creativity, as even the cross-slabs with proportionally identical crosses exhibit clear variations in the patterns applied. In developing this typology, it reinforced a belief that there was a workshop mentality at play influencing the carvers working at Govan and Inchinnan.

A surprising aspect of this typology is that it does not revolve around the oft-cited angle-knob features of recumbent monuments in the Strathclyde region. However, the inconsistency of the form of these angle-knobs suggests that they were a long-lived feature of the Govan school with continuous significance, rather than a temporally restricted trait. It is argued here that these protrusions were restricted to the memorials of high-status individuals, perhaps that of high-ranking members of the church or relatives of prominent patrons.

10.6 Groove Analysis

As laid out in Chapter 9, the results of the Groove Analysis in the context of this project can be summarised as follows. First, it quickly became apparent that the 3D models produced through photogrammetry were of sufficient accuracy and quality that they could be used with Groove Analysis to identify differences and similarities between carving samples. Secondly, the analysis of the Govan sarcophagus suggests that at least two individuals worked together to carve it. It appears that they divided their work so that one person was responsible for creating the panel outlines and figures, while the other focused on the creation of the interlace and the associated median-incisions. Thirdly, the 'Alpha' symbol on the hindquarters of the horse, which had previously been suggested to be a later addition to the sarcophagus, does not differ significantly from the carving style identified in the other details of the Govan horseman. It is likely that this letter was part of the original design of the sarcophagus. Finally, in the comparison the results of this analysis for Govan 12 and Inchinnan 1, while these are similar in motif choice and cross form, they do not appear to have been made by the same carver. These results will be further discussed in relation to the concept of a centralised school or workshop in the Strathclyde region below.

First, as mentioned above and analysed more thoroughly in Section 5.1.4, Structure-from-Motion photogrammetry is capable of producing 3D models that are just as accurate as those produced through terrestrial laser scanning and white-light scanning. As seen in the description of the Groove Analysis methods outlined in Section 5.6 and Chapter 9, enough geometric detail has been captured from the grooves to calculate the variables intrinsic to the analysis. Even when digitally eroded, the worn and unworn versions of the same groove sample can be matched together; this process confirmed that the work of individual carvers, even when worn, can be identified through this statistical analysis (See Sections 5.6.4 and 9.4).

In the case of Govan 1, it was necessary to divide the thirty-seven samples based on the 'types' of carving they represented. From the eight clusters that were initially identified; it was determined that these likely represented variations on a minimum of two carving styles, differentiating between approaches to simpler carving and more complex carving that would have required more caution (See Section 9.3 for details). As mentioned above and discussed more thoroughly in Section 9.8.1, there is also evidence for a division of labour in the construction of the sarcophagus; one individual appears to have been responsible for outlining the panels, and the carving of figural sculpture and their details; another carver focused on the creation of the interlace patterns. Whether the relationship between the two sculptors was one between master and apprentice or equals who excelled in different types of carving is unclear. However, if the sarcophagus is indeed the earliest carved stone monument in the Govan collection, as has recently become the consensus as suggested in Section 3.1, the results from this Groove Analysis indicate that multiple carvers were working together to produce sculpture in Strathclyde from early in the sequence.

Another significant result from this analysis is that there is nothing to suggest that the 'Alpha' symbol was carved by a different individual from the one that carved the fine details on the sarcophagus's horseman. While Spearman and others have suggested that the carving of the symbol appears to be a later addition (1994, 43), perhaps because it appears 'fresher' than the rest of the decoration, it is illustrated in Section 9.8.1.1 how this may be a sort of optical illusion due to the uneven surface of the stone. This does little to refine the dating of the sarcophagus, because similarly constructed 'Alpha' symbols have been found on sculpture across Britain from the 7th century AD onwards (Spearman 1994, 43), but the rest of the sculpture of Govan lacks any other contemporary inscriptions. While a single letter does not necessarily confirm that the carvers were literate, this letter form is quite similar to that found on several folios in the Book of Kells (Meehan 2012, 49, 56, 58–59) recently at Tintagel (English Heritage 2018), in Durham at Hartlepool (Cramp 1984a, 98), and in Wales, at St David's (Edwards 2001, 66). This highlights that the carvers were at least familiar with the letter form and the significance this would have had for the viewer's interpretation of the rider.

Finally, after critical evaluation of the Groove Analysis data, we can say with some confidence that Govan 12 and Inchinnan 1 were carved by two different individuals, despite the similarity of their design. Close inspection of the groove profiles for each stone suggests that the carver of Inchinnan 1 was more consistent and skilled than the carver of Govan 12 (Figure 10.1 and Figure 10.2). There is also the possibility that Govan 12 represents the work of an inexperienced carver who, over time, became more skilled in the craft and created Inchinnan 1 (for Kitzler Åhfeldt's comment on the effects of increasing skill on Groove Analysis results, see 2002, 92; Kitzler 1998, 91–92); however, the narrow typological window within which they fall suggests that a relatively short period of time would have elapsed between the carving of the two monuments.

This allows us to speculate about what type of relationship existed between these two individual carvers. As stated above, the duplication of several elements of design at differing scales and the alteration of others is intriguing. It is unclear which would have been carved first – did a skilled sculptor create Inchinnan 1 first, followed by an apprentice who attempted to replicate some elements and make their own artistic impact upon others? Or is it more likely that a relative unskilled carver created Govan 12, only to have their design improved upon by a more practised carver?

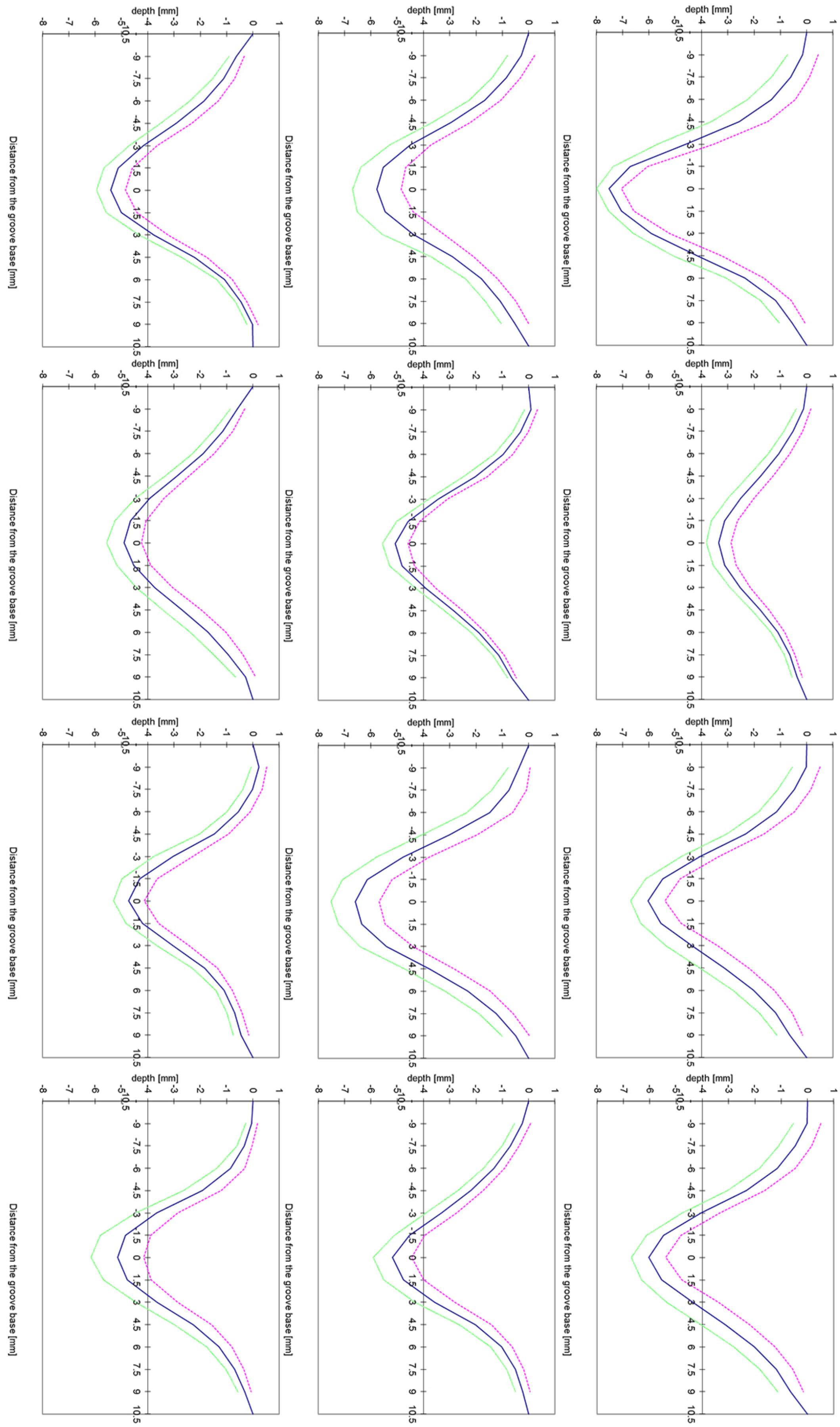


Figure 10.1. Average Groove Profile of the samples taken from Govan 12. Their groove profiles vary in depth from 4-8 mm, and the standard deviation in a single sample is quite large.

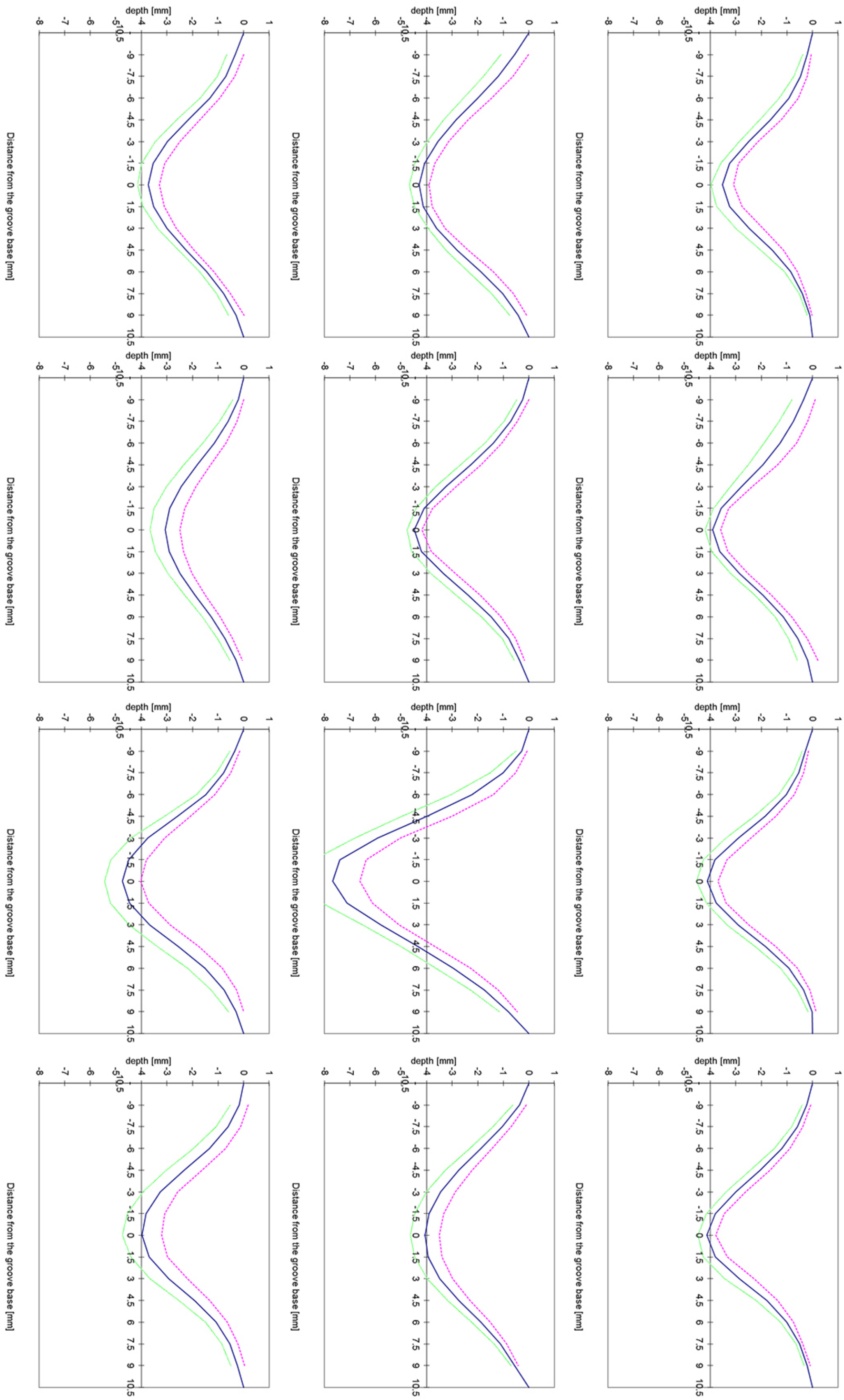


Figure 10.2. Average Groove Profiles of the samples taken from Inchinnan 1. Their groove profiles usually vary from 3-5mm in depth and the standard deviation for each sample is quite narrow and consistent.

It is clear from this analysis that photogrammetry can produce 3D models that are sufficiently detailed to identify consistencies and differences in carving technique. Govan 12 and Inchinnan 1, two stones which are closely related in pattern type and cross-form, do not appear to have been carved by the same individual. While it is impossible to tell which of the above scenarios is more likely, this evidence, paired with the suggested minimum of two carvers of the sarcophagus, strongly supports the concept that there was a group of carvers working in the same region and adhering to a set of design principles.

10.7 The Govan School

From the above analyses, the strongest evidence for the existence of a Govan School of carving are the several phases of standardisation found across the recumbent cross-slabs at Govan, the ties the standardisations highlight with the sculpture at Inchinnan, and the results of the Groove Analysis, which suggest that different individuals were conforming to these standards. The above typology indicates that the style of the sculpture changed through time, likely reflecting shifts in local preferences. The following section discusses these results from Govan and Inchinnan in the context of wider sculptural connections. These art historical connections of shared ornamentation types and themes are often referred to as a 'school,' sometimes out of convenience as a descriptor to acknowledge these similarities, as stated in Section 4.2, but it does imply a centralised location where the carvers work or where they are instructed in their craft (or both) (Driscoll et al. 2005, 141–142). Because these analyses have been combined to shed some light on how the monument carvers at Govan might have been organised, it is worth considering what archaeological evidence might indicate the presence of a training centre (school) or a centralised stone-carving workshop and which of the sites in the broader Strathclyde region might fit these descriptions.

The combination of the above analyses has offered a slightly clearer picture of the Govan School. The recumbent cross-slab typology has highlighted several shifts of uniform trends in design; it is argued here that these most likely represent changes in standards either agreed upon by the members of the workshop or imposed by a master craftsperson through time. What underlying meaning the paired proportional crosses might have had in the recumbent cross-slabs is uncertain, though it was clearly a conscious decision on the part of the carvers to replicate them so exactly. It seems to indicate some sort of social connection, perhaps indicative of a familial relationship between the two deceased individuals commemorated by the paired monuments. Similarity in these design elements could also be tied to the results of the Groove Analysis between Govan 12 and Inchinnan 1. While carved by different individuals, it seems most likely that there was a social relationship between the sculptors of these two monuments; perhaps one (likely Inchinnan 1) was carved by a more experienced carver and the other (Govan 12) by their apprentice or trainee. Whether this was the case or not, these two monuments provide clear, physical evidence for a connection between Govan and Inchinnan during the early medieval period, likely through a shared tradition of carving.

This analysis only offers a brief glimpse into the organisation of the carvers who created the sculpture in the Strathclyde region. It is still unclear if a stone-carving workshop or school would have been housed at Govan, or if the carvers were trained or based off-site. In her comprehensive work on Irish motif pieces, O'Meadhra highlights that there is a fundamental change in craftwork at the turn of the millennium largely due to the development of towns and the impact of changes in ecclesiastic traditions (1987, 104), which makes it difficult to identify the social organisation of craftworkers. Most of the Irish written sources she utilised suggest that craftspeople of all kinds were based in static workshops, though they could travel to deliver commissions (O'Meadhra 1987, 168). However, the training centres for these craftspeople would not necessarily need to be based at a monastic institution, as there is evidence for this through the proliferation of motif pieces at secular and high status sites (O'Meadhra 1987, 76–77, 100). Archaeologically, a centralised stone carving workshop would be difficult to detect, as Meggen Gondek has stated; one might expect an excess of fragmented stone, or forgotten or broken carving tools, though these could be easily recycled into other features or objects (2006, 110–111). As far as identifying craftwork training centres archaeologically, O'Meadhra argues that the identification of motif-pieces composed by artists-in-training requires evidence of repetition (and possibly corrections by a different artist), and the depiction of simple motifs where principles of alternation are practiced (1987, 98–99).

When searching for these possible locations in Strathclyde, it is important to consider the sculptural connection between St Blane's on Bute, Govan, and Inchinnan. Historical records indicate that St Blane's was a bishopric that became a monastic institution in the eighth century AD (Radford 1967b, 115–116; Laing et al. 1998, 553); however, the site falls out of mention in the Irish Annals, its last mention recorded in 790 AD (Laing et al. 1998, 554–555). This is attributed to Viking intervention and eventual Norse influence over the site (Radford 1967b, 116; Laing et al. 1998, 553), a familiar story when considered alongside the current narrative of Govan. The date of this sudden disappearance from the Irish record coincides with a similar silence on the fate of Dumbarton Rock after a Viking raid some eighty years later (Alcock & Alcock 1990, 98–99; Clancy 2006, 1818). It is possible that this historical narrative, the sudden appearance of a sculptural tradition at Govan in the 9th century AD, and the stylistic links between the carved stones from Bute to the Govan sculpture could all be connected.

This similarity in style between St Blane's and Govan is not often included in discussions on the 'Govan school' (Driscoll et al. 2005; Craig 1994b), likely because it originally played a more prominent role in a Dalriadan context (Laing et al. 1998, 553), but several distinctly shared features are worth comment. Not only did one of the now-missing recumbent cross-slabs from St Blane's exhibit angle-knobs, but one of the cross-shafts shares a similar angular interlace pattern found on Govan 8 (as depicted in Figure 7.3 in Section 7.1). Excavations at St Blane's has also produced a number of slate inscriptions, and one of the slate motif-pieces from St Blane's depicts a simplified ring-knot like that found on Govan 18 and Inchinnan 5 (Kasten In press b). While the motif of the ring-knot is skilfully done, the carver of the interlace pattern on another piece of slate does not attempt to maintain a consistent over-under relationship between strands, and a fragmentary hunting scene is different to that found on the sarcophagus because it only features three thin dogs and one poorly-executed deer (Anderson 1900, 314–315). It is difficult to say whether these motifs would meet O'Meadhra's above criterion of repetition to qualify these as the work of trainees because of the artefacts' fragmentary nature, but the interlace patterns are relatively simple motifs and a carver clearly struggles with the more complicated of the two. Other evidence for learning can be found in other motif pieces from the site which have been inscribed with letter forms broadly dated by Lloyd Laing to the 9th-12th centuries AD (1996, 130–134). The more recently excavated monastic community on the island of Inchmarnock, which was likely associated with the church at St Blane's, produced over a hundred pieces of incised slate. Several of these exhibit both Latin and Gaelic inscriptions, in both ogham and Roman scripts, and most of them date between the 7th and 9th centuries AD (Forsyth & Tedeschi 2008, 130–131). Again, those slates lacking inscriptions share some motifs in common with the Govan material, specifically the attempt of another hunting scene (Lowe 2008, 162–165), a simple swastika, the beginnings of a mitre pattern, and two bands of step pattern (Lowe 2008, 157, 168). In contrast, no motif pieces have been recovered from the various excavations at Govan (Driscoll 2004; Cullen & Driscoll 1995; Driscoll 1995), though this could be a preservation issue, as motif pieces can be carved into a variety of material.

It could be that the institution at St Blane's (and possibly the associated Inchmarnock) trained carvers in the Strathclyde Style, after which they moved to a workshop near Govan, where demand for carved stone was apparently greatest for the commemoration of elite patrons or ecclesiastical figures. Admittedly this is based on tenuous evidence in some cases and absence of evidence in others, but it is still a useful exercise to consider what physical evidence we as researchers might expect when considering an art historical school. There is clearly a significant relationship between St Blane's and Govan, as has previously been noted by others (Gondek 2003, 144; Laing et al. 1998, 553); this is physically substantiated by the shared sculptural trends, specifically the angle-knobs of the now missing recumbent slab from St Blane's and the striking resemblance between St Blane's No. 2 (Allen & Anderson 1903, 2, 407) and Govan 9 (a similarity previously identified in Section 7.1). However, further excavation at these sites would be instrumental in developing a better understanding of how they were interrelated in the 9th-11th centuries.

In conclusion, it is difficult to discuss the organisation of individual carvers within a region without coming to grips with what physical reality the art historical concept of a 'School of carving' might have taken. O'Meadhra refers to Irish historical sources from the 6th to 8th centuries AD to support the idea of training centres (often in monasteries, though not exclusively) where pupils were instructed in writing along with craftwork of all kinds, including manuscripts, metalwork, and sculpture (1987, 99–103) and argues that motif pieces can be indicative of the presence of a learning institution (1987, 98–99). Archaeologically, a stone-carving workshop would be difficult to identify, as Meggen Gondek has stated, as the by-products of stone carving could be incorporated into other site features, such as a metalled road (Gondek 2006, 110), one of which has been identified at Govan (Driscoll 2004, 17), or recycled, in the case of broken tools. Govan was clearly a 'consumer', for lack of a better term, as a mother church and place of burial for elite patrons or clergy of some status, so it could be that a workshop was situated at the site or nearby to better meet demand. While it is unclear how the different sites in Strathclyde and along the Firth of Clyde would have interacted, it is clear through the sculptural evidence that there are connections, though they will only be better understood through further excavation and analysis.

10.8 Future Research

This project has demonstrated that 3D imaging and RTI are indispensable research tools in the study of carved stone and has highlighted several directions for future research. Details can be recovered from worn stone using these techniques and could be applied to the analysis of other worn artefacts in different materials; identification of significantly worn decoration can be more easily facilitated by the creation of 'digitally worn comparative collections' of similar material. Additional research into the Govan school is still required; the application of Groove Analysis to stones within and without the Govan collection would give a clearer indication as to how many carvers were part of this workshop, though a detailed geological study of the stones is required for the comparative condition of each stone can be fully considered. Finally, this project illustrates how an updated digital corpus of early medieval carved stones in Scotland would be immensely beneficial to the study of this material.

10.8.1 Insight into Worn Surfaces

Chapter 6 has demonstrated that, by using photogrammetry and RTI, worn carved stones can now be more acutely analysed and brought into future research. Not only has this process enabled the classification of many worn patterns from the stones at Govan, but it has also led to the discovery of previously unidentified early medieval sculpture (Kasten In press b). There are still stones in the Govan collection and many more in the Govan school that would benefit from this analysis. In Section 6.4, it was highlighted that the obscured surface of Govan 10 appears to retain the carved form of a house-shaped shrine. RTI has the potential to identify smaller details that could either support or refute this interpretation; unfortunately, because this portion of the 3D model was produced with photographs from a cellphone camera, there is a great deal of noise that makes the use of digital RTI less desirable in this case. It is recommended here that RTI be applied to this surface if the monument is redisplayed in the near future to determine if this identification can be further substantiated.

