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Metrology and proportion in the window tracery of medieval Ireland:

An empirical study of Ormond and Connaught

In 3 Volumes
Volume 1: Text, Chapters 1-4

A Thesis submitted to Trinity College Dublin for the degree of PhD

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Summary

This study developed a methodology to investigate whether evidence could be found for the application of systems of proportion and metrology to the design of late medieval window tracery in Ireland. Source data was collected for over two-hundred windows, across three medieval kingdoms, using the three-dimensional measurement technique of stereo photogrammetry. Measurements of window width and height, light width and height, mullion width, tracery field height, and arch span were extracted for each window. Two full building investigations were made using terrestrial laser scanning to generate three-dimensional ground plans and models of a range of architectural details. Measurements from the windows, plans, and details were interrogated using a set of Visual Basic for Applications macros in Microsoft Excel to indicate the preferred unit(s) of measurement and any evidence of the presence of defined ratios between significant features.

The range of tested units, from 0.212m to 0.372m in steps of 0.001m, was chosen after research into medieval standards throughout Europe. Each measurement taken per window was divided by each unit and fractions of that unit ($\frac{1}{1},\frac{1}{2},\frac{1}{3},\frac{1}{4},\frac{2}{3}$ and $\frac{3}{4}$). The remainders after this operation were compared and the lowest value extracted, since this represented the most likely candidate unit for this particular window. Margins of error were also included in the analysis to make allowance for inaccuracies in the original setting out and in the modern measurement process, and in recognition of medieval tolerance, which was taken as 0.010m.

The proportions used in this study were derived from research into the geometric design of architecture throughout Europe. The ratios investigated were: $1:\sqrt{2}$, $1:\sqrt{3}$, $1:\sqrt{5}$, 1:1, 1:2, 1:3, 1:4, 2:3, 2:5, 3:4, 3:5, 4:5, 5:6, 13:23, 377:610 (golden ratio). No precedent existed for an examination of the proportions used in tracery design. Therefore, each window measurement was divided by a range of other measurements to extract values which were compared against the numeric values of the above-listed ratios. Again, margins of error were included to account for inaccuracies.

The results of the metrological and proportional investigation were considered on a regional basis to establish whether evidence could be found in architecture for known cultural and political differences between the more Anglo-Norman kingdom of Ormond and the Gaelic kingdom of Connaught. Data from sites in the neighbouring medieval kingdom of Desmond was also compared against these regions as a form of control.

The investigation found that some units of measurement were used throughout all three regions, although other units were unique to particular locations. The detected units ranged in length from ~0.225m to ~0.368m, and some units appear to have been in contemporary use based on comparison with documentation. Some standards probably arrived in Ireland with the Anglo-Normans, since their origins could be traced in England, Wales and Saxony. Significant evidence was found in support of a 'new' Romanesque/Anglo-Saxon unit of 0.280m, and a number of 'long' foot units were also identified. The results found limited use of the standard foot of 0.3048m, indicating that legal interventions to stop short-selling of measures had little or no effect on the building industry. Insufficient information is available from these ~200 windows to establish a chronology of Irish medieval measures but contemporary windows within buildings could be suggested.

Masons throughout medieval Ireland used ratios in the design of window tracery but the choice of ratio and its application was inconsistent. As with metrology, some patterns of regional association were uncovered in this study, but in each region many systems of proportion were applied contemporaneously.

Inferences made from the metrological and proportional results demonstrated that the influence of patrons was difficult to detect. The importance of economics was demonstrated by the reuse of materials, and by suiting the dimensions of objects, for instance window mullions, to the size of the available stone and thus minimising labour costs. Proportional design was not affected by the installation of windows in existing building, by the type of building, or by the window location in the building.

Windows which shared similar tracery field designs typically did not share proportion or metrology. This suggested that Irish medieval masons often designed from geometric principles rather than by using some form of template; a conclusion that is significantly different to those reached in some English and continental European studies.

The results of this work demonstrated that empirical investigation of architecture using semi-automated macros and data acquired by remote sensing has the potential to increase our understanding of design methods and, by inference, of Irish medieval architectural practice. Finally, the view that medieval masons were fixed in their application of systems of metrology and proportion has been challenged, and a new model, where masons were able to choose from a broad portfolio of systems, has been proposed in its stead.

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Metrology and proportion in the window tracery of medieval Ireland:
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1 Introduction

"It is in vain for us to hope to seize the spirit of early models, if we content ourselves with copying their decorative features, and neglect the principles of their construction."

Edmund Sharpe, 1849[1]

Definitions of medieval Gothic architecture, no matter how different, always focus on the essential stylistic and constructional elements of pointed arches, rib vaults, flying buttresses and, crucially, windows or light.[2] When combined, these characteristics enabled medieval masons to create structures that were bigger, taller and more ambitious than any buildings previously attempted. The pointed arches and rib vaults worked together to focus the roof loads at particular points along the walls and these points in turn were reinforced by buttresses, and eventually flying buttresses, leaving the rest of the walls without much structural function.[3] Buildings could now be designed to incorporate many more, and taller, windows than it had been possible to include in any previous style, thus leading to the description of Gothic as 'illuminated architecture'.[4]

As a result the windows, while having the main function of providing light to the interior of the building, replaced the mosaics and wall paintings of the Romanesque era and became a decorative canvas consisting of the dual elements of glass and stonework, or tracery. The historical information that can be derived from stained glass has been studied by many authors and its utility in providing information about patrons and builders has been clearly proven.[5] However, in locations such as Ireland, where no original medieval

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[1] E. Sharpe, *A Treatise on the Rise and Progress of Decorated Window Tracery in England. Illustrated with Ninety-Seven Woodcuts and Six Engravings on Steel.* London: John van Voorst, Paternoster Row, 1849 (hereafter *Decorated Treatise*).

[2] O. Von Simson, 'The Gothic Cathedral: Design and Meaning', *The Journal of the American Society of Architectural Historians,* 1952, 11 (3), 6-16 (hereafter 'Gothic Cathedral'); L. Grodecki, *Gothic Architecture,* London: Faber and Faber Ltd., 1978 (hereafter *Gothic Architecture)*; F. Bond, *Gothic architecture in England: an analysis of the origin and development of English church architecture from the Norman Conquest to the dissolution of the monasteries,* London: Batsford, 1905 (hereafter *Gothic Architecture*); J. Harvey, *The Gothic World 1100-1600: A Survey of Architecture and Art,* London: B. T. Batsford Ltd., 1950 (hereafter *Gothic World)*; G. Lesser, *Gothic Cathedrals & Scared Geometry,* London, England: Alec Tiranti, 1957 – although much of Lesser's work has been debated and refuted his definition of Gothic is still valid. L.R. Shelby, *Gothic Design Techniques: The Fifteenth-Century Design Booklets of Mathes Roriczer and Hanns Schmuttermayer,* London, England: 1977 (hereafter *Gothic Design*). Many other authors have also addressed the subject.

[3] L. Grodecki, *Gothic Architecture,* p. 150.

[4] G. Webb, *Architecture in Britain: The Middle Ages,* Harmondsworth: Pelican History of Art, 1965.

[5] For historical information see M.P. Lillich, *Studies in medieval stained glass and monasticism,* London: Pindar, 2001, P. Frankl, 'Unnoticed Fragments of Old Stained Glass in Notre-dame de Paris', *The Art Bulletin,* 1957, 39 (4), 299-300 and R. Marks, *Stained Glass in England during the Middle Ages,* London: Routledge, 1993. For patrons and builders see Jean Gimpel's book on Cathedral builders contains a number of stained glass samples from French sites which include masons or references to the craft of masonry. J.

stained glass has remained intact, and where very few fragments have been found, even through archaeological investigation, study of the second window element, the tracery, becomes significantly more important in architectural historical investigations.[6]

Tracery is much less studied, or utilised, in architectural historical contexts than stained glass, both within and outside of Ireland.[7] This is despite the fact that, unlike the glass, which would have been produced by a glass-maker and/or painter, the tracery, being stonework, would usually have been designed and executed by, or under the supervision of, the same masons who designed the building. In his work on Westminster Abbey, Robert Branner described tracery as "perhaps the most expressive medium for the Gothic architect in 1250" and its artistic importance continued throughout the late medieval period.[8] Thus, window tracery can potentially provide an insight into a mason's inspirations, as well as his technical skills and knowledge.

Seen in this light it is surprising that so few architectural historical investigations have sought to exploit tracery as a resource. Perhaps this is because, on its own, tracery can be difficult to interpret, particularly because it was easily copied, and because most historians have only regarded tracery stylistically, without reference to its design and construction.[9] This study proposes a more holistic approach to investigating the potential role that tracery can play in architectural historical studies. Traditional stylistic evaluation, which in only a few published cases has been supplemented by measurements of the window width, will be enhanced through evaluation of the tracery's full, measured three-dimensionality.[10] This will facilitate analysis of the tracery in its entirety and in its correct setting.

This research aims to demonstrate how measured tracery, subjected to three-dimensional analysis techniques, can assist in deconstructing the design methods used by medieval masons, in particular the use of proportion and geometry, thus providing new information about medieval masons and their craft. Furthermore, an attempt will be made

Gimpel, *The Cathedral Builders*, Trans. C.F. Barnes. Evergreen Profile Book. no. 21. London: Evergreen Books, 1961 (hereafter *Cathedral Builders*).

[6] J. Moran, 'The shattered image: archaeological evidence for painted and stained glass in medieval Ireland.' *Art and Devotion in Late Medieval Ireland*. Eds. R. Moss, C. O'Clabaigh and S. Ryan. Dublin: Four Courts Press, 2006. 121-41 (hereafter 'Shattered Image').

[7] This term will be more clearly defined in the following section.

[8] R. Branner, 'Westminster Abbey and the French Court Style', *The Journal of the Society of Architectural Historians*, 1964, 23 (1), 3-18, p. 7.

[9] British Library Add. Ch. 17634 published by Rev. C. Chitty, 'Kessingland and Walberswick Church Towers', *Suffolk Archaeology*, 1950, 25 relates the stipulation in a contract for the building of Walberswich church tower in 1425 that its windows should be modelled on the pattern of those of Halesworth. See chapter two, section copying for further discussion.

[10] R. Fawcett, 'A Group of Churches by the Architect of Great Walsingham', *Norfolk Archaeology*, 1980, 37 (3), 227-94 (hereafter 'Great Walsingham Churches').

to establish the preferred unit of measurement of the period based on the same tracery information, which, when analysed spatially, temporally, and in association with contemporary documentation, has the potential to provide evidence on metrological systems and how these were influenced by legislation, regional preferences, and over time.

Consideration will also be given as to how an analysis of window tracery might expand our knowledge of the organisation and movement of masons in medieval Ireland and, when aligned with contextual political, economic and geographical information, might assist our understanding of the effect of a number of external factors on the ecclesiastical architecture of the period.

1.1 Resources for tracery studies in Ireland

Before beginning to address the subject of medieval window tracery in Ireland, it is important to first define the range of resources available to the researcher. Eric Fernie has suggested that studies in architectural history can utilise three methods: evidence from documentary or written sources, visual or stylistic analysis of the design, or physical (archaeological) investigation of the fabric of the building.[11]

In Ireland evidence from written sources is sparse, particularly when compared with the contemporary documentation available in England and Europe. Architectural historians in England and much of continental Europe can call upon material such as the fabric rolls, ledger books, and city registers which provide details of the names of masons and their wages, together with information on the materials used, and these can give significant insight into the methods of the time.[12] While some of these documents contain

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[11] E. Fernie, 'Archaeology & Iconography: Recent developments in the Study of English Medieval Architecture', *Architectural History,* 1989, 32, 18-29 (hereafter 'Archaeology & Iconography').

[12] For example see the multiple works of Knoop & Jones or the seminal works of Harvey and Salzman on English medieval architecture, its organisation and its craftsmen. D. Knoop and G.P. Jones, *The Medieval Mason: An Economic History of English Stone Building in the Later Middle Ages and Early Modern Times.* 3rd ed. Manchester: Manchester University Press, 1967; D. Knoop and G.P. Jones, 'Masons and Apprenticeship in Mediaeval England', *The Economic History Review,* 1932, 3 (3), 346-66 (hereafter 'Apprenticeship'); D. Knoop and G.P. Jones, 'The Impressment of Masons in the Middle Ages', *The Economic History Review,* 1937, 8 (1), 57-67; D. Knoop and G.P. Jones, 'The English Medieval Quarry', *The Economic History Review,* 1938, 9 (1), 17-37 (hereafter 'Medieval Quarry'); J. Harvey, *The Mediaeval Architect.* London, England: Wayland Ltd, 1972, and L.F. Salzman, *Building in England down to 1540: A Documentary History,* Oxford, England: Oxford University Press, 1952 (hereafter *Building in England*). Sources for European documentary evidence can be found in the bibliographies of works such as P. Frankl and P. Crossley, *Gothic Architecture.* Yale University Press Pelican History of Art. Rev. ed. New Haven; London: Yale University Press, 2000 (hereafter *Gothic Architecture*); C. Wilson, *The Gothic Cathedral: The Architecture of the Great Church 1130-1530.* London, England, 1990 (hereafter *The Gothic Cathedral*) and J. Gimpel and C.F. Barnes, *Cathedral Builders.*

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references to Ireland they are rarely comprehensive, and only a few Irish examples of this type of material exist.[13]

The best known Irish historical sources of the medieval period are the Annals, produced by monastic settlements but which, unfortunately for the architectural historian, focus not on architecture but rather on the chronicling of significant events, particularly those related to monasteries, abbots, and bishops or their patron kings and lords. In some cases references have been made to progress on particular buildings, but these references are rare in the period of investigation and generally quite superficial.[14] Of the few specific mentions of windows are Isabella Palmer's erection and glazing of the front of the choir for the Franciscans in Kilkenny and Thomas Mag Uidhir junior's building of the eastern gable of "the church of Achadh-urchaire".[15] While fragments of this window now protected in a stone store show that this window had a Perpendicular design, no particular mention was made of its Englishness, even through reference was made to a 'French roof'.[16]

Historical records specific to both the Anglo-Norman and Gaelic medieval communities also provide some useful resources. The surviving private records of manorial estates include those of the Butler earls of Ormond, the Red Book of Kildare, the Shees and Poers of Kilkenny, Tipperary and Wexford, the Prestons of Louth, Kildare, Meath and Dublin, and a number of other families who held lands in Leinster or east Munster. Records relating to Connaught and Ulster lands in charge of the Mortimer earls were lost in the fifteenth century and no other known manorial records survive.[17]

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[13] In particular, see later discussions on Metrology and governance, and Craft Organisation.

[14] The Annals of Connaught contain a reference to the abbot who oversaw the initiation of work on Ballintober Abbey: 'Annala Connacht.' The Annals of Connaught. Ed. P. Bambury: CELT online at University College, Cork, Ireland, 2001, 21: "1225.34 Moelbrigte O Maicin, abbot of Ballintober, a virgin and sage, rested in Christ. By him the church of Ballintober was begun, and its sanctuary and crosses (?) finished with great labour, in honour of Patrick, Mary our Lady, John and the Apostles."

[15] "1347.2 Item, eodem die apud Kylkenniam humo domina Isabella Palmer traditur, que frontem chori fratrum erigi fecit, laudabili senio vitam transegit, hac in viduitate religiose et honorifice vixit annis circiter lxx., et in virginitate ut dicebatur et creditur de hoc seculo migravit." F.J. Clyn, 'Annalium Hiberniae Chronicon ad annum MCCCXLIX.' Corpus of Electronic Texts Edition: L100011. Ed. R. Butler: CELT online at University College, Cork, Ireland, 2003 and "1447.6 This year a ribbed vault was put by Thomas Mag Uidhir junior, namely, king of Fir-Manach, on the church of Achadh-urchaire in honour of God and SS. Tighernach and Ronan. And it was he that built the eastern gable of the church for the good of his own soul, and so on." 'The Annals of Ulster.' Corpus of Electronic Texts Edition: T100001C. Eds. M. Balé and E. Purcell: CELT online at University College, Cork, Ireland, 2003.

[16] R. Moss, 'Revivalist tendencies in the Irish Late Gothic: defining a national identity?' *Reading Gothic architecture: Studies in the visual cultures of the Middle Ages.* Ed. M.M. Reeve. Vol. 1. Turnhout, Belgium: Brepols, 2008, p. 135.

[17] P. Connolly, *Medieval Record Sources.* Dublin, 2002, pp. 50-2.

In relation to the Gaelic nobility, Katharine Simms has inferred significant information about Gaelic settlement through analysis of the bardic house poems.[18] Sometimes written in commemoration of a particular event, such as "the building of a new house" or "the destruction of the family home in the course of war with the English", these poems were also used by Gaelic bards to praise specific features of a chieftain's house, thus providing some information on secular building which can be transferrable to ecclesiastical works. These house poems, although literary rather than historical sources and, therefore, more likely to contain inaccuracies or exaggeration, are an important resource for information on contemporary Gaelic life because of the paucity of sources such as building plans, elevations, estate papers, land surveys, diaries, letters, contracts, and regulations for craftsmen.[19] Furthermore, the topographical drawings of buildings in their landscape, which sometimes exist in the early modern era, are absent in Gaelic contexts.[20]

Ecclesiastical records are also relatively sparse in comparison with the documentation available in England. However, the cartularies of a number of monastic houses, as well as fragmentary proctor's and vestry accounts for St. Werburgh's parish church, St. Patrick's cathedral and Christchurch cathedral, all in Dublin, are available.[21] These contain some references to spends made on the repair of windows but are of limited relevance here because they occur outside the area of investigation.

Thus, while documentary records are sparse, useful information can be gleaned for some locations, although it is seldom sufficiently comprehensive to include specific details on tracery. However, Eric Fernie's second and third resources for the architectural historian, visual or stylistic analysis of the design, or physical (archaeological)

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[18] K. Simms, 'Native sources for Gaelic Settlement: The House Poems.' *Gaelic Ireland c.1250-c.1650: Land, Lordship & Settlement.* Eds. P.J. Duffy, D. Edwards and E. FitzPatrick. Dublin: Four Courts Press, 2004. 246-70 (hereafter 'Native sources').

[19] "Building plans and elevations by Gaelic craftsmen are not known. Estate papers and land surveys are very rare, and diaries and letters by owners about the process of building are lacking. Contracts with architects and craftsmen are not known to have survived. Reference to regulations governing carpentry is only known from a lost tract, called *Bretha Luchtine*.": K. Simms, 'The brehons of later medieval Ireland.' *Brehons, serjeants and attorneys: studies in the history of the Irish legal profession.* Eds. D. Hogan and W.N. Osborough. Blackrock: Irish Academic Press in association with the Irish Legal History Society, 1990. 51-76, p. 62.

[20] R. Loeber, 'An Architectural History of Gaelic Castles and Settlements, 1370-1600.' *Gaelic Ireland c.1250-c.1650: Land, Lordship & Settlement.* Eds. P.J. Duffy, D. Edwards and E. FitzPatrick. Dublin: Four Courts Press, 2004. 271-314.

[21] J.T. Gilbert, ed. *Chartularies of St Mary's Abbey, Dublin: with the Register of Its House at Dunbrody and the Annals of Ireland.* 2 vols. London, 1884; A. Empey, *The Proctors' accounts of the parish church of St Werburgh, Dublin, 1481-1627.* Dublin: Four Courts Press in association with the Representative Church Body Library, 2009.

investigation of the fabric of the building, have the potential to prove more useful to the Irish medieval architectural historian.[22]

1.2 What is tracery?

Tracery is defined as the intersecting stonework forms of mullions and transoms that hold glass or shuttering in place in windows.[23] Edmund Sharpe more specifically pronounced that:

> "A window cannot be said to contain Tracery unless the whole of the Window-head is pierced though to the plane of the glass, so as to leave no plain surface, or solid mass of stone, in the spandrels between the principal Tracery-bars and the Window-arch." [24]

Where it is used, window tracery performs both decorative and constructional functions, with the latter purpose being twofold. The main constructional function was to facilitate the fixing of iron bars, which held glass or shuttering in place, while the secondary role was to help to withstand the forces of wind upon the glass. When the arch design was weak, such as with ogee forms, the tracery also reinforced the stability of the window.[25]

The stonework of the tracery did not always come into direct contact with the glass because of the medieval practice, which continued until relatively late, where "the glass was often inserted in wooden frames, which were carried about by the rich from house to house".[26] This evidence is further corroborated by D.J. Steward in his study of Ely cathedral where he revealed that the original glass in the transept was fixed in wooden frames and these, in turn, were wedged into the window openings.[27] Both of these examples demonstrate Francis Bond's cautionary note that "the absence of a glazing groove or rebate does not necessarily mean that a window was not glazed". It should also be recognised that a third alternative to glazing and shuttering for medieval windows

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[22] E. Fernie, *Archaeology & Iconography*, pp. 18-29.

[23] J.S. Curl, *Encyclopaedia of Architectural Terms.* 2nd ed. Dorset, England: Donhead Publishing Ltd., 1992, p. 320 (hereafter *Encyclopaedia*).

[24] E. Sharpe, *A Treatise on the Rise and Progress of Decorated Window Tracery in England. Illustrated with Ninety-Seven Woodcuts and Six Engravings on Steel.* London: John van Voorst, Paternoster Row, 1849, p. 21.

[25] F. Bond, *Gothic Architecture* and J. Harvey, *The Gothic World 1100-1600: A Survey of Architecture and Art.* London: B. T. Batsford Ltd., 1950, p. 505 (hereafter *Gothic World*).

[26] F. Bond, *Gothic Architecture* and J. Harvey, *Gothic World*, p. 459.

[27] D. J. Stewart, *On the Architectural History of Ely Cathedral.* London: John van Oorst, 1868. Relatively few separate cases of evidence have been found for this practice although it has been frequently quoted in the literature.

existed. Either as a temporary or longer term measure the window could be covered with canvas, as demonstrated by Close Roll 35 of Henry III from 1251 where one of the expenses incurred in the Irish mint was for "32 ells of canvass to make sacks, and for the window of the mint".[28]

Of the two functions of tracery, it is the decorative one which has received most attention from architectural historians and, both within Ireland and overseas, a number of stylistic examinations have been undertaken, as outlined below. However, before examining these studies, it is first necessary to briefly explain some general characteristics of tracery.

The use of tracery became prominent once masons realised that their walls were strong enough to withstand the presence of openings of significant width.[29] This realisation probably arose through the gradual, but successful, reduction in the distances between adjacent windows. Although by the early twelfth century glass manufacturing techniques had significantly improved, limitations still existed on the size of panes which could be created and supported. Therefore, rather than merging adjacent windows further to form very wide openings, the wall spaces were typically subdivided into a number of lights, constructed within a single arch but separated by bars of stonework, called mullions, which could adequately support the glass.

1.2.1 Plate tracery

The earliest recognised form of tracery is known as plate tracery and it is formed by piercing flat masonry panels or wall sections. In windows, these panels are the spandrels which are formed between the heads of adjacent groups of lights and the surmounting arch. The piercing typically takes the form of a circular, foiled or other opening between the peaks of the heads of the lights.[30] Only a limited amount of variation can be achieved with this type of tracery. In Ireland this style occurs in a number of windows of the early thirteenth century.[31] At Cahir Augustinian priory, county Tipperary a window in the south

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[28] Although a number of mints existed in Ireland this document simply specifies "Expenses incurred in the Mint, Ireland": H.S. Sweetman, *Calendar of documents relating to Ireland, preserved in Her Majesty's Public Record Office, London.* Vol. 1. 5 vols. London: Longman: Trübner, 1875, p. 475 (hereafter *Calendar*).

[29] Although significant is difficult to define here it means wider than *c.* 30cm. Many early Irish windows were, however, much narrower than this. H.G. Leask, *Irish Churches & Monastic Buildings.* Vol. I. Dundalk, Ireland: Dundalgan Press Ltd., 1955. 4th (hereafter *Irish Churches I*).

[30] J.S. Curl, *Encyclopaedia*, p. 320.

[31] In England Francis Bond listed the earliest occurrence of plate tracery as in the "Norman window of St. Maurice, York, which may be of *c.* 1160" followed by Transitional windows in St. Mary's, Shrewsbury, *c.*

of the nave was created after this fashion, as was the east window of the south transept at Cong Augustinian abbey, county Mayo (Figure 1.1). However, in Ireland examples of this type are rare, possibly because they were replaced during the later middle ages.

Figure 1.1 Window at the eastern end of the south wall of the nave, Cahir Augustinian priory, county Tipperary: (left) and south transept east window, Cong Augustinian abbey, county Mayo[32]

1.2.2   Bar tracery

Probably due to the limited variety possible through the use of plate tracery, window design developed to extend the moulded mullions from between the lights to meet at their heads, thus leaving the rest of the spandrel open and available for the insertion of decorative bars of stonework. In France, multiple small developments of window design and construction techniques occurred from 1210 onwards at Reims Cathedral, at Amiens Cathedral, and at Notre-Dame de Paris where the architect took the final step needed to create bar tracery in that he lengthened the stonework in the mullion 'binding them together with clamps' making the entire construction "structurally coherent". Such windows could now act as a medium for the mason to display "his virtuosity as a designer" particularly through decorative handling of the "*découpage* [cutting] of the

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1180; Bishop's Hall, Lincoln, "begun before 1200 and finished before 1224"; Winchester Castle Hall, finished 1234; and Bishop's Hall, Wells "not later than 1239". F. Bond, *Gothic architecture*, p. 468.
[32] Roger Stalley has suggested that the Cong windows are sixteenth century in origin. Personal communication.

curved parts".[33] However, the origin of this advance cannot be explicitly linked to this one occasion in France since similar architectural developments were proceeding throughout much of the Gothic world, including Ireland, and too much has been lost for us to reconstruct a definitive chronology.

The overall effect of bar tracery was to allow as much light as possible into a building, thus enabling worshipers to feel closer to the heavenly. Further to this function, Otto von Simpson considered that the windows underscored their own tracery as well as the ribs and shafts of the vaults, thus showing off the near perfection with which every single stone block was shaped and suggesting "a new aesthetic appreciation of the dignity of structural perfection".[34] While this description may be reading too much into the motivations of the masons, it is not unreasonable to remark that developments in tracery design were frequently part of a greater design plan. Thus, as medieval architecture matured, the space between the lights and the arch was filled with increasingly complex designs of stonework as masons vied to 'perfect' the windows. Each major change in pattern of design helped to define the style of the building. In the following, a number of ancillary themes, relevant to the interpretation of tracery, will now be discussed.

1.2.3 Foiling, cusping and subordination of tracery

In most stylistically-based analyses of window tracery, certain decorative details have been shown by architectural historians to be useful indicators of origin and influence.[35] These include foiling, which involves the addition of indentations into the shape of the pointed arch of the lights and has been in use since the transitional period for the decoration of lancet heads.[36] When these indentations are made into the shape of the curve of the tracery elements, typically at the intersection of pairs of curves, they become known as cusps.

Thus, when masons wanted to add variety into simple tracery designs they could use foiling of window heads (trefoiled, quatrefoiled and cinquefoiled) and cusping within the tracery area. The complexity of both elements could be increased by the use of orders

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[33] R. Branner, 'Paris and the Origins of Rayonnant Gothic Architecture down to 1240', *The Art Bulletin*, 1962, 44 (1), 39-51, pp. 48-9.

[34] O. von Simson, *Gothic Cathedral*, p. 7.

[35] R. Fawcett, 'Scottish Mediaeval Window Tracery.' *Studies in Scottish antiquity presented to Stewart Cruden.* Ed. D.J. Breeze. Edinburgh: Donald, 1984 (hereafter *Scottish Tracery*) and R. Mullin, 'A regional study of late medieval window tracery in Ireland', M.Phil. Queen's University, Belfast, 1999 (hereafter *A regional study*).

[36] E. Sharpe, *Decorated Treatise*, p. 33.

of moulding, which allowed the mason to demonstrate his skill in design while working within budgetary constraints imposed by his clients or their patrons.

True masters of the design of tracery were also very skilled in the use of subordination; that is introducing a reduction in the size and projection of the mullions and tracery bars as the complexity of the tracery increases. Francis Bond described the use of subordination as "one of the most beautiful features of the more highly developed medieval windows".[37] In some Irish windows this distinction is lacking and the balance of the tracery is lost, for example the east window of the north chapel in the south transept at Holycross Cisterican abbey, county Tipperary.

1.3 Influences on tracery

Window tracery cannot be examined in isolation. As a physical medium it was affected by the objects that it was designed to contain and by the materials from which it was crafted. There is also a human side to these windows and tracery was the product of individuals who operated in a community of practice; a building trade that was very different in Ireland to elsewhere in Europe at that time.

1.3.1 Stained glass

Neither stained glass nor tracery can be critically examined in isolation from each other. The ideas to be expressed or story to be told by the glass painter needed a structured housing, thus leading to some of the stylistic changes in tracery to be described in the following.[38] The mason and glazier were required to work in tandem during both the initial installation of the window and during subsequent re-glazing campaigns.[39] In the latter case, the stonemason was often only involved to the extent of drilling new holes for the insertion of iron to hold the glass, but in some cases both glass and stonework were altered simultaneously. However, the essential nature of iron in medieval windows is demonstrated in a contract between a mason and Hornby Church, Yorkshire from *c.*1400, which refers to both the glass and ironwork elements of the windows in the south aisle of

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[37] F. Bond, *Gothic Architecture*, p. 505.

[38] For an example of the imagery see the example of the specific instructions issued by Henry III in 1246 that the windows of the king's hall in Guildford should include images of the King and Queen on their thrones. Liberate Roll 30 of Henry III, m. 17. Quoted in full in L.F. Salzman, *Building in England*, pp. 383-4.

[39] P.Z. Blum, 'Thirteenth-Century Glass of the Salisbury Chapter House', *Gesta*, 1998, 37 (2 Essays on Stained Glass in Memory of Jane Hayward (1918-1994)), 142-9, p. 143.

the building.[40] It is also important to note that glass did not always come into direct contact with the stonework of the tracery because of the use of wooden frames as a barrier. Thus groves in the stonework to hold the glass would not have been necessary.

It was not always possible to manufacture glass on site because of the specialist facilities required, i.e. hot furnaces, ready access to raw materials, significant space upon which to lay out the sheets, and glass-houses if coloured glass was required.[41] In England there is some evidence for the purchase of glass "bought ready-made" or which was "composed in a distant workshop". The examples of this practice given by L.F. Salzman include Guildford Castle 1292, Westminster Palace 1322, Windsor Castle 1351-2, Carisbrooke Castle 1353 and Durham 1486.[42] Whether this is evidence for the manufacture of window glass in standard sizes, or whether the measurements were sent from site to a distant glazer, is unclear. If standard sized panes were used then an amount of variability in dimensions would have been acceptable when wooden frames were used.

In Ireland, no research on standardisation of pane size has yet taken place, thus it is hoped that the results of this study will assist in resolving this question. Whether Irish medieval coloured glass was imported or indigenously produced, it is possible that there was standardisation of pane sizes to match a fixed light width. However, it is also possible that the standardisation was at sheet sizes in order to facilitate regulation of payment, and that these would be cut to fit the lights by local glaziers, rather than being related to panes.[43]

Significantly in Ireland the survival rates for medieval stained glass have been very poor. Josephine Moran produced a review of the archaeological evidence for glass, producing a catalogue of a number of relevant examples, but no *in situ* glass has been found. However, glass was widely used in ecclesiastical settings as made clear from the many references to glass in the assets of the monasteries when dissolved after 1539.[44] Furthermore, excavations in Limerick, at St. Saviour's Dominican priory, and in Kilkenny, at Kells Augustinian priory and St. Canice's cathedral, have produced significant, although incomplete, collections.[45] Ecclesiastical settings were not the only

[40] L.F. Salzman, *Building in England*, 1952, pp. 482-3 quoting H.B. Maccall, Richmondshire Churches - Illustrated. London: Elliot Stock, 1910, p. 62.
[41] See descriptions in J. Blair and N. Ramsey, eds. *English Medieval Industries*. London: The Hambledon Press, 1991, pp. 251-2.
[42] L.F. Salzman, *Building in England*, p. 181.
[43] J. Moran, 'Shattered Image', p. 127.
[44] J. Moran, 'Shattered Image', p. 122.
[45] J. Moran, 'Shattered Image', p. 124. In the catalogue of finds for excavations at Kells Priory, 1622 glass fragments from the thirteenth to sixteenth centuries were found with 788 featuring illustration: J. Moran, 'The Window Glass.' *Kells Priory, Co. Kilkenny: archaeological excavations by T. Fanning & M. Clyne.* Eds. M. Clyne and T. Fanning. Dublin: Stationery Office, 2007. 261-316. In relation to general comments on

ones where glass was used. An entry in the close rolls of Henry III from 1243 recorded a decree that the King's hall at Dublin Castle should have a size of 120 feet by 80 feet and should be made with glazed windows after the manner of the hall of Canterbury. A round window of 30 feet was also to be included in the new hall.[46]

In the context of Gaelic documentary references to stained glass, Katharine Simms noted that the word '*fuinneóg*' is already encountered in the thirteenth century with reference to the stained glass windows of the newly-built cathedral in Armagh in a celebratory poem.[47] Later, in the fourteenth century, the windows of chieftains' houses are frequently noted in the Gaelic house poems written by bards in praise of their patrons. However, the first unambiguous reference to glass in such windows comes only in the seventeenth century.[48]

Records of donations of windows to religious establishments sometimes specify glass, tracery or both elements. One of the best-Irish known occasions of this practice is recorded in the *Regestrum* of Athenry Dominican priory, county Galway from 1462 when Edmund Lynch paid for the windows in the north part of the church "*sculptis et vitratis*".[49]

1.3.2 Building stones

In medieval Ireland, as now, the quality of available building materials would have had a significant influence on the window tracery that could be created. The best stones for a mason are those described as 'freestone' which means that they are "fine-grained and uniform enough to be worked in any direction and can thus be carved".[50] These stones are

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Irish medieval stained glass Arthur Champneys said that "the Glass but rudely painted and scarce transparent, probably done in the Infancy of the Invention": A.C. Champneys, *Irish Ecclesiastical Architecture: with some notice of similar or related work in England, Scotland and elsewhere*. London: G. Bell and Sons, Ltd., 1910, p. 199 (hereafter *Irish Ecclesiastical Architecture*).