While the worn comparative collection from Govan was employed in the recovery of ornamentation from Inchinnan 5 (Kasten In press b), it is unclear if it would be sufficient to recover patterns from sculpture belonging to different schools in other parts of Scotland. Different types of carving (incised vs pecked vs relief) would likely require the creation of new 3D comparative collections. These techniques are not limited to early medieval carved stones; they could feasibly be applied to any worn object. However, a 3D comparative collection of a variety of similar material would need to be produced before significantly worn patterns could be identified. This could feasibly be applied to other artefacts where patterns are 'carved' into a material and can be worn away, like pottery. It is possible that machine-learning could speed up the process of identification of worn patterns in the future (Zhou et al. 2018).

10.8.2 Further Investigation of the Govan School

This thesis has established that Groove Analysis can be used to discern differences in carving style from photogrammetric three-dimensional models of the pecked groove carving of the Govan school. Expanding the Groove Analysis to include more of the stones in the Govan collection and other stones from the Strathclyde region would be beneficial in understanding the structure of the school, but this analysis cannot be applied without due consideration of the geology and differential wear experienced by each stone.

While three comparatively well-preserved monuments were analysed in Chapter 9, comparing groove profiles between monuments becomes difficult when there are clear indications of differing levels of wear. While this was less of an issue when comparing identically placed samples from the pristine version and digitally worn copy of Govan 7, this becomes more problematic when comparing across stones because groove profiles from different stones cannot be standardized separately. When grooves are of the same ‘type’ (if they are all forming the exterior of a band of interlace, or if the samples all come from median-incisions), the actual measurements are needed to compare them faithfully. If not, a carver with a wider range and less consistent technique may skew the results.

To expand this analysis to the Govan school, it will be necessary to first classify the worn stones according to elements that are missing from the design, and to only compare those in the same ‘wear classification’. For example, if the stone is worn enough that the median-incised lines from the interlace and the thin boundary around the cross are missing, but the primary carving of the patterns is still intact, this could be compared more reliably to a stone with a similar wear pattern. In the case of Inchinnan 1 and Govan 12, both retain their median-incision (in most areas of the interlace), most of their cross outline, and interlace patterns, so it was decided it was acceptable to compare them on this basis. An in-depth geological analysis for each stone would also lend additional confidence to these future analyses.

However, the usefulness of Groove Analysis should not be restricted to early medieval sculpture alone. As long as instances of differential weathering are taken into consideration, and any stones that are being compared share some amount of artistic similarity and context, like the Govan school, Groove Analysis could be applied to any carving style that can be described as a ‘groove’. For example, this could be used to analyse the inscriptions on the Roman distance slabs from the Antonine Wall to determine whether a single carver was stationed with a particular legion or if multiple carvers were commissioned. A significant time investment is required to obtain these samples and to make sense of them with multivariate statistics, but the fresh perspective offered by the results are well worth the effort.

In future analyses, it would also be worth comparing the Groove Analysis results against emerging developments in geometric morphometrics. One unfortunate, but necessary, requirement of Groove Analysis is that 2D measurements are taken from 3D data so that statistics can be employed; this process loses some information that is preserved in its 3D form. While previous studies in geometric morphometrics have often relied on the same premise, recent developments have found that it is possible to develop a full 3D analysis to identify distinguishing landmarks and semi-landmarks to differentiate between different butchery techniques on bone (Otarola-Castillo et al. 2018). Understanding individual techniques for different types of action and production is an evolving area of research, and a future project comparing and contrasting these two approaches would further this field of study.

10.8.3 3D Corpus of Early Medieval Monuments of Scotland

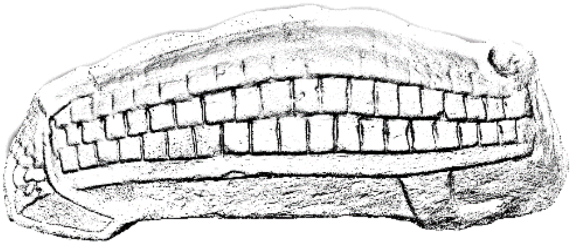
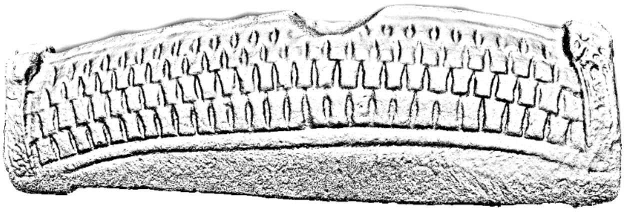
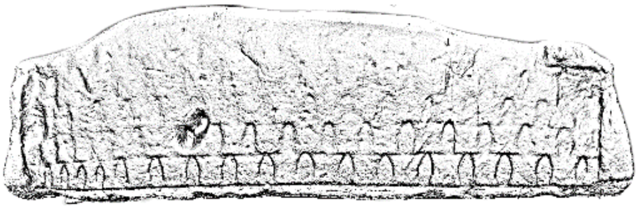
It has become clear through this project that the creation of an updated corpus of the early medieval monuments of Scotland with an associated 3D model for each stone would be an invaluable resource for future research. As discussed here and examined in Section 5.7, there are issues that need to be fully considered to ensure that the data is maintained and made available in the most accessible way possible in a centralised location. It is proposed here that the 3D corpus of the Govan material produced by this thesis be used as a pilot study for exploring the options for dissemination as outlined below.

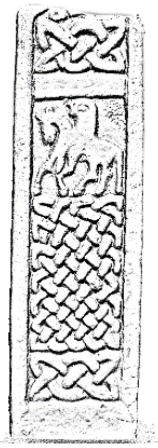
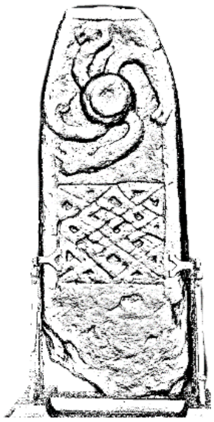
As is more thoroughly explored in Section 5.7, the maintenance of this relatively large dataset (consisting of the Agisoft Photoscan and RTI projects, the associated images, the finished and recarved 3D models in .obj format, the Groove Measure spreadsheets and all of the associated metadata) is a challenge and requires that the data is archived with a reliable data management service. The data produced by this thesis will be archived with the University of Glasgow's Enlighten service as well as with Historic Environment Scotland. If this research had been conducted outside of the university, it would have been deposited with the Archaeology Data Service, which would have had cost implications.

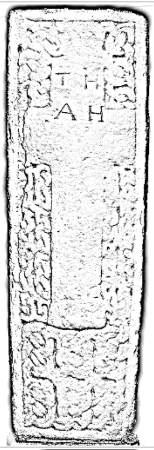
As well as archival issues, the dissemination of a large corpus of 3D data requires planning. An attractive solution is that provided by the 'Ogham in 3D' website, which makes their 3D models available for viewing and download in multiple formats. This addresses at least two different levels of the 'Digital Divide,' (DiMaggio & Hargittai 2001; Mihelj et al. 2019). The first-level divide considers who has or does not have access to the data; this relates to issues such as the limits that are imposed by lower internet speeds and the costs of the different software required to open these files (Mihelj et al. 2019, 5–6). To address this issue, smaller file sizes and decimated versions of the 3D model can be made available for rapid download. The second level of divide concerns the skill or knowledge required to be able to utilise the digital resource (Mihelj et al. 2019, 6). This can be combated in the way that 'Ogham in 3D' does, by using accessible platforms, like Sketchfab, and familiar file types, like Adobe PDF. However, producing the digital material and making it available does not ensure that audiences will be drawn to the resource (Department for Digital, Culture, Media and Sport 2018). This was confirmed by Mihelj, Leguina and Downey, who found that digitized materials are more likely to be used in conjunction with museum visits instead of attracting new audiences, and clearly more qualitative analysis is required to determine what prevents a wider audience from engaging with these digital resources (2019, 17–18).

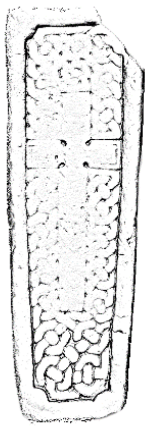
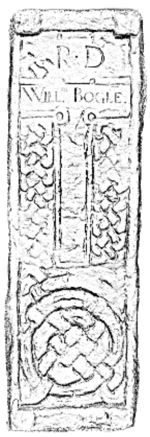
If a digital corpus of Scotland's early medieval sculpture were to be produced with accompanying 3D models of each stone, the issues outlined above and discussed more thoroughly in Chapter 5 would need to be considered from the outset. A significant amount of funding would be needed to archive the plethora of digital components of the project. Ideally the project would be based at an institution with adequate support capacity, such as a University, though there are commercial archival alternatives available. In terms of accessibility, the 'Ogham in 3D' project is commendable because while academic researchers may be the most frequent users, the provision of multiple platforms allows individuals with different levels of computer skills to engage with the 3D records of these stones. In the context of a digital corpus there remains a need for a comprehensive entry for each stone, including the stone's context, an art historical description, still photographs and drawings, historic images, and associated bibliography. It would be beneficial to test this concept of a digital corpus before going further, perhaps beginning with this challenging but manageable collection of early medieval sculpture at Govan.

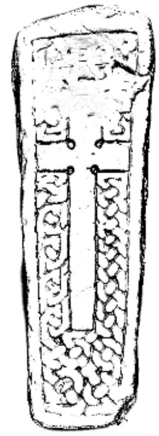
Appendix A Govan Concordance

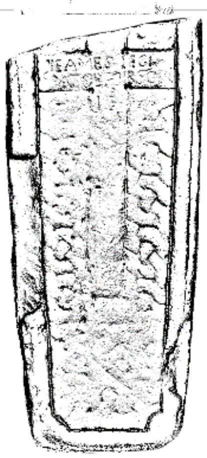
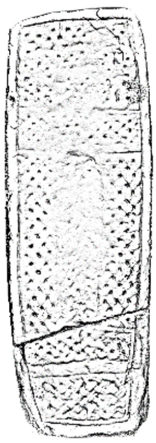
Govan Stone Number (Stirling Maxwell 1899)		**Corresponding Identifications** (ECMS, Lang)	**File name**
Govan 1		ECMS 1	Govan001_ 3Dfinal.OBJ
Govan 2		ECMS 2, Lang 1	Govan002_ 3Dfinal.OBJ
Govan 3		ECMS 12, Lang 3	Govan003_ 3Dfinal.OBJ
Govan 4		ECMS 3, Lang 4	Govan004_ 3Dfinal.OBJ
Govan 5		ECMS 11, Lang 5	Govan005_ 3Dfinal.OBJ
Govan 6		ECMS 10, Lang 2	Govan006_ 3Dfinal.OBJ

Govan Stone Number (Stirling Maxwell 1899)		**Corresponding Identifications** (ECMS, Lang)	**File name**
Govan 7		ECMS Jordanhill	Govan007_3Dfinal.OBJ
Govan 8		ECMS 4	Govan008_3Dfinal.OBJ
Govan 9		ECMS 5	Govan009_3Dfinal.OBJ
Govan 10		ECMS 29	Govan010_3Dfinal.OBJ

Govan Stone Number (Stirling Maxwell 1899)		**Corresponding Identifications** (ECMS, Lang)	**File name**
Govan 11		ECMS 9	Govan011_ 3Dfinal.OBJ Govan011_ 3Drecarved. OBJ
Govan 12		ECMS 13	Govan012_ 3Dfinal.OBJ
Govan 13		ECMS 38	Govan013_ 3Dfinal.OBJ Govan013_ 3Drecarved. OBJ
Govan 14		ECMS 32	Govan014_ 3Dfinal.OBJ Govan014_ 3Drecarved. OBJ

Govan Stone Number (Stirling Maxwell 1899)		**Corresponding Identifications** (ECMS, Lang)	**File name**
Govan 15		ECMS 34	Govan015_ 3Dfinal.OBJ Govan015_ 3Drecarved. OBJ
Govan 16		ECMS 14	Govan016_ 3Dfinal.OBJ Govan016_ 3Drecarved. OBJ
Govan 17		ECMS 35	Govan017_ 3Dfinal.OBJ Govan017_ 3Drecarved. OBJ
Govan 18		ECMS 7	Govan018_ 3Dfinal.OBJ Govan018_ 3Drecarved. OBJ

Govan Stone Number (Stirling Maxwell 1899)		**Corresponding Identifications** (ECMS, Lang)	**File name**
Govan 19		ECMS 28	Govan019_ 3Dfinal.OBJ
Govan 20		ECMS 8	Govan020_ 3Dfinal.OBJ Govan020_ 3Drecarved. OBJ
Govan 21		ECMS 33	Govan021_ 3Dfinal.OBJ Govan021_ 3Drecarved. OBJ
Govan 22		ECMS 27	Govan022_ 3Dfinal.OBJ

Govan Stone Number (Stirling Maxwell 1899)		**Corresponding Identifications** (ECMS, Lang)	**File name**
Govan 23		ECMS 31	Govan023_3Dfinal.OBJ Govan023_3Drecarved.OBJ
Govan 24		ECMS 6	Govan024_3Dfinal.OBJ Govan024_3Drecarved.OBJ
Govan 25		ECMS 23	Govan025_3Dfinal.OBJ Govan025_3Drecarved.OBJ
Govan 26		ECMS 21	Govan026_3Dfinal.OBJ Govan026_3Drecarved.OBJ

Govan Stone Number (Stirling Maxwell 1899)		**Corresponding Identifications** (ECMS, Lang)	**File name**
Govan 27		ECMS 17	Govan027_ 3Dfinal.OBJ Govan027_ 3Drecarved. OBJ
Govan 28		ECMS 15	Govan028_ 3Dfinal.OBJ Govan028_ 3Drecarved. OBJ
Govan 31		ECMS 16	Govan031_ 3Dfinal.OBJ Govan031_ 3Drecarved. OBJ
Govan 36		ECMS 25	Govan036_ 3Dfinal.OBJ Govan036_ 3Drecarved. OBJ
Govan 42		N/A	Govan042_ 3Dfinal.OBJ

Appendix B Groove Analysis Sample Excerpt

	-0.304	-1.064	-2.033	-2.871	-3.863	-4.781	-5.43	-5.731	-5.575	-4.873	-3.642	-2.634	-1.625	-0.445	-0.445					
	-0.45	-1.362	-2.366	-3.329	-4.309	-5.447	-6.178	-6.449	-6.13	-5.123	-3.935	-2.798	-1.606	-0.365	-0.365					
	-0.216	-1.304	-2.419	-3.6	-4.633	-5.788	-6.778	-7.064	-6.652	-5.466	-4.253	-2.957	-1.74	-0.477	-0.477					
	-0.013	-0.896	-2.205	-3.482	-4.803	-5.833	-7.103	-7.449	-6.952	-5.761	-4.323	-3.099	-1.778	-0.663	-0.663					
	0.156	-0.801	-2.168	-3.468	-4.998	-6.11	-7.339	-7.833	-7.221	-5.977	-4.523	-3.179	-1.778	-0.744	-0.744			n		
	0.213	-0.834	-2.338	-3.739	-5.275	-6.409	-7.605	-8.129	-7.629	-6.222	-4.731	-3.267	-1.942	-0.771	-0.771	-7.78		-0.35	TRUE	1
	0.244	-0.865	-2.503	-3.937	-5.485	-6.684	-7.837	-8.335	-7.84	-6.492	-4.85	-3.395	-2.037	-0.816	-0.816	-8.02		-0.32	FALSE	
	0.345	-0.898	-2.735	-4.129	-5.608	-6.979	-8.067	-8.582	-8.135	-6.639	-4.977	-3.614	-2.252	-0.885	-0.885	-8.17		-0.41	FALSE	
	0.341	-0.958	-2.876	-4.537	-5.949	-7.268	-8.204	-8.717	-8.401	-6.999	-5.27	-3.91	-2.615	-1.027	-1.027	-8.27		-0.45	FALSE	
	0.277	-0.866	-2.995	-5	-6.465	-7.559	-8.211	-8.695	-8.574	-7.446	-5.619	-4.223	-2.802	-1.146	-1.146	-8.32		-0.37	FALSE	
	0.36	-0.871	-3.314	-5.334	-6.873	-7.765	-8.153	-8.619	-8.389	-7.623	-5.762	-4.267	-2.898	-1.176	-1.176	-8.34		-0.28	FALSE	
	0.364	-0.874	-3.521	-5.804	-7.207	-7.812	-8.034	-8.328	-8.218	-7.54	-5.779	-4.351	-2.979	-1.126	-1.126	-8.33	0.00	n	FALSE	
	-0.919	-3.562	-6.389	-7.432	-7.849	-7.927	-8.11	-8.125	-7.511	-5.719	-4.437	-2.941	-1.094	-1.094	-1.094	-8.29	0.16	n	FALSE	
	-1.064	-3.315	-6.489	-7.464	-7.769	-7.845	-8.004	-8.123	-7.592	-5.821	-4.567	-2.788	-1.112	-1.112	-1.112	-8.20	0.08	n	FALSE	
	-1.147	-3.171	-5.868	-7.021	-7.485	-7.689	-7.898	-8.054	-7.462	-5.895	-4.622	-2.844	-1.196	-1.196	-1.196	-8.10	0.05	n	FALSE	
	-1.285	-3.264	-5.419	-6.596	-7.108	-7.583	-7.873	-8.058	-7.325	-5.913	-4.7	-2.932	-1.276	-1.276	-1.276	-7.99		-0.07	TRUE	1
	-1.541	-3.429	-5.053	-6.308	-6.917	-7.54	-7.895	-8.023	-7.288	-5.933	-4.689	-2.997	-1.326	-1.326	-1.326	-7.87		-0.15	FALSE	
	-1.426	-3.384	-4.796	-5.871	-6.572	-7.393	-7.768	-7.835	-7.021	-5.683	-4.346	-2.813	-1.307	-1.307	-1.307	-7.77		-0.06	FALSE	
	0.537	-1.296	-3.25	-4.669	-5.646	-6.317	-7.157	-7.675	-7.665	-6.835	-5.374	-4.026	-2.646	-1.308	-1.308	-7.68	0.01	n	FALSE	
	0.462	-1.231	-3.294	-4.828	-5.704	-6.268	-7.025	-7.609	-7.529	-6.613	-5.124	-3.905	-2.673	-1.213	-1.213	-7.58		-0.03	TRUE	1
	0.381	-1.216	-3.314	-4.928	-5.816	-6.375	-6.929	-7.424	-7.258	-6.226	-4.889	-3.817	-2.623	-1.095	-1.095	-7.48	0.05	n	FALSE	
	0.243	-1.344	-3.384	-5.145	-6.046	-6.554	-7.007	-7.36	-7.029	-6.027	-4.827	-3.832	-2.666	-1.009	-1.009	-7.37	0.01	n	FALSE	
	0.264	-1.389	-3.543	-5.306	-6.227	-6.64	-7.043	-7.229	-6.778	-5.867	-4.829	-3.822	-2.484	-0.938	-0.938	-7.27	0.04	n	FALSE	
	0.232	-1.402	-3.811	-5.564	-6.312	-6.728	-7.048	-7.129	-6.701	-5.891	-4.809	-3.738	-2.227	-0.954	-0.954	-7.19	0.06	n	FALSE	
	0.25	-1.364	-3.888	-5.671	-6.32	-6.788	-6.953	-6.991	-6.68	-5.965	-4.826	-3.532	-1.991	-0.986	-0.986	-7.13	0.14	n	FALSE	
	0.297	-1.261	-3.652	-5.575	-6.302	-6.759	-6.894	-6.924	-6.688	-6.144	-4.864	-3.254	-1.865	-0.999	-0.999	-7.08	0.15	n	FALSE	
	0.31	-1.144	-3.467	-5.413	-6.267	-6.656	-6.887	-6.897	-6.803	-6.278	-4.921	-3.019	-1.737	-1.001	-1.001	-7.03	0.13	n	FALSE	
	0.294	-1.2	-3.27	-5.232	-6.128	-6.652	-6.855	-6.912	-6.871	-6.303	-4.987	-2.953	-1.669	-1.026	-1.026	-6.99	0.08	n	FALSE	
	0.221	-1.159	-3.116	-5.008	-6.019	-6.582	-6.82	-6.972	-6.93	-6.315	-4.982	-2.722	-1.633	-1.048	-1.048	-6.97		-0.01	TRUE	1
	0.006	-1.303	-3.092	-4.745	-5.953	-6.597	-6.866	-7.025	-6.95	-6.251	-4.977	-2.64	-1.666	-1.012	-1.012	-6.95		-0.07	FALSE	
	-0.114	-1.517	-3.179	-4.594	-5.924	-6.7	-6.904	-6.975	-6.833	-6.084	-4.64	-2.647	-1.728	-0.993	-0.993	-6.94		-0.03	FALSE	
	1.037	-0.044	-1.463	-3.144	-4.601	-5.886	-6.675	-6.895	-6.866	-6.544	-5.575	-4.055	-2.634	-1.842	-1.037	-6.94	0.04	n	FALSE	

Figure B.1. Excerpt from the Groove Measure template provided by Laila Kitzler Åhfeldt; fifteen columns of measurements from Groove Sample 701.

X-axel mm.	-10.5	-9	-7.5	-6	-4.5	-3	-1.5	0	1.5	3	4.5	6	7.5	9	10.5
N.		156	156	156	156	156	156	156	156	156	156	156	156	156	
Avg. G	0	-0.438629	-1.815243	-3.3362	-4.7677	-5.893171	-6.577157	-6.8684	-6.536757	-5.554271	-4.256114	-3.00904	-1.9649	-1.18237	0
Std.		1.2234502	1.8319496	1.9003213	1.5089298	1.062471	0.9044252	0.897798	0.8916757	0.8895057	0.7882122	0.638434	0.57279	0.477779	
Avg+Std.G		0.7848216	0.0167068	-1.435879	-3.25877	-4.8307	-5.672732	-5.970602	-5.645081	-4.664766	-3.467902	-2.37061	-1.39211	-0.70459	
Avg-Std.G		-1.662079	-3.647192	-5.236521	-6.27663	-6.955642	-7.481582	-7.766198	-7.428433	-6.443777	-5.044326	-3.64748	-2.53769	-1.66015	
Ste.		7.2111026	7.2111026	7.2111026	7.2111026	7.2111026	7.2111026	7.2111026	7.2111026	7.2111026	7.2111026	7.211103	7.211103	7.211103	
Avg+Ste.		6.772474	5.3958597	3.8749026	2.4434026	1.3179311	0.6339454	0.3427026	0.6743454	1.6568311	2.9549883	4.20206	5.246203	6.028731	
Avg-Ste.		1.2234502	1.8319496	1.9003213	1.5089298	1.062471	0.9044252	0.897798	0.8916757	0.8895057	0.7882122	0.638434	0.57279	0.477779	
Calculation of mean profile data for euclidean diagram															
AvgX		-1.890071		SteX	7.2111026										
AvgY		-4.511907		SteY	7.2111026										
AvgZ		-6.556957		SteZ	7.2111026										
Calculation of the "hypothetical"/idealized groove depth (see Kitzler Åhfeldt 2002 for explanations)															
		tan a	-0.6032		a	31.096379									
		tan b	-0.7602		b	37.242616									
		m	3.3160												
		h1	-3.206341		h2	-2.040436									
		D=h1+d1	-6.5425		D=h2+d2	-5.0495									
Vdata			**Pdata**												
Sample_nr	**Groove ang**	**D**	**AvgX**	**AvgY**	**AvgZ**										
	111.661	-6.543	-1.890	-4.512	-6.557										
STAdata	Data referring to the cross-section						Data referring to the cutting rythm								
Sample_nr	**v**	**D**	**Object**	**AvgX**	**AvgY**	**AvgZ**	**mindiff**	**plusdiff**	**meddiff**	**n**	**w**				
701	111.66101	-6.542541	Govan007ur	-1.890	-4.512	-6.557	4.38	4.75	0.15	16.00	9.13				
Sampl_nr	**Object**	**v**	**D**	**AvgX**	**AvgY**	**AvgZ**	**mindiff**	**plusdiff**	**meddiff**	**w**	**k**	**n**			
701	Govan007ur	111.66101	-6.542541	-1.890	-4.512	-6.557	4.38	4.75	0.15	9.13	0.52	16.00			

Figure B.2. Excerpt from the Groove Analysis template provided by Laila Kitzler Åhfeldt; calculating the variables included in the analysis from Sample 701.

Appendix C Why Hierarchical Cluster Analysis?

There are various statistical methods that can be used to identify clusters offered by SPSS 24, including: ‘k-means cluster analysis’, ‘Two-Step Cluster Analysis’, and ‘hierarchical cluster analysis’. K-means cluster analysis requires that you indicate how many clusters you expect from the analysis, then “iteratively estimates the cluster means and assigns each case to the cluster for which its distance to the cluster mean is the smallest” (Norušis 2012, 376). In this analysis, because we do not know how many carvers are represented in these samples, k-means analysis was not ideal. This method is also very sensitive to outliers (Norušis 2012, 388). Outliers are samples which fall far outside the range of the other samples in a dataset (Drennan 2010, 4). They are often considered undesirable by statisticians because they affect any statistics based on the mean or ‘average’ of a batch of samples, including the standard deviation, and so can give a skewed perception of the data. Several methods of removing outliers have been developed to eliminate them without compromising the statistical integrity of the batch (Drennan 2010, 20–23). However, in multivariate statistical analyses outliers can be particularly interesting (Stevens 2009, 15); in this analysis, outliers have been retained as they may represent an under-sampled carver (Kitzler Åhfeldt 2001, 140), so k-means analysis was clearly unsuited to the identification of clusters in the Govan Groove Analysis. Two-Step Cluster Analysis first identifies ‘preclusters’, then uses hierarchical clustering to cluster these preclusters (Norušis 2012, 376). This approach is intended for exceptionally large datasets and those that require comparisons between both categorical and continuous variables (Norušis 2012, 394). Because the sample sizes for the Groove Analysis at Govan are quite small by statistical standards, this analysis tended to assign all cases to the same cluster, despite the clear presence of outliers, and so was not used in this analysis. Hierarchical Cluster Analysis was the best option available for reasons outlined in Section 9.4.

C.1 Combining Clusters

SPSS offers a variety of options to tailor the Discriminant Analysis function to the researcher’s needs. In this case, there were two options utilised: the standard method Discriminant Analysis in which independent variables selected by the researcher are entered together, and Discriminant Analysis using the Forward

Stepwise method based on the Mahalanobis distance were used. The main difference between these is that by using the first option, the researcher can input any number of the original variables, all of which the algorithm will then use to identify the best separation between the predefined groups. In the second option, only variables that pass a significance test involving the F value – a ratio of variance calculated for each variable that reflects the "extent to which a variable makes a unique contribution to the prediction of group membership" (StatSoft, Inc. 2013). In this cluster-combining step described by Kitzler Åhfeldt (2002a, 96–98), she used the Discriminant Analysis function from a different statistics package (STATISTICA) which offered slightly different options. In her analysis, using the standard method of Discriminant Analysis, she was able to compare the relative distances between groups expressed by p-levels to determine if clusters needed to be grouped together (2002a, 96). Unfortunately, this option is unavailable through SPSS unless the forward stepwise option is selected. For this reason, in this case the results of both the standard and forward stepwise results were considered.

C.2 Govan 1 'Shallow' Tables

The Principal Components Analysis identified that only the first two components were reliable. The variables v, AvgZ, and k were chosen from the first Component, while variables mindiff, plusdiff and w were chosen from the second Component for consideration in the following steps (Table C.1). As can be seen in Table C.2 - Table C.9 and Figure C.1, the groups were well-defined by these variables. It was clear from the results of both methods of Discriminant Analysis that these groups were well-defined and proceeded to the next stage of analysis.

C.2.1 Govan 1 'Shallow' Principal Components Analysis Results

Table C.1. Principal Components Analysis of Govan 1 shallow samples - highlighted boxes indicate Loadings that pass the 'absolute value >.60' threshold set out by Stevens. Only the first two components consist of four variables exceeding .60 or three variables exceeding .80. For guidance on reading the Component Matrix chart, see Appendix D.3.1.

Component Matrix[a]

	Component			
	1	2	3	4
Zscore(v)	0.872	-0.051	-0.416	-0.168
Zscore(D)	0.915	-0.193	-0.256	-0.176
Zscore(Avg X)	0.260	-0.642	0.673	-0.091
Zscore(Avg Y)	0.693	-0.537	0.458	-0.097
Zscore(Avg Z)	0.918	-0.341	-0.035	-0.168
Zscore(min diff)	0.196	0.828	0.278	-0.443
Zscore(plu sdiff)	0.710	0.637	0.024	0.197
Zscore(me ddiff)	0.245	0.350	0.578	0.502
Zscore(w)	0.543	0.806	0.151	-0.092
Zscore(k)	0.623	-0.103	-0.253	0.683

Extraction Method: Principal Component Analysis.

a. 4 components extracted.

Table C.2. Total variance explained by the Principal Components of the 'Shallow' Govan 1 samples - the first two Components account for 70% of variance in the sample. For guidance on reading the Total Variance Explained chart, see Section D.3.2.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.274	42.737	42.737	4.274	42.737	42.737
2	2.730	27.299	70.036	2.730	27.299	70.036
3	1.401	14.010	84.046	1.401	14.010	84.046
4	1.068	10.682	94.728	1.068	10.682	94.728
5	0.504	5.036	99.764			
6	0.019	0.185	99.949			
7	0.003	0.029	99.978			
8	0.002	0.019	99.997			
9	0.000	0.003	100.000			
10	3.881E-16	3.881E-15	100.000			

Extraction Method: Principal Component Analysis.

C.2.2 Govan 1 'Shallow' Standard Discriminant Analysis Results

Table C.3. Wilks' Lambda of the Discriminant Analysis (standard method) of the 'Shallow' Govan 1 samples. For guidance on reading the Wilks' Lambda chart, see Section D.4.1.

Wilks' Lambda

Function(s)	Lambda	Chi-square	df	Sig.
1 through 2	0.053	23.459	10	0.009
2	0.755	2.248	4	0.690

Table C.4. Structure Matrix of the Discriminant Analysis (standard method) of the 'Shallow' Govan 1 samples. For guidance on reading the Structure Matrix of the Discriminant Analysis (Standard) chart, see Section D.4.2.

Structure Matrix

	Function	
	1	2
AvgZ	.792*	-0.507
v	0.363	-.716*
plusdiff	0.092	-.517*
k	0.152	-.412*
w[b]	0.040	-.378*
mindiff	-0.029	-.142*

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.

*. Largest absolute correlation between each variable and any discriminant function

b. This variable not used in the analysis.

Table C.5. Casewise Statistics for Discriminant Analysis (standard method) of 'Shallow' Govan 1 groups. For guidance on reading the Casewise Statistics for Discriminant Analysis (standard), see Section D.4.3.

Casewise Statistics

Case Number		Actual Group	Predicted Group	P(G=g | D=d)	Discriminant Scores Function 1	Discriminant Scores Function 2
Original	1	1	1	0.965	0.404	0.401
	2	1	1	0.995	-0.022	1.026
	3	1	1	0.999	-0.669	1.309
	4	2	2	0.987	2.911	0.499
	5	2	2	0.940	2.443	0.600
	6	2	2	0.856	2.124	0.578
	7	2	2	1.000	4.392	-1.787
	8	2	2	1.000	4.506	0.207
	9	2	2	0.941	1.575	-1.693
	10	3	3	1.000	-5.402	-1.357
	11	3	3	1.000	-4.483	0.997
	12	3	3	0.995	-3.358	-0.131
	13	3	3	1.000	-4.421	-0.648
Cross-validated[b]	1	1	1	0.531		
	2	1	1	0.916		
	3	1	3**	1.000		
	4	2	2	0.941		
	5	2	2	0.891		
	6	2	2	0.768		
	7	2	2	1.000		
	8	2	2	1.000		
	9	2	1**	0.999		
	10	3	3	1.000		
	11	3	3	0.988		
	12	3	3	0.993		
	13	3	3	1.000		

For the original data, squared Mahalanobis distance is based on canonical functions.

**. Misclassified case

b. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

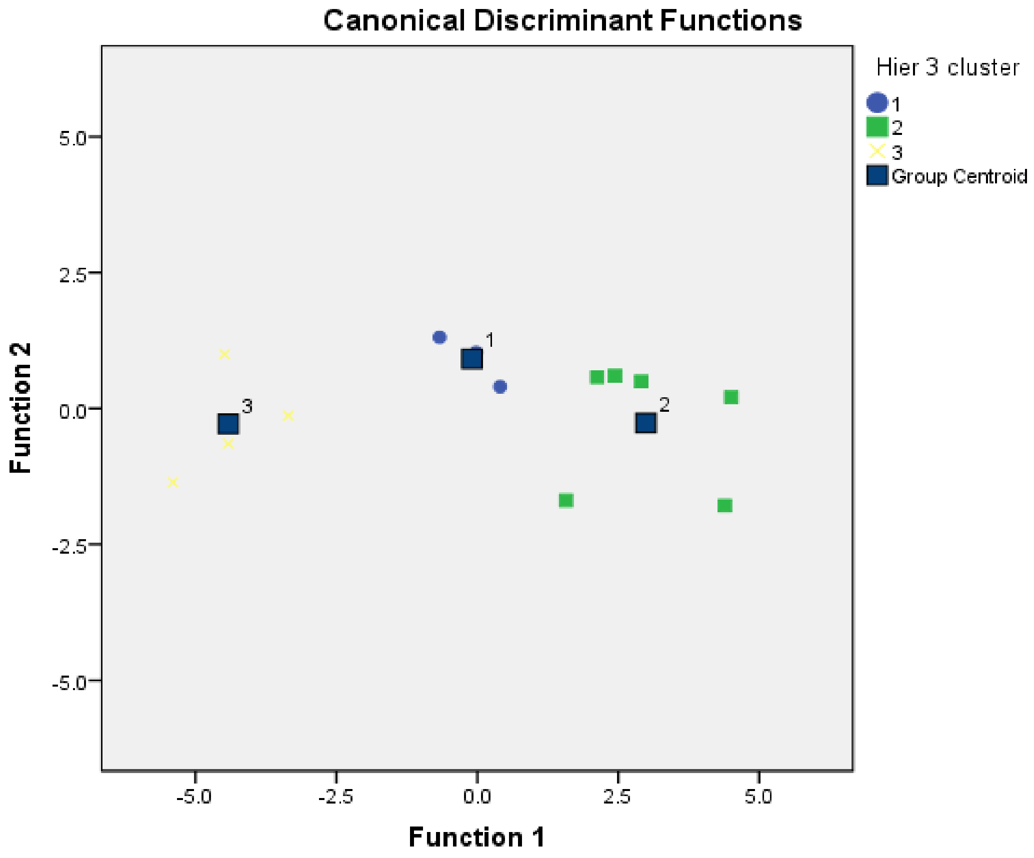


Figure C.1. Each sample plotted according to the first and second Discriminant Functions. For guidance on reading the Canonical Discriminant Functions plot, see Section D.4.4.

C.2.3 Govan 1 'Shallow' Forward Stepwise Discriminant Analysis Results

Table C.6. The only variable that qualified for the Forward Stepwise Discriminant Analysis of the 'Shallow' Govan 1 groups was AvgZ. For guidance on reading the Variables Entered/Removed chart, see Section D.5.1.

Variables Entered/Removed[a,b,c,d]

		Min. D Squared					
				Exact F			
Step	Entered	Statistic	Between Groups	Statistic	df1	df2	Sig.
1	Zscore(AvgZ)	7.927	1 and 3	13.588	1	10.000	0.004

At each step, the variable that maximizes the Mahalanobis distance between the two closest groups is entered.

a. Maximum number of steps is 12.

b. Maximum significance of F to enter is .1.

c. Minimum significance of F to remove is .11.

d. F level, tolerance, or VIN insufficient for further computation.

Table C.7. Wilks' Lambda and Equality of Group means for each variable included in the Forward Stepwise Discriminant Analysis of the 'Shallow' Govan 1 groups. For guidance on reading the Tests of Equality of Group Means chart, see Section D.5.2.

Tests of Equality of Group Means

	Wilks' Lambda	F	df1	df2	Sig.
Zscore(v)	0.345	9.508	2	10	0.005
Zscore(Avg Z)	0.107	41.758	2	10	0.000
Zscore(min diff)	0.982	0.090	2	10	0.915
Zscore(plu sdiff)	0.834	0.996	2	10	0.403
Zscore(w)	0.937	0.338	2	10	0.721
Zscore(k)	0.736	1.796	2	10	0.216

Table C.8. Pairwise Group Comparisons resulting from the Forward Stepwise Discriminant Analysis of the 'Shallow' Govan 1 samples. For guidance on reading the Pairwise Group Comparisons chart, see Section D.5.3.

Pairwise Group Comparisons[a]

Step			1	2	3
1	1	F		18.526	13.588
		Sig.		0.002	0.004
	2	F	18.526		82.386
		Sig.	0.002		0.000
	3	F	13.588	82.386	
		Sig.	0.004	0.000	

a. 1, 10 degrees of freedom for step 1.

Table C.9. Casewise Statistics from the Forward Stepwise Discriminant Analysis for the 'Shallow' Govan 1 samples. For guidance on reading the Casewise Statistics for the Forward Stepwise Discriminant Analysis, see Section D.5.4.

Casewise Statistics

Case Number		Actual Group	Predicted Group	P(G=g | D=d)	Discriminant Scores Function 1
Original	1	1	1	0.876	0.338
	2	1	1	0.938	-0.964
	3	1	1	0.934	-0.989
	4	2	2	0.986	2.385
	5	2	2	0.861	1.583
	6	2	2	0.839	1.527
	7	2	2	1.000	4.511
	8	2	2	0.999	3.389
	9	2	2	0.879	1.636
	10	3	3	0.954	-3.019
	11	3	3	0.998	-4.226
	12	3	3	0.867	-2.611
	13	3	3	0.989	-3.558
Cross-validated[a]	1	1	1	0.817	
	2	1	1	0.917	
	3	1	1	0.912	
	4	2	2	0.979	
	5	2	2	0.838	
	6	2	2	0.813	
	7	2	2	1.000	
	8	2	2	0.999	
	9	2	2	0.858	
	10	3	3	0.938	
	11	3	3	0.998	
	12	3	3	0.834	
	13	3	3	0.984	

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

C.3 Govan 1 Deep Tables

The Principal Components Analysis indicated, again, that only the first two Components were significant and accounted for 71.1% of variance (Table C.10; Table C.11). Variables v, AvgZ, mindiff, plusdiff and w were chosen from these Principal Components to be used in the Discriminant Analyses. The Discriminant Analyses (both standard and Forward Stepwise methods) confirmed that these variables successfully separated the five clusters into distinct groups (see Table C.12-Table C.18 and Figure C.2).

C.3.1 Govan 1 'Deep' Principal Components Analysis Results

Table C.10. Principal Components Analysis of the 'Deep' Govan 1 samples.

Component Matrix[a]

	Component		
	1	2	3
Zscore(v)	0.822	-0.134	-0.049
Zscore(D)	0.928	-0.187	-0.016
Zscore(AvgX)	0.804	-0.233	-0.113
Zscore(AvgY)	0.876	-0.277	-0.101
Zscore(AvgZ)	0.967	-0.227	-0.070
Zscore(mindiff)	0.153	0.831	-0.521
Zscore(plusdiff)	0.531	0.804	0.177
Zscore(meddiff)	-0.033	0.394	0.743
Zscore(w)	0.399	0.902	-0.151
Zscore(k)	0.462	0.068	0.807

Extraction Method: Principal Component Analysis.
a. 3 components extracted.

Table C.11. Total Variance Explained by the Principal Components Analysis of the 'Deep' Govan 1 samples.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.566	45.663	45.663	4.566	45.663	45.663
2	2.545	25.449	71.112	2.545	25.449	71.112
3	1.560	15.604	86.716	1.560	15.604	86.716
4	0.792	7.917	94.632			
5	0.488	4.881	99.513			
6	0.031	0.311	99.824			
7	0.012	0.117	99.941			
8	0.005	0.047	99.988			
9	0.001	0.012	100.000			
10	-2.364E-16	-2.364E-15	100.000			

Extraction Method: Principal Component Analysis.

C.3.2 Govan 1 'Deep' Standard Discriminant Analysis Results

Table C.12. Wilks' Lambda for the Discriminant Analysis (standard method) of the 'Deep' Govan 1 samples.

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 4	0.020	72.117	16	0.000
2 through 4	0.638	8.307	9	0.504
3 through 4	0.939	1.171	4	0.883
4	0.989	0.210	1	0.647

Table C.13. Structure Matrix for the Discriminant Analysis (standard method) of the 'Deep' Govan 1 samples.

	Function 1	2	3	4
Zscore(Avg Z)	.975*	0.087	-0.028	-0.201
Zscore(v)	0.294	.703*	-0.641	-0.091
Zscore(min diff)	-0.002	0.610	.783*	-0.123
Zscore(w)[b]	0.038	0.588	.725*	0.357
Zscore(plu sdiff)	0.064	0.466	0.548	.692*

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.
*. Largest absolute correlation between each variable and any discriminant function
b. This variable not used in the analysis.

Table C.14. Casewise Statistics for the Discriminant Analysis (standard method) of the 'Deep' Govan 1 samples.

Casewise Statistics

Case Number		Actual Group	Predicted Group	P(G=g | D=d)	Discriminant Scores Function 1	Function 2	Function 3	Function 4
Original	1	1	1	0.990	-7.782	-0.086	0.166	-0.566
	2	1	1	1.000	-8.281	1.300	0.544	0.396
	3	1	1	1.000	-8.400	2.540	-0.667	0.225
	4	2	2	0.990	2.716	-0.397	-1.395	0.258
	5	2	2	0.999	3.584	0.691	1.218	1.467
	6	2	2	0.994	2.666	1.126	0.811	-1.025
	7	2	2	1.000	4.826	-1.182	-0.239	-0.989
	8	2	2	0.995	2.839	0.403	0.385	-0.787
	9	2	2	0.777	1.720	-0.077	-0.352	0.179
	10	3	3	0.886	-1.940	-0.258	-0.204	-0.307
	11	3	3	0.986	0.333	-0.449	-0.137	2.841
	12	3	3	0.980	0.308	-0.963	0.522	-0.704
	13	3	3	0.997	-1.345	0.688	1.767	-0.167
	14	3	3	0.998	-0.435	-1.083	1.443	-1.487
	15	3	3	0.999	-0.671	-1.040	0.432	0.668
	16	3	3	0.953	0.308	0.321	-2.041	-0.256
	17	3	3	0.864	0.844	-0.379	-0.148	-0.004
	18	4	4	0.997	-4.622	0.653	-0.697	-0.368
	19	4	4	0.997	-4.021	0.262	0.691	0.275
	20	4	4	0.997	-3.680	-1.765	-0.187	-0.459
	21	4	4	0.999	-5.817	-1.980	-1.172	0.472
	22	5	5	1.000	7.689	-1.000	0.482	0.811
	23	5	5	1.000	8.617	1.480	-1.496	-0.931
	24	5	5	1.000	10.545	1.198	0.274	0.457
Cross-validated[a]	1	1	1	0.930				
	2	1	1	1.000				
	3	1	1	1.000				
	4	2	2	0.970				
	5	2	2	0.998				
	6	2	2	0.984				
	7	2	2	0.993				
	8	2	2	0.993				
	9	2	2	0.677				
	10	3	3	0.846				
	11	3	3	0.577				
	12	3	3	0.968				
	13	3	3	0.980				
	14	3	3	0.995				
	15	3	3	0.998				
	16	3	3	0.570				
	17	3	3	0.838				
	18	4	4	0.987				
	19	4	4	0.987				
	20	4	4	0.989				
	21	4	4	0.972				
	22	5	5	0.950				
	23	5	5	1.000				
	24	5	5	1.000				

For the original data, squared Mahalanobis distance is based on canonical functions.
For the cross-validated data, squared Mahalanobis distance is based on observations.

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

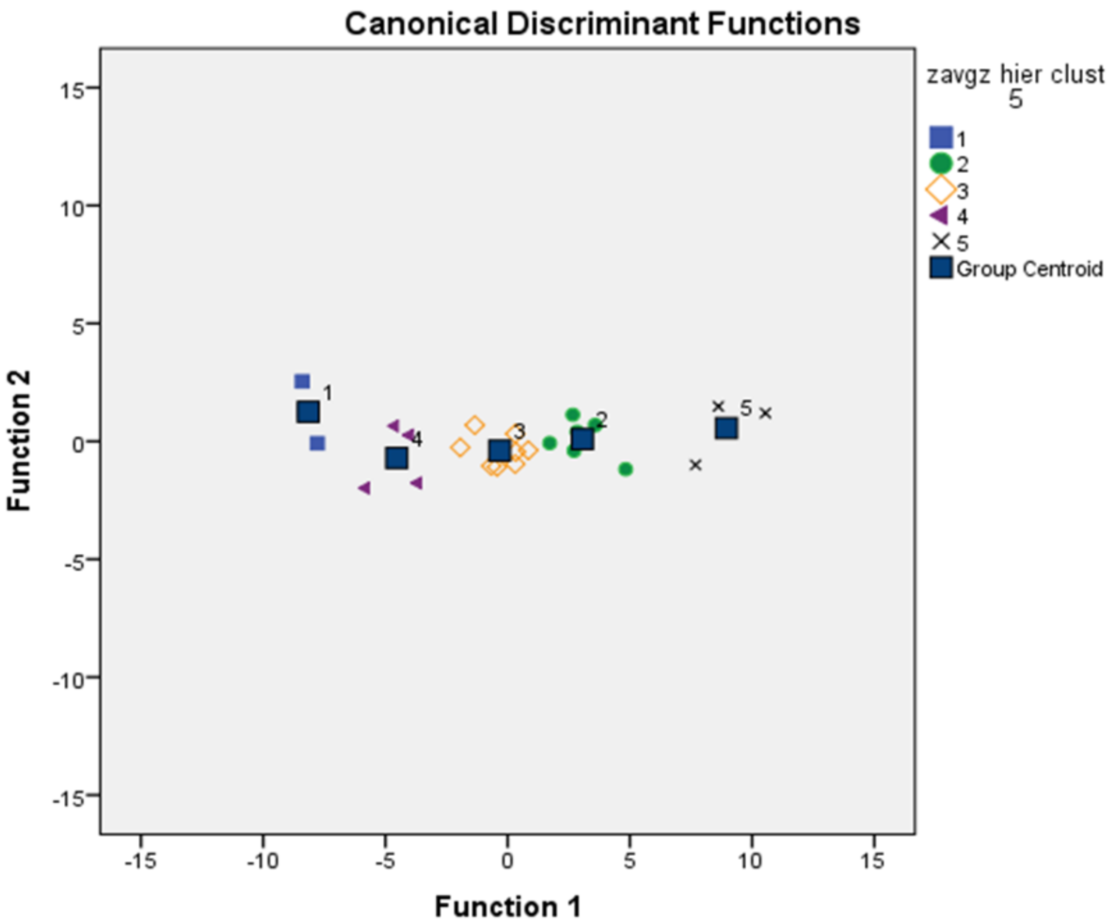


Figure C.2 Plot of Discriminant Functions for the 'Deep' Govan 1 Groups.