[46] "That out of the King's profits they cause to be constructed in the castle of Dublin, a hall 120 feet in length and 80 feet in breadth, with glazed windows after the hall of Canterbury; and that they cause to be made in the gable beyond the dias a round window 30 feet in diameter. They shall also cause to be painted beyond the dais the King and Queen seated with their baronage; and a great portal shall be made at the entrance to the hall" from H.S. Sweetman, *Calendar*, p. 389: Close Rolls 27 Henry 3 p. 1, m. 9.

[47] Late 13th century: 'Ceannphort Éirenn Ard Macha': Williams, Poems of Giolla Brighde, poem no. xvii – on Armagh cathedral in K. Simms, 'Native sources'.

[48] T. Ó Donnchada, ed. *Leabhar Cloinne Aodha Buidhe. Arna Chur I N-Eagar Do Thadhg O'Donnchadha*. Baile Átha Cliath: Ireland Irish Manuscripts Commission, 1931.

[49] "*Edmundus Lynche...causa quacumque accedentes honorifice in suo hospicio reficere consueverat et inde cum gratiarum actione recedebant. Item fecit fabricari nova reparatione aram muralem existentem ex opposite columnarum dicti monasterii ex parte Boreali com omnibus fenestris ibidem sculptis et vitratis in suis propriis expensis.*" A. Coleman, 'Regestum monasterii fratum praedicatorum de Athenry', *Archivium Hibernicum*, 1912, 1, 201-21, p. 211.

[50] J.S. Scott and C. Bayliss, *A dictionary of building*. Penguin reference books. 2nd ed. Harmondsworth: Penguin, 1974.

generally limestones or fine-grained sandstones.[51] The other characteristics required by building stones are strength and durability, where the latter relates to two factors: porosity and resistance to chemical change. While tracery stones did not need to be particularly strong, a lack of durability would reduce the longevity of the stones, thus making them unfavourable to masons. Particularly for limestone, masons preferred to work stones quickly after quarrying because once removed from the beds the stones become hard and difficult to carve.[52]

Roger Stalley identified "native sandstone, granite and hard carboniferous limestone, along with imported oolite" (frequently Dundry stone from near Bristol) as much-used in Irish medieval architecture.[53] Sandstones were particularly sought after during the Romanesque period, almost to the exclusion of all other stone, because it facilitated the fine carving required to produce the intricate ornamentation favoured in the period.[54] By the later middle ages, Stalley suggested that the Irish masons had become "more adept at handling the local carboniferous limestone" although the availability of this material throughout Ireland may have been a factor, given that the cost of transporting stone was greater than carving it.[55] The suitability of a limestone area for quarrying depends on the natural bedding planes in which the composite materials were laid down. The direction of the plane must be considered in relation to choosing stone for different parts of a building.[56] For instance, for arches the bedding planes "should be placed as near as possible normal to the curve of the arch", overhanging planes should be set with the bedding planes vertical, and otherwise the planes should be horizontal.[57]

The widespread use of limestone in the architecture of the fifteenth century may have greatly limited the repertoire of most masons simply because of its difficulty for carving and the time that would have been required. A stone that is not easily carved would not encourage experimentation in the details required for window tracery, such as

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[51] R. Durman, *Ham Hill: portrait of a building stone*. Reading: Spire Books Ltd, 2006, p. 41 (hereafter *Ham Hill*).
[52] R. Durman, *Ham Hill*, p. 39.
[53] R. Stalley, 'Masons and their Materials in Medieval Ireland.' *Working With Limestone: The Science, Technology, and Art of Medieval Limestone Monuments*. Ed. V. Olson. Vol. 7. *AVISTA Studies in the History of Medieval Technology, Science and Art*. Aldershot, England: Ashgate Publishing Ltd., 2011. 209-26, p. 225 (hereafter 'Materials in Medieval Ireland').
[54] R. Stalley, 'Materials in Medieval Ireland', p. 213.
[55] R. Stalley, 'Materials in Medieval Ireland', p. 223 and D. Knoop and G.P. Jones, 'Medieval Quarry'.
[56] E.G. Warland, *Modern Practical Masonry*. Shaftesbury: Donhead, 1929, p. 120 (hereafter *Modern Practical Masonry*).
[57] E.G. Warland, *Modern Practical Masonry*, p. 129.

cusps, foliation, and mouldings. Despite this a number of authors have commented on the quality of carving achieved by Irish masons.[58]

1.3.3 Irish medieval building practice

One other influence on Irish tracery, which was different to England and continental Europe, is the way in which the Irish medieval building industry was organised. Outside Ireland, masons' lodges were the cornerstone of building activities (Figure 1.2). They were a feature of every building project and served as a location for indoor work, a store, and a base for the masons.[59] The lodges were temporary structures for the duration of the project but big endeavours, as most of the European and English gothic cathedrals were continued, in some cases, for hundreds of years.[60] The lodges, thus, were centres for training, for innovation, and for organisation, as well as influencing architectural ideas for a hinterland.[61]

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[58] "The builders of Corcomroe were excellent masons but rather poor architects": R. Stalley, *The Cistercian Monasteries of Ireland*. London & New Haven: Yale University Press, 1987, p. 49 (hereafter *Cistercian Monasteries*) and D. O'Donovan, 'Building the Butler Lordship 1405–c. 1552', Ph.D. Trinity College, Dublin, 2007 (hereafter 'Building Butler'), on the carving at St. Mary's collegiate church, Callan.

[59] N. Coldstream, *Masons and sculptors*. Medieval craftsmen. London: British Museum Press, 1991, pp. 10-5 (hereafter *Masons and sculptors*).

[60] C. Wilson, *The Gothic Cathedral: the Architecture of the Great Church 1130-1530*. London, England, 1990.

[61] Training e.g. D. Knoop and G.P. Jones, 'Apprenticeship' and N. Coldstream, *Masons and sculptors*, p. 15; Innovation e.g. D. Turnbull, 'The Ad Hoc Collective Work of Building Gothic Cathedrals with Templates, String, and Geometry', *Science, Technology, & Human Values*, 1993, 18 (3), 315-40; Organisation e.g. D. Knoop, G.P. Jones and D. Hamer, *The Two Earliest Masonic MSS*. Medieval manuscripts; masonic lodge records. MS. Collection, Manchester; M. O'Neill, 'St. Patrick's cathedral, Dublin, and its prebendal churches: gothic architectural relationships.' *Medieval Dublin V: proceedings of the Friends of Medieval Dublin Symposium 2003*. Ed. S. Duffy. Dublin: Four Courts Press, 2004. 243-76.

Figure 1.2 Illumination from 1448-65 including a temporary mason's lodge. Bibliothèque Royal, Brussels, MS 6, fol.554v

Ireland had fewer such enterprises and, because of the scale of the edifices that were built, the duration of the projects was not as long as elsewhere. Such is the significant number of ecclesiastical buildings that were constructed in Ireland in the middle ages that not all of these could have derived influence from the limited number of lodges attached to cathedrals, etc. This probably contributed to the more limited architectural innovation that allowed tracery styles such as switchwork to remain popular for over two hundred years. Without such influential lodges the competitiveness that lead to the development of Perpendicular tracery in England and the flamboyant styles in France did not occur in medieval Ireland.

Another important indicator of the organisation of the medieval building industry relates to the marking of stones using the mason's mark. While masons' marks are most frequently found on ashlar, they were also used on coursed, roughly squared rubble and they came in two varieties: the assembly mark, indicating how sections should be joined, and the banker mark, which usually indicated the identity of the craftsman responsible for carving a given piece of stonework.[62] For the latter type, Colum Hourihane, in his study of the archbishoprics of Cashel and Dublin, supposed that marks were unique among masons because duplication was prevented through the maintenance of a "central register", with a

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[62] J.S. Alexander, 'The Introduction and Use of Masons' Marks in Romanesque Buildings in England', *Medieval Archaeology*, 2007, 51, 63-81, p. 64 (hereafter 'Masons' Marks').

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mark only transferring upon the death of a mason. He provided no evidence of where and how this register may have been maintained.[63]

It would be prudent to assume that the guilds would have been the appropriate wardens of such registers but there is no evidence to back up this suggestion. Jennifer Alexander, despite significant amounts of research, showed, from the surviving ordinances of the London guild of masons from 1356, 1481 and 1521, that "virtually no contemporary references" were made to masons' marks.[64] Douglas Knoop and G.P. Jones also found no evidence of records being taken on masons' marks until the very end of the middle ages with the Schaw Statutes of 1598, which required registration of masons with a lodge using a signature and their mark.[65] These findings, in combination with the knowledge that Irish guilds were not formally instituted until 1508, mean that Hourihane's results must be questioned. Similar marks, particularly simple ones such as arrow heads and crosses, occur so frequently on sites that connections between all of them cannot be entertained.[66]

On the question of the training of masons in Ireland, this would also have been different to English and continental practices because of the more transitory nature of nearly all mason's careers. An idea of the nature of this training was given for the pre-Anglo-Norman era by Jenifer Ní Ghrádaigh who showed that an *ugtar saer* would work with a group of typically four others.[67] These others probably included trainees because the regulations of the *Senchus Már*, which defined much Brehon Law, required that patrons who employed the master, *uctar saer*, were also required to look after pupils or apprentices, albeit at a significantly discounted rate.[68]

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[63] C. Hourihane, *The Mason and His Mark: Masons' Marks in the Medieval Irish Archbishoprics of Cashel and Dublin*. British Archaeological Reports. Eds. J. Hedges and E. Hedges. Vol. BAR 294. Oxford: British Archaeological Reports, 2002, p. 33.

[64] J. Blair and N. Ramsey, eds. *English Medieval Industries*. London: The Hambledon Press, 1991, p. xxvii (hereafter *English Medieval Industries*).

[65] D. Knoop and G.P. Jones, *Medieval Mason*, p. 260.

[66] John Harvey mentioned that in 1844 an elder mason from Canterbury Cathedral told members of the British Archaeological Association that "his own mark had belonged to his father and grandfather before him, and that 'his grandfather had it from the lodge'." The mason also explained that when a non-local mason joined an existing working group, and his mark was similar to an existing mark, then he had to apply to the lodge for a new mark. Once the 'foreign' mason left that job he could return to his old mark: J. Harvey, *The Master Builders: Architecture in the Middle Ages*. London: Book Club Associates, 1973, p. 47.

[67] J. Ní Ghrádaigh, 'A legal perspective on the saer and workshop practice in pre-Norman Ireland.' *Making And Meaning in Insular Art*. Ed. R. Moss. Dublin: Four Courts Press Ltd., 2007. 110-25, pp. 112-6 (hereafter 'Saer').

[68] J. Ní Ghrádaigh, 'Saer', pp. 112-6: "For instance, it specifies that only the master is entitled to salted meat until turcbál, and that his servants, that is his pupils or apprentices, are not. During the turcbál (non-quote: construction which seems to have been deemed more important and dangerous and thus worthy of better remuneration) process however, all the *saers* are entitled to good condiments with their bread, although a distinction is still made between the master and the rest, regarding what they get to drink." The *Senchus Már* is also sometimes known as the *Senchus Mór*.

The influence of the way that the building industry was organised in medieval Ireland impacted on the metrology and proportion of tracery will be considered in the following.

1.4 Classifications of Gothic

"To draw up a system of classes, in other words to recognize the distinctive principle of each, is comparatively easy; while to arrange the actual examples under the classes so formed is a far more difficult matter."

E.A. Freeman, 1851[69]

Numerous authors have attempted to create classifications of tracery based upon stylistic descriptions, locations, and temporal associations. Most of these classifications also link tracery with other determining architectural features such as mouldings, piers, capitals, roofing, buttressing, etc.[70] Since the terminology of classification varies depending on the author it is necessary here to define each of the typical divisions. These definitions will first be presented, in alphabetical order, mainly based on James Curl's *Encyclopaedia of Architectural Terms* for consistency, after which their adoption and application will be briefly discussed:

Curvilinear/Decorated: Also known as Middle- or Second-Pointed Gothic, this style is characterised by flowing lines and the use of ogee or S-shaped curves, as well as introducing a "naturalistic treatment of floral decoration". Shapes frequently used include the "*Vesica Piscis* or mandorla, mouchettes, crockets, and star-vaulting".[71]

Early English: Also known as First-Pointed Gothic, this is the earliest form to be adopted generally in England. Characteristics include pointed arches and lancet windows with "very sharp points or with equilateral arches." When tracery is used it is typically of the plate type and the opening is filled with simple geometrical shapes, sometimes cusped. Some later bar tracery also occurred with the focus of the design again on circles and foils, creating geometrical tracery.[72] Another form of Early English tracery is known as

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[69] E.A. Freeman, *An Essay on the Origin and Development of Window Tracery in England*. Oxford: John Henry Parker, 1851, p. 3 (hereafter *Essay*).
[70] R.K. Morris, 'An English Glossary of medieval mouldings: with an introduction to mouldings c.1040-1240', *Architectural History*, 1992, 35, 1-17 (hereafter 'Glossary').
[71] J.S. Curl, *Encyclopaedia*, p. 102 and p. 105.
[72] J.S. Curl, *Encyclopaedia*, pp. 121-3.

switchline. This is one of the simplest types of tracery and the design is created by extending the mullions at alternating angles until they reach the arch of the full window. Variation can be achieved by adding cusps, or by inserting round or foiled heads at the tops of the lights. This type of tracery was particularly predominant in medieval Ireland and its medieval use continued until the sixteenth century.

Flamboyant: Derived from Second-Pointed or Curvilinear work this style is characterised by flame-like forms of the tracery. In many places, particularly parts of the continent and France, it was the last phase of Gothic.[73]

Flowing: Flowing, and undulating, are alternative titles for Curvilinear Second-Pointed or Flamboyant Gothic tracery.[74]

Geometrical: The early part of the Second-Pointed or Decorated style, characterised by tracery which consisted almost entirely of geometrical shapes such as circles and multifoils.[75]

Perpendicular/Rectilinear: Also known as Third-Pointed or the Rectilinear style, this was the last of the styles of Gothic architecture to flourish in England, the only place where it occurred since, on the continent, elaboration of the Flamboyant styles continued until the Renaissance. Perpendicular tracery is characterized by straight verticals and horizontals, sometimes extending directly from the mullions through to the underside of the window-arches.[76]

Rayonnant: A particularly French style, the culmination of Gothic in many parts of northern France. Typified by greatly enlarged circular windows which radiate from the centre to the periphery.[77]

Much has been written on the phases of design within the Gothic style but the durations and starting dates are still the subject of much debate among authors. Figure 1.3 illustrates the temporal divisions of the Gothic period through examination of the work of

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[73] J.S. Curl, *Encyclopaedia*, p. 141.
[74] J.S. Curl, *Encyclopaedia*, p. 142.
[75] J.S. Curl, *Encyclopaedia*, pp. 154-5.
[76] J.S. Curl, *Encyclopaedia*, pp. 240-1 and p. 262.
[77] J. Elvy, *Tracery 1150-1350 AD*. Mayfield, Sussex: Cinderhill Books, 2001, p. 391.

seven prominent architectural historians. The most obvious conclusions from an examination of this chart are that a variety of terminologies was used, and that starting and finishing dates are contentious. One of the main reasons for these problems echoes back to the opening quote of this section from Edward Freeman; there are few clear breaks between one architectural period and the next, and that windows, in this case, designed in the style of one, fading period, were inserted contemporaneously, although usually at different locations, with ones in the style of a new period.

The rest of this work is not focussed on debating the merits of particular classification schemes. Rather the terminology and dating presented in the previous section has been included to provide context because classification is not the goal of this work.

	1130	1150	1170	1190	1210	1230	1250	1270	1290	1310	1320	1330	1350	1360	1370	1390	1410	1430	1450	1470	1490	1510	1530	1550
Rickman			Early English								Decorated				Perpendicular									
Sharpe					Early English			Geometrical			Curvilinear				Rectilinear									
Bond					Early English			Early Geometrical		Late Geometrical	Curvilinear/Flowing				Rectilinear									
Frankl		Early Gothic				French High Gothic		High Gothic								Late Gothic								
Harvey								Rayonnant							Perpendicular									
Wilson		Early Gothic					High Gothic				Decorated					Perpendicular								
Coldstream									Decorated															

Figure 1.3 Classifications of Gothic architecture[78]

[78] T. Rickman, *An Attempt to discriminate the Styles of Architecture in England from the Conquest to the Reformation with a sketch of The Grecian and Roman Orders*. Fifth edition with very considerable additions and new plates ed. London: John Henry Parker, 1848; E. Sharpe, *Decorated Treatise*; F. Bond, *Gothic Architecture*; P. Frankl, *Gothic Architecture*; J. Harvey, *The Perpendicular Style, 1330-1485*. London: Batsford, 1978 (hereafter *Perpendicular*); C. Wilson, *The Gothic Cathedral*; and N. Coldstream, *The Decorated Style: Architecture and Ornament 1240-1360*. Paperback 1999 ed. London: British Museum Press, 1994.

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1.5 Tracery in Irish architectural studies

In line with the buildings in which they are contained, Irish medieval traceried windows are typically smaller than those found in England or continental Europe. Even the cathedrals of the Irish middle ages are, in many cases, no bigger or more elegant than some parish churches abroad. Also, as previously indicated, Irish cathedral designs had much less influence over nearby parish churches than was found elsewhere. In relation to the houses of the religious orders, the monks or friars were typically invited to an area by a local lord who acted as patron for the building works, sometimes only initially, sometimes over longer periods.[79] In the following, research on Gothic architecture which contains references to tracery, or associated elements such as mouldings or engravings, will be presented and discussed.

Although early works on the history of Irish architecture throughout the territory were published prior to the 1900s, none included any noteworthy commentary on medieval tracery. Arthur Champneys' 1910 *Irish Ecclesiastical Architecture* examined Irish tracery in comparison with England and Scotland but with a limited examination of links between styles of tracery at different Irish sites. Champneys suggested that many types of Irish tracery "seem to have been imported ready-developed, though they were varied locally" and definitely stated that what he termed Irish 'Decorated' architecture "follows to a very large extent the English examples from which it is derived".[80] He seemed particularly fascinated by the simplicity of Irish designs, particularly Flamboyant styles, which he described as "wholly or in part destitute of cusps". His comments seemed to suggest that the absence of cusping was the result of a lack of masonic skill and this implied a lack of development on the part of Irish medieval architecture. Although Champneys discussed the definition of the "Late Irish Gothic" style, his observations were, as suggested by the work's full title, mainly concerned with noting similarities with English and Scottish architecture.

Harold Leask's countrywide study of Irish medieval architecture was published in 1955 and 1960 as Volumes 1-3 of *Irish Churches and Monastic Buildings*.[81] His research encompassed the full range of ecclesiastical building types from small parish churches, to

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[79] See Gwynn & Hadcock for details on foundation dates and patronage. A. Gwynn and R.N. Hadcock, *Medieval Religious Houses: Ireland*. 2nd ed. Blackrock, Co. Dublin: Irish Academic Press, 1988.

[80] A.C. Champneys, *Irish Ecclesiastical Architecture*, p. 165.

[81] H.G. Leask, *Irish Churches I*; H.G. Leask, *Irish Churches & Monastic Buildings*. Vol. II. Dundalk, Ireland: Dundalgan Press Ltd., 1960. 3rd (hereafter *Irish Churches II*); H.G. Leask, *Irish Churches & Monastic Buildings*. Vol. III. Dundalk, Ireland: Dundalgan Press Ltd., 1960. 5th. (hereafter *Irish Churches III*).

monastic settlements to cathedrals, and a considerable amount of content was devoted to the study of tracery. Despite its undoubted value as a record of Irish tracery, the main failing of Leask's work was his insistence on trying to apply English dating to Irish windows on the basis of stylistic similarities. Leask applied this technique despite his own comments that the longevity of certain designs, such as switchline, complicated these efforts. His solution to many of his dating problems was to suggest a time-lag of approximately fifty years between the adoption of new ideas in England and their arrival in Ireland. However, in some buildings, new types of tracery, contemporary with England, were being utilised alongside long-established styles such as lancets and simple ogee headed arches. Thus it is more true to say that Irish masons, and their patrons, while often aware of new designs simply chose not to use them.

A number of other countrywide surveys have been carried out, but typically these have been limited by the criteria of religious association. Roger Stalley's essential work on the Cistercian buildings of Ireland included a number of references to windows and tracery.[82] Similarly, Canice Mooney's work on the Franciscan order in Ireland considered particular elements related to the origin of architectural ideas, some of which are evident in details such as tracery, particularly through links with France.[83]

A significant body of work exists for ecclesiastical buildings which are linked by political boundaries or other regional considerations, including T.J. Westropp for northern Clare, Patrick Power for Waterford, and Oliver Davies for Louth.[84] However, tracery does not receive prominent consideration and none of these regions impact on this study. References to window tracery are, however, important in Michael O'Neill's research into the medieval parish churches of counties Meath and Kildare, in Danielle O'Donovan's work on Gothic moulding profile analysis in the areas controlled by the Butler family, and in Susan Mannion's study of the physical remains of the fifty-seven medieval friaries of Connaught.[85] Also mainly related to the Connaught area is Britta Kalkreuter's study of the

[82] R. Stalley, *Cistercian Monasteries*.
[83] C. Mooney, *Irish Franciscans and France*, Dublin: Clonmore and Reynolds Ltd, 1964 and C. Mooney, 'Franciscan Architecture in Pre-Reformation Ireland', *Journal of the Royal Society of Antiquaries of Ireland*, 1955, 85, 133-73; 1956, 86, 125-69 and 1957, 87, 102-24.
[84] T.J. Westropp, 'Churches with Round Towers in Northern Clare', *Journal of the Royal Society of Antiquaries of Ireland*, 1894, XXIV (1), 25-34, (2) 150-9, (3) 332-40; P. Power, 'The Ancient Ruined Churches of Co. Waterford', *Journal of the Royal Society of Antiquaries of Ireland*, 1891, I (2), 475-82 and P. Power, 'Some Old Churches of Decies', *Journal of the Royal Society of Antiquaries of Ireland*, 1938, LXVIII (I), 55-68.
[85] M. O'Neill, 'The Medieval Parish Churches in County Meath', *Journal of the Royal Society of Antiquaries of Ireland*, 2002, 132, 1-56 (hereafter 'Meath Parish Churches'), M. O'Neill, 'The Medieval Parish Churches of Kildare.' *Kildare: History and Society*. Eds. W. Nolan and T. McGrath. Dublin: Geography Publications, 2006. 153-93 (hereafter 'Kildare Parish Churches'); D. O'Donovan, 'Building Butler'; and S. Mannion, 'A

School of the West which examined a group of buildings originally defined by Harold Leask as being characterised by a stylistic similarity that did not exist elsewhere.[86] In Ken Abraham's study of landholding and patronage in medieval Meath he included a classification of tracery within his study of tower-houses and parish churches.[87]

In the only specific examination of tracery, Róisín Mullin considered windows in the regions of North Munster (Clare, Limerick, Tipperary and Kilkenny), and the Pale with North Leinster (Meath, Dublin and Louth).[88] The details of this work are further considered in the following.

A number of detailed examinations of individual buildings have also included references to tracery and the most typical of these are studies of the Irish medieval cathedrals. Both Dublin cathedrals were significantly reconstructed in the modern era making it difficult to examine their medieval form. Michael O'Neill, therefore, used the drawings of R.C. Carpenter from 1845 (Figure 1.4) to examine the medieval tracery designs of the windows of St. Patrick's Cathedral, Dublin and to help in dating portions of the building, particularly through alignment with similar windows in Bristol cathedral. He also used the drawings to appraise the influence of St. Patrick's on the prebendal churches of the English territory of the Pale.[89] Through a stylistic examination of the window forms of St. Patricks, O'Neill was able to identify windows in medieval churches which were probably influenced by the cathedral. Although it appears to have had less impact than might have been expected for a church of such prominence, O'Neill found similarities in windows in county Meath at Kilsharvan, in the Augustinian tower in Trim, at the Plunkett churches of Killeen (Figure 1.4) and Dunsany, and in county Dublin at Newcastle Lyons, Howth and Malahide.[90] In each case, the stylistic comparison was complemented and confirmed by documentary records, but no measured data was included. O'Neill's results have not been appraised in this study because of their location outside the chosen research

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study of the physical remains of the medieval friaries of Connacht', Ph.D. Queen's University, Belfast, 1997 (hereafter 'Medieval Friaries of Connacht').

[86] B. Kalkreuter, *Boyle Abbey and the School of the West*. Wordwell monograph series. 1st ed. Bray, Co. Wicklow, Ireland: Wordwell Ltd., 2001 (hereafter *School of the West*).

[87] A.S.K. Abraham, 'Patterns of Landholding and Architectural Patronage in Late Medieval Meath. A regional study of the landholding classes, tower-houses and parish churches in Ireland, c. 1300-1540', Ph.D. Queens University Belfast, Belfast, 1991 (hereafter 'Architectural Patronage in Meath').

[88] R. Mullin, 'A regional study'.

[89] M. O'Neill, 'Design sources for St. Patrick's Cathedral, Dublin, and its relationship to Christ Church Cathedral', *Proceedings of the Royal Irish Academy*, 2000, 100C (6), 207-56 (hereafter 'Design sources'); M. O'Neill, 'St Patrick's Cathedral in Dublin and its place in the history of Irish medieval architecture', Ph.D. Trinity College Dublin, Dublin, 1995 and M. O'Neill, 'St. Patrick's cathedral, Dublin, and its prebendal churches: gothic architectural relationships.' *Medieval Dublin V: proceedings of the Friends of Medieval Dublin Symposium 2003*. Ed. S. Duffy. Dublin: Four Courts Press, 2004. 243-76.

[90] O'Neill explained the limited influence as related to the extreme cost of the specific design, a lack of interest and, possibly most importantly, the continuity of use of earlier churches without renovation.

area. This methodology is not available for the areas of this study because of the limited survival of distinctive tracery forms in the cathedrals of these regions.[91]
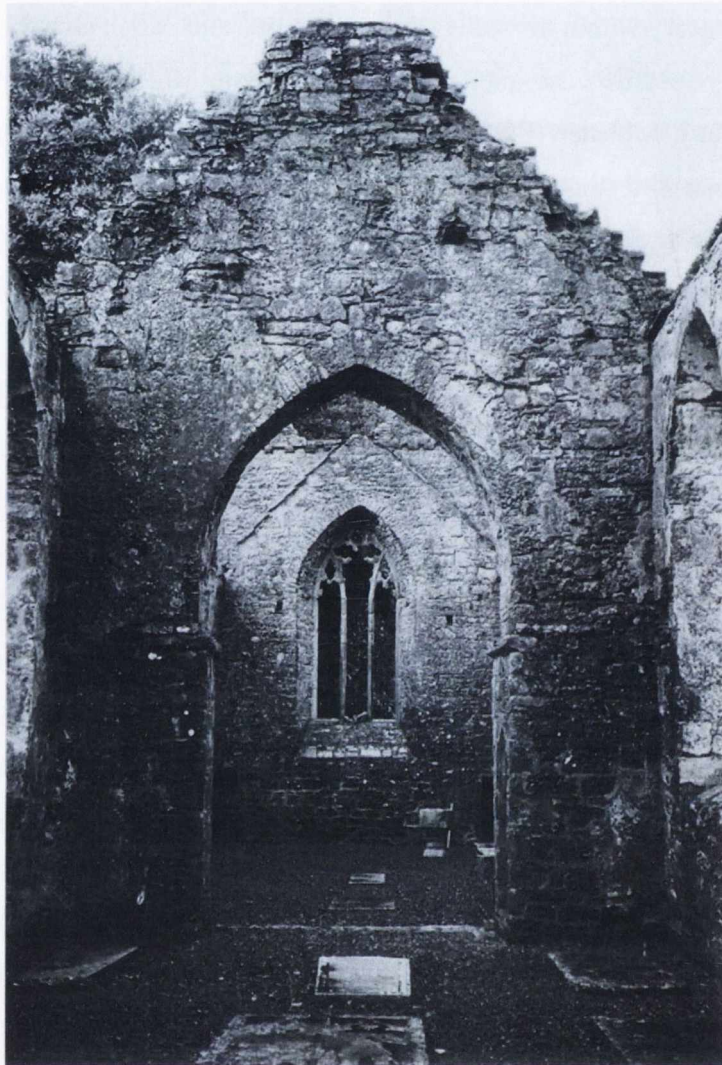
Figure 1.4 Nave west, Killeen parish church (photo credit Michael O'Neill)

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[91] Something of an exception to this rule is the similarity between window designs at St. Laserian's cathedral, Old Leighlin and a range of buildings in Ormond. The reasons for this are suspected to be different to just prebendal connections and this idea will be developed in the following.
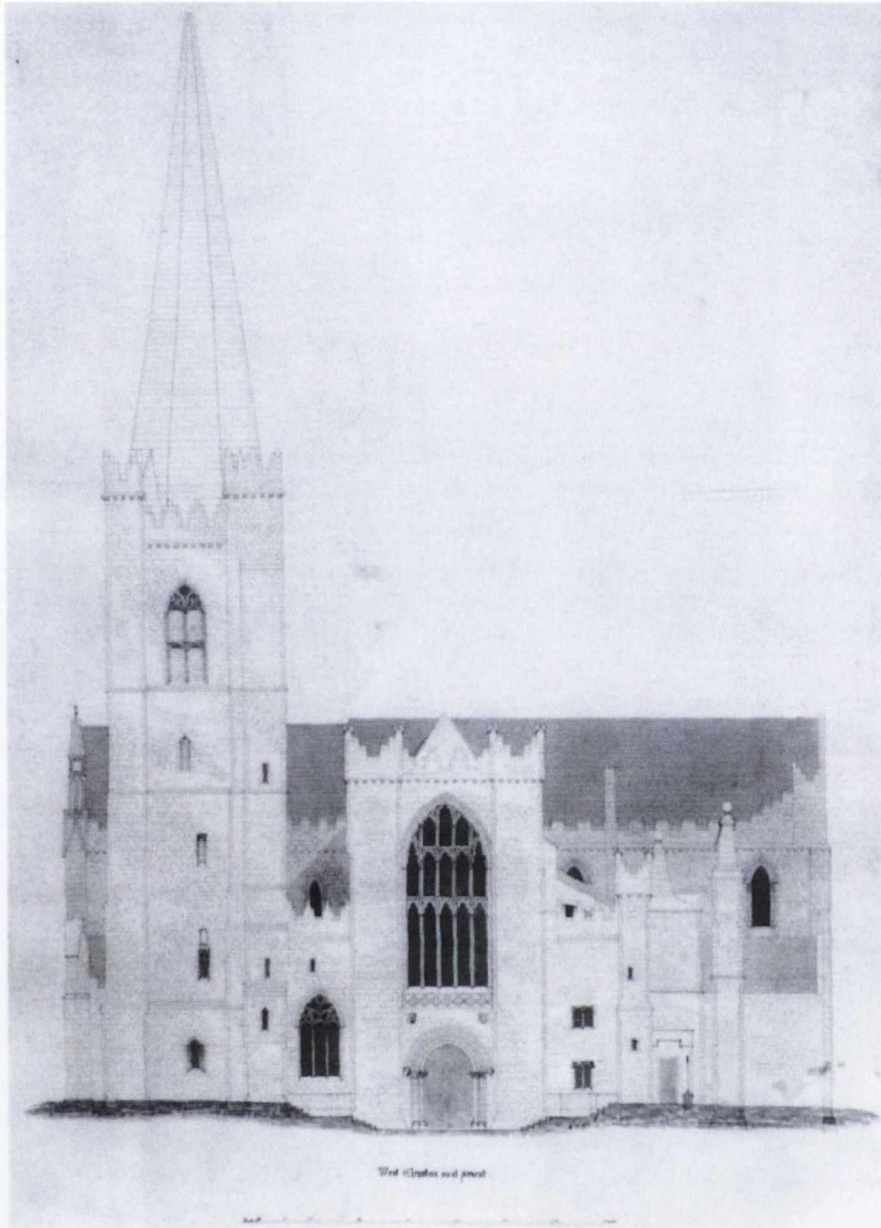
Figure 1.5 West front, St. Patrick's cathedral by R.C. Carpenter 1845[92]

Also at a Dublin cathedral, Rachel Moss's work on cataloguing the carved stone fragments in the crypt of Christ Church cathedral after G.E. Street's Victorian rebuilding produced a number of tracery-related finds.[93] Among the collection of some 1,800 carved stones are 'sixteen pieces of red sandstone window tracery', decorated with cusps, which Moss considered to possibly have originated in the east window of the fourteenth-century long choir. Another eight pieces of carved granite, which were used in a fourteenth- or

[92] M. O'Neill, 'Design sources', p. 245.

[93] R. Moss, 'Tales from the crypt: the medieval stonework of Christ Church cathedral, Dublin.' *Medieval Dublin III: proceedings of the Friends of Medieval Dublin Symposium 2001.* Ed. S. Duffy. Dublin: Four Courts Press, 2002. 95-114, 98 (hereafter 'Christ Church stonework') and R. Moss, 'A medieval jigsaw puzzle: the ancient stones of Christ Church', *Archaeology Ireland,* 2000, 14 (2) (hereafter 'Medieval jigsaw').

fifteenth-century window, were also recorded and these indicated a switchline design for the window. The rest of the tracery was lost and these elements were too insufficient to merit a more comprehensive examination. This is indicative of the problems at a number of Irish medieval sites where, without documentary evidence to replace the lost stonework, few inferences can be made.

Of the works previously mentioned few have attempted any form of empirical approach with most authors examining and evaluating their topics on the basis of stylistic and documentary considerations. However, in one piece of work a technical analysis of Irish mouldings was made by Gareth Bradshaw and Carol O'Sullivan. A promising algorithm was developed for the extraction of geometric shapes from moulding measurements by a laser profiling tool. This work demonstrated that an experimental approach based on measured observations of medieval architectural features could be successful.[94] However, the technique was never applied to any specific architectural problem, such as the comparative evaluation of mouldings, meaning that the full potential of this type of empirical method has yet to be evaluated.

The application of these studies will be discussed in more detail in the following sections.

1.5.1 Classification of Irish tracery

Typically, studies of tracery in Ireland have focused on the development of classification systems. A.C. Champneys placed windows within one of two classes: Irish or English windows of Decorated style with pointed arches surmounting intersecting mullions or Flamboyant, flowing designs; or English Perpendicular, typically square headed, one-, two- or three-light windows with ogee arches.[95] Leask followed the method of trying to align Irish developments with those occurring in England using the categories: Switch-line, either plain or with sub-arches at springing level, and Curvilinear, which he further divided between flowing or near-Flamboyant designs, and modifications of reticulated. Leask determined that most Irish curvilinear designed windows were derived from English designs although he admits that some influence may have come from France.