C.3.3 Govan 1 ‘Deep’ Forward Stepwise Discriminant Analysis Results

Table C.15. The only variable that qualified for the Forward Stepwise Discriminant Analysis of the ‘Deep’ Govan 1 samples was AvgZ.

Variables Entered/Removed[a,b,c,d]

Step	Entered	Min. D Squared					
		Statistic	Between Groups	Exact F			
				Statistic	df1	df2	Sig.
1	Zscore(AvgZ)	11.411	1 and 4	19.562	1	19.000	0.000

At each step, the variable that maximizes the Mahalanobis distance between the two closest groups is

a. Maximum number of steps is 10.

b. Maximum significance of F to enter is .1.

c. Minimum significance of F to remove is .11.

d. F level, tolerance, or VIN insufficient for further computation.

Table C.16. Wilks' Lambda scores and Test of the Equality for Group Means for the variables included in the Forward Stepwise Discriminant Analysis of the 'Deep' Govan 1 samples.

Tests of Equality of Group Means

	Wilks' Lambda	F	df1	df2	Sig.
Zscore(v)	0.257	13.723	4	19	0.000
Zscore(AvgZ)	0.033	137.727	4	19	0.000
Zscore(mindiff)	0.828	0.988	4	19	0.438
Zscore(plusdiff)	0.800	1.188	4	19	0.348
Zscore(w)	0.809	1.122	4	19	0.376

Table C.17. Pairwise Group Comparisons resulting from the Forward Stepwise Discriminant Analysis of the 'Deep' Govan 1 samples.

Pairwise Group Comparisons[a]

Step			1	2	3	4	5
1	1	F		236.239	121.998	19.562	413.901
		Sig.		0.000	0.000	0.000	0.000
	2	F	236.239		39.416	134.649	65.963
		Sig.	0.000		0.000	0.000	0.000
	3	F	121.998	39.416		44.819	182.012
		Sig.	0.000	0.000		0.000	0.000
	4	F	19.562	134.649	44.819		300.202
		Sig.	0.000	0.000	0.000		0.000
	5	F	413.901	65.963	182.012	300.202	
		Sig.	0.000	0.000	0.000	0.000	

a. 1, 19 degrees of freedom for step 1.

Table C.18. Casewise Statistics of the Forward Stepwise Discriminant Analysis of the 'Deep' Govan 1 samples.

Casewise Statistics

Case Number		Actual Group	Predicted Group	P(G=g | D=d)	Discriminant Scores Function 1
Original	1	1	1	0.989	-7.489
	2	1	1	0.998	-8.059
	3	1	1	0.998	-8.000
	4	2	2	0.987	2.602
	5	2	2	0.998	3.227
	6	2	2	0.995	2.882
	7	2	2	0.998	4.810
	8	2	2	0.996	2.951
	9	2	2	0.748	1.644
	10	3	3	0.913	-1.847
	11	3	3	0.996	-0.282
	12	3	3	0.965	0.344
	13	3	3	0.991	-1.268
	14	3	3	0.995	-0.259
	15	3	3	0.998	-0.891
	16	3	3	0.953	0.437
	17	3	3	0.857	0.795
	18	4	4	0.997	-4.358
	19	4	4	0.998	-3.974
	20	4	4	0.993	-3.645
	21	4	4	0.701	-5.907
	22	5	5	1.000	7.236
	23	5	5	1.000	8.762
	24	5	5	1.000	10.289
Cross-validated [a]	1	1	1	0.985	
	2	1	1	0.998	
	3	1	1	0.997	
	4	2	2	0.984	
	5	2	2	0.998	
	6	2	2	0.993	
	7	2	2	0.999	
	8	2	2	0.995	
	9	2	2	0.673	
	10	3	3	0.901	
	11	3	3	0.994	
	12	3	3	0.960	
	13	3	3	0.990	
	14	3	3	0.994	
	15	3	3	0.997	
	16	3	3	0.946	
	17	3	3	0.837	
	18	4	4	0.996	
	19	4	4	0.997	
	20	4	4	0.991	
	21	4	4	0.514	
	22	5	5	0.999	
	23	5	5	1.000	
	24	5	5	1.000	

For the original data, squared Mahalanobis distance is based on canonical functions.

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

C.4 Govan 12 Tables

The Principal Components Analysis of the Govan 12 samples indicated that the first two components were the most reliable (Table C.19). Variables v, AvgZ, and meddiff were chosen from the first Component for further analysis, as were variables plusdiff, w and k from the second component. These two Principal components accounted for ~75% of the variation in the samples (Table C.20).

The Discriminant Analysis (standard method) confirmed the separation of these five clusters (Table C.21-Table C.23; Figure C.3). The originally assigned groups for each case matched the predicted groups, although the process of cross-validation did not quite fit (especially when compared to the results of this analysis with the 'Deep' Govan 1 samples), which could have been due to the small sample size used in the analysis or the inclusion of the outlier 'Group 2' (Table C.23). In the Forward Stepwise Discriminant Analysis, both variables v and AvgZ qualified for the analysis (Table C.24). After these five groups were found to be separate (although groups 3 and 4 were nearly merged, as the pairwise comparison only resulted in a significance level of 0.099 in their separation, where a significance > 0.1 dictates that these groups would be merged), the averages of variable v, AvgZ, meddiff, plusdiff, w and k were calculated for each cluster (Table C.24-Table C.27).

C.4.1 Govan 12 Principal Components Analysis Results

Table C.19. Results from the Principal Components Analysis of the Govan 12 samples; only the first two Components pass the rules of thumb for reliability outlined above.

Component Matrix[a]	Component 1	Component 2	Component 3
Zscore(v)	0.848	0.137	-0.145
Zscore(D)	0.970	0.007	0.000
Zscore(Avg X)	0.621	-0.436	0.550
Zscore(Avg Y)	0.838	-0.320	0.394
Zscore(Avg Z)	0.964	-0.118	0.118
Zscore(min diff)	-0.523	0.286	0.770
Zscore(plu sdiff)	0.317	0.934	0.050
Zscore(me ddiff)	-0.896	-0.079	-0.019
Zscore(w)	-0.054	0.878	0.475
Zscore(k)	0.579	0.622	-0.459

Extraction Method: Principal Component

a. 3 components extracted.

Table C.20. Total Variance Explained by the Principal Components of the Govan 12 samples.

Total Variance Explained

	Initial Eigenvalues			Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.979	49.788	49.788	4.979	49.788	49.788
2	2.552	25.522	75.310	2.552	25.522	75.310
3	1.373	13.731	89.041	1.373	13.731	89.041
4	0.761	7.606	96.647			
5	0.321	3.211	99.858			
6	0.011	0.108	99.966			
7	0.002	0.024	99.990			
8	0.001	0.009	99.999			
9	9.650E-05	0.001	100.000			
10	-2.833E-16	-2.833E-15	100.000			

Extraction Method: Principal Component Analysis.

C.4.2 Govan 12 Standard Discriminant Analysis Results

Table C.21. Wilks' Lambda for the Discriminant Analysis (standard method) of the Govan 12 samples.

Wilks' Lambda				
Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 4	0.000	42.693	24	0.011
2 through 4	0.023	20.766	15	0.144
3 through 4	0.123	11.506	8	0.175
4	0.565	3.139	3	0.371

Table C.22. Structure Matrix for the Discriminant Analysis (standard method) of the Govan 12 samples.

Structure Matrix				
	Function			
	1	2	3	4
Zscore(meddiff)	-.193*	0.052	-0.021	-0.035
Zscore(v)	0.301	.653*	-0.398	0.333
Zscore(AvgZ)	0.596	0.130	-.704*	0.234
Zscore(w)	0.017	0.183	.472*	0.125
Zscore(k)	0.048	0.091	-0.041	.536*
Zscore(plusdiff)	0.040	0.152	0.235	.366*

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.

*. Largest absolute correlation between each variable and any discriminant function

Table C.23. Casewise Statistics for the Discriminant Analysis (standard method) of the Govan 12 samples.

Casewise Statistics

Case Number		Actual Group	Predicted Group	P(G=g | D=d)	Discriminant Scores Function 1	Function 2	Function 3	Function 4
Original	1	1	1	1.000	-6.522	0.633	2.709	-0.879
	2	1	1	1.000	-5.573	0.279	1.618	1.148
	3	1	1	0.999	-5.731	0.387	1.453	-0.399
	4	3	3	1.000	-4.170	-0.864	-1.767	0.053
	5	3	3	1.000	-4.728	1.366	-2.551	-1.995
	6	4	4	0.990	1.943	0.159	-0.657	0.171
	7	4	4	0.998	-1.181	0.115	-0.800	0.624
	8	4	4	1.000	0.095	2.167	-1.751	2.180
	9	2	2	1.000	13.016	3.139	0.980	-0.732
	10	5	5	1.000	4.892	-1.405	1.691	0.147
	11	5	5	1.000	4.625	-2.865	-1.453	-0.592
	12	5	5	1.000	3.332	-3.111	0.528	0.274
Cross-validated[b]	1	1	1	1.000				
	2	1	3**	0.829				
	3	1	3**	1.000				
	4	3	1**	0.908				
	5	3	3	0.974				
	6	4	5**	0.970				
	7	4	3**	1.000				
	8	4	3**	1.000				
	9	2	5**	1.000				
	10	5	4**	1.000				
	11	5	5	0.993				
	12	5	5	0.995				

For the original data, squared Mahalanobis distance is based on canonical functions.

**. Misclassified case

b. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

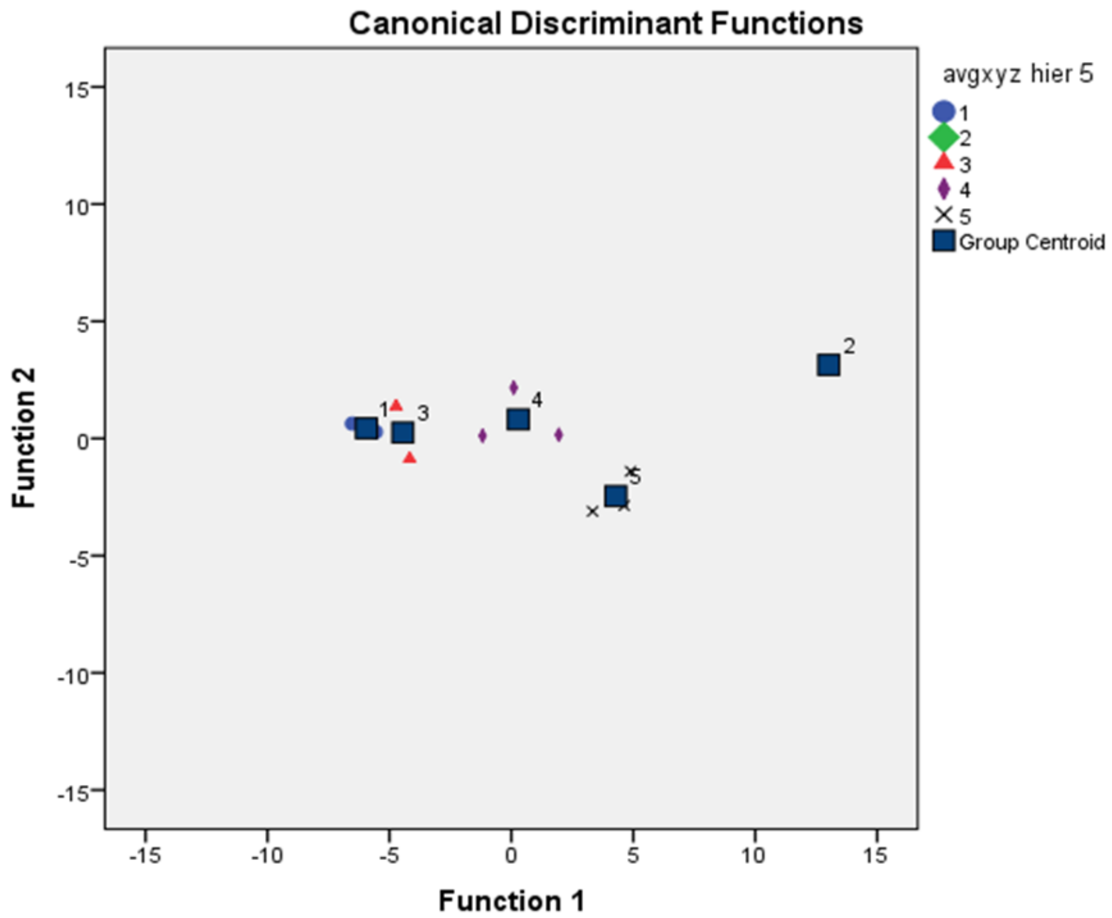


Figure C.3. Plot of Discriminant Functions (standard method) for the Govan 12 Groups.

C.4.3 Govan 12 Forward Stepwise Discriminant Analysis Results

Table C.24. Two variables qualified for the Forward Stepwise Discriminant Analysis of the Govan 12 samples: AvgZ and v.

Variables Entered/Removed[a,b,c,d]

Step	Entered	Min. D Squared						
		Statistic	Between Groups	Exact F Statistic	df1	df2	Sig.
1	Zscore(AvgZ)	0.609	4 and 5	0.913	1	7.000	0.371
2	Zscore(v)	6.796	3 and 4	3.495	2	6.000	0.099

At each step, the variable that maximizes the Mahalanobis distance between the two closest groups is entered.

a. Maximum number of steps is 12.

b. Maximum significance of F to enter is .1.

c. Minimum significance of F to remove is .11.

d. F level, tolerance, or VIN insufficient for further computation.

Table C.25. Wilks' Lambda and Tests of Equality of Group Means for the variables included in the Forward Stepwise Discriminant Analysis of the Govan 12 samples.

Tests of Equality of Group Means

	Wilks' Lambda	F	df1	df2	Sig.
Zscore(v)	0.120	12.809	4	7	0.002
Zscore(Avg Z)	0.046	36.239	4	7	0.000
Zscore(meddiff)	0.335	3.479	4	7	0.072
Zscore(plusdiff)	0.672	0.855	4	7	0.534
Zscore(w)	0.507	1.698	4	7	0.254
Zscore(k)	0.722	0.674	4	7	0.631

Table C.26. Pairwise Group Comparisons resulting from the Forward Stepwise Discriminant Analysis of the Govan 12 samples.

Pairwise Group Comparisons[a,b]

Step			1	2	3	4	5
1	1	F		110.990	14.938	56.123	71.353
		Sig.		0.000	0.006	0.000	0.000
	2	F	110.990		49.730	27.435	20.814
		Sig.	0.000		0.000	0.001	0.003
	3	F	14.938	49.730		8.041	13.619
		Sig.	0.006	0.000		0.025	0.008
	4	F	56.123	27.435	8.041		0.913
		Sig.	0.000	0.001	0.025		0.371
	5	F	71.353	20.814	13.619	0.913	
		Sig.	0.000	0.003	0.008	0.371	
2	1	F		47.954	7.024	24.456	41.105
		Sig.		0.000	0.027	0.001	0.000
	2	F	47.954		21.313	11.788	11.717
		Sig.	0.000		0.002	0.008	0.008
	3	F	7.024	21.313		3.495	10.300
		Sig.	0.027	0.002		0.099	0.011
	4	F	24.456	11.788	3.495		7.199
		Sig.	0.001	0.008	0.099		0.025
	5	F	41.105	11.717	10.300	7.199	
		Sig.	0.000	0.008	0.011	0.025	

a. 1, 7 degrees of freedom for step 1.

b. 2, 6 degrees of freedom for step 2.

Table C.27. Casewise Statistics for the Forward Stepwise Discriminant Analysis of the Govan 12 samples.

Casewise Statistics

Case Number		Actual Group	Predicted Group	P(G=g | D=d)	Discriminant Scores Function 1	Discriminant Scores Function 2
Original	1	1	1	1.000	-6.532	-0.091
	2	1	1	0.977	-4.262	-0.278
	3	1	1	0.990	-4.425	0.982
	4	3	3	0.974	-1.296	-0.439
	5	3	3	0.957	-1.466	0.509
	6	4	4	0.923	1.552	0.295
	7	4	4	0.625	0.289	-0.070
	8	4	4	0.997	1.294	2.744
	9	2	2	1.000	6.972	2.229
	10	5	5	0.954	2.193	-1.324
	11	5	5	1.000	3.983	-2.688
	12	5	5	0.977	1.698	-1.869
Cross-validated[b]	1	1	1	1.000		
	2	1	1	0.956		
	3	1	1	0.963		
	4	3	3	0.941		
	5	3	3	0.910		
	6	4	4	0.873		
	7	4	3**	0.718		
	8	4	4	0.986		
	9	2	5**	0.528		
	10	5	5	0.930		
	11	5	5	1.000		
	12	5	5	0.936		

**. Misclassified case

b. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

C.5 Inchinnan 1 Tables

The Principal Components Analysis indicated once again that only the first two Principal Components are reliable due to the small sample size (Table C.28). The variables v, AvgZ, and meddiff were chosen from the first Principal Component for the following Discriminant Analyses, as were mindiff, plusdiff, and w from the second Principal component. These two components accounted for ~75% of variance in the samples (Table C.29).

The Discriminant Analyses of the Inchinnan 1 samples indicated that these groups are well-defined by these variables, as both the standard and Forward Stepwise methods predicted that the cases belong to their assigned groups (Table C.30-Table C.36; Figure C.4). The cross-validation did not succeed as well, which, as in the case of Govan 12 above, was likely due to the limited number of samples in this analysis. The Pairwise Group Comparisons from the Forward Stepwise Discriminant Analysis confirmed that these are separate but indicated that the closest relationship between these three clusters is between Groups 1 and 2 (Table C.35).

C.5.1 Inchinnan 1 Principal Components Analysis Results

Table C.28. Results from the Principal Components Analysis of the Inchinnan 1 samples; only the first two Components pass the rules of thumb for reliability outlined above.

Component Matrix[a]

	Component		
	1	2	3
Zscore(v)	0.824	-0.013	-0.248
Zscore(D)	0.946	-0.220	-0.093
Zscore(Avg X)	0.634	-0.550	0.227
Zscore(Avg Y)	0.824	-0.463	0.175
Zscore(Avg Z)	0.943	-0.307	0.014
Zscore(min diff)	0.414	0.651	0.633
Zscore(plus diff)	0.516	0.818	-0.119
Zscore(med diff)	-0.829	-0.061	0.181
Zscore(w)	0.517	0.818	0.227
Zscore(k)	0.208	0.356	-0.850

Extraction Method: Principal Component

a. 3 components extracted.

Table C.29. Total Variance Explained by the Principal Components of the Inchinnan 1 samples

Total Variance Explained

Component	Initial Eigenvalues Total	% of Variance	Cumulative %	Loadings Total	% of Variance	Cumulative %
1	4.979	49.788	49.788	4.979	49.788	49.788
2	2.552	25.522	75.310	2.552	25.522	75.310
3	1.373	13.731	89.041	1.373	13.731	89.041
4	0.761	7.606	96.647			
5	0.321	3.211	99.858			
6	0.011	0.108	99.966			
7	0.002	0.024	99.990			
8	0.001	0.009	99.999			
9	9.650E-05	0.001	100.000			
10	-2.833E-16	-2.833E-15	100.000			

Extraction Method: Principal Component Analysis.

C.5.2 Inchinnan 1 Standard Discriminant Analysis Results

Table C.30. Wilks' Lambda for the Discriminant Analysis (standard method) of the Inchinnan 1 samples.

Wilks' Lambda

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 2	0.026	25.508	10	0.004
2	0.386	6.667	4	0.155

Table C.31. Structure Matrix for the Discriminant Analysis (standard method) of the Inchinnan 1 samples. Because three clusters were identified, the Structure Matrix is limited to two Functions.

Structure Matrix

	Function 1	Function 2
Zscore(AvgZ)	.675*	0.447
Zscore(v)	0.286	.835*
Zscore(meddiff)	-0.238	-.239*
Zscore(w)[b]	0.102	.205*
Zscore(plusdiff)	0.087	.184*
Zscore(mindiff)	0.097	.183*

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.

*. Largest absolute correlation between

b. This variable not used in the analysis.

Table C.32. Casewise Statistics for the Discriminant Analysis (standard method) of the Inchinnan 1 samples.