Leask was unable to produce "precise agreement" between Irish designs and examples in England and advised against "dogmatism" on the subject.[96] However, he still

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[94] G. Bradshaw and C. O'Sullivan, *Extracting Geometric Models from Medieval Moulding Profiles*. Dublin: Image Synthesis Group, Dept. of Computer Science, Trinity College, 2000.
[95] A.C. Champneys, *Irish Ecclesiastical Architecture*, p. 189.
[96] H.G. Leask, *Irish Churches III*, pp. 115-131.

tried very hard to find correspondence, to the extent that he wrote to John Harvey for help when preparing an article on Rathmore church (Figure 1.6).[97]

Figure 1.6 Chancel east, Rathmore parish church (photo credit Danielle O'Donovan)

However, Leask's desire to see English patterns and stylistic groupings in Irish tracery prevented him from producing an independent countrywide classification, despite the unparalleled access which he had to Irish medieval architecture.

Leask's only references to the size of windows in his descriptions were some commentaries on the widths of mullions, but only using words such as broad or narrow. Similarly, Susan Mannion frequently gave visual descriptions of parts of the windows for Connaught's medieval friaries. For instance, the upper portions of some windows were described as varying between "squatter and shorter" or "taller and ultimately more graceful", while mullions at Ballindoon (Figure 1.7) and Loughrea were described as "quite thick and stocky".[98] Mannion also carried out a stylistically-based study of the windows within her region of study identifying three types of window mullion and four types of hood moulding. However, both classifications are based on a visual comparison of shape rather than on any measured criteria.[99]

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[97] Harvey responded: "One thing I should say about the Englishness of these Irish windows; although they are clearly inspired by English ideas in design, I feel sure that they are carried out by Irish masons. They do not give the 'feel' of real English work, probably because of relatively slight differences in the proportions of the mouldings. But I should say that the (Anglo-) Irish masons in question were under (for Ireland) exceptionally strong and direct English influence". Leask papers, TCD MS 3875/37. Leask goes on to directly quote Harvey's remark about 'the feel' of English work *Irish Churches and Monastic Buildings III*, 14.

[98] S. Mannion, 'Medieval Friaries of Connacht', p. 99.

[99] S. Mannion, 'Medieval Friaries of Connacht', pp. 112-9.

Figure 1.7 Ballindoon Dominican friary: nave west window

In 1991 Ken Abraham produced a classification of Meath tracery that resulted in two groupings: those dependant on intersecting arcs and those consisting of cusped forms.[100] Even though Abraham only considered a small number of parish churches and tower houses in a limited region, this scheme could not be considered to properly reflect the variety of tracery at these sites and, therefore, cannot be more widely applied.

Róisín Mullin considered the classifications of Champneys, Leask and Abraham to be flawed because they were based on analysis of particular elements, the choice of which was "arbitrary".[101] Her approach to understanding Irish tracery was to create a system of classification based on trying to reconstruct the decision-making process adopted by the mason during the design of tracery for a particular window. Her method considered: the number of lights; the preferred form; the motifs including commas, vesicas, quatrefoils, trefoils, daggers; the use, or not, of cusping; and the decision to exactly replicate previous designs or to introduce variation. This resulted in twelve types of tracery into which she divided the windows of her study areas before analysing the spatial distribution of each type to test for validity.[102] Mullin asserted that her classification method was less arbitrary than had been used by researchers within or outside Ireland, such as Richard Fawcett in Scotland, since her method was based on the decisions of the mason. However, the resulting number and type of classes was very similar to Fawcett's results.[103]

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[100] A.S.K. Abraham, 'Architectural Patronage in Meath'.
[101] R. Mullin, 'A Regional Study', p. 11.
[102] R. Mullin, 'A Regional Study', pp. 15-48.
[103] Richard Fawcett's work will be considered in a following section.

While Róisín Mullin's method made a conscious effort to integrate the role of the mason into the classification scheme, and in so doing improved on the previous systems, she omitted the role that external influences could play on the design of tracery. For instance, L.F. Salzman showed in England that many medieval contracts included stipulation by the patron about the numbers of lights, the design of the tracery and, sometimes, the moulding profiles to be used.[104] The availability of high-quality materials and the economic status of the client were also ignored. Furthermore, while Mullin suggested that stylistic ideas were transferred through the use of masons' notebooks, she did not consider that it might have been impossible for a mason to make a free choice regarding each of the decisions listed previously because he may not have been sufficiently skilled.

Mullin's work also relied entirely on a stylistic analysis of the design of the tracery field in an unmeasured, two-dimensional sense, with supporting historical sources, but ignored the contribution that can be made by the third dimension, the depth of the window. Mullin contended that too few buildings have sufficient mouldings, but this statement has been refuted by Danielle O'Donovan's work on buildings within the area of Butler Lordship and throughout Ireland.[105]

The stylistic analyses of Susan Mannion and Róisín Mullin brought them both to the same conclusion, that Irish medieval tracery designs exhibit distinctly regional characteristics which dominate all other considerations, such as building type, religious order or patronage.[106] This contrasts with the results of Danielle O'Donovan's measurement of 500 moulding profiles at sites across the country. Moulding profiles form an integral part of any window tracery design, but none of the previous studies have attempted to combine the tracery styles with the results of moulding analysis. O'Donovan found that "the same stock of moulding forms were in use throughout the country for much of the fifteenth and early sixteenth centuries".[107] This evidence suggests that a more holistic examination of tracery, in its full three-dimensionality, is necessary in order to understand the design methods of the medieval masons and, thus, to potentially create more correct classifications and chronologies.

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[104] For English medieval contracts see: L.F. Salzman, *Building in England*, Appendices A & Bs.
[105] D. O'Donovan, 'Building Butler'.
[106] S. Mannion, 'Medieval Friaries of Connacht', p. 99 and R. Mullin, 'A regional study', p. 53.
[107] D. O'Donovan, 'Building Butler', p. 244. This work is in contrast to the development patterns evidenced in England by the work of Richard Morris & Eileen Roberts: R.K. Morris, 'The Development of Later Gothic Mouldings in England', *Architectural History*, 1978, 21, 18-57 and 1979, 22, 1-48; and E. Roberts, 'Moulding analysis and architectural research: the late Middle Ages', *Architectural History*, 1977, 20, 5-13.

Further evidence of the difficulties involved in analysing Irish tracery on a purely stylistic basis is given by Roger Stalley who described Holycross Cistercian abbey, county Tipperary (Figure 1.8 & Figure 1.9) as showing "laudable enthusiasm for experiment" but commented that the general design shows little stylistic direction with a number of windows deserving classification as debased.[108]
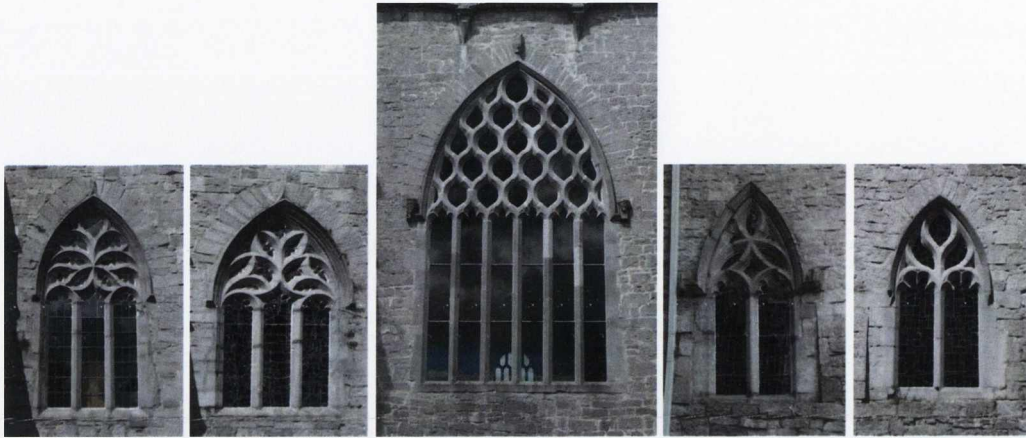
Figure 1.8 Chancel and transept east end windows, Holycross Cistercian abbey (relative scaling approximate)
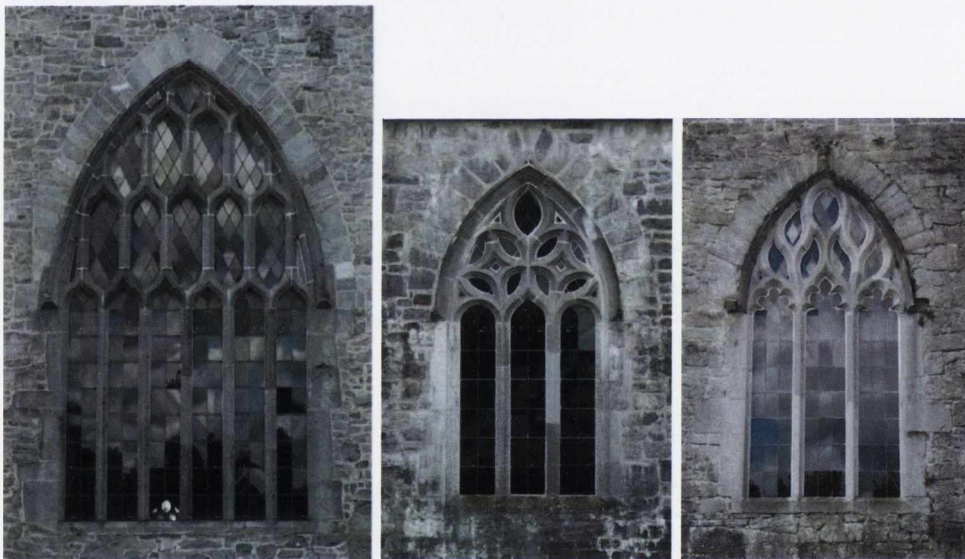
Figure 1.9 Nave west, nave north aisle north and north transept north windows, Holycross Cistercian abbey (left to right)

Stalley considered that the Irish masons working at Holycross were limited because of their lack of access to training and ideas, particularly from England, and thus their designs were local in inspiration and new variations were frequently unsuccessful.[109] This again suggests that Irish masons were required to take inspiration from English

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[108] R. Stalley, *Cistercian Monasteries*, pp. 120-1.
[109] Stalley deems it unlikely that the Holycross masons had access to current English designs because those that they did apply were already 100 years old. *Cistercian Monasteries*, p. 122.

developments, a consideration which ignores the possibility of the independent development of ideas or the sourcing of inspiration from locations other than England. Irish researchers have, perhaps, become too accustomed to the idea of aligning Irish Gothic with English Gothic to allow for a different evolution of tracery.

Thus far, no attempt has been made at an empirical study of the medieval tracery remains in Ireland, and no researcher has considered the influence of metrology or proportion, two concepts which are known to have been important to medieval architecture. Therefore, while a number of authors have proposed classification systems for Irish tracery, none has yet considered sufficient number of variables to make their results indisputable. None of these studies has examined tracery in three dimensions and few have considered any form of measurement. This is despite the obvious benefits of analysing in three dimensions objects which were crafted using three dimensional stereometrical masonry methods. The approaches used to examine tracery thus far have been entirely removed from technical considerations of the mason's craft in the middle ages: which design principles were used, in particular metrology and systems of proportion; how important were templates and drawings; what training did masons receive; did they travel or how were foreign influences imported; how was the industry organised; and how was tracery linked to the rest of the architectural process? Furthermore, only limited attention has been paid to the range of outside influences - human, political, economic and geographical - which might have impacted on masons and on their works. These are all elements which need to be examined.

1.4.2 Problems of chronology in Irish tracery

Although a number of styles of tracery were employed over a long period in medieval Ireland, the problem of chronology is particularly well explained by an examination of switchline tracery. Harold Leask dated the first occurrence of bar tracery in Ireland to an endowment in 1302 which enabled the friars of Castledermot Franciscan friary, county Kildare to insert a window with switchline tracery into the south transept of their church (Figure 1.10).[110]

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[110] H.G. Leask, *Irish Churches II*, p. 125.

Figure 1.10 South transept west window, Castledermot Franciscan friary

The form remained popular throughout the late medieval period with Susan Mannion reporting occurrences of the same switchline tracery forms from the early fourteenth to the early sixteenth centuries in the friaries of Connaught, albeit with variations in "the sub-arching, number of lights, spatial proportioning of the upper window and apical tracery modification". None of these elements were examined empirically, particularly the spatial proportions, and this will be examined in the following. Mannion also found that the adoption of newer and more elaborate styles in the friaries of Connaught was slow. However, she suggested that this was not the result of a lack of skill on the part of the mason, but rather a lack of funds available for building, and the preferred style of the mendicant friars due to their preference for austere designs.[111] The problem of a lack of funding is questionable because of the references to patronage quoted previously but preferences are still worthy of investigation. However, Roger Stalley agreed with the idea that continued use of older designs was not caused by unskilled masons, but rather, in this example at least, by stubborn or cash-strapped patrons, in his assessment of the seven lancet windows of the Franciscan friary in Kilkenny from 1321-3. He pointed out that even with this older design, the "tracery required very exact cutting of the stone and demanded considerable geometrical knowledge from the master mason at the design stage".[112]

Leask argued that some of the problems with progression in styles were caused by the near cessation of building activity in Ireland between the arrival of the plague in 1349

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[111] S. Mannion, ' Medieval Friaries of Connacht', p. 149.
[112] R. Stalley, *Architecture and Sculpture in Ireland 1150-1350*. Dublin: Gill and Macmillan, 1971, p.141.

and the middle of the fifteenth century.[113] Both Roger Stalley and Tom McNeill disagreed with this theory, suggesting that church building in the late fourteenth and early fifteenth centuries suffered rather from a slow down.[114] Mannion also disagreed with Leask and showed that building continued in Connaught from the thirteenth to sixteenth centuries without any significant gaps.[115]

A further problem in establishing chronology is caused in cases where simplistic tracery patterns, for example switchwork, were chosen when the size of a window was reduced, such as at Athenry Dominican friary, and Claregalway and Castledermot Franciscan friaries. While these changes may have been based on new fashions in tracery design, the cost of glazing may also have been a factor. Lawlor and Westropp described the purchase of 600 lb of glass between April, 1358, and 10 March, 1361 for glazing the windows of the chapel of Dublin Castle. The quantity of glass was so big that the authors assumed "that on this occasion the older glass was removed, and all the windows glazed with glass of better quality, perhaps coloured". Better quality, possibly coloured glass would be significantly more expensive than clear, perhaps making it necessary to reduce the amount required at a time when revenues were reducing in monasteries.[116] An English-based study by D.W. Crossley showed that in the sixteenth century window glass experienced significant price fluctuations between different decades and tended to be more expensive in locations where less glass was required.[117] Roger Stalley discussed the problem of the small subdivisions of Irish parishes and sees, and Susan Mannion demonstrated the high density of mendicant friaries in Connaught during the later middle ages; both reaching the conclusion that significant shortages of funds were probably experienced by religious communities, except in the case where reliable patronage was available.[118]

Thus the problem of chronology, particularly when based on stylistic comparison only, has been defined. When documents which help to date the insertion of windows exist this stylistic analysis can be supplemented, but for most Irish medieval sites this is

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[113] H.G. Leask, *Irish Churches II*, pp. 135-7.
[114] R. Stalley, 'Irish Gothic and English Fashion.' *The English in Medieval Ireland.* Ed. J. Lydon. Dublin, 1984. 65-86 and T.E. McNeill, 'Church Building in 14th Century Ireland and the 'Gaelic Revival'', *The Journal of Irish Archaeology*, 1985, 3, 61-4.
[115] S. Mannion, 'Medieval Friaries of Connacht', p. 147
[116] H.J. Lawlor and M.S.D. Westropp, 'The Chapel of Dublin Castle', *The Journal of the Royal Society of Antiquaries of Ireland*, 1923, 13 (1), 34-73, pp. 39-40.
[117] D.W. Crossley, 'The Performance of the Glass Industry in Sixteenth-Century England', *The Economic History Review*, 1972, 25 (3), 421-33, pp. 421-2. For example costs near Windsor were significantly cheaper than near Oxford.
[118] R. Stalley, *Cistercian Monasteries*, pp. 24-5 and S. Mannion, 'Medieval Friaries of Connacht', pp. 33-62.

not possible. Therefore, different analysis techniques, for instance, the as yet untried empirical approach, need to be considered.

1.6 Tracery in architectural studies outside Ireland

Tracery has also been examined in studies outside of Ireland and some of the approaches taken have produced results worthy of consideration for this research. In the following British and continental European investigations will be evaluated.

1.6.1 Britain

Although generally popularised by its use at Westminster Abbey Church in 1245, roughly a half-century before it is thought to have been adopted in Ireland, recent studies have suggested that England's first bar tracery was used for the west windows of Binham priory in Norfolk.[119] Many authors have considered tracery as an important historical determinant, but typically only through stylistic examinations. Early works by Edward Sharpe and Edmund Freeman, among others, relied entirely on stylistic comparisons of the tracery field designs.[120] The evaluations were typically based on un-scaled drawings, leading Sharpe to conclude that his work provided "a general synoptical view of the whole".[121] The potential of measurement was, therefore, not harnessed.

Interestingly in research which aimed to classify tracery, Sharpe concluded that "such is the variety of the pattern, that it is difficult to find two in the kingdom which exactly resemble each other", echoing the problems identified by Harold Leask in trying to align Irish designs with English ones.[122]

More modern studies of tracery include John Harvey's work on the Perpendicular Style from 1330 to 1485. However, similar to the previous investigations, this was essentially a visual comparison of windows of similar design and was rooted within a clearly defined period of time.[123] The significant development in this study was Harvey's ability to attribute particular designs and windows to named master masons, through the

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[119] E. Sharpe, *Decorated Treatise*, p. 13 and M. Thurlby, 'The West Front of Binham Priory, Norfolk, and the Beginnings of Bar Tracery in England.' *England in the thirteenth century: proceedings of the 1989 Harlaxton Symposium.* Ed. W.M. Ormrod. Stamford: Watkins, 1991. 155-65.
[120] E. Sharpe, *Decorated Treatise*; E. A. Freeman, *Essay.*
[121] E. Sharpe, *Decorated Treatise*, p. 111.
[122] E. Sharpe, *Decorated Treatise*, p. 111. Note the similarity with Leask's "precise agreement" comment – H.G. Leask, *Irish Churches III*, pp. 115-31.
[123] J. Harvey, *Perpendicular.*

use of supporting documentary evidence.[124] Not all of Harvey's attributions have received widespread agreement, as some of the evidence used could not be unequivocally accepted by historians working with the same sources. Even in the more reliable cases, this type of study was not possible for earlier English architectural work and is certainly not feasible in the Irish case, due to the lack of documentation detailing ecclesiastical building projects.

A slightly different approach was taken by Francis Bond since he described tracery from both aesthetic and functional points of view in a chapter on window construction.[125] He emphasised the structural value of tracery and was very critical of tracery that he judged not to appear structurally sufficient.[126] While this is another element that has not been examined in the Irish context, Bond's research was still based in stylistic comparison, rather than the use of any empirical system.

A number of other studies which concentrated on distinctive regions and the works of individual masons or schools of masonry within these locations have been undertaken in England. Many of these studies also relied on visual comparison of stylistic elements but benefited from the advantage of better supporting evidence than is typically available in Ireland from documentary sources.[127] One particularly successful investigation was Richard Fawcett's thesis on later Gothic architecture in Norfolk and his publications on groups of churches in Norfolk and by the architect of Great Walsingham.[128] In his research, Fawcett was able to identify the work of individual masons and trace the movement of architectural ideas by matching tracery patterns with documentary records.[129] His work showed that it is "in those details which required his particular technical expertise" that similarities could be found between buildings created by individual master masons.[130] He favoured the study of mouldings as a comparative

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[124] J. Harvey, *Perpendicular*, p. 25.

[125] F. Bond, *Gothic Architecture*, pp. 505-18.

[126] In one instance Bond describes the "attenuated, wiry tracery" used in the east window of Shottesbrooke church as unendurable. F. Bond, *Gothic Architecture*, p. 505.

[127] For example see Mary Markus's comparison of tracery at Brigham, Carlisle and York (M. Markus, 'The South Aisle and Chantry in the Parish Church of St Bridget, Brigham', *Architectural History*, 1996, 39, 19-35) and Paul Crossley's evaluation of similarities between the church at Kent and Henry III's Westminster Abbey (P. Crossley, 'The Nave of Stone Church in Kent', *Architectural History*, 2001, 44 (Essays in Architectural History Presented to John Newman), 195-211).

[128] R. Fawcett, 'Later Gothic architecture in Norfolk: an examination of the work of some individual architects in the fourteenth and fifteenth centuries', Ph.D. East Anglia, 1975 and Fawcett, 'Great Walsingham Churches'.

[129] D. O'Donovan, 'Building Butler', p. 244.

[130] R. Fawcett, 'Great Walsingham Churches', p. 278.

element rather than using tracery since the latter, as a very obvious decorative feature in any building, could be imitated by other masons with relative ease.[131]

However, unlike many other studies where the investigators stopped at the analysis of stylistic elements, Richard Fawcett added a comparison between the measured widths of each window. When the widths of similar windows at Great Walsingham, Beeston, Beetley, and Little Fransham were compared, they all measured between 57 and 58 inches, "suggesting that the same templates were employed".[132] The comparison of another three windows in this group with a different design also resulted in widths which varied by only one inch. These results were among the few occasions where Fawcett found that both style and measurements matched between a number of windows despite having taken measurements of several thousand windows. Thus, while tracery may have been easy to copy visually, Fawcett's results, although based on the measurement of only a single dimension, demonstrated the potential of an empirical approach to identifying windows which were produced using the same templates or by the same mason.

Moving north of the border to Scotland, important parallels can be drawn between medieval Scotland and Ireland. Due to the close proximity, both geographically and politically, of both countries to England, alterations in architectural influences occurred in alignment with political changes. For Ireland, this resulted in promotion of the Gothic style, first brought to Ireland by the Cistercians, and subsequently by the Anglo-Norman lords.[133] In Scotland, the period of influence of English designs diminished at the end of the thirteenth century as a result of the wars between the two nations. From the mid- to late-fourteenth century, Richard Fawcett suggested that it is likely that the patrons of Scottish architecture and their masons were well-acquainted with building developments in the Low Countries, which were considerably more advanced than those in France at the time due to the Anglo-French wars.[134]

The similarity between Ireland and Scotland also results from the type of buildings in which tracery occurs. Although Scottish cathedrals were neither as few, nor as small, as in Ireland, cathedral building was also more limited in Scotland than it was in England and continental Europe. In both Ireland and Scotland, most parish churches suffered from a

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[131] Fawcett provides evidence of the case at Walberswich church where the patron directly requested that the mason copy the pattern in use at Halesworth, indicating that tracery may not be solely the result of decision-making on the part of the mason (as had been suggested by Roisín Mullin in Ireland). R. Fawcett, 'Great Walsingham Churches', p. 280.

[132] R. Fawcett, 'Great Walsingham Churches', pp. 279-80.

[133] H.G. Leask, *Irish Churches II & II*; B. Kalkreuter, *School of the West*; S. Mannion, 'Medieval Friaries of Connacht' and R. Mullin, 'A regional study'.

[134] R. Fawcett, 'Late Gothic architecture in Scotland: Considerations on the influence of the Low Countries', *Proceedings of the Society of Antiquities of Scotland*, 1982, 112 (1982), 477-96 (hereafter 'Late Gothic Scotland').

similar deficiency of funds which would have resulted in simple buildings with limited decoration and, even for those medieval buildings where tracery had been installed, its survival rate is low.[135]

Most of Richard Fawcett's catalogue of Scottish tracery referred to windows at churches or monastic sites, although some secular buildings are also included.[136] Windows dating from as early as the second quarter of the twelfth century, until as late as the end of the middle ages were compared, although many were only examined using un-scaled schematic diagrams. Despite his reservations about the parallels between Scottish and English tracery, Fawcett created a typological classification that was primarily based on the chronological system established for English work by Sharpe and Freeman.[137] The catalogue also demonstrated that in Scotland some tracery designs continued in use throughout the medieval era.[138] It is strange that Richard Fawcett's Scottish work was based on entirely stylistic evaluations of tracery when he had already proven in Norfolk that the introduction of measurements could assist in interpretation. Certainly a measured study takes longer to complete, and is not an option if tracery has been destroyed, but its benefits have been demonstrated and need to become more mainstream through wider application as will be attempted in this research.

No study of British tracery has attempted to analyse the geometrical methods used by medieval masons. Fawcett, in particular, has suggested the use of templates but no examinations have been carried out into how the medieval principles of geometry, including the use of proportion, were exploited in tracery design and execution. Certainly the availability of better documentation has enabled British historians to supplement their stylistic considerations in that manner, but the evidence from the architectural objects themselves, which could prove important, has been widely ignored.

1.6.2 Continental Europe

In continental Europe, however, a number of historians have investigated the use of metrology and proportion in medieval window tracery through the application of an empirical approach.

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[135] R. Fawcett, 'Scottish Tracery'.
[136] R. Fawcett, 'Scottish Tracery'.
[137] E. Sharpe, *Decorated Treatise*; E. Sharpe, *Decorated Windows: A Series of Illustrations of the Window Tracery of the Decorated Style of Ecclesiastical Architecture, edited with descriptions*. London: J. van Voorst, 1849; and E.A. Freeman, *Essay*.
[138] R. Fawcett, 'Late Gothic Scotland', pp. 490-1.

In her study of the blind tracery of Narbonne Cathedral Vivian Paul investigated the use by medieval architects of both arithmetic elements - units of measurement - and proportional relationships.[139] The methodology involved the collection of a large sample of measurements of the plan of the building, as well as for details such as the mullions, plinths and bases of the blind tracery around the walls of the lower portion of the building. Paul commented on the difficulty of identifying the points on the object from which the mason took his measurements and the problem of identifying the original cuts when weather and use may have altered them.[140]

The former issue was overcome by using the major junctures and by looking for patterns of recurring dimensions. As regards tracery, the problem with using this study as a model for the research presented here is that the only specifics on measurement taken were for the blind tracery on the walls of the lower portion of the building; and these were never completed. From the evidence collected, it was possible to conclude that the mason used arithmetic for some elements of the process and geometry for others, but within the same set of designs. At Narbonne, the golden ratio was rarely used, but Paul found evidence of the use of root three, although no list of measured elements was provided, for the "bases of the clerestory mouldings, in the diameters of shaft sequences and, possibly, in the design of the window tracery of the clerestory windows".[141] While geometry was certainly the predominant method of setting out medieval architecture, at some point in the process arithmetic, in the form of a set measured value, had to be used. Starting from a position where accurate measurements were taken, Paul was able to identify key elements of the master mason's process, something which has yet to be attempted in Ireland.

Another more complex study which demonstrated the combined use of geometry and arithmetic was John James's study of the western rose window at Chartres Cathedral.[142] Using an architectural drawing produced during restoration work, James built a design that utilised the geometric elements of "a triangle, a square, a pentagon and hexagon, and a number of twelve and twenty-four pointed stars" and two units of measurement – "the Roman foot of 296mm" and "the *Ped Manualis* of 354mm, which is 6/5^{ths} of a Roman foot".[143] Although the extremely complex design might, at first, seem

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[139] V. Paul, 'Geometry Studies: The Blind Tracery in the Western Chapels of Narbonne Cathedral.' *Ad Quadratum: the Practical Application of Geometry in Medieval Architecture*. Ed. N.Y. Wu. Aldershot, England: Ashgate Publishing Ltd., 2002. 205-16 (hereafter 'Geometry Studies').
[140] V. Paul, 'Geometry Studies', p. 207.
[141] V. Paul, 'Geometry Studies', p. 212. The range of proportions important to medieval architecture will be discussed in the following.
[142] J. James, 'Medieval geometry: the Western Rose of Chartres Cathedral', *Architectural Association Quarterly AAQ*, 1973, 5 (2), 4-10 (hereafter 'Medieval Geometry').
[143] J. James, 'Medieval Geometry', p. 8.

unreasonable, Helen J. Dow's work on rose windows described how master masons of the Paris Basin competed to produce the most interesting designs. Furthermore, it has been suggested that these designs were imbued with symbolic and numerological meaning, making it possible that James' complicated design actually resulted from a clear plan by a particular master mason.[144] The Rayonnant style of tracery did not influence Irish works and the limited designs of rose windows, such as at Portumna Dominican friary and Rahan parish church, mean that such complexity is not found.

Although not strictly related to geometry, Richard Strobel's study of the tracery at Salem demonstrated the successful use of measured data collection in a somewhat different architectural historical context.[145] In order to assist in restoration works at Salem monastery church, photogrammetric surveys of a number of windows and their surrounding walls were carried out. The resultant three-dimensional models helped the restorers to identify previous conservation work that had been carried out in the 1800s, and facilitated the exaction of measurements of pieces that needed to be replaced. These measurements were confirmed by matching the existing designs with designs which could be set out using geometric methods, as suggested in the 1485 folio book of Hans Schuttermayer and the teaching book of Lorenz Lechler from 1516.[146] Thus, the measurements verified that the geometric process, recorded in a limited number of documents, was actually used for this particular piece of tracery design.

Although only a limited number of empirical examinations of tracery has been undertaken outside of Ireland, each has been successful in adding to our understanding of the design process for tracery and has provided us with more information about medieval architecture than could have been extracted using stylistic analysis alone.

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[144] H.J. Dow, The Rose-Window, *Journal of the Warburg and Courtauld Institutes*, 1957, 20 (3/4), 248-297.
[145] R. Strobel, Die Masswerkfenster der Klosterkirche Salem: Zur Erhaltung und Dokumentation von gotischem Masswerk, *Journal of Landesdenkmalpflege Baden-Wurttemberg*, 2003, 2, 160-167 (hereafter *Masswerkfenster*).
[146] R. Strobel, *Masswerkfenster*, p. 162. Schuttermayer is given as a goldsmith by James Bugslag in J. Bugslag, Antique models, architectural drafting and pictorial space: canopies in northern French stained glass 1200-1350, Ph.D. East Anglia, 1991.

1.7 Aims of the research

The preceding discussions have demonstrated that there are significant gaps in our understanding of Irish medieval tracery. The focus by researchers on stylistic classifications has resulted in a failure to effectively harness the potential of tracery to inform our wider knowledge of the medieval mason, his world, and his craft.

This research sets out to investigate Irish medieval tracery and its context in a new and holistic way. Through examination of medieval ecclesiastical tracery in a number of Irish regions an assessment will be made of whether empirical investigation can provide independent or supporting information on a range of issues as follows.

- Can an unbiased and viable methodology be developed for the empirical investigation of window tracery, particularly in relation to the use of metrology and proportion?
- What unit(s) of measurement was (were) used and what was its (their) origin?
- Which design principles were used in the execution of tracery; in particular, what system(s) of proportion were used?
- Was there a link between metrology and proportion?
- Can evidence be found for preferred metrology and/or proportions in particular regions or executed by particular 'schools' of masons?
- Can measured data assist in the dating of tracery?
- What level of standardisation was applied to medieval windows?
- Was metrology and/or proportion of windows influenced by the building in which they were found or the patrons who commissioned them?
- Did legal efforts to standardise linear measures impact on the medieval building industry?
- Can empirical evidence provide information on masons and their methods; particularly in relation to their design processes, their skill levels, and their mobility?

2 On Geometry and Proportion

The literature review in the last chapter demonstrated that the application of an entirely stylistic approach to the analysis of tracery design had significant shortcomings and that many gaps in our knowledge still remain. Therefore, this chapter will examine the documentary or written sources which could help improve our understanding of how medieval tracery was designed. It will then consider how historians in England and continental Europe have employed geometry and proportion in the physical investigation of buildings to solve architectural problems and to create a precedent for the work which follows in this study.

2.1 Documentary evidence

2.1.1 The medieval architect and his devices

Before detailing these craftsmen and their techniques it is first necessary to address some terminology and concepts. The terms medieval architect/master mason/designer have been used in different studies, sometimes referring to individuals carrying out the same roles.

Part of the problem with finding the correct nomenclature is, as noted by L. R. Shelby, that: "no single definition of this role will suffice, for the duties of the master mason varied from one project to the next, while on some projects he was responsible for filling several offices simultaneously." Shelby identified four typical areas of activity for holders of this office: "as architect of the building, as administrative official of the building fabric, as building contractor, and finally, as technical supervisor of construction".[1] The term 'architect' is particularly problematic because of its continued usage for an individual who carries out a different set of tasks in a modern building scenario.[2] John Harvey identified L.F. Salzman's definition of an architect as "probably the best definition of the term". Salzman characterized an architect as someone "who is capable of envisaging a building, complete and in detail, before one stone is laid upon another and is also capable of so conveying his vision to the actual builders that they are able to translate it into actual reality".[3]

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[1] L.R. Shelby, 'The Role of the Master Mason in Mediaeval English Building', *Speculum,* 1964, 39 (3), 387-403, pp. 387-8.

[2] J. Harvey, *The Mediaeval Architect.* London, England: Wayland Ltd, 1972, p. 10 (hereafter *Mediaeval Architect*).

[3] L.F. Salzman, *Building in England down to 1540: A Documentary History.* Oxford: Oxford University Press, 1952, pp. 4-5 (hereafter *Building in England*).

The term 'master mason' has often been preferred to 'architect', partly to avoid the ambiguity caused by the modern term and partly to demonstrate a link with the masons who carried out the building works. The link, in the case of small-scale works, could be very real and relate to the progression of an individual from rough hewing, through carving, to designing. However, for large-scale works such as the great cathedrals, the master mason was a very distinctive individual with an entirely different education and geometrical knowledge to that of the average mason.[4] His separation from the hands-on roles of the rest of the masons is exemplified by a contemporary complaint from the preacher Nicholas de Baird: "The masters of the masons, carrying a baguette [measuring rod] and gloves, ordered others to 'cut it there for me', and worked not at all, although they received a larger payment; it is this way with many prelates."[5]

The term designer is sometimes used more specifically that the other two terms; typically in reference to architectural detailing such as tracery, capitals, bases, and other ornamentation. This term will be used most often in this study because no documentary evidence exists to support the idea that Irish masons fulfilled the other identified roles of a medieval architect. As, previously indicated, the medieval building industry in Ireland was very different to that in England and continental Europe meaning that the structures which supported individuals in the role of master mason were generally absent in all but a few cathedral buildings.