Casewise Statistics

Case Number		Actual Group	Predicted Group	P(G=g | D=d)	Discriminant Scores Function 1	Discriminant Scores Function 2
Original	1	1	1	1.000	-1.426	2.936
	2	1	1	0.999	-1.504	1.848
	3	2	2	1.000	2.250	-1.085
	4	2	2	0.960	1.857	1.805
	5	2	2	1.000	1.636	-0.433
	6	2	2	1.000	1.847	-1.378
	7	2	2	1.000	2.446	-1.241
	8	2	2	1.000	1.269	-0.730
	9	2	2	0.999	2.088	0.629
	10	2	2	0.698	-0.935	-0.265
	11	2	2	0.999	0.512	-0.874
	12	3	3	1.000	-10.040	-1.211
Cross-validated[b]	1	1	2**	1.000		
	2	1	2**	1.000		
	3	2	2	1.000		
	4	2	1**	1.000		
	5	2	2	1.000		
	6	2	2	1.000		
	7	2	2	1.000		
	8	2	2	0.999		
	9	2	2	0.970		
	10	2	1**	1.000		
	11	2	1**	0.528		
	12	3	1**	1.000		

**. Misclassified case

b. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

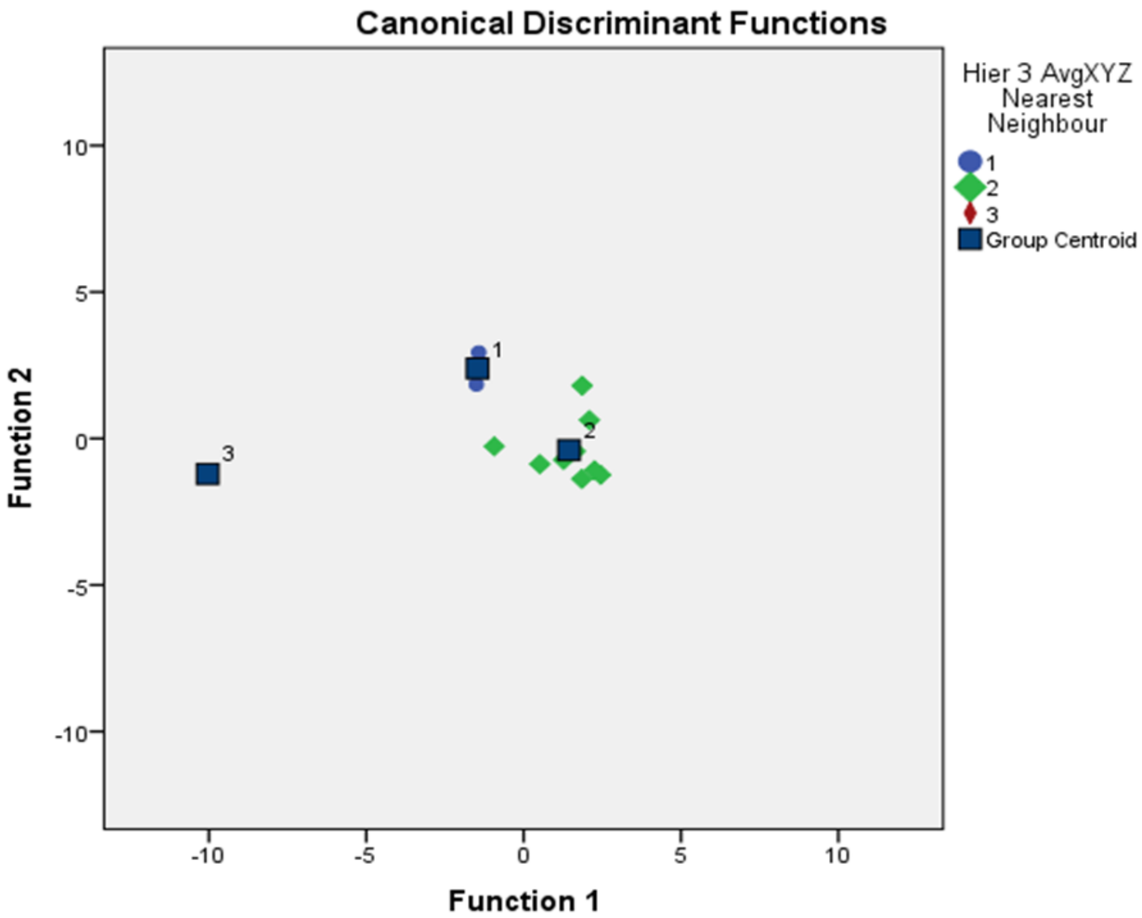


Figure C.4. Plot of Discriminant Functions (standard method) for the Inchinnan 1 Groups.

C.5.3 Inchinnan 1 Forward Stepwise Discriminant Analysis Results

Table C.33. Two variables qualified for the Forward Stepwise Discriminant Analysis of the Inchinnan 1 samples: AvgZ and v.

Variables Entered/Removed[a,b,c,d]

Step	Entered	Min. D Squared		Exact F			
		Statistic	Between Groups	Statistic	df1	df2	Sig.
1	Zscore(v)	2.241	1 and 2	3.667	1	9.000	0.088
2	Zscore(AvgZ)	11.896	1 and 2	8.651	2	8.000	0.010

At each step, the variable that maximizes the Mahalanobis distance between the two closest groups is

a. Maximum number of steps is 12.

b. Maximum significance of F to enter is .1.

c. Minimum significance of F to remove is .11.

d. F level, tolerance, or VIN insufficient for further computation.

Table C.34. Wilks' Lambda and Tests of Equality of Group Means for the variables included in the Forward Stepwise Discriminant Analysis of the Inchinnan 1 samples.

Tests of Equality of Group Means

	Wilks' Lambda	F	df1	df2	Sig.
Zscore(v)	0.309	10.045	2	9	0.005
Zscore(AvgZ)	0.132	29.649	2	9	0.000
Zscore(mindiff)	0.846	0.820	2	9	0.471
Zscore(plusdiff)	0.864	0.707	2	9	0.519
Zscore(meddiff)	0.534	3.922	2	9	0.060
Zscore(w)	0.827	0.939	2	9	0.426

Table C.35. Pairwise Group Comparisons resulting from the Forward Stepwise Discriminant Analysis of the Inchinnan 1 samples.

Pairwise Group Comparisons[a,b]

Step			1	2	3
1	1	F		3.667	19.856
		Sig.		0.088	0.002
	2	F	3.667		14.116
		Sig.	0.088		0.005
	3	F	19.856	14.116	
		Sig.	0.002	0.005	
2	1	F		8.651	16.345
		Sig.		0.010	0.001
	2	F	8.651		32.812
		Sig.	0.010		0.000
	3	F	16.345	32.812	
		Sig.	0.001	0.000	

a. 1, 9 degrees of freedom for step 1.

b. 2, 8 degrees of freedom for step 2.

Table C.36. Casewise Statistics for the Forward Stepwise Discriminant Analysis of the Inchinnan 1 samples.

Casewise Statistics

Case Number		Actual Group	Predicted Group	P(G=g | D=d)	Discriminant Scores Function 1	Discriminant Scores Function 2
Original	1	1	1	0.998	-1.387	2.028
	2	1	1	0.997	-1.049	2.288
	3	2	2	1.000	2.687	-0.915
	4	2	2	0.953	2.041	1.659
	5	2	2	0.999	1.547	-0.611
	6	2	2	1.000	1.661	-1.614
	7	2	2	1.000	1.462	-1.352
	8	2	2	0.984	0.095	-0.609
	9	2	2	0.839	0.766	0.998
	10	2	2	0.850	-0.836	-0.542
	11	2	2	0.993	0.891	-0.201
	12	3	3	1.000	-7.878	-1.130
Cross-validated[b]	1	1	1	0.995		
	2	1	1	0.994		
	3	2	2	1.000		
	4	2	1**	0.830		
	5	2	2	0.999		
	6	2	2	1.000		
	7	2	2	1.000		
	8	2	2	0.969		
	9	2	2	0.781		
	10	2	1**	0.752		
	11	2	2	0.988		
	12	3	1**	1.000		

**. Misclassified case

b. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

Appendix D How to Read the Charts and Tables in this Thesis

D.1 Dendrograms

A dendrogram creates 'a visual representation of the distance at which clusters are combined'(Norušis 2012, 384). The black vertical lines on the diagram represent the point at which samples or clusters are combined by the algorithm. In this thesis, dendrograms are used to determine how many clusters into which the samples should be divided. This is a subjective process that is informed by the dendrogram itself. Because this analysis is attempting to define samples of carved grooves as the work of different individuals, it is more conservative to assume hypothetically that the samples clustered below represent the work of three individuals; subsequent statistical steps provide more opportunities for identifying similarities and for combining the clusters further. In the example below, the samples have been divided into three clusters by making the division (drawing a vertical line) somewhere between 1 and 7 on the dendrogram (Figure D.1).

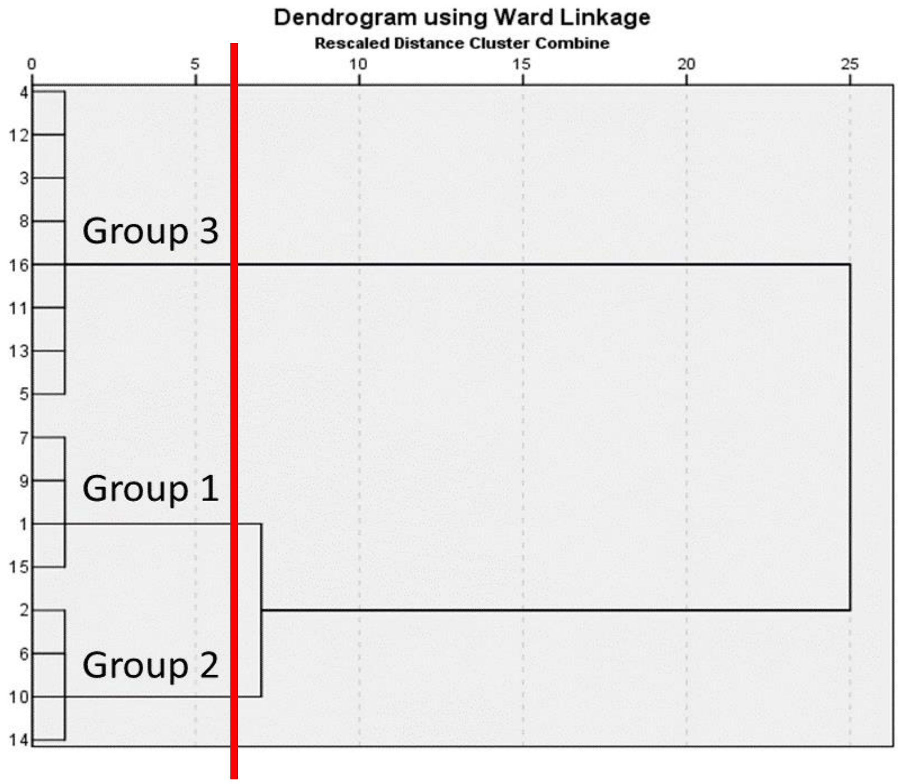


Figure D.1. Diagram from Figure 5.21 to demonstrate how dendrograms can be used for defining clusters.

D.2 K-means clustering

K-means cluster analysis is a clustering method by which the researcher inputs the number of clusters that they expect to see. The algorithm estimates the mean for each of these clusters and reassigns each sample to the nearest cluster mean (Norušis 2012, 376). The expected number of clusters can be changed by the researcher until the samples appear well-clustered. The members of the final clusters are visually defined with a different shape and colour. An example is provided below (Figure D.2).

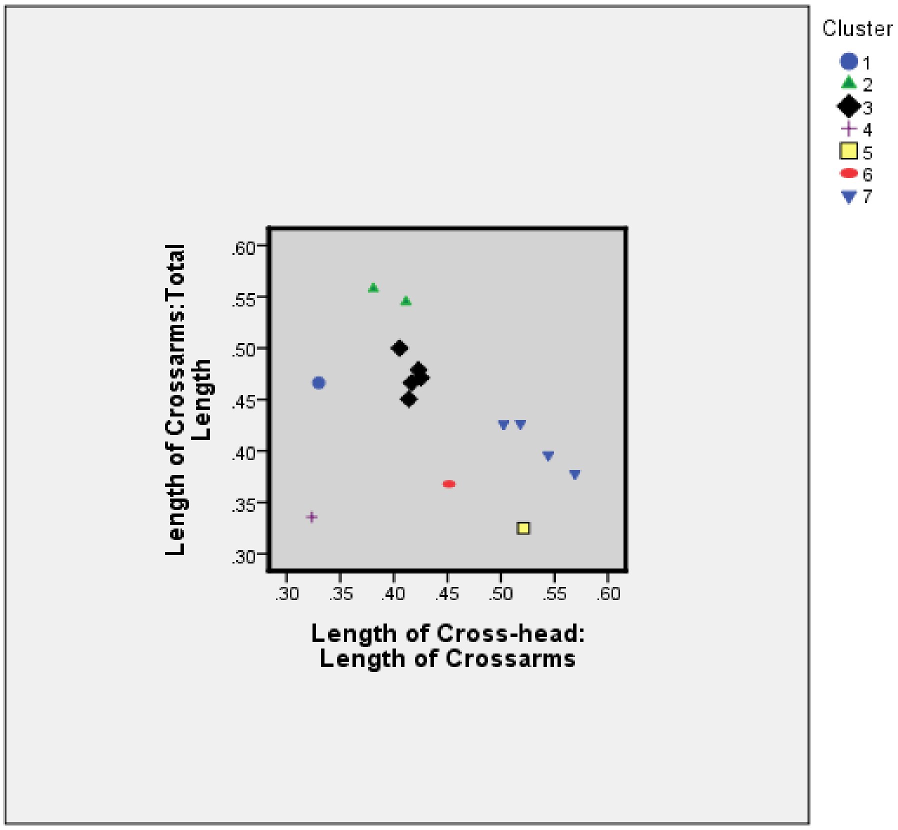


Figure D.2. Graph from Figure 8.12 to visualise how clusters are formed using k-means analysis.

D.3 Principal Components Analysis

As described in Section 5.6.3, Principal Components Analysis (PCA) is an abstract mathematical approach, used for “reducing a large number of variables to a much smaller number of variables that still reflects reasonably accurately…the major patterns in the original dataset…a set of variables that all show strong correlations with each other are all responding to the same underlying thing" (Drennan 2010, 300).

D.3.1 Component Matrix

The first chart produced by this analysis is the Component Matrix, which provides the Principal Components and their component loadings; the loadings indicate how strongly each of the original variables correlate to the underlying Principal Components (Table D.1). In this analysis, the rule of thumb outlined by James Stevens was followed to make certain that, despite the small sample size used in these analyses, statistically significant results were produced. Stevens' rule of thumb suggests that "components with four or more loadings above .60 in absolute value are reliable, regardless of sample size…any component with at least three loadings above .80 will be reliable…Velicer also indicated that when the average of the first four largest loadings is >.60 or the average of the three largest loadings is >.80, then the factors will be reliable" (2009, 333). In each of the analyses described here, the loadings that exceed .60 are highlighted in orange or yellow – however, for each of these, only PC 1 and 2 met the requirements to pass Stevens' test. As discussed more thoroughly in Section 9.9, it is not certain that adhering to this rule is necessary in future analyses.

Table D.1. From the analysis of the Govan 1 'Shallow' samples; highlighted cells contain loadings that have met Stevens' required level of >.60. Only PC1 and 2 meet all criteria.

Component Matrix[a]

	Component			
	1	2	3	4
Zscore(v)	0.872	-0.051	-0.416	-0.168
Zscore(D)	0.915	-0.193	-0.256	-0.176
Zscore(Avg X)	0.260	-0.642	0.673	-0.091
Zscore(Avg Y)	0.693	-0.537	0.458	-0.097
Zscore(Avg Z)	0.918	-0.341	-0.035	-0.168
Zscore(min diff)	0.196	0.828	0.278	-0.443
Zscore(plu sdiff)	0.710	0.637	0.024	0.197
Zscore(me ddiff)	0.245	0.350	0.578	0.502
Zscore(w)	0.543	0.806	0.151	-0.092
Zscore(k)	0.623	-0.103	-0.253	0.683

Extraction Method: Principal Component Analysis.
a. 4 components extracted.

D.3.2 Total variance explained

The Principal Components defined above, and the variables that contribute most to them, can be demonstrated to best illustrate a certain proportion of variance in the dataset. Because the aim of the analysis is to identify individual carving signatures, the best variable(s) to use would be those that account for the most variability between clusters in the sample, which could indicate different carving techniques. The chart below demonstrates that Principal Components 1-4 explain most of the variance in the dataset, especially in the '% of Variance' columns (Table D.2). By utilising only PC1 and 2 for these analyses only 70% of the variance in the samples is taken into consideration. As discussed more thoroughly in Section 9.9, by ignoring PC 3 and 4 in the interpretation, this may leave out important distinctions to identify individual carving techniques.

Table D.2. From the analysis of the Govan 1 'Shallow' samples; it is most important to consider how much variance is explained by each component.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.274	42.737	42.737	4.274	42.737	42.737
2	2.730	27.299	70.036	2.730	27.299	70.036
3	1.401	14.010	84.046	1.401	14.010	84.046
4	1.068	10.682	94.728	1.068	10.682	94.728
5	0.504	5.036	99.764			
6	0.019	0.185	99.949			
7	0.003	0.029	99.978			
8	0.002	0.019	99.997			
9	0.000	0.003	100.000			
10	3.881E-16	3.881E-15	100.000			

Extraction Method: Principal Component Analysis.

D.4 Standard Discriminant Analysis

After defining clusters, a statistical process called Discriminant Analysis can use the variables in this study and the clusters of samples defined as 'hypothetical carvers' in Section 9.4 to calculate the maximum difference between these groups and the minimum distance between the samples within the groups. Having done so, these calculations can be used by the software to create formulae to best separate the groups. These rules can be used to determine how consistently the samples fall within the 'hypothetical carver' groups (Tharwat et al. 2017; Teknomo 2015). If samples were found not to fit within these groups as a result of the Discriminant Analysis and Forward Stepwise Discriminant Analysis, they were moved to the group suggested instead.

D.4.1 Wilk's Lambda

The Wilk's Lambda is a measure of statistical significance, which "tests how well each level of independent variable contributes to the model" (Statistics How To 2017). In the case of Discriminant Analysis, it determines how well the functions defined by the statistical process (functions which are defined in the Structure Matrix below) contribute to the separation of clusters in the model (Table D.3). The closer the value of Wilks' Lambda is to 0, the more that function contributes to the separation of clusters in the model, which is directly related to how statistically significant the results are. In the case of the Discriminant Analysis that was carried out the 'Shallow' samples from Govan 1 below, a test of both Functions 1 and 2 together separates the clusters quite well (because the Wilk's Lambda is very close to zero), but if one were to rely on Function 2 alone, it would result in poor separation (because it is comparatively close to 1).

Table D.3. From the analysis of the Govan 1 'Shallow' samples; the Wilks' Lambda measures the statistical significance of the functions identified by the Discriminant Analysis. Functions 1 and 2 together make significant contribution to the division of the groups, while Function 2 alone would not.

Wilks' Lambda				
Function(s)	Lambda	Chi-square	df	Sig.
1 through 2	0.053	23.459	10	0.009
2	0.755	2.248	4	0.690

D.4.2 Structure Matrix

The structure matrix indicates how each variable contributes to the Discriminant Functions (the rules developed by the Discriminant analysis that define the separation between the pre-defined clusters; Table D.4). If the values of the loadings are close to 1 or -1, the variable has a larger impact on the function. If they are closer to zero, they have less of an impact on the functions. From the chart below, it is clear that AvgZ (the depth closest to the base of the groove) has the most impact on Function 1 and a relatively strong impact on Function 2, though v (the groove angle) and plusdiff (the average space left between each peck) have more of an effect on Function 2. This chart plays less of a deciding factor in whether a sample is moved to another group or not; instead it informs the researcher how each variable is impacting the analysis.

Table D.4. From the analysis of the Govan 1 'Shallow' samples; the Structure Matrix demonstrates how much of an impact each variable has on each Function defined by the Discriminant Analysis.

Structure Matrix

	Function	
	1	2
AvgZ	.792*	-0.507
v	0.363	-.716*
plusdiff	0.092	-.517*
k	0.152	-.412*
w[b]	0.040	-.378*
mindiff	-0.029	-.142*

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.

*. Largest absolute correlation between each variable and any discriminant function

b. This variable not used in the analysis.

D.4.3 Casewise Statistics (Standard)

The Casewise Classification Statistics table indicates which group a sample was assigned to by the researcher, contrasts this with the group the sample was assigned to based on the Discriminant Scores, and provides the probability that the sample belongs to the Predicted group (George & Mallery 2016, 295). If the group the sample was assigned to by the researcher (Actual Group) matched the group that the sample was assigned to by the Discriminant Analysis (Predicted Group) in the Original results, then samples were not reassigned. Any misclassified samples would be indicated with asterisks. There is an additional option to 'cross-validate' the model these assignments are based on using the 'leave-one-out cross-validation'; while this option is not part of standard procedure for most researchers, and no reclassifications were made based on the cross-validation results, it was useful in this analysis to identify possible relationships between groups, which may advocate for clustering the groups together at a later stage (Table D.5).

Table D.5 From the analysis of the Govan 1 'Shallow' samples; contrasts the groups assigned to samples by the researcher (Actual Group) with that identified by the Discriminant Analysis (Predicted Group).

Casewise Statistics

Case Number		Actual Group	Predicted Group	P(G=g | D=d)	Discriminant Scores Function 1	Discriminant Scores Function 2
Original	1	1	1	0.965	0.404	0.401
	2	1	1	0.995	-0.022	1.026
	3	1	1	0.999	-0.669	1.309
	4	2	2	0.987	2.911	0.499
	5	2	2	0.940	2.443	0.600
	6	2	2	0.856	2.124	0.578
	7	2	2	1.000	4.392	-1.787
	8	2	2	1.000	4.506	0.207
	9	2	2	0.941	1.575	-1.693
	10	3	3	1.000	-5.402	-1.357
	11	3	3	1.000	-4.483	0.997
	12	3	3	0.995	-3.358	-0.131
	13	3	3	1.000	-4.421	-0.648
Cross-validated[b]	1	1	1	0.531		
	2	1	1	0.916		
	3	1	3**	1.000		
	4	2	2	0.941		
	5	2	2	0.891		
	6	2	2	0.768		
	7	2	2	1.000		
	8	2	2	1.000		
	9	2	1**	0.999		
	10	3	3	1.000		
	11	3	3	0.988		
	12	3	3	0.993		
	13	3	3	1.000		

For the original data, squared Mahalanobis distance is based on canonical functions.

**. Misclassified case

b. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

D.4.4 Canonical Discriminant Functions Plot

The Canonical Discriminant Functions plot illustrates how samples are best separated based on Function 1 and Function 2 (Figure D.3). The example provided below demonstrates that the samples are relatively well clustered around their centroids (defined by the Discriminant Analysis), though consultation with the cross-validation portion of the Casewise Statistics chart above (Table D.5) shows that Group 1 is less well-defined than clusters 2 and 3.