One final note on the terminology used is that when a designer's name is not known then he is typically referred to as the master of the works and this is sometimes identified with a particular master, such as the Ballintober Master.[6]

Medieval understanding of geometry

The metrology and proportion to be examined in this study are intrinsically linked with the medieval term 'geometry'. Geometry, as it was defined in the middle ages, was appreciably different from the modern understanding of the term. Two ideas of geometry appear in the twelfth century – theoretical and practical – and the following passage from Hugh of St. Victor explains the difference:

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[4] L.R. Shelby, 'The Education of the Medieval English Master Mason', *Medieval Studies,* 1970, 32, 1-26 and L.R. Shelby, 'The Geometrical Knowledge of Mediaeval Master Masons', *Speculum,* 1972, 47, 395-421 (hereafter 'Geometrical Knowledge').
[5] J. Gimpel, *The Cathedral Builders*, Trans. C.F. Barnes. Evergreen Profile Book. no. 21. London: Evergreen Books, 1961, p. 94.
[6] P. Harbison, 'The 'Ballintober Master' and a Date for the Clonfert Cathedral Chancel', *Journal of the Galway Archaeological and Historical Society,* 1976, 35, 96-9.

"The entire discipline of geometry is either theoretical, that is, speculative, or practical, that is active. The theoretical is that which investigates spaces and distances of rational dimensions only by speculative reasoning; the practical is that which is done by means of certain instruments, and which makes judgements by proportionally joining together one thing with another."[7]

These ideas relate to an important classical and medieval concept, that of the classification of the sciences. One important work in this respect is Domingo Gundisalvo's *De divisione philosophiae* from *c*.1150, which, although mainly a translation of the works of other authors, is nonetheless an important indicator of the transferral of the Arabic pattern of distinction of the sciences to the Latin West.[8] As with many contemporary works Grundisalvo's writings sought to link the sciences to knowledge that was transferred from God but also, and more importantly for this context, made a clear separation between the philosophy or theory, and the practical knowledge "or understanding of what ought to be done or executed".[9] Grundisalvo promoted "the science of devices (*de ingeniis*)" as important and within this "the instruments used by stone masons which measure bodies".[10] The treatise also included examples of practical geometry in "surveying, carpentry, iron-working, masonry and the instruments used in these crafts".[11]

In studying the design ideals of masons and master masons both the theoretical and the practical need to be considered; however, at the level of practice of most banker masons, it was practical geometry that was most useful and, indeed, essential.[12] Without simple methods and rules-of-thumb, the lofty designs of master masons and their patrons would not have been achieved.

We also know that knowledge of geometry was not optional but rather essential for building design, as was demonstrated by a section of the annals of Milan Cathedral which

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[7] R. Baron, ed. *Hugonis de Sancto Vicote opera propaedevtica: Practica geometriae, De grammatical, Epitome Dindimi in philosophiam.* Vol. 16. Notre Dame, 1966: "…*omnis geometrica disciplina aut theorica est, id est speculatiua, aut practica, id est actiua. Theorica siquidem est que spacia et interualla dimensionum rationabilium sola rationis speculatione uestigat, practica uero est que quibusdam instrumentis agitur et ex aliis alia proportionaliter coniciendo diiudicat.*" Quoted in full in L.R. Shelby, 'Geometrical Knowledge', p. 401.

[8] E. Whitney, 'Paradise Restored. The Mechanical Arts from Antiquity through the Thirteenth Century', *Transactions of the American Philosophical Society,* 1990, 80 (1), 1-169, pp. 132-134 (hereafter 'Paradise Restored').

[9] E. Whitney, 'Paradise Restored', p. 133.

[10] D. Grundisalvo, *De divisione philosophiae.* Beiträge zur Geschichte der Philosophie des Mittelalters. Ed. L. Baur. Munster: Der Aschendorffschen Buchhandlung, 1903, pp. 112-24 (hereafter *De divisione philosophiae*).

[11] D. Grundisalvo, *De divisione philosophiae*, pp. 103-12.

[12] Banker masons were typically those who worked at a bench or bank in the masons' lodge preparing the cut stone for a building.

dealt with a conference called in 1400 to consider ongoing design problems, particularly the decision of whether to design *ad quadratum* or *ad triangulum*.[13] The French architect Jean Mignot is paraphrased as saying: "technical proficiency in building is worthless if the higher geometrical principles are not employed".[14] For the master mason of the middle ages geometry represented many of the concepts which in modern times would be referred to as structural engineering. Geometry was the science of its day and without it, as attested by Jean Mignot, the architect will fail.[15]

One of the important concepts to grasp when trying to understand the practical forms of geometrical design in the middle ages is, as perfectly phrased by Lon R. Shelby, that although the methods were "certainly prescriptive" they were "not rigidly restrictive".[16] And it was this very flexibility within defined forms that allowed masons to achieve both the success and the variety that we can still observe today. The structured elements of the mason's tradition ensured, in as much as was possible, that building was successful; although a significant number of failures did occur, including Beauvais cathedral.[17] The flexibility of the rules however, allowed masons to display their virtuosity and skill. In Shelby's work on the geometrical knowledge of master masons he concluded that there were no "universal laws" of medieval geometry but rather that there were an almost infinite number of "particular procedures used by particular master masons at particular times and places"[18]. However, attempting to first define and then trace the development of these "particular procedures" and the choices made in given locations at specified times may provide us with tools for furthering our understanding the masons' craft.

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[13] *Ad quadratum*: by using square modules; *ad triangulum*: using triangles as the base forms.
[14] J.S. Ackerman, '"Ars Sine Scientia Nihil Est" Gothic Theory of Architecture at the Cathedral of Milan', *The Art Bulletin,* 1949, 31 (2), 84-111 (hereafter 'Gothic Theory') quoting from *Annali della Fabbrica del Duomo di Milano* (Milan, 1877-85), esp. I, pp. 68 ff. and 209 f.
[15] O. Von Simson, 'The Gothic Cathedral: Design and Meaning', *The Journal of the American Society of Architectural Historians,* 1952, 11 (3), 6-16, pp. 9-10 (hereafter 'Design and Meaning').
[16] L.R. Shelby, 'Geometrical Knowledge', p. 420. The phrase was used in his description of the design of medieval templates.
[17] M.I. Wolfe and R. Mark, 'The Collapse of the Vaults of Beauvais Cathedral in 1284', *Speculum,* 1976, 51 (3), 462-76. Beauvais only lasted ~60 years.
[18] L.R. Shelby, 'Geometrical Knowledge', p. 421.

Systems of proportion & geometry

Architectural proportion was not an invention of the medieval period, having been vitally important, in combination with the concept of symmetry, to classical builders.[19] As for their medieval successors, the role of proportion was not only aesthetic but also structural. In the case of small-scale building, the goal of using geometry was to ensure simplicity in execution with reliability assured through repeated successful use. There was, of course, also the issue of adherence to God's plan to consider and the influence of religious writings must be acknowledged.

Simple proportions such as 1:2 were prized in some medieval architecture. Much has been made of the considerable influence that St. Augustine's teachings on the perfect ratio, as representative of Christian harmony and reconciliation, had on St. Bernard and the buildings of the Cistercian order. The idea of a Bernardine plan was first suggested in 1953 by Karl Heinz Esser and taken up in an international survey by Hanno Hahn, proposed a system of two squares where the sides were of the ratio 3:4, before becoming an accepted conclusion.[20] Otto von Simpson, for instance, found that these principles applied to the elevation of Fontenay (1130-47) and the proportions of its ground plan, as well as measurements within the side aisle bays.[21]

Both Hahn and von Simpson's work have been subjected to re-evaluation in recent years and many of the general patterns that they observed have been reconsidered, partly because of the use of small-scale plans.[22] Roger Stalley, for instance, queried these ideas both in relation to St. Bernard's level of interest in and influence over architectural elements in the Cistercian order, and in the context of Irish Cistercian houses. Stalley pointed out that despite a prodigious literary output by Bernard "he never formulated anything that could be described as an artistic theory of his own" and his almost contemporary biographers made "few if any architectural claims for him" even though it was commonplace in the middle ages for just such details to be emphasised. In the context of the Irish Cistercian movement, the main evidence against the role of Bernard is the

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[19] This is verified by noting that in Vitruvius' Ten Books on Architecture books III, IV and VI contain specific chapters on proportion; two on columns and one on the rooms of a house: Vitruvius, *The Ten Books on Architecture*, Trans. M.H. Morgan. 1st ed. Mineola, New York: Dover Publications, 1960.

[20] K.H. Esser, 'Über den Kirchenbau des Hl. Bernard von Clairvaux', *Archiv für Mittlerheinische Kirchengeschichte,* 1953, V, 195-222; K.H. Esser, 'Les fouilles à Himmerod et le Plan Bernardin', *MélangesSB,* 1953, 311-5; and H. Hahn, *Die Frühe Kirchenbaukunst der Zisterzienser.* Berlin, Germany: Gebr. Mann Verlag GmbH., 1957, p. 20 (hereafter *Kirchenbaukunst*): "Dieses regelmäßige Grundrißschema übernahmen die Zisterzienser von den Benediktinern".

[21] O. Von Simson, 'Design and Meaning', pp. 13-4.

[22] R. Stalley, *The Cistercian Monasteries of Ireland.* London & New Haven: Yale University Press, 1987, p. 69 (hereafter *Cistercian Monasteries*).

variety in plan of the early Irish houses of Mellifont and Baltinglass, despite Bernard and St. Malachy's personal interest in the sites. Only after 1160 did dutiful copying 'of the Fontenay model begin.[23]

However, in the fifteenth century another movement towards the perfect ratio occurred as exemplified by the architecture of Alberti who preferred "the simple relations of one to one, one to two, one to three, two to three, three to four, etc.".[24] The relationship between music and medieval architecture was widely acknowledged as evidenced by Mark A. Reynolds in a range of buildings found to employ the following musical ratios: 1:1 (Square), 1:2 (Double Square), 2:3 (Major Fifth), 3:4 (Major Fourth), 3:5 (Major Sixth), 5:8 (Minor Sixth), 4:5 (Major Second), 8:9 (The Tone).[25]

Continuing with the simplest methods of geometric design, François Bucher also identified a common theme in Gothic design which continued from Gothic's conception at St. Denis to the sixteenth-century, that of 'modular geometric progression' and its application to plans and elevations.[26] Although plans were used throughout Europe as discussed later, they were not applied to dimensioning or scaling from, due to the unreliability of the parchment medium. Rather they included a basic module from which all other objects could be scaled using multiplication or subdivision.[27] The standard module would be made available on site or in the masons' lodge, and from this unit all setting out and design could be accomplished. It is for this reason that irrational numbers can so frequently be obtained when measuring distances set out in this way, because they were easily achieved through the use of practical geometry, such as with a rope, rather than through the use of arithmetic.[28]

The use of square modules was included in Villard de Honnecourt's portfolio (folio 14v) with a slightly derisory comment about the design of a Cistercian church 'from

[23] R. Stalley, 'Saint Bernard, his Views on Architecture and the Irish Dimension', *Arte medievale,* 1995, II serie, Anno VIII, 2 (1), 13-20.

[24] R. Wittkower, 'Alberti's Approach to Antiquity in Architecture', *Journal of the Warburg & Courtauld Institutes,* 1941, 4 (1/2), 1-18, p. 10.

[25] M. Reynolds, 'The Geometer's Angle: An Introduction to the Art and Science of Geometric Analysis', *Nexus Network Journal,* 2001, 3 (1), 113-21, pp. 118-9 (hereafter 'Geometric Analysis).

[26] F. Bucher, 'Design in Gothic Architecture: A Preliminary Assessment', *The Journal of the Society of Architectural Historians,* 1968, 27 (1), 49-71, p. 51 (hereafter 'Gothic Design').

[27] See, for instance the plan of St. Gall where the basic module was 40 ft with smaller units of 20, 10, 5 and 2.5 produced by sequential halving. L. Price, *The Plan of St. Gall in Brief, based on the work by Walter Horn and Ernest Born.* Berkeley: University of California Press, 1982 (hereafter *Plan of St. Gall*).

[28] F. Bucher, 'Gothic Design'.

squares' (Figure 2.1).[29] The use of modularity was a widespread concept in medieval Europe and it was not restricted to architectural design.[30]
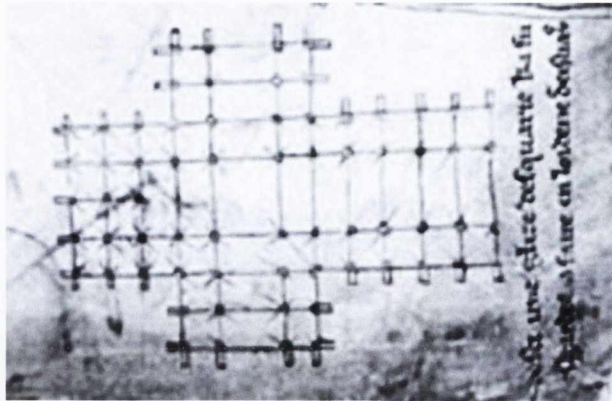
Figure 2.1 Villard de Honnecourt's portfolio, folio 14v: Cistercian church by squares

Modules based on squares were most suited to relatively small sized squares which were repeated to produce the particular layout designed by the master mason. In order to create large layouts from fewer steps methods of converting squares to rectangles were used. Kenneth Conant has presented a set of square to rectangle-based layouts, with Vitruvian influence, as a result of his studies of the various monasteries at Cluny and an evaluation of contemporary and earlier, Roman, buildings (Figure 2.2).[31] While Conant's application of particular methods to specific buildings may have been revised following subsequent re-evaluation of plans by historians the square-to-rectangle conversion methods retain their validity.

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[29] V. de Honnecourt, Sketchbook. MS. 19093. Bibliothèque Nationale Collection, Paris. Comment described in F. Bucher, 'Medieval Architectural Design Methods 800-1560', *Gesta*, 1972, 11 (2), 37-51, p. 38 (hereafter 'Design Methods').

[30] Stephen Birkett and William Jurgenson have demonstrated that a similar methodology was applied to instrument design in the middle ages: S. Birkett and W. Jurgenson, 'Why Didn't Historical Makers Need Drawings? Part I - Practical Geometry and Proportion', *The Galpin Society Journal*, 2001, 54, 242-84 and 'Part II: Modular Dimensions and the Builder's Werkzoll', 2002, 55, 183-239. This concept was expanded by Grant O'Brien, who, knowing that the design of Italian medieval stringed instruments was also based on modules, used this information to derive the local unit of measurement and, thus, draw conclusions about the origin of particular instruments and, in some cases, suggest the identity of the maker: G. O'Brien, 'The use of simple geometry and the local unit of measurement in the design of Italian stringed keyboard instruments: an aid to attribution and to organological analysis', *The Galpin Society Journal*, 1999, 52, 108-71.

[31] K.J. Conant, 'The after-Life of Vitruvius in the Middle Ages', *The Journal of the Society of Architectural Historians*, 1968, 27 (1), 33-8.
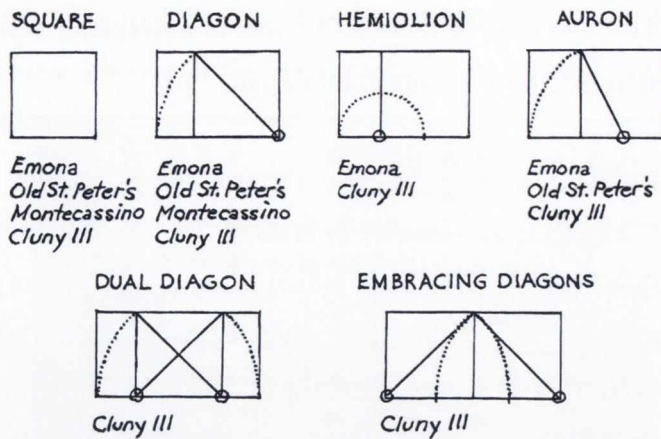
Figure 2.2 Kenneth Conant's geometrical constructions in plans which appear to show Vitruvian influence

The simplest of these conversions, the Diagon, is also known as the $1:\sqrt{2}$ ratio and Eric Fernie described it as being "overwhelmingly more popular than any other in the designing of buildings".[32] There are an infinite number of root ratios, but only a few were commonly used by medieval architects and some of these, with their arithmetic values, are as follows: $\sqrt{2} = 1.4142... : 1$; $\sqrt{3} = 1.732... : 1$; $\sqrt{4} = 2$; $\sqrt{5} = 2.236... : 1$; $\sqrt{9} = 3$; $\sqrt{16} = 4$.[33] As the list clearly shows, only in the case of a side of length equal to a prime number is the arithmetic value a whole number. It is, therefore, unlikely that these distances could have been derived using any other means of design or setting out than the use of a diagonal of a square or rectangle as demonstrated in Figure 2.3.
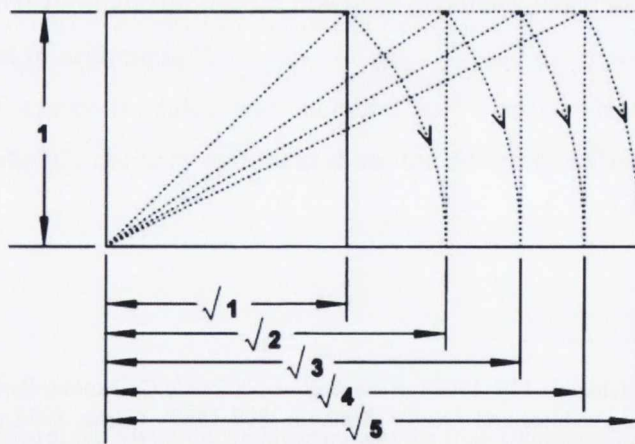
Figure 2.3 Geometric construction of root proportional ratios from successive rectangles starting with a unit square rectangle

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[32] E. Fernie, 'A Beginner's Guide to the Study of Architectural Proportions and Systems of Length.' *Medieval Architecture & its Intellectual Context: Studies in Honour of Peter Kidson.* Eds. E. Fernie and P. Crossley. London, England: The Hambledon Press, 1990. 229-37, p. 230 (hereafter 'A Beginner's Guide').
[33] M. Reynolds, 'Geometric Analysis', pp. 118-9.

One particular use of the $1:\sqrt{2}$ was at Norwich cathedral where the mason implemented the ratio throughout every element of the structure; the ground plan of the church, the layout of the piers and the relationship between the position of the church and the bishop's palace. That such consistency could be achieved was the result of designing on an empty site and the singular vision of the master mason. It is not necessarily possible to explain why a 'designer' would choose to use $1:\sqrt{2}$ except that it ruled out the need for the use of specific measured units and that it enabled the creation of "geometrical unity in complexity".[34] The $1:\sqrt{2}$ ratio is also known to have been a common denominator between English and French architecture since William of Sens, the Frenchman brought to Canterbury to rebuild the cathedral, implemented this ratio through the use of the 29:41 ratio, a multiplication of the original.[35]

This particular ratio was also used in medieval Ireland where it was implemented, at least approximately, at many Irish Cistercian sites.[36] It was also found in many friaries in Connaught and at Muckross Franciscan Friary where "remote in the mountains of Kerry, the friars of Muckross lived on the fringes of Europe, but their builders, at least, appear to have known something about the secrets of Gothic design".[37] At Muckross, Roger Stalley was able to demonstrate the use of the $1:\sqrt{2}$ layout of the cloister garden, its garth and the adjoining church. The elements of variability in the plan were the result of switching between the use of internal and external wall faces as well as the poor quality materials with which some of the elements were constructed. However, the total deviation was less than 1%.[38] The use of $1:\sqrt{2}$ was also adopted at a range of Irish parish churches as previously described.[39]

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[34] E. Fernie, 'The Ground Plan of Norwich Cathedral & the Square Root of Two', *Journal of the British Archaeological Association,* 1976, 129, 77-86 (hereafter 'Norwich Cathedral Root Two').

[35] P. Kidson, 'Gervase, Becket, and William of Sens', *Speculum,* 1993, 68 (4), 969-91, pp. 983-4.

[36] H. Hahn, *Kirchenbaukunst*; H.G. Leask, *Irish Churches & Monastic Buildings.* Vol. II. Dundalk, Ireland: Dundalgan Press Ltd., 1960. 3rd, pp. 2-3; R. Stalley, *Cistercian Monasteries* and R. Stalley, 'Irish Gothic and English Fashion.' *The English in Medieval Ireland.* Ed. J. Lydon. Dublin, 1984. 65-86.

[37] R. Stalley, 'Gaelic Friars & Gothic Design.' *Medieval Architecture & its Intellectual Context: Studies in Honour of Peter Kidson.* Eds. E. Fernie and P. Crossley. London, England: The Hambledon Press, 1990. 191-202, p. 202 (hereafter 'Gaelic Friars'); for Connaught examples see S. Mannion, 'A study of the physical remains of the medieval friaries of Connacht', Ph.D. Queen's University, Belfast, 1997 (hereafter 'Medieval friaries of Connacht').

[38] R. Stalley, 'Gaelic Friars', pp. 199-201.

[39] M. O'Neill, 'The Medieval Parish Churches in County Meath', *Journal of the Royal Society of Antiquaries of Ireland,* 2002, 132, 1-56 (hereafter 'Parish Churches Meath'); M. O'Neill, 'The Medieval Parish Churches of Kildare.' *Kildare: History and Society.* Eds. W. Nolan and T. McGrath. Dublin: Geography Publications, 2006. 153-93 (hereafter 'Parish Churches Kildare'); M. Ní Mharcaigh, 'The Medieval Churches of South-West County Dublin', *Proceedings of the Royal Irish Academy,* 1997, 96 (Sect. C), 245-96 (hereafter 'Medieval Churches'); E. FitzPatrick and C. O'Brien, *The Medieval Churches of County Offaly*: Government of Ireland, 1998 (hereafter *Medieval Churches*).

Some authors suggested that grids and squares seem to have been of much more importance for laying out ground plans and some elevations than for architectural detailing, such as tracery, as shown by an examination of tracing houses.[40] Arnold Pacey has shown that at the tracing houses of York and Wells cathedrals "it is hard to pick out more than one or two deliberately-drawn squares" (Figure 2.4).[41] This might raise the question of why consider such methods; the reason is that so little is known of Irish masonic practice because of the absence of tracing houses and engravings, as discussed below, that all possible methods must be considered.
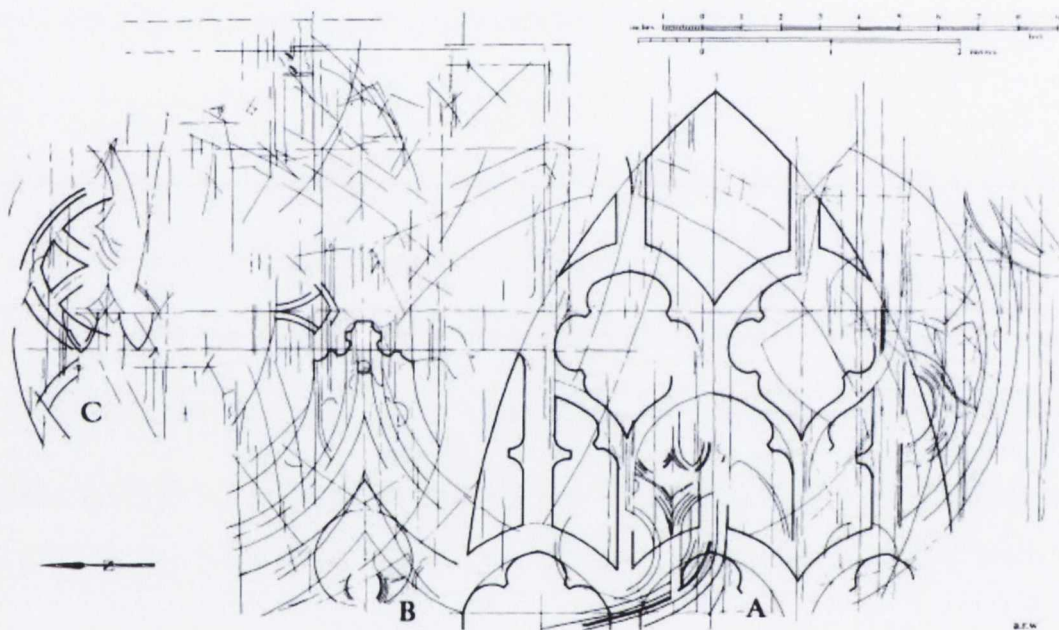
Figure 2.4 York Tracing Floor (after Harvey)

The final significant group of ratios relevant to medieval architecture are those based on the Golden Section, Divine Proportion or Phi, shown in Figure 2.2 as the 'auron'. The total length of a line divided in two parts is to the longer part as the longer part is to the shorter part (Figure 2.5). Its numerical value is 1.618, or 0.618 in reciprocal, and it is frequently referred to in a range of sometimes fantastical literature as one of the great 'secrets' of the master masons.[42]

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[40] F. Bucher, 'Design Methods', pp. 38-9.

[41] A. Pacey, *Medieval architectural drawing: English craftsmen's methods and their later persistence (c.1200-1700)*. Stroud: Tempus, 2007, p. 59 (hereafter *Medieval architectural drawing*).

[42] K. Elam, *Geometry of Design*. 1st ed. New York, USA: Princeton Architectural Press, 2001 makes a detailed discussion of the golden ratio in nature and particularly when applied to 'good design' in paintings, chairs, cars and promotional posters.

$$a \qquad b$$

$$a+b$$

$a+b$ is to a as a is to b
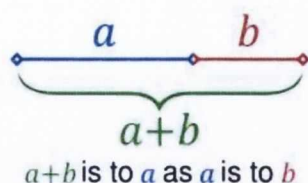
Figure 2.5 The golden ratio

While the golden ratio was certainly in use during the medieval period, the attachment of the adjective "golden" only happened during the Renaissance.[43] One of the reasons frequently given for the use of the golden ratio is that people have a natural tendency towards it when presented with a choice of shapes of rectangle, however this suggestion has been refuted by modern psychological testing of very large groups of people.[44]

As this review has shown, very many potential proportional systems exist and most of those mentioned here have been demonstrated to have been used in architecture at some point in the middle ages. However, in studying any one particular building Eric Fernie advised that "the investigator should restrict the exercise to one or two such systems at a time" warning that "authors who pick and choose between a myriad of proportions to explain the dimensions of any particular structure may dazzle by their footwork, but they convince in inverse ratio to the complexity in which they indulge".[45]

Medieval concepts of copying

Since one of the goals of this study is to try to see if it is possible to identify tracery or features designed by the same mason at different locations it is important to explain the meaning of the term 'copy' from a medieval perspective. This is particularly necessary because documentary evidence has often been found describing or prescribing particular designs as being 'after', 'like' or 'from' another location.

The problem of the medieval sense of copying has been considered in detail by Richard Krautheimer, although he focussed more on building plans than on architectural

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[43] D.E. Smith, 'Golden Section', *Archiv der Mathematik und Physik*, 1844, 4, 15-22 in G. Markowsky, 'Misconceptions about the Golden Ratio', *The College Mathematics Journal*, 1992, 23 (1), 2-19 (hereafter 'Misconceptions').

[44] This belief was first promoted in the work of Gustav Fechner who conducted experiments on preference in the 1860's where individuals were presented with a choice of 10 rectangles and a significant proportion chose the golden section rectangle. G.T. Fechner, *Vorschule der Aesthetik*. Leipzig, 1876. However, George Markowsky countered this idea in a modern study where significantly more people were queried and where many more choices of rectangle were presented. His results showed that there is little evidence for a preference for the golden ratio and that "the only reasonable claim would be that people prefer ratios in a certain range": G. Markowsky, 'Misconceptions', pp. 14-5.

[45] E. Fernie, 'A Beginner's Guide', p. 230.

details. Using many examples, particularly copies of fundamentally important buildings such as the Holy Sepulchre in Jerusalem and St. Peter's in Rome, Krautheimer found that:

> "Often when two buildings are compared with one another in mediaeval writings the modern reader may wonder how the author came to see any resemblance between the two."[46]

After discussions of how buildings of different shapes with very different details, such as apses, ambulatories, and vaulting, could be described as similar Krautheimer concluded that: "an approximate similarity of the geometrical pattern evidently satisfied the minds of mediaeval men as to the identity of two forms." [47]

On the subject of specific details L.F. Salzman cited a contract from 1425 between citizens of Walberswich Suffolk and two masons which specified how the steeple of the church at Walberswich was to be copied from Dunstale but the door and a number of the windows were to be after Halesworth.[48] A later contract from 1487/8 for Helmingham Church, also in Suffolk, specified that the design of the tower should be "of knapped flint, like that at Framsden, with certain features copied from Brandeston tower" again demonstrating that multiple influences could often be forced on the mason by the patron and in a way that was contractually binding.[49] Documentary evidence has also shown that masons sometimes travelled to other locations in order to "make notes" for future work. James Ackerman cited the example of the Bolognese architect Antonio de Vicenzo travelling in 1390 to Milan cathedral during its construction to make notes for his future work at San Petronio.[50]

One Irish example of this practice of copying is recorded in the Close Rolls for thirteenth-century works prior to a proposed visit by Henry III to Dublin Castle. A new hall was to be created to measure "120 feet in length, and 80 feet in breadth, with sufficient windows and glass casements, in the style of the hall Canterbury". The request, which was sent directly by Henry from Bordeaux on the 23rd of April 1243, continues "They shall have made in the gable, beyond the dias, a round window, thirty feet in

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[46] R. Krautheimer, 'Introduction to an "Iconography of Mediaeval Architecture"', *Journal of the Warburg & Courtauld Institutes,* 1942, 5, 1-33, p. 2 (hereafter 'Iconography').

[47] R. Krautheimer, 'Iconography', p. 6.

[48] "A wyndowe of two dayes (lights) above the dore sewtly after the wyndowe of thre days of Halesworth, And fhre wyndowes ate nether Soler and eche wyndowe of two dayes, and foure wyndowes ate ouerer soler the wyndowe of thre dayes sewtly after Halesworth": L.F. Salzman, *Building in England*, pp. 499-500 quoting B. M. Add. Ch. 17634.

[49] L.F. Salzman, *Building in England*, pp. 547-9 quoting Bodleian Library, Tanner MS. 138, f. 87.

[50] J.S. Ackerman, *Gothic Theory*, p. 88.

circumference".[51] The level of detail in this example, particularly the inclusion of measurements, makes this particularly useful as an example of how specific patrons' requests for windows could be.

Drawings and pattern books

Some of our knowledge of medieval design methods has originated in examination of drawings on vellum, parchment, or similar which have survived until the modern era. One of the earliest such sources is the ninth-century Plan of St. Gall, which was shown by analysis in the 1960s and 1970s to have been designed with an entirely consistent use of a clearly definable scale, despite many later surviving drawings not serving the same function.[52] The later drawings tended to be more interested in modularity or geometric consistency, but Eric Fernie's investigations showed that the plan of St. Gall was able to fulfil this second function as well, since they plausibly demonstrated that the proportion 1:√2 was intended.[53] Further re-evaluation of, in particular, Horn and Born's work on the plan of St. Gall, showed that some of the calculations used in forming theories about the use of a forty-foot grid were not sufficiently precise or accurate.[54] Walter Sanderson also showed that the premise that the "square schematism" of the Plan of St. Gall represented a typical Carolingian method is flawed because comparable examples could not be found.[55]

François Bucher published on approximately 2,200 mostly continental European existing medieval plans, working drawings, designs and treatises providing evidence for the significant amount of material which must have been lost.[56] There is little doubt that drawings were in use on the continent from as early as the thirteenth century, known from

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[51] H.S. Sweetman, *Calendar of documents relating to Ireland, preserved in Her Majesty's Public Record Office, London.* Vol. 1. 5 vols. London: Longman: Trübner, 1875, p. 188 (hereafter *Calendar*), Close Rolls, Roll 9, p.1 m.13 and p. 389, Close Rolls, Roll 27, p.1 m.9. and J.T.S. Gilbert, *History of the Viceroys of Ireland; with notices of the Castle of Dublin and its chief occupants in former times.* Dublin, 1865, p. 514 (hereafter *Viceroys*).

[52] W. Horn and E. Born, *The Plan of St. Gall: a study of the architecture & economy of, & life in a paradigmatic Carolingian monastery.* 3 vols. Berkeley (California): University of California Press, 1979; W. Horn and E. Born, 'The "Dimensional Inconsistencies" of the Plan of Saint Gall and the Problem of the Scale of the Plan', *Art Bulletin,* 1966, 48, 285-308 (hereafter 'Saint Gall Inconsistencies') and for later, scale-inconsistent drawings P.J. Fergusson, *Architecture of Solitude: Cistercian Abbeys in Twelfth-Century England.* 1st ed. Princeton, New Jersey: Princeton University Press, 1984, p. 5.

[53] E. Fernie, 'The Proportions of the St. Gall Plan', *Art Bulletin,* 1978, 60 (4), 583-9.

[54] D. Parsons, 'Consistency and the St. Gallen Plan: A Review Article', *Archaeological Journal,* 1981, 138, 259-65.

[55] W. Sanderson, 'The Plan of St. Gall Reconsidered', *Speculum,* 1985, 60 (3), 615-32, pp. 626-9. Other revaluations of the plan's meaning have been provided by L. Nees, 'The Plan of St. Gall and the Theory of the Program of Carolingian Art', *Gesta,* 1986, 25 (1), 1-8 and 'Heaven on Earth: The Plan of St. Gall', *The Wilson Quarterly (1976-),* 1980, 4 (1), 171-9.