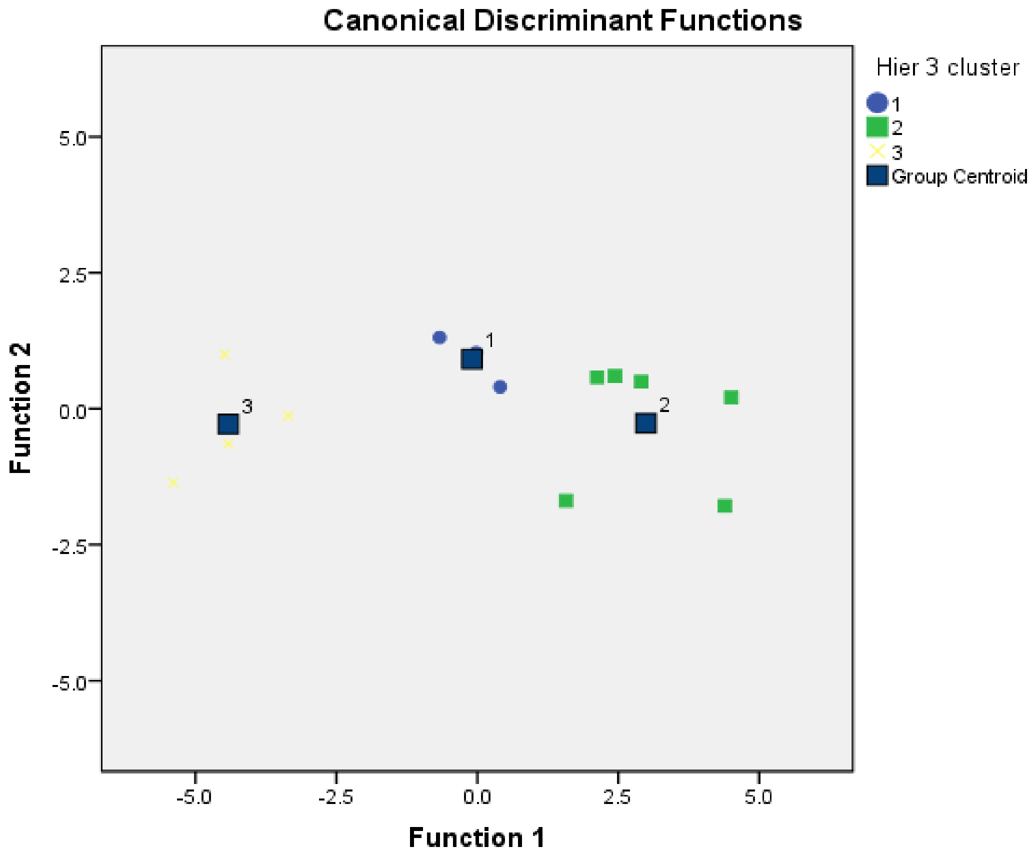


Figure D.3. From the analysis of the Govan 1 'Shallow' samples; illustrates how the samples are separated by Function 1 and Function 2, defined by the Discriminant Analysis.

D.5 Forward Stepwise Discriminant Analysis

Forward Stepwise Discriminant Analysis is similar to the Standard application of Discriminant Analysis, but the main difference is that it is more discerning about which variables are included in the analysis. 'At each step, the variable that contributes least to the prediction of group membership is eliminated' and so it will only 'keep the "important" variables in the model…those that contribute the most to the discrimination between groups'(StatSoft, Inc. 2013).

D.5.1 Variables Entered/Removed

The variables entered/removed table does as its title suggests: it lists the variables that passed the F-value significance test and were incorporated into the analysis (George & Mallery 2016, 286–295). Because AvgZ was used to define the clusters in the first place, it is not surprising that this was considered the most significant variable to retain (Table D.6). What is more interesting is the comparison of this to other charts.

Table D.6. From the analysis of the Govan 1 'Shallow' samples; lists the variables that passed the F-value significance test and were used in the Forward Stepwise Discriminant Analysis. In this case, only AvgZ was used.

Variables Entered/Removed[a,b,c,d]

		Min. D Squared						
					Exact F			
Step	Entered	Statistic	Between Groups	Statistic	df1	df2	Sig.
1	Zscore(AvgZ)	7.927	1 and 3	13.588	1	10.000	0.004

At each step, the variable that maximizes the Mahalanobis distance between the two closest groups is entered.

a. Maximum number of steps is 12.

b. Maximum significance of F to enter is .1.

c. Minimum significance of F to remove is .11.

d. F level, tolerance, or VIN insufficient for further computation.

D.5.2 Tests of Equality of Group Means

The Tests of Equality of Group Means table indicates the significance of each of the variables as they are added (George & Mallery 2016, 286–295). While only AvgZ was used to define the Discriminant Function, it is most interesting to note the significance contributed to other variables – especially variable k (the rhythm of the carving process in a sample), which is more significant than would be expected given that it was not used to define the initial clustering of the samples (p=0.216; Table D.7). While tests of statistical confidence employed in other disciplines often require 95% significance to state that they are confident in a result, archaeologists are often happy with 80% confidence or more given the limits imposed by availability of sample size (Drennan 2010, 157–162).

Table D.7. From the analysis of the Govan 1 'Shallow' samples; shows the significance of each of the variables as they were added to the Forward Stepwise Discriminant Analysis.

Tests of Equality of Group Means

	Wilks' Lambda	F	df1	df2	Sig.
Zscore(v)	0.345	9.508	2	10	0.005
Zscore(AvgZ)	0.107	41.758	2	10	0.000
Zscore(mindiff)	0.982	0.090	2	10	0.915
Zscore(plusdiff)	0.834	0.996	2	10	0.403
Zscore(w)	0.937	0.338	2	10	0.721
Zscore(k)	0.736	1.796	2	10	0.216

D.5.3 Pairwise Group Comparisons

The Pairwise Group Comparisons indicates the distance between each group based on the variables admitted into the analysis (Table D.8); the significance of each separation is given by a p-value and an F-value (George & Mallery 2016, 286–295). The F-value is another measure of statistical significance for a variable and the 'unique contribution to the prediction of group membership' (StatSoft, Inc. 2013). As long as each of the p-values for each group was less than 0.10, as suggested by Kitzler Åhfeldt (2002a, 96; 2001, 140–142; Kitzler 2000, 93), the samples were retained in their assigned clusters.

Table D.8. From the analysis of the Govan 1 'Shallow' samples; indicates how separate the groups are based on the variables admitted into the analysis, using both the p-value and the F-value.

Pairwise Group Comparisons[a]

Step			1	2	3
1	1	F		18.526	13.588
		Sig.		0.002	0.004
	2	F	18.526		82.386
		Sig.	0.002		0.000
	3	F	13.588	82.386	
		Sig.	0.004	0.000	

a. 1, 10 degrees of freedom for step 1.

D.5.4 Casewise Statistics (Forward Stepwise)

The Casewise Statistics table produced by the Forward Stepwise Discriminant Analysis is useful in that it can be compared to the Casewise Statistics table from the standard Discriminant Analysis described above (Table D.9). As fewer variables are admitted into the Stepwise Method (although these variables are responsible for the most separation between the groups), it is useful to see if any cases are assigned to different groups due to the inclusion of fewer variables (George & Mallery 2016, 286–295).

Table D.9. From the analysis of the Govan 1 'Shallow' samples; contrasts the groups assigned to samples by the researcher (Actual Group) with that identified by the Discriminant Analysis (Predicted Group). However, because the groups were defined by AvgZ, it is unsurprising that this is perfectly classified as only AvgZ was admitted into the Forward Stepwise Discriminant Analysis for this data.

Casewise Statistics

Case Number		Actual Group	Predicted Group	P(G=g | D=d)	Discriminant Scores Function 1
Original	1	1	1	0.876	0.338
	2	1	1	0.938	-0.964
	3	1	1	0.934	-0.989
	4	2	2	0.986	2.385
	5	2	2	0.861	1.583
	6	2	2	0.839	1.527
	7	2	2	1.000	4.511
	8	2	2	0.999	3.389
	9	2	2	0.879	1.636
	10	3	3	0.954	-3.019
	11	3	3	0.998	-4.226
	12	3	3	0.867	-2.611
	13	3	3	0.989	-3.558
Cross-validated[a]	1	1	1	0.817	
	2	1	1	0.917	
	3	1	1	0.912	
	4	2	2	0.979	
	5	2	2	0.838	
	6	2	2	0.813	
	7	2	2	1.000	
	8	2	2	0.999	
	9	2	2	0.858	
	10	3	3	0.938	
	11	3	3	0.998	
	12	3	3	0.834	
	13	3	3	0.984	

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

Bibliography

Adams, W.Y., & Adams, E.W. 1991. *Archaeological typology and practical reality: A dialectical approach to artifact classification and sorting*. Cambridge: Cambridge University Press.

Adcock, G. 1974. *A study of the types of interlace and interlace types on Northumbrian sculpture*. Unpublished M.Phil. Durham: University of Durham. Available at: http://etheses.dur.ac.uk/9570/.

Adobe. 2017. Displaying 3D Models in PDFs. *Displaying 3D Models in PDFs, Adobe Acrobat*. Available at: https://helpx.adobe.com/acrobat/using/displaying-3d-models-pdfs.html [Accessed January 16, 2019].

AgiSoft PhotoScan Professional. 2016. *AgiSoft Photoscan Professional*. St. Petersburg, Russia: Agisoft LLC.

Alcock, L., & Alcock, E.A. 1990. Reconnaissance excavations on Early Historic fortifications and other royal sites in Scotland, 1974-84: 4, Excavations at Alt Clut, Clyde Rock, Strathclyde, 1974-75. *Proceedings of the Society of Antiquaries of Scotland* 120: p.95–149.

Allen, J.R. 1897. Report on the Photography of the Sculptured Stones earlier than A.D. 1100, in the District of Scotland south of the river Dee; obtained under the Jubilee Gift of His Excellency Dr. R. H. Gunning, LL.D., F.S.A. Scot. *Proceedings of the Society of Antiquaries of Scotland* 31: p.147–152.

Allen, J.R. 1903. The Early Christian Monuments of the Glasgow District. *Transactions of the Glasgow Archaeological Society* 4: p.394–405.

Allen, J.R., & Anderson, J. 1903. *The Early Christian Monuments of Scotland*. 2 vols. Reprint. Balgavies, Angus: The Pinkfoot Press.

Alon, O., & Rimokh, J. 2015. *Zbrush*. Pixologic. Available at: http://pixologic.com/zbrush/features/overview/.

Anderson, J. 1900. Description of a Collection of Objects found in Excavations at St Blane's Church, Bute, Exhibited by the Marquis of Bute. *Proceedings of the Society of Antiquaries of Scotland* 34: p.307–325.

Artec Europe. 2016. Artec Eva 3D Object Scanner/Structured-light Scanning Device. *Artec Eva 3D Object Scanner/Structured-light Scanning Device*. Available at: https://www.artec3d.com/hardware/artec-eva#specifications [Accessed July 1, 2016].

Ask, C. 2012. *Interpreting in 3D: Employing 3D modelling in field archaeology from research and public communication perspectives*. Master's Thesis in Archaeology. Lund, Sweden: Lund University. Available at: https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=2543931&fileOId=2543934 [Accessed March 3, 2017].

Atkinson, R.J.C. 1985. Foreword. In *Excavations at York Minster, Volume II: The Cathedral of Archbishop Thomas of Bayeux*, xv–xvi. London: Her Majesty's Stationery Office

Autodesk. 2018. ReCap | Reality Capture and 3D Scanning Software | Autodesk. *ReCap Overview*. Available at: https://www.autodesk.co.uk/products/recap/overview [Accessed January 3, 2019].

Backhouse, J. 1981. *The Lindisfarne Gospels*. Oxford: Phaidon in association with the British Library.

Badham, S. 2010. What Constituted a Workshop? In *Monumental Industry: The Production of Tomb Monuments in England and wales in the Long Fourteenth Century*, 12–36. Donington: Shaun Tyas

Bailey, R., & Lang, J.T. 1975. The date of the Gosforth sculptures. *Antiquity* 49: p.290–293.

Bailey, R.N. 1980. *Viking Age Sculpture in Northern England*. London: William Collins Sons & Co Ltd.

Bailey, R.N. 1994. Govan and Irish Sea sculpture. In A. Ritchie (ed) *Govan and its early medieval sculpture*, 113–122. Stroud: Alan Sutton Publishing Limited

Bailey, R.N. 1996. *England's Earliest Sculptors*. Toronto: Pontifical Institute of Mediaeval Studies.

Barnes, J. 2019. *Of Warriors and Beasts: The Hogbacks and Hammerhead Crosses of the Viking Age Landscapes of Strathclyde and Northumbria*. Unpublished PhD Dissertation. Glasgow: University of Glasgow.

Batey, C. 1994. The sculptured stones in Glasgow Museums. In A. Ritchie (ed) *Govan and its early medieval sculpture*, 63–72. Stroud: Alan Sutton Publishing Limited

Benjamin, W. 1936. The Work of Art in the Age of Mechanical Reproduction. In H. Arendt (ed) *Illuminations*, 218–251. New York: Schocken Books Available at: http://web.mit.edu/allanmc/www/benjamin.pdf.

Bennett, R. 2014. Airborne Laser Scanning for Archaeological Prospection. In *3D Recording and Modelling in Archaeology and Cultural Heritage: Theory and best practices*, 25–36. Oxford: Archaeopress

Borland, J. 2005. Understanding what we see, or seeing what we understand: graphic recording, past and present, of the early medieval sculpture at St Vigeans. In *Able Minds and Practised Hands*.The Society for Medieval Archaeology Monograph, 201–214. Scotland: Historic Scotland

Breeze, A. 1999. Simeon of Durham's annal for 756 and Govan, Scotland. *Nomina* 22: p.133–7.

Brennan, M. 2011. *The Structure of Interlace in Insular Art c. AD 400-1200*. Unpublished PhD Dissertation. Bangor: Bangor University.

Brotchie, T.C.F. 1905. *The History of Govan*. Govan: John Cossar.

Broun, D. 2007. The Scots as Ancient and Free: 'Proto-Fordun', 'Veremundus' and the Creation of Scottish History. In *Scottish Independence and the Idea of Britain: From the Picts to Alexander III*, 235–270. Edinburgh University Press Available at: http://edinburgh.universitypressscholarship.com/view/10.3366/edinburgh/9780748623600.001.0001/upso-9780748623600-chapter-009.

Brown, M. 2003. *The Lindisfarne Gospels: Society, Spirituality and the Scribe*. Cambridge: University Press.

Cameron, F. 2007. Beyond the Cult of the Replicant: Museums and Historical Digital Objects - Traditional Concerns, New Discourses. In F. Cameron & S. Kenderdine (eds) *Theorizing Digital Cultural Heritage: A Critical Discourse*, 49–76. Cambridge: MIT Press Available at: http://mitpress.universitypressscholarship.com/view/10.7551/mitpress/9780262033534.001.0001/upso-9780262033534-chapter-4?print=pdf [Accessed December 19, 2018].

Campbell, L. 2018. *Decorating the Distance Stones: pXRF and Portable Raman Spectroscopic Analysis of Pigments on the Antonine Wall Distance Stones*. Glasgow: University of Glasgow.

Carty, A. 2005. Three-dimensional recording of Pictish sculpture. In *Able Minds and Practised Hands*, 367–374. Scotland: Historic Scotland

Carver, M.O.H. 1995. Roman to Norman at York Minster. In *The Excavations at York Minster, Volume I: Part 1 The Site*, 177–195. London: Royal Commission on the Ancient and Historical Monuments of England

Chadburn, R. 1994. The geology of the Govan stones, a preliminary assessment. In *Govan and its early medieval sculpture*, 145–146. Stroud: Alan Sutton Publishing Limited

Chalmers, P. 1848. *The Ancient Sculptured Stones of the County of Angus*. Aberdeen: Bannatyne Club.

Chapman, H., Baldwin, E., Moulden, H., & Lobb, M. 2013. More Than Just a Sum of the Points: Re-Thinking the Value of Laser Scanning Data. In E. Ch'ng, V. Gaffney, & H. Chapman (eds) *Visual Heritage in the Digital Age*, 15–31. London: Springer-Verlag

Christie, H. 2019. *Pushing Boundaries: Spectral Imaging of Archaeological Small Finds*. Unpublished PhD Thesis. Glasgow: Glasgow School of Art.

Cignoni, P. et al. 2008. MeshLab: an Open-Source Mesh Processing Tool. *Sixth Eurographics Italian Chapter Conference*: p.129–136.

Clancy, T.O. 1996. *Govan: the name*. Available at: http://www.govanold.org.uk/reports/1996_the_name.html [Accessed January 25, 2016].

Clancy, T.O. 1998. *Govan, the name, again*. Available at: http://www.govanold.org.uk/reports/1998_the_name.html [Accessed October 6, 2015].

Clancy, T.O. 2002. Scottish Saints and National Identities in the Early Middle Ages. In A. Thacker & R. Sharpe (eds) *Local saints and local churches in the early medieval West*, 397–421. Oxford: Oxford University Press

Clancy, T.O. 2006. Ystrad Clud. In J. T. Koch (ed) *Celtic Culture: A Historical Encyclopedia*, 1818–1821. Oxford: ABC-Clio Available at: https://ebookcentral.proquest.com/lib/gla/reader.action?docID=265494 [Accessed May 26, 2017].

Clarke, D. 2012. Communities. In D. Clarke, A. Blackwell, & M. Goldberg (eds) *Early Medieval Scotland: Individuals, Communities and Ideas*, 69–139. Edinburgh: NMS Enterprises Limited - Publishing

Clasen, K.-H. 1943. Die Überwindung des Bösen: Ein Beitrag zur Ikonographie des frühen Mittelalters. In E. Fidder (ed) *Neue Beiträge deutcscher Forschung, Wilhelm Worringer zum 60. Geburtstag*, 13–36. Konigsberg: Kanter-Verlag

Colbert, K. 2017. Early Medieval Sculpture in Southeast Ireland: Identities, Landscape and Memory. In Glasgow

Colgrave, B., Mynors, R.A.B., & Mynors, R.A.B. eds. 1991. *Bede's Ecclesiastical History of the English People* Revised Edition. Oxford: Clarendon Press.

Conlon, V.M. 1973. *Camera Techniques in Archaeology*. London: John Baker Ltd.

Corpus of Anglo-Saxon Sculpture. 2017. Corpus News - May 2017-3-D Images of key sculptures. *The Corpus of Anglo-Saxon Sculpture: News*. Available at: http://www.ascorpus.ac.uk/news.php.

Craig, D. 1992. *The distribution of pre-Norman sculpture in South-West Scotland: provenance, ornament, and regional groups*. Doctoral Thesis Online. Durham: University of Durham. Available at: http://etheses.dur.ac.uk/1553/ [Accessed June 13, 2016].

Craig, D. 1994a. Appendix 2. Concordance and measurements of the Govan Stones. In *Govan and its early medieval sculpture*, 147–151. Stroud: Alan Sutton Publishing

Craig, D. 1994b. The early medieval sculpture of the Glasgow area. In A. Ritchie (ed) *Govan and its early medieval sculpture*, 73–91. Stroud: Alan Sutton Publishing Limited

Cramp, R. 1984a. *Corpus of Anglo-Saxon Sculpture in England: County Durham and Northumberland*. Oxford: Oxford University Press.

Cramp, R. 1984b. General Introduction. In *Corpus of Anglo-Saxon Stone Sculpture in England. Volume 1. Part 1.*, Oxford: Published for the British Academy by the Oxford University Press

Cramp, R. 1994. The Govan recumbent cross-slabs. In A. Ritchie (ed) *Govan and its early medieval sculpture*, 55–62. Stroud: Alan Sutton Publishing Limited

Crawford, B.E. 1994. The 'Norse background' to the Govan hogbacks. In A. Ritchie (ed) *Govan and its early medieval sculpture*, 103–112. Stroud: Alan Sutton Publishing Limited

Crawford, B.E. 2005. *The Govan Hogbacks and the Multi-Cultural Society of Tenth-Century Scotland*. Glasgow: Friends of Govan Old.

Cullen, I., & Driscoll, S. 1995. *Excavations at Govan Old Parish Church 1994*. Glasgow: Glasgow University Archaeological Research Division.

Cutmore, C. 1997. *An archaeological study of the memorial stones in the kirkyard of Govan Old Parish Church*. Available at: http://www.govanold.org.uk/reports/1997_tombstones.html [Accessed October 6, 2015].

Dalglish, C., & Driscoll, S. 2009. *Historic Govan: Archaeology and Development*. Edinburgh: Historic Scotland.

Daubos, T., & Ó Cróinín, D. 2009. Comparison of carved panels from two Irish high crosses using laser scans. In *O3A: Optics for Arts, Architecture, and Archaeology II*, Munich, Germany: SPIE Digital Library Available at: https://www.spiedigitallibrary.org/conference-proceedings-of-spie/7391.toc.

David, M. 2013. Bullaun Stones and Early Medieval Pilgrimage at Glendalough. In M. Herity (ed) *Ordnance Survey Letters Wicklow and Carlow: Letters relating to the Antiquities of the Counties of Wicklow and Carlow containing information collected during the progress of the Ordnance Survey 1838–1840*, 14–24. Dublin: Four Masters Press

Davidson Kelly, T.A. 1994. The Govan collection in the context of local history. In A. Ritchie (ed) *Govan and its early medieval sculpture*, 1–18. Stroud: Alan Sutton Publishing Limited

Davies, J.R. 2010. *The Cult of Saint Constantine*. Glasgow: Society of Friends of Govan Old.

Davies, W. 1998. *Whithorn and the World*. Mansefield, Whithorn: The Friends of the Whithorn Trust.

Denard, H. 2009. The London Charter for the Computer-Based Visualisation of Cultural Heritage (Draft 2.1). Available at: www.londoncharter.org [Accessed January 17, 2019].

Denard, H. 2012. A New Introduction to the London Charter. In A. Bentkowska-Kafel, D. Baker, & H. Denard (eds) *Paradata and Transparency in Virtual Heritage*, 57–71. London: Routledge Available at: http://www.londoncharter.org/introduction.html [Accessed December 19, 2018].

Department for Digital, Culture, Media and Sport. 2018. *Culture is Digital*. London: Department for Digital, Culture, Media and Sport. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/687519/TT_v4.pdf [Accessed January 25, 2019].

DGM, AB, & RM. 2012. CloudCompare: User's Manual for version 2.1. Available at: www.cloudcompare.net [Accessed May 2, 2016].

DiMaggio, P., & Hargittai, E. 2001. *From the 'digital divide' to 'digital inequality': studying internet use as penetration increases*. Princeton: Centre for Arts and Cultural Policy Studies, Princeton University. Available at: https://culturalpolicy.princeton.edu/sites/culturalpolicy/files/wp15_dimaggio_hargittai.pdf [Accessed January 25, 2019].

Doneus, M. et al. 2011. From Deposit to Point Cloud - A Study of Low-Cost Computer Vision Approaches for the Straightforward Documentation of Archaeological Excavations. *From Deposit to Point Cloud - A Study of Low-Cost Computer Vision Approaches for the Straightforward Documentation of Archaeological Excavations*. Available at: http://www.academia.edu/1417250/From_deposit_to_point_cloud_A_study_of_low-cost_computer_vision_approaches_for_the_straightforward_documentation_of_archaeological_excavations [Accessed December 4, 2016].

Doneus, M., & Neubauer, W. 2005. 3D Laser Scanners on Archaeological Excavations. *Proceedings of CIPA 2005 XX International Symposium, Torino, Italy, 26 September - 1 October 2005* 34 (5/C34/1): p.226–231.

Dörig, J. 1987. *The Olympia Master and His Collaborators*. Leiden.

Douglas, W. 1926. Culross Abbey and its charters, with notes on a fifteenth century transumpt. *Proc Soc Antiq Scot* 60: p.67–104.

Douglas-Jones, R., Hughes, J., Jones, S., & Yarrow, T. 2016. Science, value and material decay in the conservation of historic environments. *Journal of Cultural Heritage* 21: p.823–833.

Drennan, R.D. 2010. *Statistics for Archaeologists: A Common Sense Approach* Second. Pittsburgh: Springer.