[56] L.R. Shelby, 'Mediaeval Masons' Templates', *Journal of the Society of Architectural Historians,* 1971, 30, 140-54, p. 141 (hereafter 'Templates').

examples such as the Reims Palimpsest (Figure 2.6), and throughout the fourteenth and fifteenth centuries where they acted as devices for articulating the plans of the master masons to their patrons.[57]
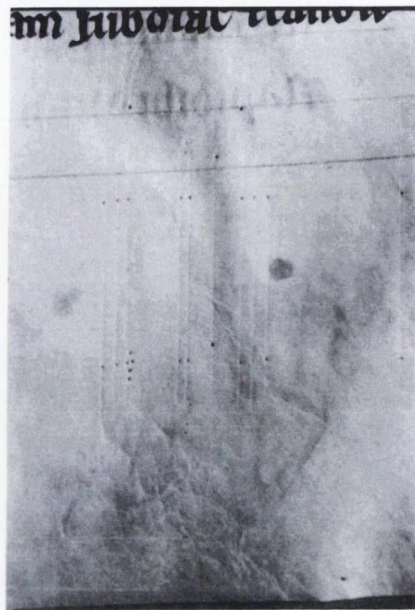
Figure 2.6 Detail from the Reims Palimpsest - lower buttress to the right of the right portal

Reims also served as the subject of some of the work included in possibly the most famous collection of medieval drawings, in the portfolio of Villard de Honnecourt from *c*.1220s or 1230s. This collection of 250 drawings on 33 parchments with extra comments by Master 2 from *c*.1250 is described by Carl F. Barnes as "sketches of things he found interesting" and debate has advanced between architectural historians about whether Villard was an interest amateur or actually a trained mason.[58] The purpose of much of the content in the portfolio is unknown but a certain amount of emphasis seems to have been

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[57] S. Murray, 'The Gothic Facade Drawings in the "Reims Palimpsest"', *Gesta,* 1978, 17 (2), 51-6 and R. Branner, 'Drawings from a Thirteenth-century Architect's Shop: The Reims Palimpsest', *Journal of the Society of Architectural Historians,* 1958, 17 (4 Part 1), 9 to 22. Further examples have been published by S.L. Sanabria, 'A Late Gothic Drawing of San Juan de los Reyes in Toledo at the Prado Museum in Madrid', *The Journal of the Society of Architectural Historians,* 1992, 51 (2), 161-73; J. Bureš, 'Der Regensburger Doppelturmplan', *Zeitschrift für Kunstgeschichte,* 1986, 49 (1), 1-28 and R. Branner, 'A Fifteenth-Century French Architectural Drawing at the Cloisters', *Metropolitan Museum Journal,* 1976, 11, 13-136. Models were also used but since these related to full buildings rather than details, they are not further considered here. The reader is referred to texts such as: M.S. Briggs, 'Architectural Models-I and II', *The Burlington Magazine for Connoisseurs,* 1929, 54 (313), 174-83 and 54 (314), 245-52; J. Bugslag, 'Antique models, architectural drafting and pictorial space: canopies in northern French stained glass 1200-1350', Ph.D. East Anglia, 1991 (hereafter 'Antique models') and M. Carpo, 'How Do You Imitate a Building That You Have Never Seen? Printed Images, Ancient Models, and Handmade Drawings in Renaissance Architectural Theory', *Zeitschrift für Kunstgeschichte,* 2001, 64 (2), 223-33.
[58] C.F. Barnes, 'Villard de Honnecourt.' *Macmillan Dictonary of Art.* Vol. 32. London: Macmillan, 1996. 569-71 and C.F. Barnes, 'Le Probleme de Villard de Honnecourt.' *Les batisseurs des cathedrales gothiques.* Ed. R. Recht. Strasbourg: Les Musees de la ville de Stasbourg, 1989. 209-23.

placed on "changes in constructional techniques".[59] However, although the portfolio contains details of tracery and templates these are not scaled drawings in the same sense as our modern understanding of architectural drawings.[60]

Drawings that are more indicative of medieval masons' methods include a fifteenth-century drawing now held in Vienna displaying the use of rotated squares for the design of a mullion (Figure 2.7). Similarly instructive drawings, particularly for the construction of spires and similar tall structures, are included Lorenz Lecher's *Unterweisung* for his son, Roriczer's *Büchlein von der Fialen Gerechtigkeit* and Schmuttermayer's *Fialenbüchlein* (Figure 2.8).[61]
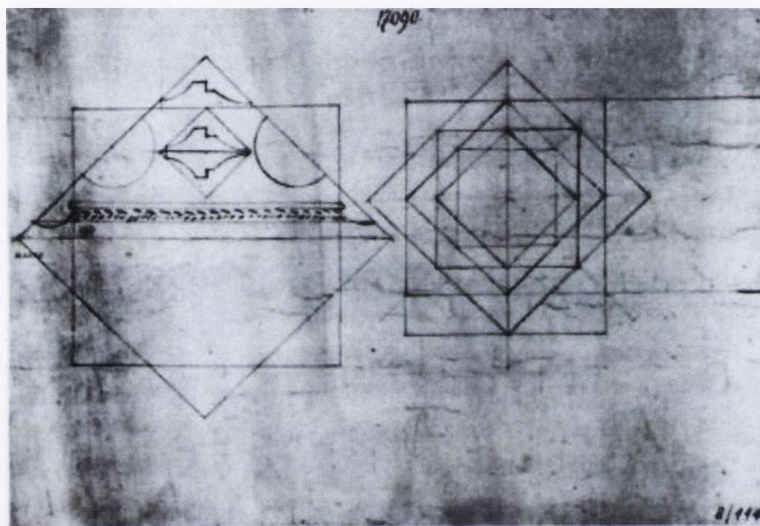
Figure 2.7 Sketch for a base, Vienna (ABK 17090)

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[59] W.W. Clark, 'Reims Cathedral in the Portfolio of Villard de Honnecourt.' *Villard's Legacy: Studies in medieval technology, science and art in memory of Jean Gimpel.* Ed. M.-T. Zenner. Aldershot, England: Ashgate Publishing Limited, 2004. 23-52, p. 34.

[60] J.S. Alexander, 'Villard de Honnecourt and Masons' Marks.' *Villard's Legacy: Studies in medieval technology, science and art in memory of Jean Gimpel.* Ed. M.-T. Zenner. Aldershot, England: Ashgate Publishing Limited, 2004. 53-69, pp. 58-61.

[61] L.R. Shelby, 'Geometrical Knowledge'.
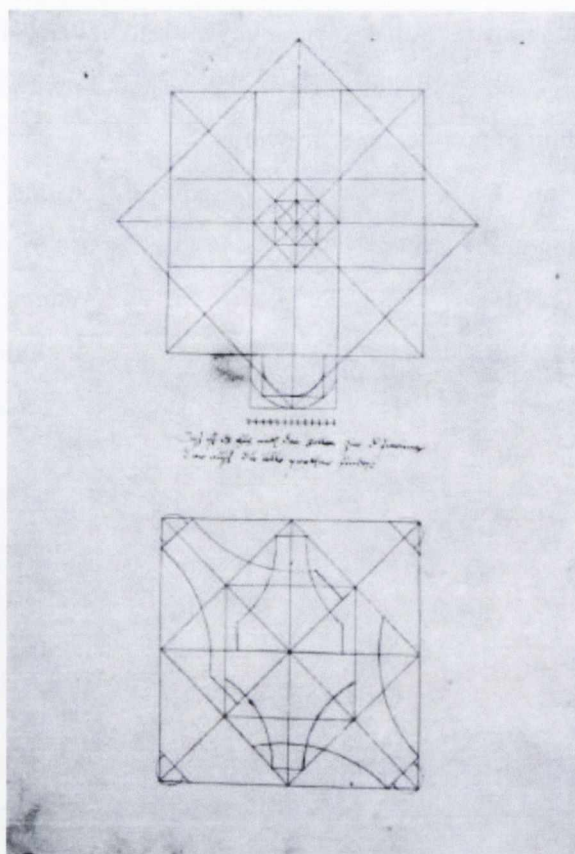
Figure 2.8 Geometrical construction of a template for a window mullion from Lecher's *Unterweisung* **(Cologne, Historisches Archiv, Handschrift Wf. 276°, fol. 42ᵛ)**

Richard Betts' work on the late medieval treatises of Francesco di Giorgio, which described geometrical methods of design for churches using a restricted number of "different function elements, geometrical forms, and proportions", demonstrated that, by the end of the fifteenth century, drawings had progressed from their limited function as a means of communication between patron and master mason, to also being used for the design of buildings.[62]

There is also evidence that drawings would have been circulated between masons' lodges and possibly to the ateliers of other craftsmen, such as glaziers. J. Bugslag suggested that, at least in Europe, this resulted in a more homogeneous design for a cathedral enabling the same designs to be reproduced at the appropriate scale in sculptural detail, such as on facades, in architectural details, such as tracery, and in the stained glass.[63]

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[62] R.J. Betts, 'Structural Innovation and Structural Design in Renaissance Architecture', *The Journal of the Society of Architectural Historians,* 1993, 52 (1), 5-25.

[63] J. Bugslag, 'Antique models' cited in M.M. Reeve, ed. *Reading Gothic architecture*. Vol. 1. Turnhout, Belgium: Brepols, 2008, pp. 65-7.

In England, although few plans survive, there is evidence of their use. Peter Fergusson translated part of a contract from 1374 between the abbot of Boxley Cistercian abbey and the master mason, Stephen Lomherst, which required the tracery and the windows, the columns and bases of the piers, and the doors of the new cloister to be "well and neatly cut, carved and polished according to the plans, measurements, moulds, and drawings then agreed between them".[64] This shows the full extent of the preliminary design that was required before contracts were signed.

When considering drawings as a medieval medium it is also important to note that these were sometimes grouped together to form so-called pattern books, as have been found for other artists such as book illustrators or wall painters.[65] In Germany at the end of the middle ages, the master mason Hans Böblinger produced a number of drawings of his father's work at the Frauenkirche in Esslingen and it is thought that these were planned for inclusion in a pattern book for distribution to other masons.[66]

In Ireland the idea of an architectural pattern book consisting of designs collected together for the reconstruction of Holycross Cistercian abbey has been suggested by Danielle O'Donovan. She suggested that after completion of the abbey these drawings were circulated, particularly in the Ormond region, resulting in significant numbers of copies of window tracery, in particular.[67] This suggestion will form the basis of some *a priori* sampling in the following

In Ireland, as yet, no surviving medieval architectural drawings/ pattern books have come to light. Although some elements of masonic practice in Ireland different from England and continental Europe, as have been discussed, it is still likely that Irish masons did use drawings. As suggested by Arnold Pacey in his review of English medieval architectural drawing, the lack of drawings on parchment does not indicate that drawings were not used, rather that the medium preferred by medieval masons related more to the materials at hand, such as plaster, boards or stone, suggesting that Irish designs were created as part of the next group of geometrical methods to be discussed.[68]

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[64] P.J. Fergusson, 'Notes on Two Cistercian Engraved Designs', *Speculum*, 1979, 54 (1), 1-17, p. 5 and L.F. Salzman, *Building in England*, pp. 448-50 quoting from Exchequer Kings Rolls Acts. 662, no. 46.

[65] D.J.A. Ross, 'A Late Twelfth-Century Artist's Pattern-Sheet', *Journal of the Warburg and Courtauld Institutes*, 1962, 25 (1/2), 119-28.

[66] F. Bucher, 'Design Methods '. Hans Böblingen's work is again considered in a later chapter.

[67] D. O'Donovan, 'Holycross and the Language of Irish Late Gothic.' *Limerick and South-West Ireland: Medieval Art and Architecture*. Ed. R. Stalley. Vol. 34. *British Archaeological Association (BAA) Conference Transaction Series*. Limerick, Ireland: British Archaeological Association, 2011 and D. O'Donovan, 'Building the Butler Lordship 1405–c. 1552', Ph.D. Trinity College, Dublin, 2007 (hereafter 'Building Butler').

[68] A. Pacey, *Medieval architectural drawing*, pp. 33-4.

Tracing houses and engravings

Designs for smaller features, such as windows and mouldings, would frequently be worked out through tracing or drawing the feature on an available surface, typically a flat floor or a wall. Drawings on walls were typically of smaller size and were useful for working out design ideas. However, for the production of templates, working on the floor, as is still frequent practice for carpenters, was more suitable (Figure 2.9).[69]
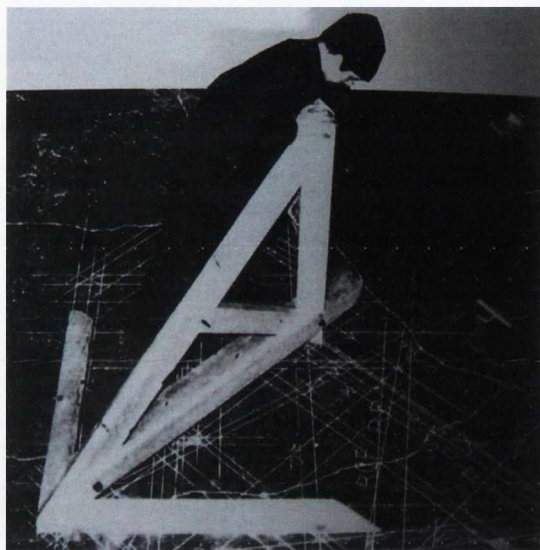
Figure 2.9 Modern use of tracings by a carpenter using a method similar to that used by medieval masons [70]

When represented at full-size these tracings enabled the designing mason to create templates for use by the banker masons. After shaping, the stone pieces could be checked against the full size engraving to ensure accuracy, particularly of the curves so essential to arches, vaults, and tracery. In a tracing house a temporary floor of fine plaster was typically laid down for this function, but many other examples exist where stone surfaces (Figure 2.10) or even beaten earth were used instead.[71] This practice was common across continental Europe and England, and physical or documentary evidence exists in a number of cases.[72]

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[69] A. Pacey, *Medieval architectural drawing*, p. 35 and p. 37.

[70] A. Erlande-Brandenburg, *The Cathedral Builders of the Middle Ages*. 5th ed. London, England: Thames & Hudson Ltd., 2002, p. 80.

[71] A. Pacey, *Medieval architectural drawing*, p.44. Types of tracing surface included wooden boards (indicated on remaining tracing surfaces by the sudden stop of linework indicating that the floor was covered in a board to be used as a template at this point); plaster which could have been created by mixing lime with sifted ashes, dung and clay; stone (French cathedrals, Byland Abbey & Gisborough Priory; reference to floor of paved stone at Ely cathedral); beaten earth and clay were sometimes used as well.

[72] For examples at Soisson cathedral see F. Bucher, 'A Rediscovered Tracing by Villard de Honnecourt', *The Art Bulletin*, 1977, 59 (3), 315-9. Further French examples of engravings have been found at Chartres Cathedral, Clermont cathedral, Clermont-Ferrand and Norte-Dame-en-Vaus at Châlons-sur-Marne: R. Branner, 'Villard de Honnecourt, Reims and the Origin of Gothic Architectural Drawing ', *Gazette des*
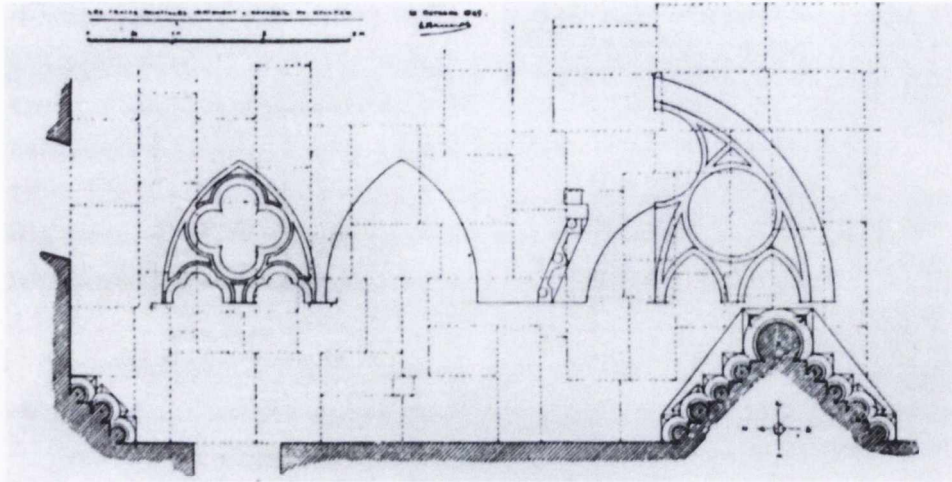
Figure 2.10 "Drawing of Engraving in Pavement of Tribune of North Tower" from Soissons, Cathedral of Notre Dame and SS, *c.*1250 from Barnes after Brunet[73]

In England the most widely known tracing houses are at York (Figure 2.4) and Wells cathedrals, over the chapter-house vestibule and above the north porch, respectively.[74] Other English examples of engravings include Roslin chapel in Scotland from *c.*1446 (Figure 2.11) and the Bishop's Eye window of the Angel Choir of Lincoln cathedral *c.*1255-80.[75] Shelby provided a description of how the engraving at Roslyn chapel was set out using compass and straight line (Figure 2.11 right): "First the draftsman (presumably a mason, perhaps the master mason) marked off the base line Al and struck the vertical axis KE. Then he seems to have marked off points D and F equidistantly respectively. From these two centers he struck arcs BM and HM to produce an arch close to what [Robert] Branner calls a fourth-point arch. But apparently the draftsman was dissatisfied with the height of this arch, so he began again by bisecting BE and HE to produce points C and G. From these he generated arcs BL and HL as the soffit and arcs NK and OK as the extrados of what Branner calls a third-point arch".

Beaux-Arts, 1963, 61 (6), 129-46; M.T. Davis, 'On the Drawing Board: Plans of the Clermont Cathedral Terrace.' *Ad Quadratum: the Practical Application of Geometry in Medieval Architecture.* Ed. N.Y. Wu. Aldershot, England: Ashgate Publishing Ltd., 2002. 183-204 (hereafter 'Drawing Board'); M.T. Davis, 'The Choir of the Cathedral of Clermont-Ferrand: The Beginning of Construction and the Work of Jean Deschamps', *The Journal of the Society of Architectural Historians,* 1981, 40 (3), 181-202, p. 197 and C. Bolgia, 'An Engraved Architectural Drawing at Santa Maria in Aracoeli, Rome', *The Journal of the American Society of Architectural Historians,* 2003, 62 (4), 436-47, pp. 436-7.
[73] C.F. Barnes, 'The Gothic Architectural Engravings in the Cathedral of Soissons', *Speculum,* 1972, 47 (1), 60-4, p. 61 and E. Burnet, 'Soissions Engraving', *Bulletin Monumental,* 1928, 94.
[74] S.H. Wander, 'The York Chapter House', *Gesta,* 1978, 17 (2), 41-9 and W.C. Leedy, 'Wells Cathedral and Sherborne Abbey: Workshop Connections in the Late Fifteenth Century', *Gesta,* 1977, 16 (1), 39-44.
[75] L.R. Shelby, 'Setting Out the Keystones of Pointed Arches: A Note on Medieval Baugeometrie', *Technology & Culture,* 1969, 10, 537-48 (hereafter 'Setting Out') and J.S. Alexander, 'Masons' marks and stone bonding.' *The Archaeology of Cathedrals.* Eds. T. Tatton-Brown and J. Munby. Vol. 42. Oxford: Oxford University Commercial Archaeological Monograph, 1996. 219-36, pp. 227-8.

Figure 2.11 Working drawings on the wall of the crypt at Roslyn Chapel, Scotland (left) and L.R. Shelby's schematic for the design process for the pointed arches (right)

Figure 2.12 Shelby's reworking of the Roslyn drawing with dimensions. Blue represents the mason's first attempt; red represents the soffit; pink represents the extrados

Shelby's reckoning was that the first attempt made by the mason was at what was called a Third-point arch (4 evenly-spaced marks on the baseline) according to fifteenth and sixteenth century texts.[76] The second attempt, which resulted in the soffit and extrados were Fourth-point arches (5 evenly-spaced marks on the baseline). This example demonstrates a geometrically-based method of shifting the centres of pointed along a baseline "to raise or lower the height of the arch to suit his fancy or his technical needs".[77] As the measurements in Figure 2.12 show, for the mason at Roslyn at least, the separation between the 4 points was not as precisely executed as the radii of curvature of the soffit arches.[78] The height to span ratio of each of the arches was as follows: attempt 1, 2:3; soffit, $1:\sqrt{2}$; and extrados, 2:3. Thus the relationship between arch height and span can be indicative of the use of geometric methods in their setting out. This information will be used to inform decisions on measurements made in this thesis.

While Shelby's sequence of steps may have been correct in relation to Roslyn, and he may have had some information about which marks appear to have been inscribed over others which he did not publish, I think that in many cases the first step would actually be the setting out BH, the gap into which the arch would be positioned.

While engravings may not have been used as general practice there is another possible reason why so few medieval examples have been found. Many engravings were made to on stones that were eventually used in the building fabric. An example from St. John's College, Cambridge from $c.1280$, which is thought to represent the east window of the chapel, although at small scale, only survived because it was reused in the wall of the building after its function as an engraving had been completed (Figure 2.13).[79]

[76] H. Saalman, 'Giovanni di Gherardo da Prato's Designs concerning the Cupola of Santa Maria del Fiore in Florence', *Journal of the Society of Architectural Historians,* 1959, 18 (1), 11-20 and P.d. L'Orme, *Nouvelles Inventions pour bien bastir et à petits fraiz.* Paris: Frédéric Morel, 1561, chapter 15.
[77] L.R. Shelby, 'Setting Out', p. 548.
[78] 25.9, 31.6 and 25.4; since the drawing was scaleless these are relative measures but do not equate to any specific unit.
[79] M. Hislop, *Medieval Masons.* Shire Archaeology. Ed. J. Dyer. Vol. 78. Princes Risborough, Buckinghamshire: Shire Publications Ltd, 2000, p. 22.
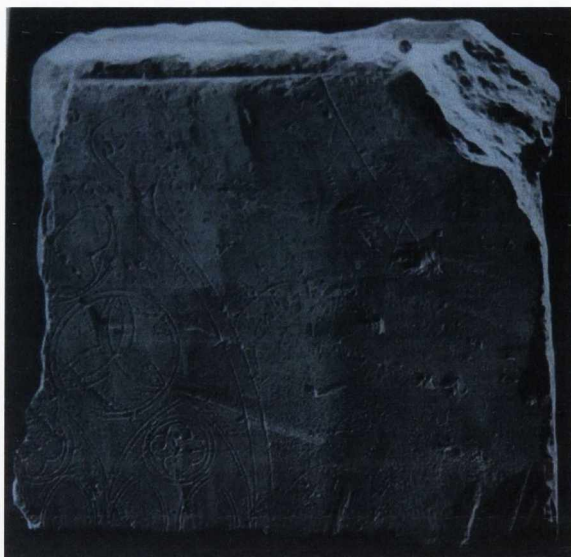
Figure 2.13 Sketch of window design incised on stone using compasses from c.1280 from St. John's College, Cambridge (University of Cambridge Museum of Archaeology and Anthropology)

In Ireland there is no surviving evidence for tracing houses or for large stone surfaces used for working out designs as at Soissons. Miriam Clyne identified a probable temporary mason's lodge during excavations at Kells Augustinian priory but even such structures are rare.[80] There is also only a single surviving example of incised architectural drawings on a plaster surface and this is at the Cistercian abbey at Corcomroe, Co. Clare (Figure 2.14). Two drawings dating from before 1228 are visible; one described by Roger Stalley as little more than architectural graffiti survives on the north wall of the south transept chapel, while the second is on the north wall of the north transept chapel. The south transept drawing does not relate to any arches or details remaining in the building but it is very useful in respect of providing evidence for the use of large compasses and rules since the compass marks are still visible at the base of the incision. The north transept drawing is complete and could have been used as a full-scale model for the elevation of a window. Stalley suggested similarity with a tomb recess in the presbytery although the design and dimensions do not correspond exactly. This suggests that the drawings were a form of "working out" for the final product, but possibly by someone who was unsure of exactly how they should proceed. This aligns with the fact that neither of the incisions was carried out to a high degree of accomplishment indicating an innate lack of understanding of the underlying geometric principles upon which Gothic details and tracery are dependent. Roger Stalley concluded that "the builders of Corcomroe were

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[80] M. Clyne and T. Fanning, *Kells Priory, Co. Kilkenny: archaeological excavations by T. Fanning & M. Clyne*. Dublin: Stationery Office, 2007.

62

excellent masons but rather poor architects".[81] This may be symptomatic of the difference between the skills required to become a designing mason and those required for the erection of simple buildings.
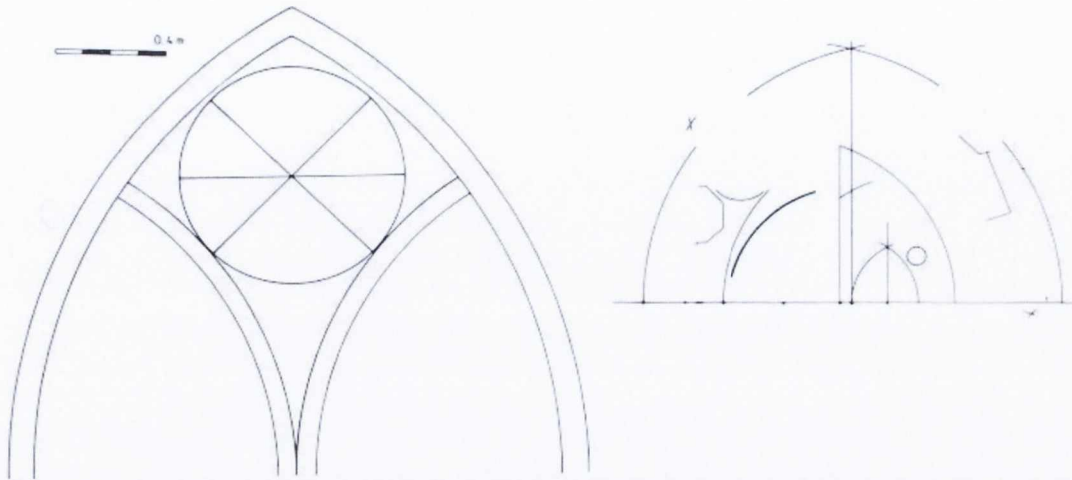
Figure 2.14 Incised drawings at Corcomroe Cistercian abbey, county Clare. North wall of the north transept (left) and north wall of the south transept chapel (right) [82]
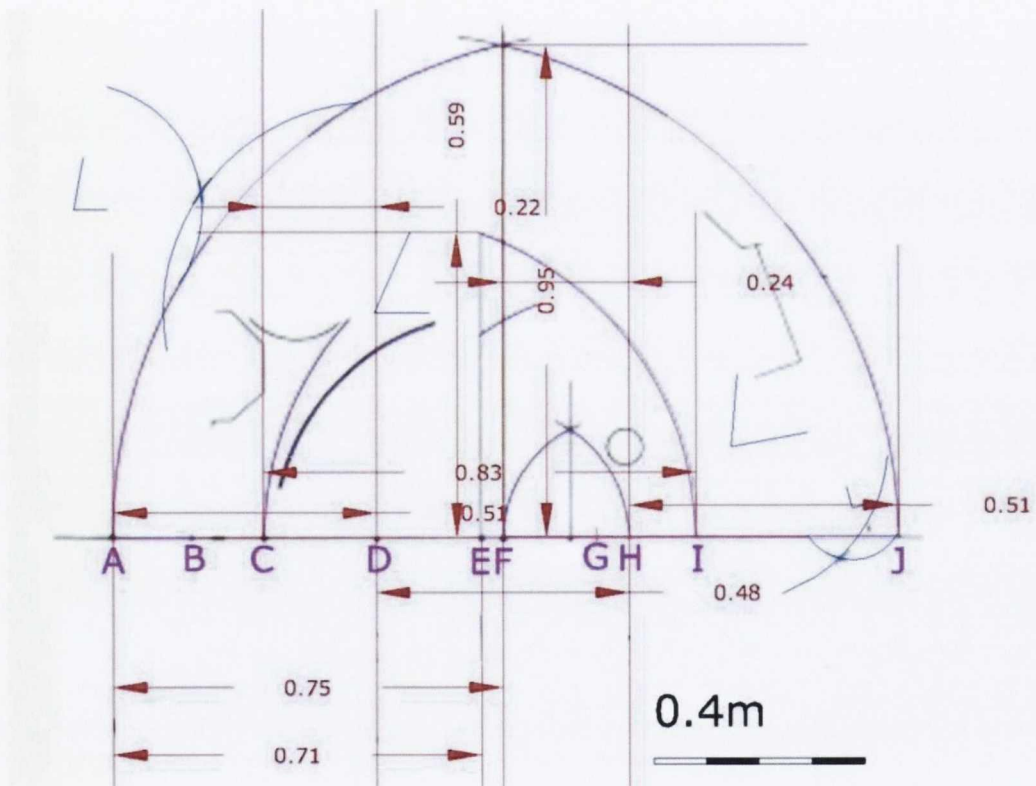
Figure 2.15 Corcomroe drawings with dimensions. Blue represents intersecting arc marks; red represents measurements between key points; pink represents arcs and arc centres

[81] R. Stalley, *Cistercian Monasteries*, p. 49.
[82] R. Stalley, *Cistercian Monasteries*, p. 49.

The marks on the baseline of the Corcomroe drawing relate to the arches as follows: outer arch ADHJ, a geometrically correct Three-point arch; middle arch CDGI, not a fixed-point arch in the medieval terminology and variously described in the twentieth century as a drop or modified gothic arch; inner arch FH, an equilateral arch. Analysing the proportions of the span to height ratio the outer arch equated to the golden section, the middle one to 1:√2, and the inner one to 5:6, although it the final arch was properly equilateral this should be 1:1.[83] All of these results, plus the presence of various arc intersections and a single moulding profile, point to a mason, perhaps an apprentice, testing both his handling of his equipment and his use of geometry in setting out a variety of arch shapes.

On a much smaller scale than the inscriptions at Corcomroe is a sketch showing the calculation of an arch moulding on the "bonding plane of an arch springer" at Duiske Cistercian abbey, Co. Kilkenny. Rachel Moss describes this as a preliminary stage design which would probably have been scaled up to full-size before building.[84] Another stone with drawings on the bonding face is on display in the National Museum of Ireland's medieval exhibition but details of its origin and characteristics have not been published.[85]

While only a few Irish tracings have been found, from the evidence from England and Europe, it might be assumed that at least some Irish masons utilised this technique. Particularly if a beaten earth floor was used or if the "tracing house" was actually a temporary structure, either within the building or separate to it, evidence is unlikely to be found, even through excavation.[86] However, no estimate of how widespread a practice this was is currently available but an evaluation of the competence with which tracery designs were executed might prove indicative of a *modus operandi*. An empirical evaluation of tracery could provide the data required.

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[83] Drop arch: P.R. Hill and J.C.E. David, *Practical Stone Masonry*. Wimbledon: Donhead Publishing, 1995, p. 81 (hereafter *Practical Stone Masonry*) and modified gothic arch: I. Cramb, *The Art of the Stonemason*. Chambersburg, Pennsylvania: Alan C. Hood & Company, Inc., 1992, p. 73.

[84] R. Moss, 'Tales from the crypt: the medieval stonework of Christ Church cathedral, Dublin.' *Medieval Dublin III: proceedings of the Friends of Medieval Dublin Symposium 2001*. Ed. S. Duffy. Dublin: Four Courts Press, 2002. 95-114, p. 102 (hereafter 'Medieval Stonework').

[85] Thanks to Rachel Moss for bringing this stone to my attention.

[86] Pacey noted that English tracing houses were often temporary being positioned in western parts of aisles or naves. For example, the Galilee porch at Ely was only occasionally used for ceremonial purposes and was therefore available to the masons for the rest of the year; Vale Royal Abbey, Cheshire – north transept of the church; possibly Salisbury Cathedral spire setting out in the cathedral nave; Upper levels: Byland above the warming house and York and Wells. A. Pacey, *Medieval architectural drawing*, p. 45.

Templates

In terms of window tracery, systems of proportion were not only used in the design of the elevation, but also in the design of the three-dimensional mouldings. From European and English evidence, templates could be considered one of the most important tools on a medieval building site. In his attempt to demystify some of the genius of the great medieval cathedrals David Turnbull described templates thus: "This small item of representational technology has much of the power of a scientific theory; it manifests the integration of science and technology and theory and practice, and it is a solution to the central problem of how knowledge was transmitted."[87] Turnbull suggests that the use of geometry, as a mechanism to enforce structural stability on building, would be impossible without the use of templates.[88]

The importance of the skill of producing templates is underlined by a number of entries in Lorenz Lechler's 1516 instruction manual which pay particular attention to the design of templates for "window mullions, tracery, vault ribs, bases and capitals of pillars, and mouldings for gables, pinnacles, and buttresses" (Figure 2.16 and Figure 2.17).[89] These diagrams give an indication of how the templates could be designed using the simple masons' tools of compass, straight edge and square. Thus a skilful mason ought to have been able to alternate between setting out new designs geometrically and modifying existing templates.
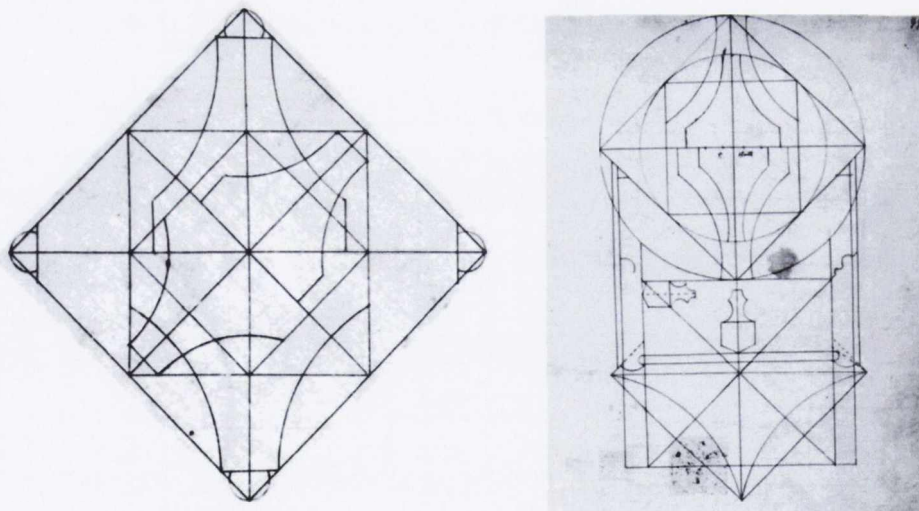
Figure 2.16 Lorenz Lecher, "Unterweisung", fol. 42v (left) and fol. 41 (right)

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[87] D. Turnbull, 'The Ad Hoc Collective Work of Building Gothic Cathedrals with Templates, String, and Geometry', *Science, Technology, & Human Values,* 1993, 18 (3), 315-40, p. 317 (hereafter 'Templates, String, and Geometry').
[88] D. Turnbull, 'Templates, String, and Geometry', p. 323.
[89] L.R. Shelby, 'Geometrical Knowledge', p. 419.
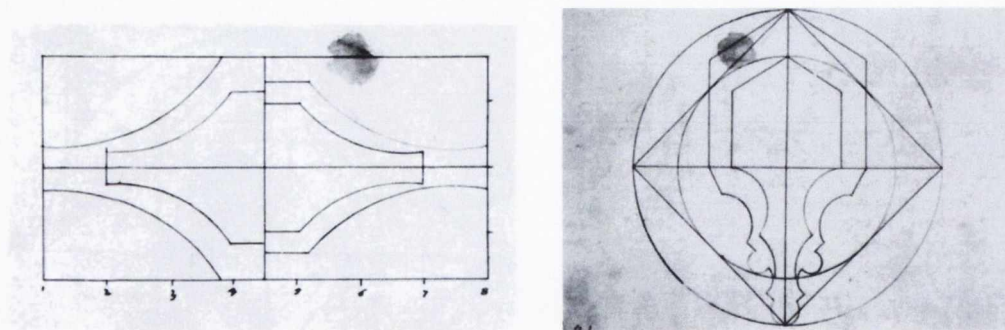
Figure 2.17 Lorenz Lecher, "Unterweisung", fol. 41v and fol. 42

The function of templates was two-fold; to make "possible the transformation of amorphous masses of stone into an enduring, stable structure" and to act as the main method by which master masons transferred their architectural ideas to the masons who actually executed those details in stone.[90] The task of creating templates was typically undertaken by the master mason and early evidence of this function is provided *c.*1174-5 in an account of the work of William of Sens when rebuilding the choir of the cathedral of Canterbury.[91] Similarly at St. Stephen's Chapel, Westminster Palace in 1331 the master mason, Thomas Canterbury, arrived on site three weeks before the rest of the workers in order to become engaged "*in trasura super moldas operanti*" i.e. creating moulds and templates in the tracing house.[92] An example from France records that the master mason Jenançon Garnache designed and sent templates to the quarry at Tonnerre for the stones of the window tracery for the east end of the nave of Troyes cathedral.[93]

Modern stonemasons use thin sheets of zinc for templates but historically wood and sometimes canvas were more popular materials.[94] L.R. Shelby provides ample evidence of the practice from the accounts of English medieval buildings such as Westminster Abbey, Norwich cathedral and Westminster palace. The practice was not limited to these very large sites as the following was recorded for the afore-mentioned Roslin Chapel in 1446 where the patron "first causd [sic] the draughts to be drawn upon Eastland boords, and made the carpenters to carve them according to the draughts thereon,

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[90] D. Turnbull, 'Templates, String, and Geometry', p. 322 and L.R. Shelby, 'Templates', p. 142.

[91] W. Stubbs, ed. *The Historical Works of Gervase of Canterbury*. Vol. 73, 1:7. London, 1879 and translation in J. Harvey, *Mediaeval Architect*, pp. 210-1.

[92] "E.101/469/11." Public Records Office. m. I and L.R. Shelby, 'Templates', p. 141. "After the sourcing of the relevant stone, two masons and an apprentice started the carving process". Also, this identification of an apprentice in this role is interesting in relation to the generally held opinion that a Guild-authorised apprenticeship system did not start until the sixteenth century.

[93] S. Murray, 'Master Jehancon Garnache (1485-1501) and the Construction of the High Vaults and Flying Buttresses of the Nave of Troyes Cathedral', *Gesta,* 1980, 19 (1), 37-49 and Archives de L'aube, MS G1570 (fabric account, 1496-1497) folio 235v.

[94] L.R. Shelby, 'Templates', p. 140 and p. 142.

and then gave them for patterns to the masons that they might thereby cut the like in stone".[95] Richard Fawcett has also suggested that templates in paper form would have been essential for travelling masons, such as those employed to work on English parish churches, as boards would have been too awkward and geometric setting out on each occasion would have been time-consuming.[96]

However, in Ireland few works on this scale took place and very little indisputable evidence has been found for the use of templates. In Rachel Moss's catalogue of the original stonework from Christchurch cathedral, Dublin she identified one stone (Figure 2.18 right), probably from the late twelfth-century choir, which was etched with "elaborate laying-out marks". The suggestion was that this "in effect, served as a mason's template" because of the amount of work required to create it.[97] This theory was supported by the presence of an exact copy of the entire feature, an engaged shaft, at Boyle Cistercian abbey in Co. Roscommon. Moss suggested that the stone arrived in Ireland pre-marked from the quarry at Dundry because of the West Country design involved.[98] This seems quite possible because cutting before transport would expose the delicate carving to potential damage and the stone itself would make a very reliable medium by which to transfer the design. Once at the location of use, a standard template in the form of canvas or wood could have been recreated to enable proliferation of the design.

At Mellifont Cistercian abbey, Roger Stalley found evidence for the use of templates on a well-preserved piece of vault rib. As seen in Figure 2.18 left, the stone was marked with lines indicating the directions of the ribs to enable alignment of the template. However, a mistake was made in drawing one of the lines and also in positioning the template (curved lines).[99]

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[95] L.F. Salzman, *Building in England*, pp. 20-1.
[96] R. Fawcett, Later Gothic architecture in Norfolk: an examination of the work of some individual architects in the fourteenth and fifteenth centuries, Ph.D. East Anglia, 1975, pp. 481-2 and p. 486: "nearly all architects would repeat moulding formations in two or more of their churches so precisely that the same template or templates cut from the same design, must have been employed".
[97] R. Moss, 'A medieval jigsaw puzzle: the ancient stones of Christ Church', *Archaeology Ireland,* 2000, 14 (2), p. 22.
[98] R. Moss, 'Medieval Stonework', p. 104-5.
[99] R. Stalley, 'Mellifont Abbey ', *Proceedings of the Royal Irish Academy,* 1980, 80 (Part C, Number 14), 263-354, pp. 325-6.
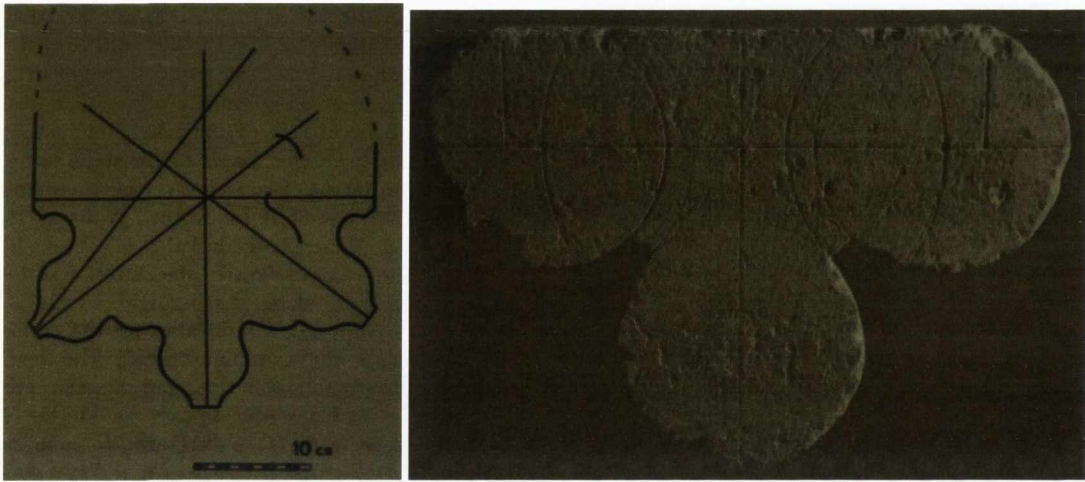
Figure 2.18 Mellifont Cistercian abbey rib vault stone (left) and Christchurch cathedral, Dublin engaged shaft section (right)

Because so little measured work has been carried out in Ireland other suggestions of the use of templates cannot be confirmed. Such is the simplicity and similarity of elements, particularly the quadrant and hollow chamfer, used in Irish mouldings, although combined in different variations, that the necessity to use templates must be questioned.[100] However, assuming that there was a similarity of practice between Ireland and England, Richard Fawcett's investigation into East Anglian late medieval architecture provides an interesting interpretation of the use of templates. The preceding examples have focused on large sites where one role of the master mason was to ensure continuity and standardisation, a function which was facilitated by issuing templates to the banker masons. But what of the masters who were not attached to such grand works but who, instead, travelled about the country designing churches, or perhaps, updating window tracery and who were, therefore, probably personally responsible for carving the stone?

Fawcett found that "nearly all architects would repeat moulding formations in two or more of their churches so precisely that the same template or templates cut from the same design, must have been employed".

Window tracery design methods

The research conducted thus far has not identified a definitive method for the design of window tracery. This section attempts to consolidate knowledge of the specific means by which a medieval mason would have created a tracery design. It also includes reference to

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[100] D. O'Donovan, 'Building Butler', p. 244.

nineteenth- and early twentieth-century stone mason's manuals in recognition of the continuity of design methods generally accepted in the architectural historical community.

Firstly, there is no guarantee that window design was a three-step process involving the sketching of a design at full scale, the production of templates, and the cutting of stones that would be checked against the full scale design. It is quite possible that templates were not used, particularly where the same mason was responsible for all stages of the process. This closely mimics the practices of medieval and modern carpenters and detailed descriptions of these methods are given by Arnold Pacey.[101]

Irrespective of the use of templates the first design stage was the production of a full-size elevation drawing of the window design. Most authors agree that the beginning point for a tracery design was the production of a base line upon which a compass point could be set to mark out important curves. Particularly for replacing windows with tracery after a new fashion the length of this base line would already be decided. A centre line at right angles to the reference line would also have been typical.[102] William Purchase's 1904 text described the general process for setting out tracery as follows:

"In setting out tracery windows generally, commence by drawing the vertical centre line of window, then the springing line at right angles to the same, and set off the span, or opening, and draw segment line of the arch. Divide the span for small openings, and draw in the mullions. This may also be obtained from the plan if first drawn. Now draw in the construction lines for centres of tracery to the required design, care being taken that the curves must properly intersect with each other, or be drawn tangential, as the case may be. The mouldings which form the mullion, on taking a curved shape in the tracery, are termed monials."[103]

He also added that for making templates "one half the window only is necessary to be set out". Purchase supported this description with Figure 2.19 which shows construction lines on one side and the completed window with relevant centres of curves on the other half.

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[101] A. Pacey, *Medieval architectural drawing*, pp. 36-7 and Chapter 4 pp. 87-116.

[102] A. Pacey, *Medieval architectural drawing*, pp. 43; E.G. Warland, *Modern Practical Masonry*. Shaftesbury: Donhead, 1929, pp. 133-8 (hereafter *Modern Practical Masonry*); W.R. Purchase, *Practical Masonry*. 5th ed. Powys: Attic Books, 1904, pp. 109-15 (hereafter *Practical Masonry*); P.R. Hill and J.C.E. David, *Practical Stone Masonry*, pp.108-10.

[103] W.R. Purchase, *Practical Masonry*, p. 109.
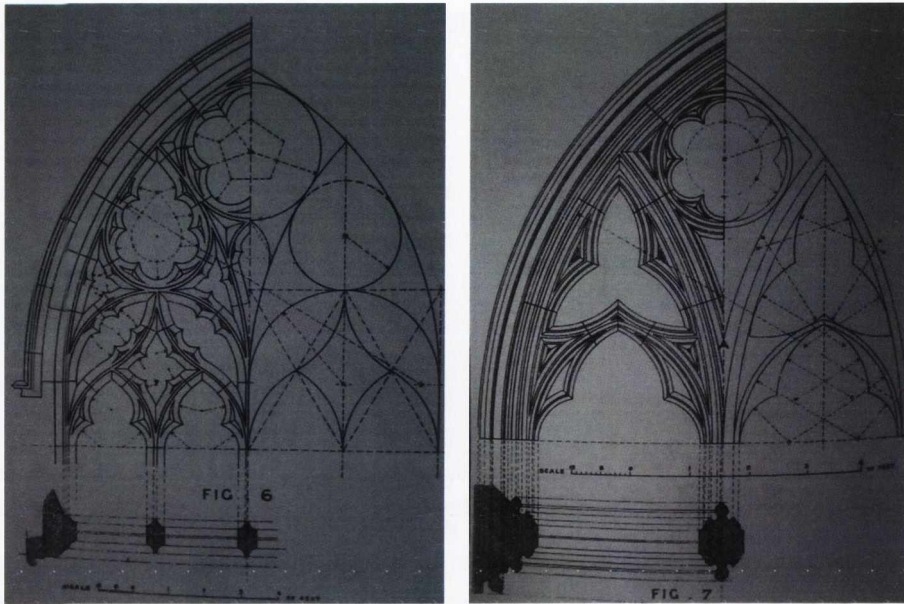
Figure 2.19 Geometrically based window tracery with significant foliation (left) and tracery with predominant circles and trefoils (right) – Purchase 1905 [104]

E.G. Warland's *Modern Practical Masonry* contained more detailed instruction on how the curved elements of the tracery were to be set out so that the mason could ensure that decorative elements such as circles and curves would be sure to intersect with the surrounding arches through the use of loci along the centre line of the monials (Figure 2.20).
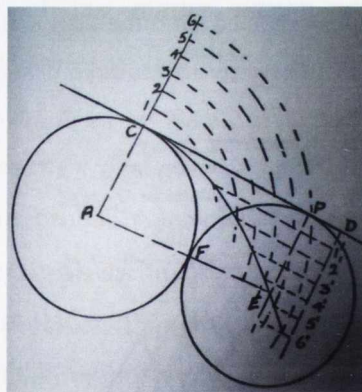
Figure 2.20 Given a circle with centre A and a tangent to the circle, describe a circle to touch the tangent at point P, and the given circle tangentially – Warland. [105]

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[104] W.R. Purchase, *Practical Masonry*, pp. 113-4.

[105] "Draw a perpendicular to the tangent as at D, and produce the normal A C from centre A, beyond the circle. Mark off on the normal produced from point C any number of equal divisions, as at 1 2 3 4 5 6. Now mark on the perpendicular line from D a corresponding number of equal divisions of the same magnitude, as at 1' 2' 3' 4' 5' 6'. With A as centre, draw parallel arcs from points 1 2 3 4 5 6 to meet lines drawn parallel to the tangent from points 1' 2' 3' 4' 5' 6'. A fair curve drawn through the points of intersection will give the locus, or *path*, containing the centres of circles that will be tangential to the given circle and the given tangent. To determine the point required on this line, from point P draw a perpendicular line, cutting the

Warland also illustrated the process in the context of tracery based on a horizontal line representing the span of the window and a vertical line perpendicularly through this line and the centre of the pointed arch (Figure 2.21).
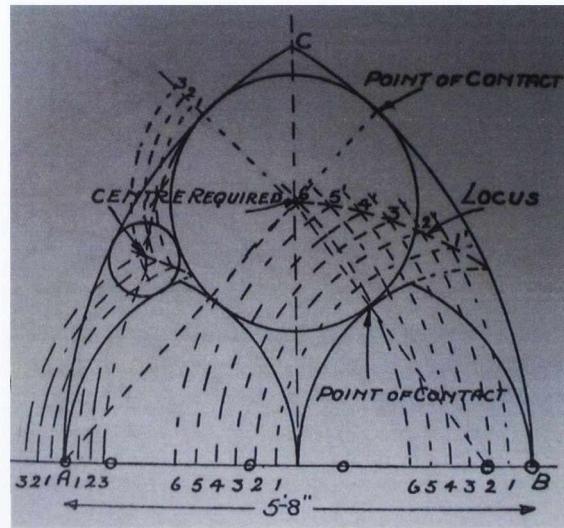
Figure 2.21 Loci for geometrical window tracery - Warland.[106]

Warland provided a further example of foliated tracery created using the same methods of finding loci based on the span of the window and the centre line of tracery perpendicular to it (Figure 2.22).
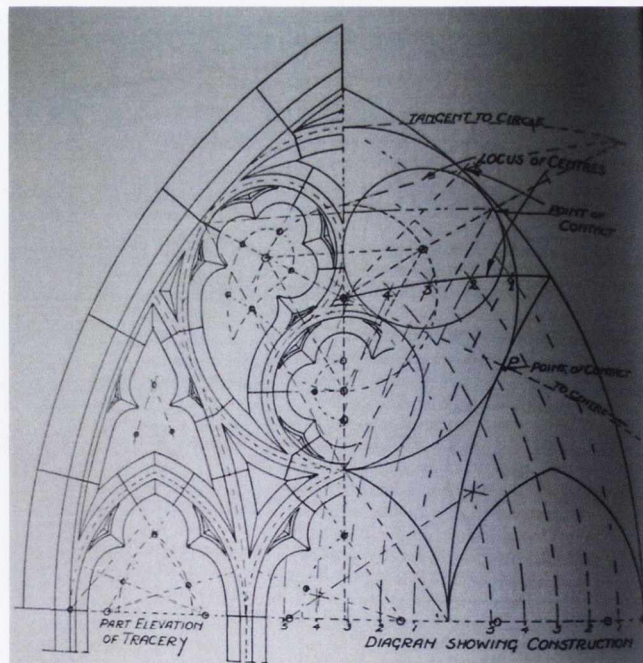
Figure 2.22 Geometrical tracery window showing loci, construction lines and completed design - Warland.[107]

locus in point E, E being the centre required. Join A E, cutting the two circles in F, then F is the point of contact between the two circles." E.G. Warland, *Modern Practical Masonry*, pp. 132-5.
[106] E.G. Warland, *Modern Practical Masonry*, p. 135.

These modern descriptions of the method of laying out tracery match well with a number of medieval examples, such as on the tracing floor at York Minster and on the wall at Corcomroe Abbey, where horizontal lines are marked with numerous compass point marks which would have been used to set out the loci and the geometrical shapes of the tracery.[108]

Irrespective of the level of detail of the tracery to be included in the arch the starting point for design work required that the span of the window be defined and that below the springing line of the arch this would be divided into a number of parts (lights) separated by the mullions. None of the construction/masonry manuals provide any specific instruction on how these decisions should be made, on the application of geometric principles or the use of particular proportions, or on the arithmetic elements (i.e. the measurements to be used). Knowing however, as we do, that setting out of ground plans was carried out using ropes or mason's rods of fixed lengths, it would be logical to assume that the same units would have been used for the spans of the windows and that the number of divisions of the lower part of the window into lights would be made on the basis of folding or subdividing that unit, as was done for ground plans. In relation to the vertical divisions of the elevation of the window tracery a portion of this decision must have been affected by the decision on the style of arch to use. Most windows in this study use either the equilateral, lancet or modified Gothic arch with the advantage in all cases being that the centres of the arches are positioned along the springing line making them easier to set out, even by inexperienced masons (either at the extremities, external to the arch or within it, respectively) (Figure 2.23). However, neither the measure of the tracery field, nor the proportion between the tracery field and the area below the springing line is mentioned in any of the medieval or modern texts.
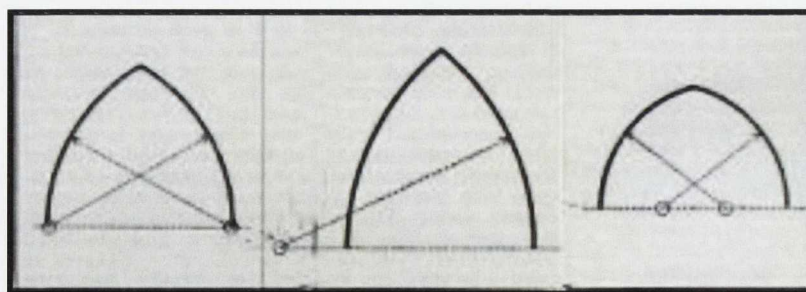
Figure 2.23 Medieval arch shapes with centres - equilateral, lancet and modified Gothic (left to right)

[107] E.G. Warland, *Modern Practical Masonry*, p. 136.
[108] R. Stalley, *Cistercian Monasteries*, p. 49 and J. Harvey, 'The tracing floor of York Minster.' *The Engineering of Medieval Cathedrals*. Ed. L.T. Courtenay. Reprint of Friends of York Minster, Annual Report 40 (1968) ed. Aldershot: Ashgate, 1997. 81-6.

Thus, for the progress of this research, there are few clearly identifiable elements of window tracery that can be specifically targeted as indicative of a mason's use of particular metrology or proportion methods. The span of the window (whether measured as a gap in stonework or from the edges of the moulded materials) and how it is subdivided with mullions of what width, as well as the overall height of the window and how it is separated into the tracery field and the lights area, are items of potential interest.

2.1.2 Medieval metrology

As has been demonstrated in the medieval geometric design studies reviewed thus far, geometry can rarely be studied independently of units of measurement and systems of arithmetic.[109] While design can be carried out using purely geometrical methods, such as employing dividers or fixed length cords to define proportional relationships between features, execution on the ground can only be accomplished through specification of an actual measure.[110] Therefore, the probability that a suspected geometric pattern was intended is significantly increased if combined with evidence for a fixed unit of measurement. Where that unit is repeated at different locations, either within a region or over a wider spatial distribution, or over a defined period of time, the argument for intentional usage is further strengthened. The importance of units to masons should not be underestimated because, in many cases, payment was received by the foot. For example, Henry Yeveley, the king's mason, was recorded on May 15th 1382 as measuring work done and giving a certificate on July 23rd.[111]

This section identifies a range of historical units important to architecture and examines the influence of governance on changes in metrological practice.

Medieval units

According to Ronald Zupko, fifty major measurement units existed in England in the late tenth century; however, by the end of the middle ages this number had risen to several

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[109] V. Paul, 'Geometry Studies: The Blind Tracery in the Western Chapels of Narbonne Cathedral.' *Ad Quadratum: the Practical Application of Geometry in Medieval Architecture*. Ed. N.Y. Wu. Aldershot, England: Ashgate Publishing Ltd., 2002. 205-16.

[110] J. Addiss, 'Measure & Proportion in Romanesque Architecture.' *Ad Quadratum: the Practical Application of Geometry in Medieval Architecture*. Ed. N.Y. Wu. Aldershot, England: Ashgate Publishing Ltd., 2002. 57-82, p. 59 (hereafter 'Measure & Proportion').

[111] J. Harvey, *Mediaeval Architect*, p. 362.

hundred major units with thousands of local variations.[112] F.P. Skinner showed that many of these units could be related to ancient times via Assyria, Egypt, Greece, Rome, and Arabia.[113] Rather than listing the relationships between relevant linear measurements in the text, tables in appendix 1 and 3 detail the main relationships between the units described in this section.[114] Fortunately for this project, research in medieval metrology in Europe has found that the units the foot, ell and rod, and their subdivisions, as integers and as proportions of their lengths, are the units which occur most prominently in architecture.[115] This certainly reduces the field of enquiry and an attempt will be made in this section to explain the origins of these main types of unit before analysing how related systems of metrology fitted together or co-existed.

Historical metrological studies indicate that measurement systems typically derived from one of two sources, the human body or agricultural achievement. Both types of system developed independently in populated areas and most, at some point in their history, required an alignment to be made between them. Frequently, it was these efforts at alignment between incompatible systems that have lead to some of the stranger units, as will be discussed later.

Units based on the human body evolved independently of each other throughout the world.[116] However, the most typical of these measurements are the digit, thumb, hand, palm, shaftment (hand width with outstretched thumb), foot, forearm (with its variants the cubit, ell, elne or yard), step and pace. In some locations a large number of these units were used while in others only a restricted few were considered.

If the foot unit was the starting point for the system, as was often, but not always, the case when used for larger measurements, this was typically divided into smaller units equal in length to the thumb – usually into twelve divisions (Figure 2.24). One twelfth of a

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[112] R.E. Zupko, 'Weights & Measures: Western Europe.' *Dictionary of the Middle Ages - 13 Volumes.* Ed. J.R. Strayer. Vol. 12. New York: Charles Scribner's Sons, Simon & Schuster, 1989. 580-96, p. 582 (hereafter 'Western Europe').

[113] F.G. Skinner, *Weights and Measures: their Ancient Origins.* OPUB 160.r.1 no.18. London: Her Majesty's Stationery Office 1967 (hereafter *Weights and Measures*).

[114] R.E. Zupko, *British weights & measures: a history from antiquity to the seventeenth century.* Madison: University of Wisconsin Press, 1977 (hereafter *British Weights & Measures*).

[115] The rod is also known as the pole or perch. Eric Fernie, 'Norwich Cathedral Root Two', pp. 77-86.

[116] The locations where such units developed included North Africa, such as those documented in Egypt, across Europe, both Roman and Barbarian, and in South America within a number of cultures. Interestingly the Mayans (Yucatan), and the neighbouring Cakchiquels (Guatamala) had a series of measures representing different heights from the ground such as to the calf, the mouth, the neck, etc. but the Aztecs of Mexico did not and nor did the European or African systems. The exact function of these units is unclear since all three cultures also had foot, pace and arm-based measures. D.G. Brinton, 'The Lineal Measures of the Semi-Civilized Nations of Mexico and Central America', *Proceedings of the American Philosophical Society,* 1885, 22 (18), 194-207.

foot is called an 'inch' as derived from Latin *uncial* (a twelfth).[117] In some cases, such as for some Roman measurements, thirteen inches made up a foot.
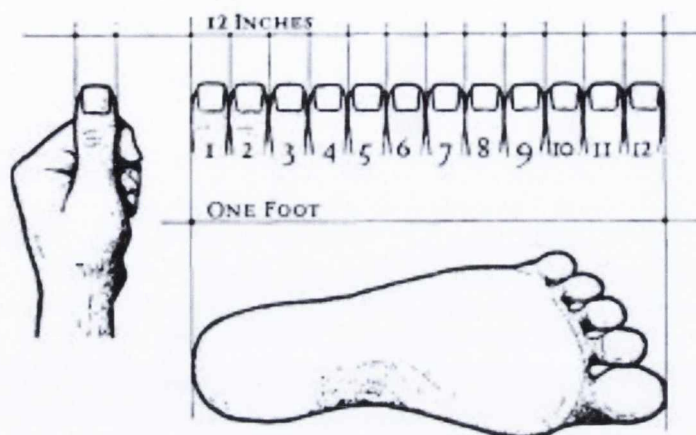
Figure 2.24 Duodecimal subdivision of the Roman or medieval foot by thumbs[118]

Units smaller than an inch were not usually derived from the body but were created via a process of continuously halving the inch using a pair of dividers – typically splitting an inch into 16 parts. The process of subdivision using dividers could also be carried out on a foot producing 16 digits. The relationship between some of these parts is given as:

1 foot = 2 shaftments = 3 hands = 4 palms = 12 inches (thumbs) = 16 digits (fingers) [119]

The variation in the length of human foot was widely acknowledged and methods of neutralizing these variations have been documented, such as the Anglo-Saxon perch in England being the total length of the left feet of the first sixteen men to leave church on a Sunday morning, or the dream of Saints Thomas the Apostle and Thomas the Martyr where the martyr measured "thirteen with right and left foot, according to the custom of his race".[120] Thus, when considering working in feet one must question the actual length of the foot and its variation in length between towns, states and countries. As commented on by Philip Grierson, 'while documents sometimes tell us much about the interrelationship of units, they rarely provide information on their absolute values'.[121]

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[117] W. Horn and E. Born, 'Saint Gall Inconsistencies', p. 287.

[118] W. Horn, 1966, 'Duodecimal division of the foot. ' The Art Bulletin.

[119] R. Rowlett, 'A Dictionary of Units of Measurement.' Chapel Hill, USA, 2004. Online article. University of North Carolina at Chapel Hill. Viewed July 2009. <http://www.unc.edu/~rowlett/units/index.html>.

[120] For the Anglo-Saxon solution see National Physics Laboratory, 'History of Length Measurement.' Teddington, 2008. National Physics Laboratory. Viewed June 2009. <http://www.npl.co.uk/educate-explore/posters/history-of-length-measurement/history-of-length-measurement-(poster)>. For the saints see J.C. Robertson, *Materials for the history of Thomas Becket, archbishop of Canterbury (canonized by Pope Alexander III, A.D. 1173)*. Rerum Britannicarum medii aevi scriptores ; no. 67. London: Longman, 1875, p. 531.

[121] P. Grierson, *English Linear Measures: an essay in origins*. The Stenton Lectures. Reading, Berkshire, RG6 2AA: The Publications Officer, Department of History, University of Reading, 1972, pp. 3-4 (hereafter *English Linear Measures*).

When dealing with metrological systems with an agricultural basis the most common unit is the medieval rod (also known as a pole or a perch), the length of which is typically given as a quarter of the width of an acre, where the area of an acre is 4 rods by 1 furlong.[122] In this system, the rod typically has a length of 5.03m and 4 rods end-to-end resulted in a length of 1 chain or 66 ft; a measurement that is still used to define the length of a cricket pitch.[123] However, the metric value for the rod is not always the same. The system of lengths into which the perch fits is as follows: [124]

Inches	Feet	Yards	Perches	Furlongs	Miles
12	1				
36	3	1			
198	16.5	5.5	1		
7,920	660	220	40	1	
63,360	5,280	1,760	320	8	1

Frequently agricultural measurements started with the acre and worked down to the smaller units by subdivision. The important issue then arises, as noted in the Doomsday Book and most contemporary English land measurement records, that such units were based upon the amount of land that could be ploughed in one day by a team of eight oxen.[125] Depending on the slope of the ground and the composition of the soil, this quantity could vary. Similarly, in the prehistoric and early Christian eras in Ireland, and throughout the Roman empire, land measures varied in size according to the quality of the land.[126] Thus attempts at deriving a standard measurement unit from concepts as abstract as these results in difficulty.

Ronald Zupko's research resulted in a list of versions of the perch, as used by different trades, consisting of 9, 9 1/3, 10, 11, 11 ½, 12, 15, 16, 18, 18 ¼, 18 ¾, 19 ½, 20, 21, 22, 22 ½, 24, 25, and 26 feet.[127] Converted to metric this produces perch lengths from 2.743m to 7.925m, when using a standard foot length of 0.3048m, a method which is

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[122] P.J. Huggins, 'Anglo-Saxon Timber Building Measurements: Recent Results', *Medieval Archaeology*, 1991, 35, 6-28, p. 7 (hereafter 'Anglo-Saxon').
[123] P.J. Huggins, 'Anglo-Saxon', p. 25.
[124] P. Grierson, *English Linear Measures*, p. 15.
[125] F.W. Maitland, *Domesday Book and beyond: three essays in the early history of England*. Cambridge: University Press, 1897.
[126] F. Kelly, *A Guide to Early Irish Law. Early Irish Law Series 3*. Dublin, Ireland: Dublin Institute of Advanced Studies, 1995 (hereafter *Early Irish Law*) and O.A.W. Dilke, *The Roman Land Surveyors – An introduction to the Agrimensores*. Devon: David & Charles Limited, 1971.
[127] R.E. Zupko, 'Western Europe', p. 588.

further complicated by research from Ronald Zupko and F.G. Skinner who between them list 19 different medieval foot lengths, not including the Carolingian foot of 0.3207m.[128] This is why, as early as the twelfth century, successive administrations became involved in trying to standardise measurement through legal intervention.[129]

When examining medieval metrology it is also important to remember that systems did not necessarily operate in isolation from each other. Measurements which derived from different foot values were necessarily unconnected and required some forced fitting to create a system whereby units of both origins could be accommodated. Furthermore, to try to logically relate an agrarian measure, such as the perch, to a cloth measure, such as the yard or elne, is an impossible task since any link between them is "wholly irrational". For example, the English yard was adapted in the twelfth century by legislation in Richard I's Assize while the perch went unchanged.[130]

In an earlier era, the occurrence of two metrological systems in a single time and place is also suggested by a Greek Metrological relief at the Ashmolean Museam at Oxford (Figure 2.25 and Figure 2.26). Eric Fernie demonstrated that this relief was not used as a comparative standard, as was previously though, but as a representation of the relationship between two systems in use at a point in time.[131] Therefore, any metrological investigations should be open to the possibility that more than one unit or system of units was in use at the time of enquiry.

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[128] R.E. Zupko, 'Western Europe'; F.G. Skinner, *Weights and Measures* and L. Price, *Plan of St. Gall*, p. 13.
[129] The process took over 500 years and even as late as 1737 Julian Hoppit reveals that the Clerk of the Market of the royal household reported that he had made 1265 prosecutions for false weights and 342 for false balances that year: J. Hoppit, 'Reforming Britain's Weights and Measures, 1660-1824', *The English Historical Review,* 1993, 108 (426), 82-104.
[130] P. Grierson, *English Linear Measures*. Also usage of the term *elne,* sometimes known as the *ulne,* can cause confusion as variations occur between versions of the unit used for measuring land and those used for measuring cloth. A detailed description of the variety of cloth lengths in use in the late middle ages is given in E. Fernie, 'Pergolotti's Cloth Lengths.' *Studies of Medieval Art, Liturgy and Metrology presented to Christopher Hohler.* Eds. A. Borg and A. Matindale. Vol. 111: BAR International series, 1981. 397-412.
[131] A. Michadlis, 'The Metrological Relief at Oxford', *The Journal of Hellenic Studies,* 1883, 4, 335-50 (hereafter 'Metrological Relief') and E. Fernie, 'The Greek Metrological Relief in Oxford', *The Antiquaries Journal,* 1981, 61, 372-82. Another relief example from Salamis, Greece related the common Greek, Helenistic, Doric and Attic feet: I. Dekoulakou-Sideris, 'A Metrological Relief from Salamis', *American Journal of Archaeology,* 1990, 94 (3), 445-51 and M. Wilson Jones, 'Doric Measure and Architectural Design 1: The Evidence of the Relief from Salamis', *American Journal of Archaeology,* 2000, 104 (1), 73-93.