Driscoll, S., Will, R.S., & Shearer, I. 2008. *Water Row, Govan Archaeological Evaluation 2007*. Glasgow: Glasgow University Archaeological Research Division.

Driscoll, S.T. 1995. *Trial excavations at Govan Old Parish Church 1994*.

Driscoll, S.T. 1998. Church archaeology in Glasgow and the kingdom of Strathclyde. *Innes Review* 49(2): p.95–114.

Driscoll, S.T. 2004. *Govan from Cradle to Grave*. Glasgow: Friends of Govan Old. Available at: http://eprints.gla.ac.uk/3147/ [Accessed October 12, 2015].

Driscoll, S.T. 2016. Reading Govan Old: interpretive challenges and aspirations. In F. Hunter & A. Sheridan (eds) *Ancient Lives: Object, People, and Place in Early Scotland. Essays for David V Clarke on his 70th birthday.*, 73–91. Leiden: Sidestone Press Available at: http://eprints.gla.ac.uk/130579/7/130579.pdf [Accessed March 8, 2017].

Driscoll, S.T., O'Grady, O., & Forsyth, K.S. 2005. The Govan School revisited: searching for meaning in the early medieval sculpture of Strathclyde. In S. Foster & M. Cross (eds) *Able Minds and Practised Hands*, 135–158. Scotland: Historic Scotland

Driscoll, S.T., & Will, R.S. 1997. *Govan Old Parish Church and Water Row*. Glasgow: Glasgow University.

Dublin Institute for Advanced Studies: School of Celtic Studies. 2017. Ogham in 3D. *Ogham in 3D*. Available at: https://ogham.celt.dias.ie/menu.php?lang=en [Accessed March 29, 2018].

Dunbabin, K.M.D., & Dickie, M.W. 1983. Invida Rumpantur Pectora. The Iconography of Phthonos/Invidia in Greco-Roman Art. *Jahrbuch für Antike iund Christentum* 26: p.7–37.

Earl, G., Martinez, K., & Malzbender, T. 2010. Archaeological Applications of Polynomial Texture Mapping: Analysis, Conservation, and Representation. *Journal of Archaeological Science* 37(8): p.2040–2050.

Edwards, N. 2001. Monuments in a landscape: the early medieval Sculpture of St David's. In *Image and Power in the Archaeology of Early Medieval Britain*, 53–77. Oxford: Oxbow Press

English Heritage. 2018. Ancient Writing Discovered at Tintagel Castle. *Ancient Writing Discovered at Tintagel Castle | English Heritage*. Available at:

https://www.english-heritage.org.uk/about-us/search-news/tintagel-archaeology/.

Eve, S. 2012. Embodied GIS HowTo: Part 1a - Creating RTIs using Blender (an aside). *Dead Men's Eyes*. Available at: http://www.dead-mens-eyes.org/embodied-gis-howto-part-1a-creating-rtis-using-blender-an-aside/ [Accessed March 16, 2018].

Eve, S. 2014. *Dead men's eyes: embodied GIS, mixed reality and landscape archaeology*. Oxford: Archaeopress.

Ewart, G., Gallagher, D., & Ritchie, A. 2007. The Dupplin Cross: recent investigations. *Proceedings of the Society of Antiquaries of Scotland* 137: p.319–336.

Fisher, I. 1994. The Govan cross-shafts and early cross-slabs. In A. Ritchie (ed) *Govan and its early medieval sculpture*, 47–54. Stroud: Alan Sutton Publishing Limited

Fisher, I. 2005. Christ's Cross Down into the Earth. In S. M. Foster & M. Cross (eds) *Able Minds and Practised Hands: Scotland's Early Medieval Sculpture in the 21st Century*.The Society for Medieval Archaeology Monograph, 85–94. Scotland: Historic Scotland

Fisher, J. 2011. Stone workers. In A. Patrizio (ed) *Stone: A Legacy and Inspiration for Art*, 76–127. London: Black Dog Publishing

Forsyth, K. 2000. Evidence of a lost Pictish source in the Historia Regum Anglorum of Symeon of Durham. In S. Taylor (ed) *Kings, Clerics and Chronicles in Scotland, 500-1297*, 19–34. Dublin: Four Courts Press

Forsyth, K. 2008. 'Knots and Crosses': Exploring the Ornament of Govan's sculpture.

Forsyth, K. 2009. The Latinus Stone: Whithorn's earliest Christian monument. In J. Murray (ed) *St Ninian and the Earliest Christianity in Scotland: Papers from the conference held by The Friends of the Whithorn Trust in Whithorn on September 15th 2007*.BAR British Series, 19–41. Oxford: Archaeopress

Forsyth, K., & Tedeschi, C. 2008. Text-inscribed slates. In *Inchmarnock: An early historic island monastery and its archaeological landscape*, 128–151. Edinburgh: Society of Antiquaries of Scotland

Foster, S. 2015. Circulating agency: The V&A, Scotland and the multiplication of plaster casts of 'Celtic Crosses'. *Journal of the History of Collections* 27(1): p.73–96.

Foster, S., & Halbstein, D. 2014. *Integrating 3D Modeling, Photogrammetry and Design*. New York: Springer. Available at: http://download.springer.com.ezproxy.lib.gla.ac.uk/static/pdf/560/bok%253A978-1-4471-6329-9.pdf?originUrl=http%3A%2F%2Flink.springer.com%2Fbook%2F10.1007%2F978-1-4471-6329-9&token2=exp=1494594091~acl=%2Fstatic%2Fpdf%2F560%2Fbok%25253A978-1-4471-6329-9.pdf%3ForiginUrl%3Dhttp%253A%252F%252Flink.springer.com%252Fbook%252F10.1007%252F978-1-4471-6329-9*~hmac=f292877003812f0d10e27a3ce3169f4f248f91b44dc77c113465043e44e92984 [Accessed May 12, 2017].

Foster, S., Jones, S., & Jeffrey, S. 2018. Concrete and non-concrete: An ethnographic study of the contemporary value and authenticity of historic replicas. *Concrete and non-concrete - Concrete and non-concrete - University of Stirling*. Available at: https://www.stir.ac.uk/cehp/projects/concreteandnon-concrete/ [Accessed March 29, 2018].

Foster, S.M. 2005. Introduction. Able Minds and Practised Hands: historical fact, 21st-century aspiration. In *Able Minds and Practised Hands*.The Society for Medieval Archaeology Monograph, 1–12. Scotland: Historic Scotland

Freedspace/Thinglab. 2016. Artec MHT 3D Scanner - Thinglab. *Artec MHT 3D Scanner - Thinglab*. Available at: http://www.thinglab.com.au/scan/3d-scanners/2013-08-20-04-18-46/artec-mht [Accessed July 1, 2016].

Freij, H. 1990. Tracing a Rune-Carver by Groove Profile and Cut-Marks. *Norwegian Archaeological Review* 23(1–2): p.150–152.

Freij, H. 1996. Studier av runstensspårs profiler och huggmärken.

Frischer, B. 2014. 3D Data Capture, Restoration and Online Publication of Sculpture. In *3D Recording and Modelling in Archaeology and Cultural Heritage: Theory and best practices*, 137–144. Oxford: Archaeopress

Gabov, A., & Bevan, G. 2011. Recording the Weathering of Outdoor Stone Monuments Using Reflectance Transformat (RTI): The Case of the Guild of All Arts (Scarborough, Ontario). *Journal for the Canadian Association for Conservation* 36: p.3–14.

Galeazzi, F. 2018. 3-D Virtual Replicas and Simulations of the Past: 'Real' or 'Fake' Representations? *Current Anthropology* 59(3): p.268–286.

George, D., & Mallery, P. 2016. *IBM SPSS Statistics 23 Step by Step: A Simple Guide and Reference* 14th ed. New York: Routledge, Taylor & Francis Group. Available at: https://books.google.co.uk/books?id=vKLOCwAAQBAJ&source=gbs_navlinks_s [Accessed July 10, 2018].

Glasgow School of Art. 2016. Archaeology Community Co-Production of Research Data. *Archaeology Community Co-Production of Research Data*. Available at: http://www.gsa.ac.uk/research/research-centres/digital-design-studio/research/current-projects/accord/ [Accessed June 29, 2016].

Gondek, M. 2003. *Mapping sculpture and power: symbolic wealth in early medieval Scotland, 6th-11th centuries AD*. PhD. Glasgow, Scotland: University of Glasgow. Available at: http://theses.gla.ac.uk/988/ [Accessed January 24, 2019].

Gondek, M. 2006. Investing in Sculpture: Power in Early-historic Scotland. *Medieval Archaeology* 50(1): p.105–142.

Goskar, T. 2018. A Little Less Mute: 3D Laser Scanning Rock Art and Inscribed Stones. In A. M. Jones & H. Quinnell (eds) *An Intellectual Adventurer in Archaeology: Reflections on the work of Charles Thomas*, 175–182. Oxford: Archaeopress

Gray, T.E. 1997. Photographic Recording of Carved Stones. In *Photographing Carved Stones*, 4–21. Balgavies, Angus: The Pinkfoot Press

Grussenmeyer, P., Landes, T., Doneus, M., & Lerma, J.L. 2016. Basics of Range-Based Modelling Techniques in Cultural Heritage 3D Recording. In E. Stylianidis & F. Remondino (eds) *3D Recording, Documentation, and Management of Cultural Heritage*, 305–368. Dunbeath, Scotland: Whittles Publishing

Halbrucker, É. et al. 2017. Potentials of a 3D approach for microwear analysis on flint artefacts. In Maastricht

Hale, A. et al. 2017. Disrupting the heritage of place: practising counter-archaeologies at Dumby, Scotland. *World Archaeology* 49(3): p.372–387.

Harrison, K. 1960. The Pre-Conquest Churches of York: with an Appendix on Eighth-Century Northumbrian Annals. *The Yorkshire Archaeological Journal* 40: p.232–249.

Harvey, J. 2011. Foreward. In A. Patrizio (ed) *Stone: A Legacy and Inspiration for Art*, 8–15. London: Black Dog Publishing

Hawkes, J. 2003. Reading Stone. In *Theorizing Anglo-Saxon Stone Sculpture*.Medieval European Studies, 5–30. Morgantown: West Virginia University Press

Henderson, I. 1993. Introduction: The Making of The Early Christian Monuments of Scotland. In *The Early Christian Monuments of Scotland*, one-forty-eight. Balgavies, Angus: Pinkfoot Press

Henderson, I. 1996. *Pictish monsters: symbol, text and image*. Cambridge: Department of Anglo-Saxon, Norse, and Celtic, University of Cambridge.

Hickie, A. 2015. Avoch Community Archaeology. *Avoch Community Archaeology*. Available at: https://www.facebook.com/digavoch/.

Higgitt, J. 1990. Early medieval sculpture at Dumbarton. *Proceedings of the Society of Antiquaries of Scotland* 120: p.139–142.

Higgitt, J. 2005. Towards a 'New ECMS': the proposal for a new Corpus of Early Medieval Sculpture in Scotland. In *Able Minds and Practised Hands*, 375–380. Scotland: Historic Scotland

Hill, P. 1997. *Whithorn and St Ninian: The Excavation of a Monastic Town, 1984-91*. Stroud: Sutton.

Historic Environment Scotland. 2019. 3D Models. *3D Models - Scotland's Rock Art Project*. Available at: https://www.rockart.scot/images/3d-models/.

Holloway, R.R. 2000. The Master of Olympia: The Documentary Evidence. *The Master of Olympia: the Documentary Evidence | Joukowsky Institute for Archaeology | Brown University*. Available at: https://www.brown.edu/academics/archaeology/publications/olympia [Accessed April 2, 2018].

Hughes, S. 2011. CT Scanning in Archaeology. In L. Saba (ed) *Computed Tomography - Special Applications*, 57–70. InTech Available at: https://www.researchgate.net/publication/221920121_CT_Scanning_in_Archaeology [Accessed November 9, 2017].

Hunter, F. 2008. The Oil Shale Artefacts and Related Material. In *Inchmarnock: An early historic island monastery and its archaeological landscape*, 193–202. Edinburgh: Society of Antiquaries of Scotland

Hurcombe, L.M. 2007. *Archaeological Artefacts as Material Culture*. Oxon: Routledge.

IBM Corporation. 2016. *IBM SPSS Statistics for Windows*. Armonk, NY: IBM Corp.

Inchinnan Historical Interest Group. 2018. 597 AD St Conval to All Hallows - 1420 Years and Counting. Available at: https://myinchinnan.org.uk/2017/10/project-round-up/.

Jeffrey, S. 1998. A Simple Technique for Visualising Three Dimensional Models in Landscape Contexts. *Internet Archaeology* (10). Available at: http://intarch.ac.uk/journal/issue10/jeffrey/toc.html [Accessed March 15, 2016].

Jeffrey, S. 2003. *Three Dimensional Modelling of Scottish Early Medieval Sculpted Stones*. PhD Dissertation. Glasgow: University of Glasgow.

Jeffrey, S. 2005. The missing dimension: future directions in digital recording of early medieval sculptured stone. In *Able Minds and Practised Hands*, 353–366. Scotland: Historic Scotland

Jeffrey, S. 2010. Resource Discovery and Curation of Complex and Interactive Digital Datasets. In *Revisualizing Visual Culture*, 45–60. Surrey: Ashgate Publishing Limited

Jeffrey, S. 2012. A new Digital Dark Age? Collaborative web tools, social media and long-term preservation. *World Archaeology* 44(4): p.553–570.

Jeffrey, S. 2015. Challenging Heritage Visualisation: Beauty, Aura, and Democratisation. *Open Archaeology* 1: p.144–152.

Jeffrey, S. 2018. Digital heritage objects, authorship, ownership and engagement. In P. Di-Giuseppantonio-Di-Franco, F. Galeazzi, & V. Vassallo (eds) *Authenticity and cultural heritaqge in the age of 3D digital reproductions*, 49–56. Cambridge: McDonald Institute for Archaeological Research

Jones, A.M. et al. 2015. Digital imaging and prehistoric imagery: a new analysis of the Folkton Drums. *Antiquity* 89(347): p.1083–1095.

Jones, S. 2006. 'They Made it a Living Thing Didn't They...': The Growth of Things and the Fossilization of Heritage. In R. Layton, S. Shennan, & P. Stone (eds) *A Future for Archaeology*, 107–126. Walnut Creek, CA: Left Coast Press

Jones, S., Jeffrey, S., Maxwell, M., Hale, A., & Jones, C. 2017. 3D heritage visualisation and the negotiation of authenticity: the ACCORD project. *International Journal of Heritage Studies* 24(4): p.333–353.

Kantner, J. 2000. Realism Vs. Reality: Creating Virtual Reconstructions of Prehistoric Architecture. In J. Barceló, M. Forte, & D. H. Sanders (eds) *Virtual Reality in Archaeology*.BAR International Series, 47–52. Oxford: Archaeopress

Kasten, M. In press b. Inchinnan 5 – The Discovery and Reconstruction of an Early Medieval Carved Stone. *Proceedings of the Society of Antiquaries of Scotland*.

Kasten, M. In press a. Shadows of a Legacy : The Use of Reflectance Transformation Imaging in the Reconstruction of the Govan Stones. In *Proceedings of the Virtual Heritage Network: Ireland conference.*, University College Cork

Kitzler Åhfeldt, L. 2000. The Sparlösa Monument and its Three Carvers. A Study of Division of Labour by Surface Structure Analysis. *Lund Archaeological Review* 6: p.99–121.

Kitzler Åhfeldt, L. 2001. Öpir – A Viking-Age Workshop for Rune Stone Production in Central Sweden? A study by surface structure analysis into the division of labour. *Acta Archaeologica* 72(2): p.129–157.

Kitzler Åhfeldt, L. 2002a. Individual variability in Rune Carving on Rock: A comparison between individuals and workshops. *Journal of Nordic Archaeological Science* 13: p.79–101.

Kitzler Åhfeldt, L. 2002b. *Work and Worship: Laser Scanner Analysis of Viking Age Rune Stones (Summary)*. Doctoral Dissertation. Stockholm: Stockholm University. Available at: https://www.academia.edu/3445594/Work_and_Worship_Laser_Scanner_Analysis_of_Viking_Age_Rune_Stones_Summary_ [Accessed October 20, 2015].

Kitzler Åhfeldt, L. 2009a. Celtic and Continental handicraft traditions; Template use on Gotlandic Picture Stones analysed by 3D-scanning. In A. Ney, H. Williams, & F. Charpentier Ljungqvist (eds) *Á austrvega: Saga and East Scandinavia: Preprint papers of The 14th International Saga Conference Uppsala, 9th–15th August 2009*, 498–505. The University of Gävle

Kitzler Åhfeldt, L. 2009b. Keltiskt eller kontinentalt? Om mallanvändning på Gotlands bildstenar. In C. Hedenstierna-Jonson, T. Svensson, & E. Lundberg (eds) *Spaden och pennan. En minnesskrift till Erik B Lundberg och Bengt G Söderberg.*, 131–154. Visby

Kitzler Åhfeldt, L. 2009c. The rune stone fragments at Köpingsvik, Öland. In E. Regner, C. von Heijne, L. Kitzler Åhfeldt, & A. Kjellström (eds) *From Ephesos to Dalecarlia : reflections on body, space and time in medieval and early modern Europe*, 83–100. Statens Historiska Museum

Kitzler Åhfeldt, L. 2010. *3D-Scanning at the Archaeological Research Laboratory 2006-2009*. Stockholm: Archaeological Research Laboartory Stockholm University.

Kitzler Åhfeldt, L. 2012a. Carving Technique and Runic Literacy. In K. Zilmer & J. Jesch (eds) *Epigraphic Literacy and Christian identity: modes of written discourse in the newly Christian European North*, 63–97. Turnhout: Brepols Available at: https://www.academia.edu/3445006/Carving_Technique_and_Runic_Literacy [Accessed October 20, 2015].

Kitzler Åhfeldt, L. 2012b. Picture Stone Workshops and Handicraft Traditions. In M. H. Karnell (ed) *Gotland's Picture Stones: Bearers of an Enigmatic Legacy*.Reports from the Friends of the Historical Museum Association, 183–212. Gotland: Gotlands Museum

Kitzler Åhfeldt, L. 2013. 3D scanning of Gotland picture stones with supplementary material: Digital catalogue of 3D Data. *Journal of Nordic Archaeological Science* 18: p.55–65.

Kitzler Åhfeldt, L. 2015. Picture-stone workshops on Viking Age Gotland - a study of craftworker's traces. In W. Heizmann & S. Oehrl (eds) *Bilddenkmäler zur germanischen Götter- und Heldensage*.Reallexikon der Germanischen Altertumskunde - Ergänzungsbände, 397–462. Berlin, Boston: De Gruyter Available at: https://www.academia.edu/30042217/Picture-stone_workshops_on_Viking_Age_Gotland_a_study_of_craftworkers_traces [Accessed January 5, 2017].

Kitzler Åhfeldt, L. 2017a. Groove Measure Tutorial.

Kitzler Åhfeldt, L. 2017b. Groove Analysis Spreadsheet.

Kitzler, L. 1998. Learning to know a Rune Carver and his cutting technique. A method study and some results. *Laborativ Arkeologi* 10–11: p.89–103.

Kitzler, L. 2000. Surface Structure Analysis of Runic Inscriptions on Rock. *Rock Art Research* 17(2): p.85–98.

Konecny, G. 1985. The International Society for Photogrammetry and Remote Sensing - 75 Years Old, or 75 Years Young. *Photogrammetric Engineering and Remote Sensing* 51(7): p.919–933.

Laing, L. 1996. Alternative Celtic Art - Early Medieval Non-Pictish Sketches on Stone in Britain. *Studia Celtica* 30: p.127–146.

Laing, L., Laing, J., & Longley, D. 1998. The Early Christian and later medieval ecclesiastical site at St Blane's, Kingarth, Bute. *Proceedings of the Society of Antiquaries of Scotland* 128: p.551–565.

Lang, J. 1994. The Govan hogbacks: a reappraisal. In A. Ritchie (ed) *Govan and its early medieval sculpture*, 123–132. Stroud: Alan Sutton Publishing Limited

Lang, J. 1995. Finds of the early medieval period, c AD 400-1100: Pre-Conquest sculpture. In M. O. H. Carver (ed) *Excavations at York Minster Volume 1: Part 2 The finds*, 433–467. London: H.M.S.O

Lang, J. 2001. *Corpus of Anglo-Saxon Stone Sculpture, 6, Northern Yorkshire*. Oxford: Oxford University Press.

Lang, J.T. 1974. Hogback Monuments in Scotland. *Proc Soc Antiq Scot* 105: p.206–235.

Lang, J.T. 1976. The sculptors of the Nunburnholme Cross. *The Archaeological Journal* 133: p.75–94.

Lang, J.T. 1978. Continuity and Innovation in Anglo-Scandinavian Sculpture. A Study of the Metropolitan School at York. In J. T. Lang (ed) *Anglo-Saxon and Viking Age Sculpture and its Context: papers from Collingwood Symposium on insular sculpture form 800 to 1066.*BAR British Series, 145–172. Oxford: British Archaeological Reports

Lang, J.T. 1983. Recent Studies in the pre-Conquest sculpture of Northumbria. In F. H. Thompson (ed) *Studies in Medieval sculpture*, 177–189. London: Society of Antiquaries of London

Lang, J.T. 1984. The Hogback. A Viking Colonial Monument. In S. Chadwick Hawkes, J. Campbell, & D. Brown (eds) *Anglo-Saxon Studies in Archaeology and History*, 85–176. Oxford: Oxford University Committee for Archaeology

Lang, J.T. 1991. *Corpus of Anglo-Saxon Stone Sculpture, 3, York and Eastern Yorkshire*. Oxford: British Academy by Oxford University Press.

Larsen, N.G. 2016. Iron Age Housing: The Virtual and the Scale Model. : p.77–94.

Latour, B., & Lowe, A. 2011. The migration of the aura, or how to explore the original through its fascimiles. In T. Bartscherer (ed) *Switching Coes*, 275–298. Chicago: Chicago University Press

Leica Geosystems. 2012. Leica Scanstation C10/C5: System Field Manual Version 5.0. Available at: https://kb.sccssurvey.co.uk/download/138/leica-c5-c10/2195/leica-scanstation-c10-c5-system-field-manual.pdf [Accessed December 19, 2018].

Lerma, J.L., & Muir, C. 2014. Evaluating the 3D documentation of an early Christian upright stone with carvings from Scotland with multiples images. *Journal of Archaeological Science* 46: p.311–318.

Lowe, C. 2008. Non-text-inscribed slates. In *Inchmarnock: An early historic island monastery and its archaeological landscape*, 151–175. Edinburgh: Society of Antiquaries of Scotland

Lucas, G. 2001. *Critical Approaches to Fieldwork: Contemporary and Historical Archaeological Practice*. London: Routledge.

Luigi, D.N., L. Luchi, M., Muzzupappa, M., & Rizzuti, S. 2001. A Semi-Automatic Procedure for the Recognition and Classification of Pieces of Archaeological Artefacts. Available at: https://www.researchgate.net/publication/238687782_A_Semi-Automatic_Procedure_for_the_Recognition_and_Classification_of_Pieces_of_Archaeological_Artefacts [Accessed September 7, 2017].

Mac Lean, D. 1993. Snake-Bosses and Redemption at Iona and in Pictland. In *The Age of Migrating Ideas: Early Medieval Art in Northern Britain and Ireland*, 245–253. Phoenix Mill, Stroud: Alan Sutton Publishing Limited

MacGregor Chalmers, P. 1893. The Ancient Tombstones in Govan Churchyard. *Glasgow Herald*: p.9.

MacGregor Chalmers, P. 1898. The Regality Club. *Glasgow Herald*: p.10.

MacGregor Chalmers, P. 1902. *The Govan Sarcophagus. The Shrine of St. Constantine*. Glasgow: Carter & Pratt.

MacLean, D. 1995. The status of the sculptor in Old Irish Law and the evidence of the crosses. *Peritia* 9: p.125–155.

Macquarrie, A. 1993. The kings of Strathclyde, c.400-1018. In A. Grant & K. Stringer (eds) *Medieval Scotland: Crown, lordship, and community: essays presented to G.W.S. Barrow*, 1–19. Edinburgh: Edinburgh University Press

Macquarrie, A. 1994. The historical context of the Govan stones. In A. Ritchie (ed) *Govan and its early medieval sculpture*, 27–32. Stroud: Alan Sutton Publishing Limited

Macquarrie, A. 2006. *Crosses and Upright Monuments in Strathclyde: Typology, Dating, and Purpose*. Glasgow: The Society of Friends of Govan Old.

Macquarrie, A.D. 1997. *The Govan Cross at Jordanhill and at Govan*. Available at: http://www.govanold.org.uk/reports/1997_govan_cross.html [Accessed October 6, 2015].

Mäkelä, I. 2007. *DeskArtes Design Expert: Groove Measure*. Finland: DeskArtes Oy. Available at: http://www.deskartes.fi/.

Maldonado, A.D. 2011. *Christianity and burial in late Iron Age Scotland, AD 400-650*. PhD. Glasgow, Scotland: University of Glasgow. Available at: http://theses.gla.ac.uk/2700/ [Accessed January 10, 2017].

Mallison, H. 2015a. Photogrammetry tutorial 11: How to handle a project in Agisoft Photoscan. *dinosaurpaleo*. Available at: https://dinosaurpalaeo.wordpress.com/2015/10/11/photogrammetry-tutorial-11-how-to-handle-a-project-in-agisoft-photoscan/ [Accessed November 3, 2016].

Mallison, H. 2015b. Photogrammetry tutorial add-on: The consequences of optimizing a sparse point cloud. *dinosaurpaleo*. Available at: https://dinosaurpalaeo.wordpress.com/2015/10/11/photogrammetry-tutorial-add-on-the-consequences-of-optimizing-a-sparse-point-cloud/ [Accessed January 12, 2017].

Malzbender, T., Gelb, D., & Wolters, H. 2001. Polynomial texture maps. In Los Angeles, USA: ACM Available at: www.hpl.hp.com/research/ptm/papers/ptm.pdf.

Mantegna, E. 2015. *Downloading Digital Artefacts: Impacts, Implications, and Limitations of Current 3D Scanning, Modelling, and Printing Applications on Curation Approaches and User Access within Museums*. Master of Arts Thesis. London: University College London. Available at: https://www.academia.edu/17230132/Downloading_Digital_Artefacts_Impacts_Implications_and_Limitations_of_Current_3D_Scanning_Modelling_and_Printing_Applications_on_Curation_Approaches_and_User_Access_within_Museums [Accessed December 1, 2015].

Manx National Heritage. 2018. manxnationalheritage (@manxnationalheritage) - Sketchfab. *manxnationalheritage (@manxnationalheritage) - Sketchfab*. Available at: https://sketchfab.com/manxnationalheritage [Accessed February 8, 2019].

Maxwell, I. 2005. Scotland's early medieval sculpture in the 21st century: a strategic overview of conservation problems, maintenance, and replication methods. In *Able Minds and Practised Hands*.The Society for Medieval Archaeology Monograph, 159–174. Scotland: Historic Scotland

McCamy, C.S., Marcus, H., & Davidson, J.G. 1976. A Color-Rendition Chart. *Journal of Applied Photographic Engineering* 2(3): p.95–99.

McComish, J., & Petts, D. 2008. Excavations at Fey Field, Whithorn: Excavations by David Pollock and Amanda Clarke. Available at: http://www.iadb.co.uk/yat/publish.htm?PUB=58 [Accessed January 25, 2018].

McIntosh, J. 1999. *The Practical Archaeologist: How we know what we know about the past* 2nd ed. New York: Checkmark Books.

McPherron, S.P., Gernat, T., & Hublin, J.-J. 2009. Structured light scanning for high-resolution documentation of in situ archaeological finds. *Journal of Archaeological Science* 36(1): p.19–24.

Meehan, B. 2012. *The Book of Kells*. London: Thames and Hudson.

Mihelj, S., Leguina, A., & Downey, J. 2019. Culture is digital: Cultural participation, diversity and the digital divide. *New Media & Society*: p.1–21.

Miller, S., & Ruckley, N.A. 2005. The Role of Geological Analysis of Monuments: A Case Study from St Vigeans and Related Sites. In *Able Minds and Practised Hands:*

Scotland's Early Medieval Sculpture in the 21st Century.The Society for Medieval Archaeology Monograph, 277–292. Scotland: Historic Scotland

Molina Sánchez, C. 2014. Guide for Digital Documentation of Gravestones: Introduction to RTI.

Nikon. 2017. ModelMaker MMDx - Handheld scanner for 3D inspection & reverse engineering. *ModelMaker MMDx | Handheld scanning | Laser scannning | Nikon Metrology*. Available at: https://www.nikonmetrology.com/en-us/product/modelmaker-mmdx [Accessed April 10, 2018].

Norušis, M. 2012. *IBM SPSS Statistics 19 Statistical Procedures Companion*. Upper Saddle River, NJ: Prentice Hall. Available at: http://www.norusis.com/pdf/SPC_v19.pdf [Accessed July 4, 2018].

Ó Carragáin, T. 2010. *Churches in Early Medieval Ireland: Architecture, Ritual and Memory*. New Haven and London: For the Paul Mellon Centre for Studies in British Art by Yale University Press.

Ó Carragáin, T. 2014. 'Is there an archaeology of lay people at early Irish monasteries?' in Au seuil du cloître: la présence des laïcs (hôtelleries, bâtiment d'accueil, activités artisanales et de services) entre le Ve et le XIIe siècle, Actes des journées d'études monastique, Vézelay, juin 2013. *Bulletin du centre d'études médiévales d'Auxerre* Hors-série No. 8. Available at: https://journals.openedition.org/cem/13620.

Olson, B.R., & Placchetti, R.A. 2015. A Discussion of the Analytical Benefits of Image Based Modeling in Archaeology. In B. R. Olson & W. R. Caraher (eds) *Visions of Substance: 3D Imaging in Mediterranean Archaeology*, 17–26. Grand Forks, North Dakota: The Digital Press @ University of North Dakota Available at: https://www.scribd.com/document/253067331/Visions-of-Substance-3D-Imaging-in-Mediterranean-Archaeology#download&from_embed [Accessed March 9, 2018].

O'Meadhra, U. 1987. *Early Christian, Viking and Romanesque Art Motif-Pieces From Ireland*. Stockholm: Almqvist & Wiskell International.

Opitz, R. 2015. Three dimensional field recording in archaeology: An example from Gabii. In B. R. Olson & W. R. Caraher (eds) *Visions of Substance: 3D Imaging in Mediterranean Archaeology*, 73–87. Grand Forks, North Dakota: The Digital Press @ University of North Dakota Available at: https://www.scribd.com/document/253067331/Visions-of-Substance-3D-Imaging-in-Mediterranean-Archaeology#download&from_embed [Accessed March 9, 2018].

Opitz, R., Mogetta, M., & Terrenato, N. 2017. The Gabii Project. Available at: https://opencontext.org/projects/3585b372-8d2d-436c-9a4c-b5c10fce3ccd [Accessed March 16, 2018].

Opitz, R.S., Ryzewski, K., Cherry, J.F., & Moloney, B. 2015. Using Airborne LiDAR Survey to explore Historic-era archaeological landscapes of Montserrat in the Eastern Caribbean. *Journal of Field Archaeology* 40(5): p.523–541.

Otarola-Castillo, E. et al. 2018. Differentiating between cutting actions on bone using 3D geometric morphometrics and Bayesian analyses with implications to human evolution. *Journal of Archaeological Science* 89: p.56–67.

Parcak, S. 2009. *Satellite Remote Sensing for Archaeology*. Abingdon: Routledge.

Pascale, D. 2017. The ColorChecker Pages (Page 1/3). *Babel Color: Color Measurement and Analysis, The ColorChecker Pages*. Available at: http://www.babelcolor.com/colorchecker.htm [Accessed April 10, 2018].

Patay-Horváth, A. 2015. The East Pediment and the Temple of Zeus Reconstructed in Virtual Reality. In *New Approaches to the Temple of Zeus at Olympia*.Proceedings of the First Olympia-Seminar 8th-10th May 2014, 188–200. Newcastle upon Tyne: Cambridge Scholars Publishing

Patay-Horváth, A., & Christiansen, L. 2017. From Reconstruction to Analysis. Re-use and Re-purposing of 3D Scan Datasets Obtained from Ancient Greek Marble Sculpture. *Studies in Digital Heritage* 1(2): p.491–500.

Pausanias. 1918. *Description of Greece*. London: Harvard University Press. Available at: http://www.perseus.tufts.edu/hopper/text?doc=Paus. [Accessed April 2, 2018].

Phillips, D. 1985. *Excavations at York Minster, Volume II: The Cathedral of Archbishop Thomas of Bayeux*. London: Her Majesty's Stationery Office.

Piggott, S. 1978. *Antiquity Depicted: Aspects of Archaeological Illustration*. London: Thames and Hudson.

Poller, T., Watterson, A., Baxter, K., Anderson, J., & Duncan, K. 2017. Designing Digital Engagements: The SERF Hillforts Project. *Serious Animation : Designing Digital Engagements : The SERF Hillforts Project*. Available at: http://www.seriousanimation.com/hillforts/ [Accessed March 16, 2017].

Rabinowitz, A. 2015. The Work of Archaeology in the Age of Digital Surrogacy. In B. R. Olson & W. R. Caraher (eds) *Visions of Substance: 3D Imaging in Mediterranean Archaeology*, 27–42. Grand Forks, North Dakota: The Digital Press @ University of North Dakota Available at: https://www.scribd.com/document/253067331/Visions-of-Substance-3D-Imaging-in-Mediterranean-Archaeology#download&from_embed [Accessed March 9, 2018].

Radford, C.A.R. 1967a. The Early Christian Monuments at Govan and Inchinnan. *Transactions of the Glasgow Archaeological Society* 15(4): p.173–88.

Radford, C.A.R. 1967b. The early Church in Strathclyde and Galloway. *Medieval Archaeology* 11: p.105–26.

Reinhard, A. 2015. Three- and Four-Dimensional Archaeological Publication. In B. R. Olson & W. R. Caraher (eds) *Visions of Substance: 3D Imaging in Mediterranean Archaeology*, 43–50. Grand Forks, North Dakota: The Digital Press @ University of North Dakota Available at: https://www.scribd.com/document/253067331/Visions-of-Substance-3D-Imaging-in-Mediterranean-Archaeology#download&from_embed [Accessed March 9, 2018].

Richards, J.D., Niven, K., & Jeffrey, S. 2013. Preserving Our Digital Heritage: Information Systems for Data Management and Preservation. In E. Ch'ng, V. Gaffney, & H. Chapman (eds) *Visual Heritage in the Digital Age*, 311–326. London: Springer-Verlag

Richardson, H., & Scarry, J. 1990. *An Introduction to Irish High Crosses*. Dublin: Mercier Press.

Ritchie, A. 1999. *Govan and its carved stones*. Balgavies,Forfar: Pinkfoot Press.

Ritchie, A. 2004. *Hogback gravestones: at Govan and beyond*. Glasgow: Friends of Govan Old.

Ritchie, J.N.G. 1998. *Recording Early Christian Monuments in Scotland*. Rosemarkie, Black Isle: Groam House Museum Trust.

Rollason, D.W. 1982. The cults of murdered royal saints in Anglo-Saxon England. *Anglo-Saxon England* 11: p.1–22.

Roscommon 3D. 2015. roscommon3d on Sketchfab - Sketchfab. *roscommon3d on Sketchfab - Sketchfab*. Available at: https://sketchfab.com/roscommon3d [Accessed June 29, 2016].

Roskams, S. 2001. *Excavation*. Cambridge: Cambridge University Press.

San José Alonso, J.I., Martínez Rubio, J., Fernández Martín, J.J., & García Fernández, J. 2011. Comparing Time-of-Flight and Phase-Shift. The Survey of the Royal Pantheon in the Basilica of San Isidoro (León). *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XXXVIII-5/W16: p.377–385.

ScARF. 2015. *Thinking on Carved Stones in Scotland: Workshop 1: Digital recording of carved stones for research: Where are we and where can we go?* Society of Antiquaries of Scotland. Available at: https://www.scottishheritagehub.com/content/8-carved-stone-workshop-documentation [Accessed September 24, 2018].

ScARF. 2016. Future Thinking on Carved Stones in Scotland. In S. Foster, K. Forsyth, S. Buckham, & S. Jeffrey (eds) *Scottish Archaeological Research Framework*, Society of the Antiquaries of Scotland Available at: https://www.scottishheritagehub.com/content/future-thinking-carved-stones-scotland.

Schenk, T. 2005. *Introduction to Photogrammetry*. Columbus: Department of Civil and Environmental Engineering and Geoditic Science, Ohio State University. Available at: http://www.mat.uc.pt/~gil/downloads/IntroPhoto.pdf.

Schmidt, H. 1973. The Trelleborg house reconsidered. *Medieval Archaeology* 17: p.52–77.

Schreck, T. 2017. What features can tell us about shape. *IEEE computer graphics and applications* (3): p.82–87.

Seaby, W., & Woodfield, P. 1980. Viking Stirrups from England and their Background. *Medieval Archaeology* 24(1): p.87–122.

Sengoku-Haga, K. et al. 2015. Polykleitos' Works 'From One Model': New Evidence Obtained from 3D Digital Shape Comparisons. In A. Patay-Horváth (ed) *New Approaches to the Temple of Zeus at Olympia*.Proceedings of the First Olympia-Seminar 8th-10th May 2014, 201–222. Newcastle upon Tyne: Cambridge Scholars Publishing

Silver, M. 2016. Conservation Techniques in Cultural Heritage. In E. Stylianidis & F. Remondino (eds) *3D Recording, Documentation and Management of Cultural Heritage*, 15–107. Dunbeath, Scotland: Whittles Publishing

Skene, W.F., & Skene, W.F. eds. 1871. *The Historians of Scotland by John of Fordun*. Edmonston and Douglas. Available at: https://archive.org/details/historiansscotl03unkngoog [Accessed June 30, 2017].

Sketchfab. 2018. Plans & Pricing - Sketchfab. Available at: https://sketchfab.com/plans [Accessed January 7, 2019].

Spearman, R.M. 1994. The Govan sarcophagus: an enigmatic monument. In A. Ritchie (ed) *Govan and its early medieval sculpture*, 33–46. Stroud: Alan Sutton Publishing Limited

Spectrum Heritage. 2017. Inchinnan - a 3D model collection by Spectrum Heritage. *Inchinnan - a 3D model collection by Spectrum Heritage*. Available at: https://sketchfab.com/SpectrumHeritage/collections/inchinnan [Accessed March 14, 2018].

Stalley, R. 1996. *Irish High Crosses*. Dublin: Country House.

Stalley, R. 2014. Irish sculpture of the early tenth century and the work of the 'Muiredach Master': problems of identification and meaning. *Proceedings of the Royal Irish Academy: Archaeology, Culture, History, Literature* 114C: p.141–179.

Statistics How To. 2017. Wilks' Lambda: Simple Definition. *Wilks' Lambda: Simple Definition*. Available at: http://www.statisticshowto.com/wilks-lambda/ [Accessed July 10, 2018].

StatSoft, Inc. 2013. Discover Which Variables Discriminate Between Groups, Discriminant Function Analysis. *Discover Which Variables Discriminate Between Groups, Discriminant Function Analysis*. Available at: http://www.statsoft.com/Textbook/Discriminant-Function-Analysis [Accessed July 10, 2018].

Stevens, J.P. 2009. *Applied Multivariate Statistics for the Social Sciences* Fifth. New York, NY: Routledge, Taylor & Francis Group.

Stirling Maxwell, J. 1899. *Sculptured Stones in the Kirkyard of Govan*. Glasgow. Available at: https://ia801400.us.archive.org/26/items/sculpturedstone00maxwgoog/sculpturedstone00maxwgoog.pdf [Accessed October 21, 2015].

STONE project. 2007. 1 What is Reductive Thinking? *STONE Project: 1 What is Reductive Thinking?* Available at: http://www.stoneproject.org/1-what-is-reductive-thinking.html [Accessed February 27, 2017].

Stuart, J. 1856. *The Sculptured Stones of Scotland*. Aberdeen: Spalding Club.

Štuhec, S. 2017. What do the stones say? - 3D documentation and analysis of shepherd stone shelters in Kras, Slovenia.

Stylianidis, E., Georgopoulos, A., & Remondino, F. 2016. Basics of Image-Based Modelling Techniques in Cultural Heritage 3D recording. In E. Stylianidis & F. Remondino (eds) *3D Recording, Documentation and Management of Cultural Heritage*, 253–305. Dunbeath, Scotland: Whittles Publishing

Teknomo, K. 2015. Discriminant Analysis Tutorial. *Linear Discriminant Analysis (LDA) Tutorial*. Available at: http://people.revoledu.com/kardi/tutorial/LDA/ [Accessed July 9, 2018].

Tharwat, A., Gaber, T., Ibrahim, A., & Hassanien, A.E. 2017. Linear Discriminant analysis: A detailed tutorial. *Ai Communications* 30: p.169–190.

The Board of Trinity College Library Dublin. 2012. Book of Kells. *Book of Kells*. Available at: https://digitalcollections.tcd.ie/home/index.php?DRIS_ID=MS58_003v [Accessed November 13, 2018].

The Discovery Programme. 2015. 3D Icons Ireland. *3D-ICONS.IE*. Available at: http://www.3dicons.ie/ [Accessed February 18, 2019].

Thibaud, P. 2015. Volume measurement by photogrammetry: Applications for the weighing metrology studies. In 197–202. Benevento, Italy Available at: https://www.academia.edu/20134999/Volume_measurement_by_photogrammetry._Applications_for_the_weighing_metrology_studies [Accessed March 28, 2018].

Thickpenny, C.R. 2019. *Making Key Pattern in Insular Art: AD 600-1100*. Unpublished PhD Dissertation. Glasgow: University of Glasgow.

Thomas, C. 1994. Christianity at Govan: but when? In A. Ritchie (ed) *Govan and its early medieval sculpture*, 19–26. Stroud: Alan Sutton Publishing Limited

Thompson, V. 2017. Meigle, Hybridity and the Pictish Uncanny. In Glasgow

Thurlkill, M. 2016. *Sacred Scents in Early Christianity and Islam*. Lanham, Maryland: Rowman & Littlefield. Available at: https://books.google.co.uk/books?id=cnCPDAAAQBAJ&pg=PA104&lpg=PA104&dq=early+christianity+oil+secondary+relics&source=bl&ots=js_cVqS8SZ&sig=-gBm8hAV5EfCFMEHdeZ1rObg4rA&hl=en&sa=X&ved=0ahUKEwi4-Ne3_5fVAhVmD8AKHWACCTwQ6AEISjAF#v=onepage&q=early%20christianity%20oil%20secondary%20relics&f=false.

Trilling, J. 1995. Medieval Interlace Ornament: The Making of a Cross-Cultural Idiom. *Arte Medievale* 9.2: p.59–86.

University of Glasgow. 2017a. Constantine’s Cross. *Constantine’s Cross - Cradle of Scotland*. Available at: https://serfexhibition.archaeology.arts.gla.ac.uk/index.php/constantines-cross/ [Accessed January 3, 2019].

University of Glasgow. 2017b. Forteviot Arch - Cradle of Scotland. *Cradle of Scotland*. Available at: https://serfexhibition.archaeology.arts.gla.ac.uk/index.php/forteviot-arch/ [Accessed January 3, 2018].

Van Dam, R. 2004. *Glory of the Martyrs by Gregory of Tours* Reprint. Liverpool: Liverpool University Press.

Van Leusen, M. 1993. Cartographic Modelling in a cell-based GIS. In *Computing the Past*, 105–123. Aarhus: Aarhus University Press Available at: http://proceedings.caaconference.org/files/1992/11_Leusen_CAA_1992.pdf [Accessed March 28, 2018].

Vergne, R., Pacanowski, R., Barla, P., Granier, X., & Schlick, C. 2010. Radiance scaling for versatile surface enhancement. *Proceedings of the 2010 ACM SIGGRAPH symposium on Interactive 3D Graphics and Games*: p.143–150.

Verhoeven, G. 2016. Basics of Photography for Cultural Heritage Imaging. In E. Stylianidis & F. Remondino (eds) *3D Recording, Documentation, and Management of Cultural Heritage*, 127–252. Dunbeath, Scotland: Whittles Publishing

Ward, J.H. 1963. Hierarchical Groupings to optimize an objective function. *Journal of the American Statistical Association* 58: p.236–244.

White, R.H. 2013. Resolving the Carving: The Application of Laser Scanning in Reconstructing a Viking Cross from Neston, Cheshire. In E. Ch'ng, V. Gaffney, & H. Chapman (eds) *Visual Heritage in the Digital Age*, 33–41. London: Springer-Verlag

Whitworth, V. 2016. The Royal Tombs of Govan: A New Interpretation of the Hogbacked Grave-Stones.

Williams, H. 2015. Hogbacks: The Materiality of Solid Spaces. In H. Williams, J. Kirton, & M. Gondek (eds) *Early Medieval Stone Monuments: Materiality, Biography, Landscape*, 241–268. Woodbridge: The Boydell Press

Wilson, D.R. 1982. *Air Photo Interpretation for archaeologists*. London: B. T. Batsford Ltd.

Woolf, A. 2007. *Where was Govan in the Early Middle Ages?* Glasgow: Society of Friends of Govan Old.

Yasin, A.M. 2009. *Saints and Church Spaces in the Late Antique Mediterranean*. Cambridge: Cambridge University Press.

York Archaeological Trust. Wemyss Caves 4D. *Wemyss4D*. Available at: http://www.4dwemysscaves.org/.

Zelinsky, C. 2018. *Seeing the Unseen: A Comparison of Virtual and Non-Virtual Reflectance Transformation Imaging from Photogrammetric Models*. Unpublished MSc thesis. Glasgow: Glasgow School of Art.

Zhou, J. et al. 2018. Design Identification of Curve Patterns on Cultural Heritage Objects: Combining Template Matching and CNN-based Re-Ranking. *arXiv preprint arXiv:1805.06862*.