Figure 2.25 Oxford metrological relief [132]
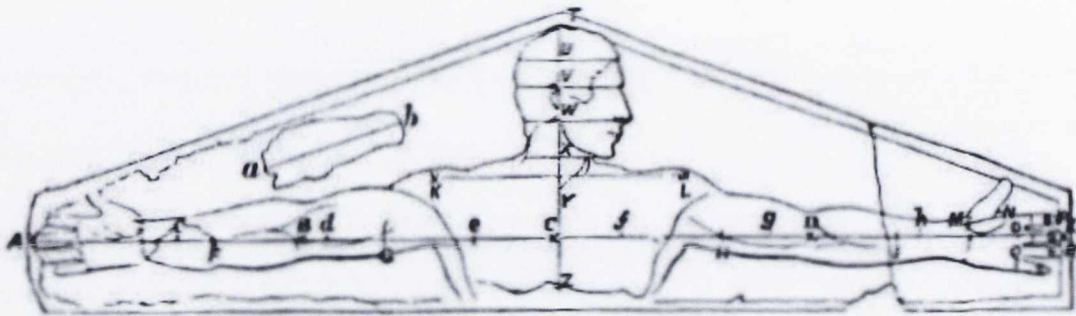
Figure 2.26 Complete Oxford metrological relief with marked relationships [133]

While there seem to be no purely architectural units, P.J. Huggins listed the shaftment as being 'suited to the needs of carpenters and builders' because of the ease with which hands could be passed over each other on wood or masonry.[134] Certainly this unit could have been an original standard but no evidence has been found for its direct usage from legal or building documentation. However, when the yard became the legal standard, it was subdivided into three feet, and a shaftment was half a foot. Therefore, architectural historical studies that result in foot values which do not agree with any known standards could actually be identifying a particular mason's shaftment size.

Documentary evidence for the shaftement is limited but the other units worth considering because they relate to upper body measurements are the yard and the elle/elne; the latter measuring a yard and a quarter or 3.75 feet. These units were used for a range of commodities and through trade Irish merchants, at least, must have come into contact with them. The sixteenth-century port records for Bristol, through which much trade with Ireland, particularly the Ormond ports of Waterford, Ross, and Wexford, was made, include a number of relevant entries.

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[132] Thanks to Robert Ovington for taking this picture for me.
[133] A. Michadlis, 'Metrological Relief'. The markings are not directly relevant to this study.
[134] P.J. Huggins, 'Anglo-Saxon', p. 21.

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Cloth was traded by a range of measures including the bolt, role, dozen, goad, ell, yard, piece (the length was not always specified but sometimes varying yard lengths were given), and centum or centarium.[135] The centum could mean "(a) a hundredweight or (b) a 'long hundred' of 120 pieces, for example with fish and sheep skins or a hundred of 100 ells when looking at certain cloths." Breton Canvas was listed as having a measure of "C (yards)" in a 1503/4 account and cloth and Canvas was traded "per C (presumably yards)" in 1525/6, by the yard and bolt in the 1540s, and by the ell, piece and yard in 1600/1.[136] While some wood, such as fir, spruce, and meighborow originating from Norway were sold by the piece, Irish wood or boards ("a piece of timber sawn thin, and having considerable extent of surface") were traded by the centum, although it is not clear whether this is the weight or length measure: "Wood, Irish (Irish boards): Valued at 20s. per C in the pre-1558 accounts".[137] Finally, cord which could be interpreted as "ropes of a ship, the string of a bow", or "strands of wire twisted or woven together" were traded "at 10s. per c in 1503/4".[138]

Masons were probably in contact with traders of cloth, particularly canvas, and of boards since these materials were used in the manufacture of templates, as has previously been demonstrated. Although a more tenuous link, it is known that cords were sometimes used to fix the module for modular design of buildings and, since cord was traded by the yard or similar, this could also have created points of contact. Although we know that stone was imported into Ireland from as early as the twelfth century for the construction of sites such as Christchurch cathedral, Dublin, most references to quantities of stone mention "loads" rather than any other measure.[139] Thus the units that were used in trade would have become known to individuals in the building industry, perhaps influencing their choice of metrology.

With the exception of a few references to ells in contracts, most sources suggest that rods or feet were the typical building units.[140] The length of the preferred architectural unit is called into further confusion by an examination of a range of contemporary illustrations (Figure 2.27). In Gunter Binding's collection of medieval illustrations related

[135] S. Flavin and E.T. Jones, *A glossary of commodities, weights and measures found in the sixteenth-century Bristol customs account*. Bristol: University of Bristol, 2009, pp. 110-20 (hereafter *Bristol customs account*).

[136] S. Flavin and E.T. Jones, *Bristol customs account*, pp. 111-3.

[137] S. Flavin and E.T. Jones, *Bristol customs account*, p. 109.

[138] S. Flavin and E.T. Jones, *Bristol customs account*, p. 23.

[139] For example: D. Knoop and G.P. Jones, 'The English Medieval Quarry', *The Economic History Review*, 1938, 9 (1), 17-37 and R. Durman, *Ham Hill: portrait of a building stone*. Reading: Spire Books Ltd, 2006, p. 113.

[140] For example, a contract from Chester in 1322-3 required the building of a round tower "10 ½ ells in diameter and 24 ells in height; also a wall, 8 ells in height": L.F. Salzman, *Building in England*, pp. 428-9.

to architecture the mason's staff varies in length from approximately 1 foot to 4 feet.[141] While such illustrations are rarely true to scale throughout, the representations of masons' tools are typically correctly sized relative to the people. Therefore, the variation in staff length is conceivably correct and this could, of course, have had an impact on comparisons of architecture.
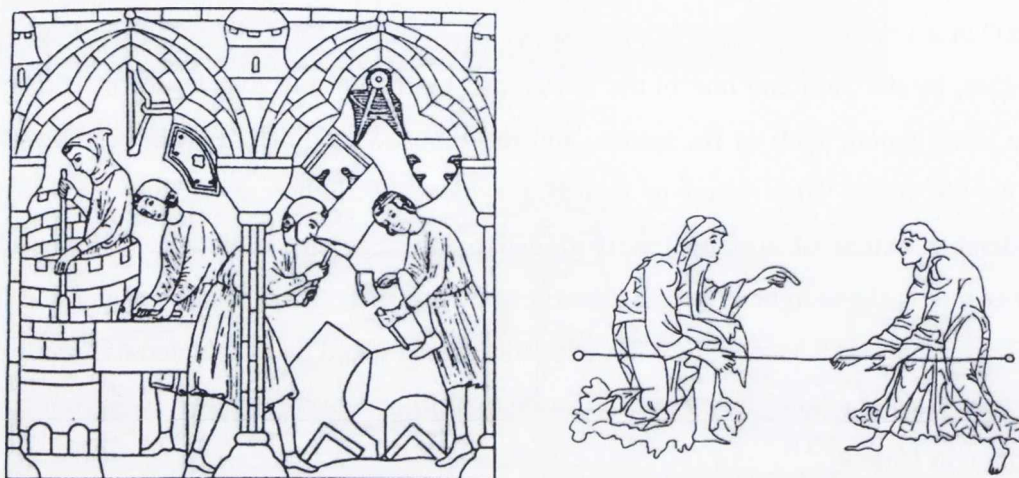
Figure 2.27 Stained glass window from Chartres cathedral, *c.* 1220-25 (left) and Anglo-Saxon illustration from the ninth or tenth century from the Cotton MS Cleopatra C VII, British Museum, London (right)

The use of feet and rods in building is documented in many contracts from England and some in Ireland.[142] A number of legal documents include architectural references where feet are mentioned such one from the 1429 parliament which pledged that anyone in Co. Louth who would build a castle or tower within the next five years "in length twenty feet, in breadth sixteen feet, in height forty feet' would receive a subsidy of £10.[143] The previously cited example of the thirty foot round window for the hall in Dublin Castle indicates that the size of individual architectural details were also, sometimes, specified.[144] However, glass was also sometimes purchased by weight as verified by an entry in the Dublin Castle accounts recording that £22 8s 6d was paid for 600lbs of glass for renovations on the chapel.[145]

However, the complexity of the relationship between feet and rods is exemplified by a contract from Cambridge, England from 1457 for the building of a wall which

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[141] G. Binding, *Medieval Building Techniques*. Stroud: Tempus, 2004.
[142] See L.F. Salzman, *Building in England* for English contracts and, in particular, R. Stalley, *Architecture and Sculpture in Ireland 1150-1350*. Dublin: Gill and Macmillan, 1971 for some Irish examples.
[143] Statutes of Ireland, 12-22 Edward IV, p. 43.
[144] H.S. Sweetman, *Calendar*, p. 188, Close Rolls, Roll 9, p.1 m.13 and p. 389, Close Rolls, Roll 27, p.1 m.9. and J.T.S. Gilbert, *Viceroys*, p. 514.
[145] J.T.S. Gilbert, *Viceroys*, p. 545.

included the specification that there should be 18 feet per rod, 1.5 feet more than the typically acknowledged standard of 16.5 feet. However, these feet were the local standard which was probably shorter than the king's standard.[146] The relationship between the perch/rod and the foot provides a particularly clear example of the problems of trying to relate one unit to another when so many plausible permutations exist. Eric Fernie showed that the standard length of the English perch at 5.03m equals 17 Roman feet of 0.2959m, 16 ½ English feet of 0.3048m and 16 Rheinish feet of 0.3144m.[147] Furthermore, an Irish perch of 21 English feet (6.4008 meters) or 14/11 English perch also existed, further muddying the already contaminated waters. It is certainly possible that multiple perch units, and by association multiple foot units, were in use at the same time in medieval Ireland.

One particular way in which the English perch could have arrived in Ireland was through the practice of burgage in Anglo-Norman towns. Burgage plots or tenements were "tracts of land within a medieval town which were allocated to the burgesses, who were the freemen and in many instances the members of the council".[148] Traditionally their size was strictly controlled and they normally had a fixed amount of road frontage with significant space for the necessary buildings of the trade to the rear. The frontage was usually measured in perches with examples from Cricklade, Wiltshire where most plots were 2 perches wide by 12 perches long and Charmouth, Dorset, with plots of 4 perches wide by 20 long, as defined by a charter from 1320. In some towns where the layout was not along narrow streets but rather in a gridded system, such as Salisbury, burgage plots measured 3 perches by 7 perches. Measurement of town streets where medieval planning has been allowed to continue to the present day would indicate the use of burgage if plot sizes were divisible by perch units.[149]

Turning specifically to evidence of Irish metrology from native sources, Irish linear measurement was quite varied with some quantities being measured using a combination of multiple units, some body-based, some more abstract. These Irish measures may first have been set down as early as the third century, but with only minor

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[146] L.F. Salzman, *Building in England*, p. 531-2 quoting R. Willis and J.W. Clark, *The Architectural History of the University of Cambridge, and of the Colleges of Cambridge and Eton ... Edited with large additions, and brought up to the present time, by J. W. Clark*. Vol. 1. 4 vols. Cambridge: University Press, 1886, p. 310: "*Ad longitudinem 4 rodarum et di' qualibet roda continente xviij pedes de standardo region.*"

[147] E. Fernie, 'Anglo-Saxon Lengths: The 'Northern' System, the Perch and the Foot', *Archaeological Journal*, 1985, 142, 246-54, p. 250 (hereafter 'Anglo-Saxon Lengths').

[148] Freemen were those who were entitled to practise a trade and to elect members of the town's ruling council.

[149] T.R. Thomson, *Materials for a history of Cricklade*. Revised ed. Oxford: University Press for the Cricklade Historical Society, 1958 and B. Purvis, *Salisbury: the changing city*. Derby: Breedon, 2003. Further examples are given in R.E. Zupko, *British Weights & Measures*, p. 42 and pp. 46-9.

changes they persisted until the arrival of the Anglo-Normans or, in some cases, until the seventeenth century.[150] The fist unit appeared in early Irish (Brehon) law tracts during a description of the type of man who is a suitable candidate for the role of *ráth*.[151] Part of the man's wealth is denoted by having a shield of "five fists (in diameter)" and a sword of "six fists (in length)". If a fist contained 6 inches, this would make the sword 0.914m in length – an impressive but reasonable value. Laurence Ginnell describes the hand as the more commonly used standard of measure and defined it as extending 'four inches across the palm at the roots of the fingers, six inches across at the thumb with the thumb extended'; i.e. approximately the measure of a shaftement.[152] Ginnell provided no evidence of the precedence of the hand measure and did not mention it again. However, the fist is also mentioned in relation to "a handful of candles eight fists in length" being used as a form of payment.[153]

Of the more abstract measures of distance, if not an actually unit, represented the area of sanctuary around the dwelling-house of a clansman which was defined as the distance that he could throw, while sitting in his house, a *cnairseach*. The *cnairseach* is usually described as a spear that had a head of iron attached to a wooden handle 'twelve fists' in length, approximately 1.828m.[154] If a sucking-pig were stolen the retribution was payment of 2 *máms*, "a mám being all the corn it was possible to raise between the two hands".[155] The use of a range of upper body measurements suggests that some of these might have made their way into common usage for activities such as building works.

Before leaving this discussion on the origin of medieval architectural units, a final reminder must be given of the possibility that systematic errors could have existed in some measurements.[156] This means that the measuring instrument used by a mason no longer agreed with a specified standard and therefore all measurements made with that rod were short or long by a fixed amount.[157] It is unlikely that this study would be able to detect

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[150] L. Ginnell, *The Brehon Laws, A Legal Handbook*, Ori Publication: The Gresham Press, Unwin Brothers, Chilworth & London. London: T. Fisher Unwin, 1894. A booksulster.com digital reproduction, p. 6 (hereafter *Brehon Laws*).
[151] The witness and surety giver in a deal: F. Kelly, *Early Irish Law*, pp. 170-1.
[152] L. Ginnell, *Brehon Laws*, p. 209.
[153] L. Ginnell, *Brehon Laws*, p. 117.
[154] L. Ginnell, *Brehon Laws*, pp. 208-9.
[155] L. Ginnell, *Brehon Laws*, p. 197.
[156] A systematic error is an error which occurs with the same sign and the same magnitude every time that a particular piece of equipment is used. Its effect is cumulative and in modern surveying can be removed through the use of calibration techniques i.e. the checking of one piece of equipment against a higher quality, reliable standard.
[157] Matthew Raper quoted the example from 1668 of a "mason's foot" which was found "to exceed the foot of the Chatelet by 5/72 of a Paris inch, which is about 1/14 of a London inch". M. Raper, 'Enquiry into the Measure of the Roman Foot', *Philosophical Transactions*, 1760, 51 (ii), 774-823, p. 823 (hereafter 'Enquiry') quoting Picard in De Mensuris, in Divers Ouvrages de Mathematique et de Physique, par Messrs, de

such an issue, being more likely to be traceable in ground plans, but this serves as a reminder that units which do not agree with documented or known values could still have originated as standards but over time they became damaged through use or intention.

Metrology and governance

Any comprehensive studies of metrology have concluded that change in measurement standards is a reluctant process and is usually not undertaken without the influence of outside stimulus.[158] Legal impetus is responsible for most changes although trade and the movement of peoples can also have an influence. This section seeks to identify the possible Irish impacts of legal and governmental intercessions as regards metrology and, later, to align these policies or changes with evidence from medieval buildings. The content in this section is supplemented by the data included in appendix 2, which charts a significant number of references to measurement-related information from the rolls and statutes of the English and Irish parliaments from the late twelfth to the early sixteenth centuries.[159]

Although English legal influence over Ireland did not truly begin until the twelfth or possibly thirteenth centuries, but it is important to note that efforts at standardisation of trade measures, particularly the ell and the yard in the context of length, had begun in the ninth and tenth centuries with Kings Ethelred, Edgar and Cnut.[160] The most significant twelfth century efforts at standardisation were Henry I's (1100-1135) issuing of the Iron Ell, said to represent the length of his arm, and Richard I's (1189-1199) 1189 London Assize of building which included a regulation that walls must be built with particular

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l'Academie Royale des Sciences, Paris 1693, in folio, and afterwards printed in the 4th vol. of Ouvrages adoptez.

[158] See, for example, the works of P. Grierson, *English Linear Measures*; P. Kidson, 'A Metrological Investigation', *Journal of the Warburg & Courtauld Institutes*, 1990, 53, 71-97 (hereafter 'Metrological Investigation'); W.H. Prior, 'Notes on the Weights and Measures of Medieval England', *Bulletin Du Cange, Archivum Latinitatis Medii Aevi*, 1924, 1, 77-97, 141-70; F.G. Skinner, *Weights and Measures*; R.E. Zupko, *British Weights & Measures*.

[159] A good review of general laws related to weights and measures in England from the eleventh century onwards is given by J.T. Rosenthal, 'The Assizes of Weights and Measures in Medieval England', *The Western Political Quarterly*, 1964, 17 (3), 409-22 and for a less modern perspective see H.J. Stephen, *New Commentaries on the Laws of England*. 4 ed. Vol. 2. 4 vols. London: Hodges, Smith & Co., 1858, pp. 527-9.

[160] 865-871, The Laws of King Ethelred demonstrated that attempts were being made to protect English citizens from the problems of a lack of standardisation with a recommendation that the use of "false weights and wrongful measure" result in the perpetrator being "earnestly shunned". B. Thorpe, *Ancient Laws and Institutes of England, comprising laws enacted under the Anglo-Saxon Kings from Æthelbirht to Cnut, with an English translation of the Saxon; the laws called Edward the Confessor's; the laws of William the Conqueror, and those ascribed to Henry I. Also, Monumenta ecclesiastica Anglicana, from the seventh to the tenth century; and the ancient Latin version of the Anglo-Saxon laws. With a compendious Glossary, etc.* Ed. B. Thorpe. London: Record Commission of Great Britain, 1840, pp. 132, 137.

dimensions given in feet.[161] By 1197 Richard had made and circulated standards for measurement made of iron of a length of 1 yard (*ulna*), subdivided into feet, each of twelve inches, and the foot measuring 0.305m.[162]

In relation to the effect of these standards on building, Peter Kidson believed that the only professionals who would have been likely to have enough copies of the standard issued by Richard I's government would have been architects; therefore, use of the standard should be evident in the buildings of the time.[163] Some evidence has been shown by Eric Fernie for the arrival of the foot of 0.3048m at a similar time, but the introduction was by no means effective enough to remove all other units.[164]

The first references to Ireland in the records containing information about measures can be found in the Close Rolls of John I from 1211, where 14 ells of cloth imported from Ireland are to be dyed in the grain.[165] Although Ireland was not yet fully under English governance, a number of grants of Civil Liberties had been made to Dublin in 1192 and Drogheda in 1194, and these included specific regulation of trading activities, although not yet standardisation of measures.[166] As contact between Irish and English merchants grew it would be safe to assume that they would have needed for find some form of compatibility between measures and, as the dominant trading partner, the English standards probably took precedence.

King John I's Irish version of the *Magna Carta* of 1216 included the specification that certain measures were to be observed although the only linear measure included was the ell.[167] From the early thirteenth century onwards evidence becomes readily available for the use of ells as the standard cloth measure although the exact length or the relationship with other variants is never specified. Grants for murage and defensive works

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[161] J.A. Giles, *William of Malmesbury's Chronicle of the kings of England. From the earliest period to the reign of King Stephen.* London: Henry G. Bohn, 1847, p. 445. William credits Richard I with this proclamation but since Henry II was still on the throne it is more likely that the law was passed during his reign. Nothing is written of how these measures were distributed or monitored. J. Harvey, *The Master Builders: Architecture in the Middle Ages.* London: Book Club Associates, 1973, p. 51.

[162] W. Stubbs, *Chronica magistri Rogeri de Houedene.* Rerum Britannicarum medii aevi scriptores. Vol. IV. London: Longmans, Green, Reader, and Dyer, 1868, pp. 33-4. At the time of issue this unit was also designated for use in the measurement of cloth, but this was later replaced by a specific cloth ell/elne: R.E. Zupko, *British Weights & Measures*, pp. 91. Also see the regulations in The House of Commons of Great Britain, *The Statutes of the Realm.* Searchable Text ed. Vol. 1. 2 vols. Burlington, Ontario, Canada: TannerRitchie Publishing, 1810 (hereafter *Statutes*), Roll 25, Statute 3, c. 1; Cap X. and Roll 25, Statute 5, c. 10.

[163] P. Kidson, 'Metrological Investigation', p. 86.

[164] E. Fernie, 'Anglo-Saxon Lengths'.

[165] H.S. Sweetman, *Calendar*, p. 70.

[166] E. Curtis and R.B. McDowell, *Irish historical documents, 1172-1922.* London: Methuen, 1968, pp. 24-31.

[167] For a review of the measurement information in the *Magna Carta* see J.C. Holt, *Magna Carta.* 2nd ed. Cambridge: Cambridge University Press, 1992, p. 461.

for the city of Waterford in 1223 and 1234 included taxation upon cloth and canvas by the ell.[168] Oars of ash were made in Ireland in lengths of 12, 13 and 14 ells to be sent to Winchelsea and in 1243 Henry began work on the hall of Dublin Castle, with its glazed window, 120 feet by 80 feet after the style of Canterbury.[169] Also at this time issues relating to land in Dublin routinely included measurements in feet, as demonstrated by a number of entries in the Dublin White Book.[170]

An entry in the Close Rolls of June 1244 records an order from Henry III to Maurice FitzGerald, justiciary of Ireland, that the model for standardisation in all Ireland is to be taken "from the weights and measures used in the city of Dublin if they be such as can be followed".[171] This document, for the first time, clearly stated that the Dublin standard became the Irish standard, but no examples of the former exist and no documentation states how the Dublin measures related to other known measures.

Somewhere between 1272 and 1303 either Henry III or his successor Edward I, who also demonstrated a laudable enthusiasm for standardisation, oversaw the composition and issue of a bill known as the Composition of Yards and Perches, *Compositio ulnarum et perticarum*, for both England and Ireland, which was the first legal intervention in the connection of measures of length and area. This document contained the specification of:

3 round and dry barleycorns	= 1 inch
12 inches	= 1 foot
3 feet	= 1 yard
5 ½ yards	= 1 rod (perch)
40 rods in length and 4 in breadth	= 1 acre

The standards produced to support this regulation were iron yard bars upon which were marked feet and inches, meaning that the regulation size of each of the smaller units was not based upon multiplication of the smallest unit, the barleycorn, but rather on subdivision of the yard. The inclusion of the awkward calculation of 1 rod equalling 5 ½

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[168] H.S. Sweetman, *Calendar*, p. 177, Letters Patent, Roll 8, p.3 m.9 and p. 316, Close Rolls, Roll 19, 2133. The citizens of Waterford received a further grant in 1250 for fortification and enclosure. H.S. Sweetman, *Calendar*, p. 456, Close Rolls, Roll 34, m. 4.

[169] H.S. Sweetman, *Calendar*, p. 188, Close Rolls, Roll 9, p.1 m.13 and p. 389, Close Rolls, Roll 27, p.1 m.9.

[170] J.T. Gilbert, *History of Dublin*. Vol. 1. 3 vols. Dublin: J. Dollard, 1903 (hereafter *History of Dublin*). For examples see p. 84 from 1238, grant to Radulf le Porter of "ten feet of their ground, in breadth"; p. 95, 1263, settlement of a dispute over "ground, which is sixty feet in length and seven feet in breadth in the front".

[171] H.S. Sweetman, *Calendar*, p. 404, Close rolls, Roll 28, m.8.

yards demonstrates the compromise that these new standards were trying to achieve between units already in use.[172]

Evidence for the ultimate in governmental control, the issuing of physical standards, was not found in Ireland until 1272. A memorandum from the Birmingham Tower, Dublin Castle, recounted by Sir J.T. Gilbert recorded the following:

> "Memorandum, That on the fourteenth day of November, in the first year of the reign of King Edward (I.), William de Balligavoran, late keeper of the King's measures in Ireland, delivered into the Exchequer of Dublin, to Roger Smalrys, appointed by a letter of the King from England to keep the aforesaid measures in the place of the above mentioned William, one standard bushel, one brazen gallon, one brazen quart, not yet proved, one rod for a standard, and three seals, namely, one for sealing weights, another for sealing measures, and a third for sealing ells, one wooden beam, with one pair of leathern scales, half of a piece of lead, one brazen weight, two pounds filled with lead, and one brazen pound filled with lead."[173]

This inventory of standards and materials for the authentication of measures reveals the serious intentions of the English administration as regards weights and measures. The rod, one assumes, was the standard length of the iron yard and the seals were provided as a means of distributing these standards throughout the "cities and vills" of Ireland. The possible link between the timings of these administrative interventions and changes in building practice will be investigated in this research since no connections have yet been made in any Irish architectural historical or archaeological work.

One further item of note in the 1272 memorandum is that the keeper of the King's measures in Ireland was a William de Balligavoran. Balligavoran, also known as Bealach Gabhrain, Belach Gabrán or Beallach Gabhran is an Anglicisation of the Irish for 'Gap of Gowran'. Variants of spelling occur in medieval documentation but researchers in Ormond have mentioned a Butler manor at Ballygaveran associated with the grant of land by William Marshall to Theobald Walter.[174] Descendants such as Theobald le Butiller (descendant of Theobald fitz Walter) held 4 knights' fees at Baligaveran, Gowran and elsewhere in 1247 while in 1317 Edmund le Botiller (descendant of Theobald of 1247) also held 4 knights' fees at Baligaveran, Gowran and elsewhere, thus continuing the Butler connection through the time when the aforementioned William was keeper of measures. Whether William was associated with the Butler family or not could be speculated upon

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[172] R.E. Zupko, *British Weights & Measures*, p. 21.
[173] J.T. Gilbert, *History of Dublin*.
[174] E.S.J. Brooks, 'Machtalewi, a Leinster chieftain', *Journal of the Royal Society of Antiquaries of Ireland*, 1941, LXXI (11 Part 2), 53-5.

but without a documentary link the result is unlikely to be reliable. Irrespective of his familial connections or rank, particular attention must be paid to the use of measurement at St. Mary's Collegiate church, Gowran, which was patronised by the Butler family.

Some standardisation as regards building works in England in the fifteenth century has been shown by an entry in the Parlimentary Rolls from 1442 relating to the strengthening of the Turn Bridge at Snaith over the river Dyke as a result of flooding and its impact on trading throughout the region, including at York, Hull, Beverley and Grimsby. The dimensions of the new bridge specified that it should be "longer in length by 5 yards of the king's standard measure, and in height a yard and a half by the same measure higher than the said bridge now stands". However, in specifying the width of the drawbridge the measure used was "4 feet in breadth using the Paul's foot". Since the two measures are compatible this is not a problem but it is interesting to note the terminology that was used. Presumably it identifies that other options were available for the foot and that the foot of 0.3048m had not yet caused the disappearance of all other units. In further building related legislation, Edward IV's government of 1478 specified the exact size of roof tiles in inches at 10 ½ length by 6 ¼ width by ¾ thick.[175]

Due to continuing problems with the acceptance of standards, when Henry VII took to the crown in 1485 he again reissued the standards, the oldest of their kind still in existence, bearing a "stamp of a crowned letter H".[176] For the first time the legislation also includes a list of the towns to which standards were sent but no Irish towns or cities were included.[177]

This review of English administration of weights and measures from the twelfth century to the end of the fifteenth century has clearly demonstrated that despite increasingly concentrated efforts to standardise measures successive governments were only partially successful. Even when keepers of measures were employed their roles were open to corruption and the quality of the standards that they used was hugely variable. References relevant to regulation of building work are limited to the mid- to late-fifteenth century although grants of land in Ireland made from the twelfth-century onwards specify plot sizes and locations in feet. Which feet these are, however, is not specified, unlike when the foot of St. Paul's is mentioned in some English texts. However, with such

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[175] C. Given-Wilson, P. Brand, A. Curry, R. E. Horrox, G. Martin, W. M. Ormond and J. R. S. Philips, eds. *Parliament Rolls*, Edward IV, January 1478, vi-189, m. 1-2.

[176] R.D. Connor, *The weights and measures of England*. London: Her Majesty's Stationary Office, 1987, pp. 232-78.

[177] C. Given-Wilson, P. Brand, A. Curry, R. E. Horrox, G. Martin, W. M. Ormond and J. R. S. Philips, eds. *Parliament Rolls*, Henry VII, October 1495, tr-vi-508, m. 27.

emphasis being placed on the control of trade it is likely that some of these standards would have transferred into crafts such as masonry and carpentry, at least for dealing in raw materials; quarries dealt in yards and feet, timber in feet, and canvas in ells. Therefore, it is likely that these linear measurements transferred into the masons' craft at some point during the middle ages. With so little documentary evidence, it now becomes a task for the building investigator to try to find evidence for any change in measurement which may align with the legislative interventions considered in this section.

The study which follows will use objective measurement and analysis to try to find the measurements of choice for Irish medieval tracery and, where possible try to link these findings with our knowledge of efforts by successive English governments to control the standard length of medieval measures.

2.1.3 Conclusions on documentary sources of evidence

The findings presented thus far in this chapter have demonstrated that it was possible to gather significant information about tracery, and the tracery-related elements of medieval architecture, from a search of documentary sources. However, most of this information relates to English or continental European masons while only limited evidence exists about Irish medieval masons. Therefore, the third approach to architectural investigation, that of examining the architectural fabric, must be attempted in order to fill as many of the gaps identified at the end of chapter one as possible.

2.2   Physical investigation

This method of investigation has the significant advantage of enabling the researcher to utilise the same materials as those used by the medieval masons. Since no physical investigations of tracery other than those related to stylistic analysis of tracery have been carried out in Ireland, this research must examine the limited number of Irish, British and continental European investigations into the use of geometry and metrology for guidance in how to proceed.

2.2.1 Proportion

Most Irish studies where proportion was specifically examined related to the ground plans of churches.[178] The use of geometric schemes in the setting out of buildings was commonplace from the earliest Irish stone buildings. Harold Leask referred to a Brehon Law Tract which attaches payment to an *ollamh sáer* for a building of dimensions 15 ft by 10 ft, which can be expressed numerically as 0.666 or as the ratio 2:3, and equated this with the average ratio.[179] For stone roofed churches he found occurrences of the 2:3 proportion (including at Gallarus, Kerry and St. Kevin's church, Glendalough).[180] For other stone roofed churches though, a sample from Leask's work showed that the ratios 3:5, 4:5, and 1:√3 had also been used.[181] In his sample of mortared stone churches 2:3 and 3:5 continued to be used as well as some evidence being found for use of 1:2, for example at the cathedral at Clonmacnoise.[182] Meanwhile, during the Romanesque era a sample of ground plans again showed evidence of the use of the proportions 2:3 and variants thereof, 1:2, 2:3, 3:5, 1:√3, as well as the additional ratio of 2:5.[183]

Leask's findings were reconfirmed by Peter Harbison and Lloyd Laing who found that Irish churches prior to the twelfth century were typically of small size, when compared to their European contemporaries, rarely exceeding 40 foot in length, and they often had a length to breadth ratio of 3:2, although the nave and chancel type was sometimes proportioned as a double square.[184] In a more recent study, Tomás Ó'Carragáin carried out a detailed examination of "180 or so" examples of stone churches built between the fifth century and approximately 1100 and found that a wide range of proportions were in use. In the largest grouping of his study, the mortared churches post-900, O'Carragáin demonstrated that the internal dimensions of most churches had ratios between 1:1.3 (0.769 scaling to ~3:4) and 1:1.8 (0.555 scaling to ~13:23), with external dimensions between 1:1.2 (0.833 scaling to exactly 5:6) and 1:1.65 (0.606 scaling to

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[178] Dorothy Kelly studied both proportion and metrology in Columban High Crosses in Ireland and Scotland from the ninth and tenth centuries and found that "a system of proportions which included both rational and irrational ratios, particularly 1:√2" was used. D. Kelly, 'A Sense of Proportion: The Metrical and Design Characteristics of Some Columban High Crosses', *The Journal of the Royal Society of Antiquaries of Ireland*, 1996, 126, 108-46.

[179] H.G. Leask, *Irish Churches & Monastic Buildings*. Vol. I. Dundalk, Ireland: Dundalgan Press Ltd., 1955. 4th, pp. 49-50 (hereafter *Irish Churches I*) and Trinity College Dublin, MSS. H, 2, 16.

[180] H.G. Leask, *Irish Churches I*, p. 22 and p. 32.

[181] H.G. Leask, *Irish Churches I*, p. 22, p. 32 and pp. 49-78.

[182] H.G. Leask, *Irish Churches I*, p. 32, p. 37, pp. 63-4, p. 72.

[183] H.G. Leask, *Irish Churches I*, pp. 79-155.

[184] P. Harbison, *Guide to the National & Historic Monuments of Ireland*. 3rd ed. Dublin 12, Ireland Gill & Macmillan Ltd., 1992, p. 21 and L. Laing, *The Archaeology of Late Celtic Britain & Ireland c.400-1200AD*. London, England: Methuen & Co. Ltd., 1975, pp. 174-5.

~377:610, the Golden ratio).[185] He particularly focused on the four "symbolically significant ratios" of 1:√2, 1:1.5 (2:3), 1:1.618 (Golden) and 4:7 but could not find statistically more occurrences of these ratios than any others, although they did tend to occur at major sites such as Clonmacnoise, Glendalough and Armagh.

Looking at architectural details rather than ground plans Ó'Carragáin's examination of windows found that few original windows survived in the early Irish churches and those that did were small (widths of typically 0.2 – 0.4m and heights of 0.4 and 0.6) but without the greater standardisation that he found for doors: "door heights are consistent [at either *circa* 1.7m or at a little over 1.9m] while their proportions are not".[186]

The great variety of proportions found by a number of researchers, although mostly in the context of ground plans, suggests that the masons of early Irish stone buildings did not think it necessary to follow a particular pattern of ground plan layout, although they did seem to see value in making close approximations to regular ratios. Continuity of methods, down to the end of the Romanesque, seems to have been achieved suggesting either familial ties or an organised method of apprenticeship, as previously suggested by the documentary evidence.

In the late medieval era, however, both the golden section and the 1:√2 proportions were used either independently or together in parish churches in counties Meath and Kildare, in south-west county Dublin, in county Offaly and as part of county Louth's Archaeological Survey.[187] Michael O'Neill's Meath work demonstrated that a number of medieval churches were proportioned width to length using 1:√2 and that the starting point for the geometric work was the definition of the width of the chancel, at one perch in length, based on the foot of 0.3048m.[188] The same 1:√2 proportion was utilised in a number of medieval friaries in Connaught, at Muckross Franciscan friary, and at a number of Cistercian abbeys throughout the country.[189] Tadhg O'Keeffe found that the plan of Fethard Holy Trinity church demonstrated construction according to proportional design principles with the width of the nave, including the aisle, being twice as wide as the width

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[185] T. Ó'Carragáin, *Churches in early medieval Ireland: architecture, ritual, and memory*. London & New Haven: Yale University Press, 2010, pp. 110-113 (hereafter *Churches*).

[186] T. Ó'Carragáin, *Churches*, p. 94 and p. 112.

[187] M. O'Neill, 'Parish Churches Meath'; M. O'Neill, 'Parish Churches Kildare'; M. Ní Mharcaigh, 'Medieval Churches'; E. FitzPatrick and C. O'Brien, *Medieval Churches;* V. Buckley and D. Sweetman, *Archaeological Survey of County Louth*. Dublin: Government of Ireland, 1991.

[188] M. O'Neill, 'Parish Churches Meath', pp. 35-42.

[189] S. Mannion, 'Medieval friaries of Connacht'; R. Stalley, *Gaelic Friars* and R. Stalley, *Cistercian Monasteries*.

of the chancel.[190] The method of investigation for each of these studies simply involved measurement of the length and breadth of the ground plan of a building. No attempts were made to extend the examination to any architectural details.

Of the above-mentioned studies, only Tomás Ó'Carragáin's early medieval work included any investigation of architectural details, thus a gap in our knowledge exists and this thesis uses window tracery specifically to start to fill this.

Britain

In Britain, as in Ireland, architectural historians have tended to concentrate on stylistic analyses of medieval architecture, supported by documentary evidence, rather than on measured examinations of fabric. While there is a general belief in the use of geometry and in the dominance of the $1:\sqrt{2}$ proportion, very little research has been produced where investigators have shown, through empirical approaches, how widespread the use of proportion actually was. Many examples of the geometric layout of ground plans have been recorded but architectural details have not. A major discussion between two noted historians might demonstrate why many researchers avoid this method of study, while also providing some precedent for how this work can proceed.

One of the great medieval cathedrals of England at Norwich has been the subject of study with respect to geometry and systems of proportion for two authors, Eric Fernie and Nigel Hiscock.[191] Fernie explained that this cathedral was a very good candidate in which to search for proportional systems because of its accurate dating to the last years of the eleventh century, and because it was set out on a vacant site on which no previous buildings had been constructed.[192] To facilitate the investigation Fernie produced a detailed set of measurements of the cathedral including the lengths of each bay, overall dimensions of the nave, chancel, transepts and cloister, widths of walls, and detailed measurements of the shape and size of the piers. His analysis concluded that a system of proportion based on $\sqrt{2}$ was used, not only for laying out the plan of the building, but also for setting out the details of the major and minor piers, and for relating the position of the Cathedral to the bishop's palace. This, he proposed was part of the designer's "fascination

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[190] T. O'Keeffe, 'Townscape as text: the topography of social interaction in Fethard, county Tipperary, AD 1300-1700', *Irish Geography,* 1999, 32 (1), 9-25, p. 17.

[191] E. Fernie, 'Norwich Cathedral Root Two'; E. Fernie, *An architectural history of Norwich Cathedral.* Oxford, England: Clarendon Press, 1993; N. Hiscock, 'A Schematic Plan for Norwich Cathedral.' *Ad Quadratum: the Practical Application of Geometry in Medieval Architecture.* Ed. N.Y. Wu. Aldershot, England: Ashgate Publishing Ltd., 2002. 83-122 (hereafter 'Norwich Schematic Plan').

[192] This is a rare occurrence throughout the medieval world. E. Fernie, 'Norwich Cathedral Root Two', 77.

by the square root of two" which lead to its widespread usage in the building and may indicate "a desire for some form of geometrical unity in complexity".[193]

In Nigel Hiscock's study of the same cathedral, he showed that the Platonic geometrical shapes of the "equilateral triangle, square and pentagon" were used extensively in the planning of the building using measurements taken with an Electronic Distance Measuring instrument and analysed in Computer Aided Drawing software.[194] Three geometrical figures were used during the design of the plan of the cathedral resulting "in a grid for a greater crossing from which the rest of the layout can be constructed, and it accounts for the differential spacing of the wall and arcade piers".[195] The process required sixteen steps in order to set out the full ground plan and the locations of the piers.

In the introduction to the AVISTA *Ad Quadratum* volume in which Hiscock's results are published, Fernie disagreed with Hiscock's conclusions claiming that they are "unnecessarily complicated" since Hiscock's theory "requires two overlaid systems". Fernie also believed that one of the parts of the result was "more likely to be the result of errors in construction".[196] Hiscock responded to this criticism stating that "circumstantial evidence, however abundant, does not amount to proof" and that theories need to respond to new questions as the "debate moves on".[197] This discussion indicates that even though digital and accurate measurement and analysis techniques can facilitate investigations into geometric systems, they do not guarantee the production of an explanation that is acceptable to all.

In agreement with Eric Fernie's comments on this work I find it difficult to believe that such complexity would have been chosen over the much simpler scheme of 1:√2 for which contemporary written evidence, although not on this site, is available. Nigel Hiscock's scheme was not proven through any clear link to documentary evidence and seems unnecessarily complicated, particularly in relation to the methods described for transferring from the tracing house to the ground.

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[193] E. Fernie, 'Norwich Cathedral Root Two', p. 86.
[194] N. Hiscock, 'Norwich Schematic Plan', p. 86.
[195] N. Hiscock, 'Norwich Schematic Plan', p. 106.
[196] E. Fernie, 'Introduction' *Ad Quadratum: the Practical Application of Geometry in Medieval Architecture.* Ed. N.Y. Wu. Aldershot, England: Ashgate Publishing Ltd., 2002. 1-9 (hereafter 'Introduction').
[197] N. Hiscock, 'Norwich Schematic Plan', p. 106.

Continental Europe

As in other locations only a limited number of measured investigations of the use of geometry in continental Europe have been reported.[198] Marie-Thérèse Zenner and James Addis have both carried out noteworthy studies of the use of geometry at the cathedral of Saint-Etienne in Nevers.[199] While Addis' methods are conventional, it is in Zenner's study that we find a new and relevant method of analysis. Zenner theorised that this cathedral was not set out using the techniques of squares, diagonals, or *ad quadratum* but rather that all dimensions were based on "three measures, or whole fractions thereof and the rotation of these measures to form circles or arcs of circles".[200] Of particular significance to the present investigation is the application of this hypothesis to the third dimension by including elevations and the height of the crossing dome. The suggestion that the use of proportion in all three-dimensions occurred is interesting for this investigation although Zenner herself warned about the dangers of drawing too many conclusions based on a single building.

Although not describing a new methodology for data collection, Michael T. Davis also demonstrated the flexibility and relevance of AutoCAD as an analysis tool by showing its ability to explain the geometrical basis of the tracings on the terrace of Clermont Cathedral. He copied the tracings before scanning them into AutoCAD where they could be successfully compared with a range of geometrical solutions.[201] A similar CAD-based method was used by Danielle O'Donovan in her analysis of the cloister arches of the Augustinian friary at Adare. She theorised that a skilled English mason controlled construction during the building of early parts of the cloister, but that after he left the Irish

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[198] Potentially, a large number of the papers contained in the Avista volume N.Y. Wu, ed. *Ad quadratum: the practical application of geometry in medieval architecture*. Aldershot: Ashgate, 2002 (hereafter *Ad quadratum*) could be included in this review since they refer to the evidence found for geometric planning in English and European cathedrals and churches. However, the methods used are very similar and reveal little more than that a set of measurements is required before starting to investigate geometry. The relevant papers not mentioned in the following are: E.M. Shortell, 'The Plan of Saint-Quentin: Pentagon & Square in the Genesis of High Gothic Design', V. Paul, 'Geometry Studies: The Blind Tracery in the Western Chapels of Narbonne Cathedral', 205-16 (hereafter 'Geometry Studies'); S. Murray, 'Reconciling the Feet at Beauvais & Amiens Cathedrals', 169-182 (hereafter 'Reconciling'). Similar published work includes: S. Murray, 'Bleuet and Anthoine Colas, Master Masons of Troyes Cathedral. Artistic Personality in Late Gothic Design', *The Journal of the American Society of Architectural Historians*, 1982, 41 (1), 7-14 and M.T. Davis, 'On the Threshold of the Flamboyant: The Second Campaign of Construction of Saint-Urbain, Troyes', *Speculum*, 1984, 59 (4), 847-84.

[199] M.-T. Zenner, 'A Proposal for Constructing the Plan & Elevation of a Romanesque Church Using Three Measures.' *Ad Quadratum: the Practical Application of Geometry in Medieval Architecture*. Ed. N.Y. Wu. Aldershot, England: Ashgate Publishing Ltd., 2002. 25-56 (hereafter 'Three Measures'); J. Addiss, 'Measure & Proportion in Romanesque Architecture.' *Ad Quadratum: the Practical Application of Geometry in Medieval Architecture*. Ed. N.Y. Wu. Aldershot, England: Ashgate Publishing Ltd., 2002. 57-82 (hereafter 'Measure & Proportion').

[200] M.-T. Zenner, 'Three Measures', p. 25.

[201] M.T. Davis, 'On the Drawing Board'.

masons in charge of completing the cloister were unable to achieve the same type of three-centred arches because of their lack of skill in geometrical design and execution.[202] Such methods have already been employed in this review to analyse the tracings at Corcomroe Cistercian abbey and Roslyn church.

Reference must also be made to possibly the most closely-related study to this work which was carried out by Vivian Paul on Narbonne cathedral and which was reviewed previously.

This brief summary demonstrates that a significant number of historical studies have attempted to uncover the geometrical plans behind medieval architecture. They all agree that the most critical requirement for any investigation is the extraction of a variety of measurements, preferably in three dimensions, which can be tested against a variety of possible schemes but without making the result overly-complicated.

2.2.2 Metrology

This section sets out the methods by which metrological standards can be derived using physical investigations of an object's fabric, as carried out in examples from Ireland and abroad.

Medieval tolerance

Any study of the physical evidence of buildings must take cognisance of the tolerance with which the original builders worked. Knowledge of the original units used helps to make sense of measurements being made, such as found by, among many others, Matthew Cohen in relation to various Italian braccio lengths when investigating Brunelleschi's Basilica of San Lorenzo in Florence.[203] However, when the object of the study is to derive the unit of measurement, Eric Fernie's advice is: "the smaller the size of the object the more accurate the measurements of both the builder and the investigator, and hence the greater the robustness of the analysis." Given that the objects in question in this study are windows, then high accuracy is required. But what is the meaning of 'high accuracy'?

A thorough review was conducted of the possible foot measurements that were in use in Europe in the middle ages, with the conclusion that few overlapped by more than

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[202] D. O'Donovan, 'Building Butler', pp. 240-1.
[203] M.A. Cohen, 'How Much Brunelleschi? A Late Medieval Proportional System in the Basilica of San Lorenzo in Florence', *Journal of the Society of Architectural Historians,* 2008, 67 (1), 18-57.

1cm (Table 2.1).[204] Observation of the stone of many of the windows to be measured in this study suggested that obtaining measurements more accurate than 1cm would be difficult owing to wear and damage to the stone, most window being cut from deteriorating limestone as a result of unprotected exposure over long periods. Therefore, it was assumed that the medieval tolerance was unlikely to have been higher than 1cm which approximates to 3% of the standard foot of 0.3048m.

Table 2.1 Relevant foot units and their lengths in metres

Unit	Value (m)
Dodorans	0.2232
Natural or Pythic foot	0.2490
Pan (French) or Welsh foot	0.2516
Bettess's Anglo-Saxon foot (Jarrow)	0.2800
Standard Roman foot	0.2963
English or Irish foot	0.3048
Rhineland or Prussian foot	0.3140
English foot (medieval)	0.3170
French foot or *pied du roi*	0.3248
Celtic or North German foot	0.3350
Ped manualis	0.3540

Guidelines for metrology studies

It is recognised that one of the most necessary requirements for any study of ancient buildings is the availability of accurate measurements upon which to "test theories by calculation".[205] However, even where measurements have been made using the most robust methods, caution must still be exercised. Scholars working in the field of historical metrology have long acknowledged that "one can get any foot from any building".[206] Therefore, to avoid such incorrect outcomes Eric Fernie has put forward a set of three safeguards for those studying medieval metrology; restricting solutions to known units of length, checking for the use of incommensurate or irrational ratios, and not dismissing unusual numbers of units.[207]

The inclusion of the final safeguard is a development from Fernie's expressed ideas of 1978 which stated that only units "already known from archaeological or documentary sources" should be used else the "field of possibilities is so large that one can hardly avoid arriving at an answer". Aligning results with known units is particularly pertinent to and problematic for Irish medieval studies because of the acknowledged

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[204] The relationships between these units is presented graphically in Appendix 3.
[205] E. Fernie, 'Introduction', p. 1.
[206] M. Raper, 'Enquiry'.
[207] E. Fernie, 'Introduction', p. 3.

shortage of contemporary reference sources.[208] It is very probable, in fact almost certain, that some of the units which were used in Ireland in the middle ages were sparsely documented, if at all, and that in many cases those documents have not survived to modern times. Therefore, while attempts must be made to identify known units, results which point to undocumented units must also be considered, provided the evidence is reliable and based on statistically significant samples.

It is also important to remember that the decision about the building unit may not have been made by the master mason or the designer, but rather by the craftsman setting out the building on the ground. The modular or scaleless types of design exemplified by some of the drawings discussed previously demonstrate that it was essential for the mason to be able to transfer the design onto the ground using the simplest of techniques; thus the use of the great compass and cords of fixed length as well as measuring rods. With these methods masons were able to ensure that the "angles remain the same in the transfer and likewise the proportions".[209]

Paul Frankl suggested that "the mason would have had to have his footrule cut whenever he arrived at a new place". This suggests that the individuals cutting the footrule would then have used the local version of the foot measure which, of course, varied from region to region.[210] While it is plausible that this happened on some or many occasions, there is also the possibility that the master mason brought his own standard with him, as was the cause of the discrepancies at Beauvais and Amiens cathedrals which are discussed in the following.[211]

Some attention must also be paid to the possibility that there is a distinction between "what was meant and what was built".[212] For example, owing to the necessity for a mason to provide his own tools and the mobile nature of his work place, had a measuring rod been damaged or broken, it is likely that the mason would have continued using it despite its condition.[213] This is the same fate that befell many of the measurement standards issued by governments throughout the middle ages.[214] Therefore, while the

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[208] For a detailed description of the "calamities to befall Irish official records since the middle ages" see P. Connolly, *Medieval Record Sources*. Dublin, 2002 particularly pp. 9-13.

[209] P. Frankl, *The Gothic: Literary Sources and Interpretations through Eight Centuries*. Princeton, New Jersey: Princeton University Press, 1960, p. 51.

[210] P. Frankl, 'The Secret of the Medieval Masons', *Art Bulletin*, 1945, 27, 46-60, p. 49.

[211] S. Murray, 'Reconciling'.

[212] N. Hiscock, *The Wise Master Builder: Platonic Geometry in Plans of Medieval Abbeys & Cathedrals*. Aldershot, England www.ashgate.com: Ashgate Publishing Ltd., 2000.

[213] L.R. Shelby, 'Geometrical Knowledge'.

[214] R.E. Zupko, 'The weights and measures of Scotland before the Union', *Scottish Historical Review*, 1977, 56, 119-45, p. 121.

mason may have intended to use an English foot measure, he may, in reality, have used an English foot with a portion removed.

Unit extraction methods

During excavations at Jarrow abbey Fred Bettess observed a series of dimensions for wall lengths and window and door openings, ensuring that all measurements were taken using the same tension on a steel tape and for parts of the building that were contemporary, all being from an early phase.[215] He then used the statistically reliable technique of least squares, which evaluates the probability of one result being more likely than any other by searching for a minimum difference from the true value, to source the unit of measurement.[216] The general method is entirely objective as any unit can be tested against the measurement set – units from 0.250m to 0.360m were used in the case of Jarrow - and the correctness of the returned most probable unit can be evaluated via reliability statistics. Bettess' derived value of a foot of 0.280m for this site during the Anglo-Saxon phase of building compared well with a value of 0.281m given by Brian Hope-Taylor for a building at Yeavering.[217] The two buildings "are not all that far apart in time or place" making the result more plausible although evidence from a larger sample would be helpful.[218] From the statistical perspective Bettess' work, although objective, useful, and successful, could be challenged because of the very small sample of test measurements. Fred Bettess acknowledged this shortcoming and recommended the use of more measurements to increase the reliability, thus creating a sound methodology that merits consideration in this research.

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[215] F. Bettess, 'The Anglo-Saxon Foot: A Computerised Assessment', *Medieval Archaeology,* 1991, 35, 44-50 (hereafter 'Anglo-Saxon Foot'). The use of window opening is an interesting precedent for the work which follows in this study as this quantity is also assessed.

[216] A form of probability test frequently used in geomatics and land surveying where "a set of measurements must relate to each other, e.g. within a defined algorithm such as the equation of a line or the definition of a plane, such that the sum of the squares of the differences equals a minimum". See B.D.F. Methley, *Computational Models in Surveying & Photogrammetry.* Bishopbriggs, Glasgow G64 2NZ: Blackie & Son Ltd, 1986. Imagine trying to fit a straight line through three non-linear points in two-dimensional space; for each possible position of the line a measurement can be made of the distance between each point and that line; if we identify a large number of possible straight lines through these three points we will produce three distance difference measurements for each possible line; since sometimes the difference will be positive and sometimes negative it is necessary to 'square' the measurements to remove the influence of the sign; for each group of three measurements related to one line these squared differences can be summed; when the summed differences are compared by finding the smallest one, i.e. the least squares, we have found the best possible location for the straight line, that is the line which best fits between the three available points. The technique is not limited to specific numbers of points or to two-dimensional problems, and has been proven to be very reliable in deriving solutions to complex problems.

[217] B. Hope-Taylor, *Yeavering: an Anglo-British centre of early Northumbria.* London: H.M.S.O., 1977.

[218] F. Bettess, 'Anglo-Saxon Foot', p. 50.

Harry Sunley improved upon Fred Bettess's technique mainly by significantly increasing the number of measurements from which his conclusions were drawn. He sampled some 2000 measurements of English Norman parish churches, cathedrals and monastic sites. He too divided each measurement by potential unit values, from 0.05m to 0.60m, finding that the most likely unit had a length of 0.280m. Sunley found difficulty in aligning his result with any known unit and was reluctant to suggest its links to Fred Bettess' result because of the latter's small sample.[219]

David Walsh studied measurement and proportion at Bordesley Cistercian abbey and contemporary Cistercian sites.[220] His method was to analyse measurements of the masonry of the buildings, which were taken during excavations, by dividing them by whole numbers and checking the resulting quotients "against known lengths of medieval feet".[221] Using this method Walsh was able to define both the system of proportion, 3:4 ratio, and the unit of measurement, 0.295m. Walsh then compared these results with two contemporary abbeys, Fountains and Kirkstall, which "were planned and built within a generation of Bordesley".[222] While the same unit of measurement seems to have been used at all three sites the method of planning varied. At Kirkstall the same ratio of 3:4 was probably used, while at Fountains a simple grid was more likely. Walsh suggested that some of the differences in design may be explained by more "continental influence" at Kirkstall. However, only simple integer searches were used to find these answers and the potential use of ratios of the primary unit was not considered.

In a computational approach which has some similarity to Bettess's method, Wolfgang Wiemer and Gerhard Wetzel addressed the issue of finding systems of geometrical design and the preferred unit of measurement in the church of the Cistercian abbey of Ebrach, Franconia.[223] The origins of some of the geometric arrangements tested were derived from the fifteenth-century lodge books of Matthäus Roriczer and Hans Schmuttermayer.[224] Wiemer and Wetzel specified that all measurements must be taken "either in the external, internal, or axial measurement, or in succession between these, but not together" otherwise there is "a relatively high probability that the relation of any two

[219] H. Sunley, 'The Quest for the Linear Measure Used in Norman England', *Corpus of Romanesque Sculpture in Britain and Ireland,* 2004, Spring 2004, 3-5.
[220] D.A. Walsh, 'Measurement and Proportion at Bordesley Abbey', *Gesta,* 1980, 19 (2), 109-13 (hereafter 'Bordesley Abbey').
[221] D.A. Walsh, 'Bordesley Abbey', p. 110. Walsh does not mention which "medieval feet" values were used.
[222] D.A. Walsh, 'Bordesley Abbey', p. 110.
[223] W. Wiemer and G. Wetzel, 'A Report on Data Analysis of Building Geometry by Computer', *Journal of the Society of Architectural Historians,* 1994, 53 (4), 448-60 (hereafter 'Geometry by Computer').
[224] W. Wiemer and G. Wetzel, 'Geometry by Computer', pp. 451-2.

measurements will accidentally fall into the range of one of these coefficients".[225] Based on the results from the program written to carry out the search for patterns, the authors were able to conclude that the unit of measurement for the building was the *pied du roi* of 0.3196m and that the precision of construction was "surprisingly high". They also found that one geometrical unit formed the basis of the entire system of planning, and that the golden section was influential.[226]

The unit extraction method used by James Addis in his study of the cathedral of Saint-Etienne in Nevers was simply based on integers where a distance was measured in metric form and was divided by a standard Roman foot to see if the result was an integer or fractions of an integer.[227] Addis mentioned that the actual values for the foot obtained using this method were more correctly 0.2954m and 0.2953m, but that 0.2957m was used because it "is a norm, not an invariable and exact measure".[228] Addis did not consider any other units of measurement in his study, however, he did verify that this unit was in use at the time of building and cited other buildings where it had been employed, such as Cluny III and Le Puley.[229]

One other method reported in the literature that was considered prior to the commencement of this study was that devised by David Kendall in order to evaluate whether a fixed unit of measurement, the so-called quantum, was used in the layout of megalithic sites throughout Britain and what that unit might be.[230] The simplest explanation of the method was that all available measurements, for some 200 sites, needed to fit the equation $X = Mq + \varepsilon$ (where X is the measurement, M is the number of whole numbers, q is the value of the quantum and ε is the error in the measurement). While his tests involved some complex probability interrogation, Kendall's conclusion was that, based on the available evidence, he could not rule out the possibility that a quantum unit existed. While not very conclusive and somewhat remote in the subject of its investigation this study has been included because it demonstrates the need expressed by statisticians for a high degree of certainty in concluding that a unit was used for a particular set of measurements.[231]

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[225] W. Wiemer and G. Wetzel, 'Geometry by Computer', p. 456 and E. Fernie, 'Anglo-Saxon', p. 2.
[226] W. Wiemer and G. Wetzel, 'Geometry by Computer', p. 459.
[227] J. Addiss, 'Measure and Proportion'.
[228] J. Addiss, 'Measure and Proportion', p. 61.
[229] J. Addiss, 'Measure and Proportion', p. 67.
[230] D.G. Kendall, 'Hunting Quanta', *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences,* 1974, 276 (1257), 231-66 (hereafter 'Hunting Quanta'). Kendall suggested that a whalebone rod or pacing may have been used or, perhaps, the height of a man in order to facilitate easy transferral of the unit and method over space and time.
[231] D.G. Kendall, 'Hunting Quanta', p. 232.

The approach taken in this study is a variation on the methods employed by Fred Bettess, David Walsh and James Addiss, cognisant of the lessons learned in the other studies reviewed above, and is described in detail in Chapter 3.

Multiple units on single sites

Although the previous group of studies resulted in simple solutions where the evidence clearly pointed at one preferred unit of measurement, there were also cases where more than one unit was used on site, and not only during different phases of building. Some examples are given in the following.

In his study of Beauvais and Amiens cathedrals, Stephen Murray proposed that a number of units of measurement may have been used during building as a result of differences in practice between the "out-of-town master mason" and the "local labourers and artisans".[232] The units that Murray found to be evident in the buildings were the royal foot (0.325m) and a smaller local unit (~0.295m). The local foot can be traced to the standard Roman foot, while the royal foot would typically have been the unit of choice for master masons who travelled with their craft. Murray also commented that it would have suited the local labourers to prefer the local unit where payments were made in respect of units excavated and built.[233]

It is also important to mention that most medieval buildings, including the ones utilised in this study, were altered over the course of their useful lives. This factor certainly contributed to the possibility of variation in the metrological system adopted during building. As commented by James Addiss "designers were constantly experimenting, and if one approach ever became standard for a time or in a place, we do not yet know it".[234] For instance, Elizabeth Sunderland found evidence for the use of two feet at the monastery of Charlieu, the Roman foot of 0.296m for the ninth century church and 0.320m for the tenth century rebuild. However, the contemporary tenth-century monastic buildings on the same site were set out using a Carolingian foot of 0.340m, while by the time that the twelfth century porch was added another derivative of the Roman foot, this time at 0.295m, was used. Sunderland demonstrated that a similar range of foot lengths had been used at the contemporary work at Cluny, suggesting that the variation was caused by a change of abbot and that this new abbot ushered in new metrology which

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[232] S. Murray, 'Reconciling', p. 170.
[233] S. Murray, 'Reconciling', p. 171.
[234] J. Addiss, 'Measure and Proportion', p. 69.

was disseminated to the other Clunaic houses, such as Charlieu.[235] Presumably the change of abbot meant a change of mason which could, given the range and localisation of possible units available in the middle ages, have resulted in systematic change. Sunderland also suggested that by tracking changes in measurement it may be possible to improve the dating of structures, provided relevant parallels can be found.[236]

This study will attempt to identify whether such standardisation can be found to have occurred in medieval Ireland.

Irish medieval metrology studies

As stated in the introduction to this thesis, part of the reason for this study is that very little is known about the units of choice of medieval Irish masons. A number of authors have intimated the use of certain units but frequently without recourse to actual measured evidence. This section will review a number of studies not yet discussed in relation to geometry or tracery.

Starting with pre-medieval Irish stone building in the form of round towers, Roger Stalley acknowledged that the "exact length of the Irish foot is unknown" and that it is possible that the length of an Irish foot may have varied from region to region. However, he provided evidence from a range of round tower measurements to suggest that 0.3048m was a preferred unit based on heights of 100ft and a ratio between height and circumference of 1:2.[237] This echoes George Petrie's assessment that round towers have a standard measurement.[238] Since Stalley also suggested that the heights of many round towers throughout Ireland approximate to half this value, this would then lead us to assume that we could expect to find evidence for the use of this unit within our study.

In his work on the Cistercians in Ireland Roger Stalley commented that: "it has been assumed that the Irish Cistercians were using a measure based on the old English foot of twelve inches, though one cannot be certain of this".[239] This unit has a metric value of 0.3048m but Stalley also mentions a number of other medieval foot units that merit

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[235] E. Sunderland, 'Feet and Dates at Charlieu', *The Journal of the Society of Architectural Historians*, 1957, 16 (2), 2-5 (hereafter 'Feet and Dates').

[236] E. Sunderland, 'Feet and Dates', p. 5.

[237] R. Stalley, 'Sex, Symbol, and Myth: Some Observations on Irish Round Towers.' *From Ireland coming: Irish art from the early Christian to the late Gothic period and its European context.* Ed. C. Hourihane. Vol. 4. *Index of Christian art occasional papers.* Princeton: Princeton University Press, 2001, pp. 27-47 and pp. 38-39.

[238] G. Petrie, *The Ecclesiastical Architecture of Ireland anterior to the Anglo-Norman Invasion, comprising an Essay on the Origin and Uses of Round Towers of Ireland.* 2nd ed. Dublin, 1845, pp. 361-2.

[239] R. Stalley, *Cistercian Monasteries*, p. 71.

consideration: Roman (0.2957m), Carolingian (0.3329m) and French *pied royale* (0.3248m). The direct connection with the Clairvaux house emanating from St. Malachy's visit to France and the arrival of the monk Robert to assist with its foundation suggests that the French *pied royale* may have been used at Mellifont. However, Stalley refuted this suggestion by saying that, when the main measurements for Mellifont are calculated in *pieds royals* they do not make any sense since they do not equate to any integers or logical parts thereof. Furthermore, Stalley noted that "several Irish cloisters approximate to a hundred English feet" providing more support for the possibility that this unit was preferred. [240]

In work on the early thirteenth-century sections of Christ Church cathedral, Dublin, which has been shown to have strong English West Country connections, Roger Stalley suggested that the proportions used in both plan and elevation were based on the width of the bay which measures 16ft 2 ½ in (using the modern Irish or English foot value of 0.3048m). This measurement is "close" to the perch of 16ft 6in and Stalley hinted that this may have been "the theoretical starting point".[241] As well as demonstrating the usage of common units between Ireland and England, this evidence clearly shows the difficulty of separating the intended measurement from that which was actually executed.[242]

Earlier work relating to architectural sculpture by Dorothy Kelly found that the Roman Standard foot of approximately 0.296m was used in the design of Columban High Crosses of the ninth and tenth centuries. With the scale of Irish medieval ecclesiastical building works being small enough that the same mason may have been responsible for sculptural detailing as well as stone carving, such as tracery, it is possible that a measurement significant to sculptors in the early middle ages would still be evident in works of the later period.[243]

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[240] In his work on Muckross Franciscan friary Stalley suggested that the intended width of the cloister was 50ft but admits that it is only possible to achieve this if an external wall is included, and even then only on one side. Whether this lack of regularity shows that the 50ft dimension was not actually intended or that the builders were incapable of executing the monks' requirements may never be solved. R. Stalley, 'Gaelic Friars' and R. Stalley, *Cistercian Monasteries*, p. 71.

[241] R. Stalley, 'Three Irish Buildings with West Country Origins.' *Medieval Art & Architecture at Wells and Glastonbury*. Eds. N. Coldstream and P. Draper: British Archaeological Association Conference Transactions, 1981. 62-80, p. 74.

[242] However, the main focus of Stalley's work was to provide evidence that strong influence was exerted on Irish building of the early thirteenth-century by West County buildings and masons; N. Hiscock, 'Wise Master Builder', p. 201.

[243] Dorothy Kelly studied both proportion and metrology in Columban High Crosses in Ireland and Scotland from the ninth and tenth centuries. D. Kelly, 'A Sense of Proportion: The Metrical and Design Characteristics of Some Columban High Crosses', *The Journal of the Royal Society of Antiquaries of Ireland*, 1996, 126, 108-46, pp. 137-9.

2.2.3 Conclusions

One of the conclusions of this review of physical investigations of architecture is that no exact precedent exists for how an empirical study of metrology and proportion should proceed. However, taking the most successful elements of a number of these studies will create a methodology that I believe will be capable of answering the questions posed at the end of chapter one, particularly those not addressed through the use of a documentary approach. Furthermore, this work will comprehensively test the utility of an empirical approach to tracery investigation.

3   Methodology

Having identified the need for a physical examination of the building fabric, in this chapter the applied method will be described in respect of site measurement and analysis, as well as the regions and era of study. The first two sections explain the choice of data collection methods, the safeguards implemented to ensure reliability and the processing steps designed to extract the required information, that is, to address the aims of this work. The third section defines the temporal context and limits of this investigation. The remaining sections describe the study regions and the reasons for their selection.

The findings of the investigations into tracery and geometrical design studies discussed in chapter two have shown that accurate measurements are a prerequisite for any geometric or metrological evaluation of medieval architecture. While the requirement for measured data is agreed amongst historians, the method by which such information can be collected is still the subject of much debate. Some researchers, as recently as 2001, still forcefully advocated the use of steel tapes and plumb-bobs, techniques that promote "the use of physical contact", to the exclusion of all other instrumentation. Costantino Caciagli, for instance, would "ban every optic instrument" because of the distance that it places between the researcher and the building of interest.[1] This view of measurement is entirely opposite to the *modus operandi* of the professional surveyor which, over the last twenty years, has adapted significantly in order to embrace the benefits of a number of new developments in measurement technology; in particular increased accuracy and speed as well as a reduction in the need for physical contact with the object.[2] If high accuracy measurements can be acquired as quickly as lower accuracy ones then the former option should be taken, mainly because high quality measurements can be easily downgraded, if necessary. In further defence of the use of high quality, remote techniques, one of the modern guiding principles of survey data acquisition is that of "collect once, use many times". This tenet demands that spatial data collection occurs only once at the highest available accuracy in order that it might prove useful for multiple different applications, some of which may not be known at the moment of collection.[3] Therefore, high accuracy remotely sensed data has been collected as part of this study.

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[1] C. Caciagli, 'On Precision in Architecture', *Nexus Network Journal*, 2001, 3 (1), 5, p. 13.

[2] When using tapes and plumb-bobs, measurements can typically only be taken during renovation works while scaffolding is in place. See, for example, J. James, 'Medieval geometry: the Western Rose of Chartres Cathedral', *Architectural Association Quarterly AAQ*, 1973, 5 (2), 4-10.

[3] This change has been driven by the move towards Spatial Data Infrastructures (SDIs) within the European Union and the OECD. See, for example, *OECD Principles and Guidelines for Access to Research Data from Public Funding*. Paris: Organisation for Economic Co-operation and Development, 2007.

Of course, as previously discussed, not all architectural historians have limited themselves to the use of nineteenth-century techniques, and a small few have taken full advantage of new technologies, becoming advocates of their advantages for this specific field of research.[4] However, even when measurements have been acquired with high accuracy, this does not mean that we can blindly accept the conclusions of researchers who have adopted these new techniques. Care still needs to be taken in the data collection phase since the level of automation and the 'black-box' nature of some instrumentation can make it difficult for the untrained user to detect errors.[5] Furthermore, although methods such as those described below aim to produce unbiased results, an element of human interpretation is still needed. Notwithstanding these caveats, the collection of measurements by researchers who understand both the high-end data collection technologies and the requirements of architectural historical studies can significantly minimise the occurrence of all types of errors, thus making the insistence on having physical contact with the object obsolete.[6]

The research presented in this thesis seeks to evaluate the potential of applying modern remote sensing methodologies to particular architectural historical questions. Thus far, few Irish studies have demonstrated the potential of these techniques, even though a general acceptance has been growing in the related fields of conservation and virtual tourism. Photogrammetric and laser scanning studies are increasingly used in the preparation of pre- and post-conservation records because they facilitate full documentation of the spatial location of all parts of an object and because they can readily

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[4] N. Hiscock, *The Wise Master Builder: Platonic Geometry in Plans of Medieval Abbeys & Cathedrals.* Aldershot, England www.ashgate.com: Ashgate Publishing Ltd., 2000, pp. 293-4 stated that "In the foreseeable but still distant future, the application of the laser and the computer to building surveys will perhaps become general, providing objective data, readily verifiable."

[5] "Black-box nature" here means that the instrumentation is of such a level of sophistication that an uneducated user can obtain results without having any knowledge of the internal workings of the instrument. This makes such instrumentation easy to use, when everything is operational, but when problems occur the user may be entirely unaware (a) that they have happened, (b) how significant they are and (c) how to fix them.

[6] While physical contact is not a requirement for measurements there is still significant benefit to be gained from spending prolonged periods of time observing and considering the object being measured. With new technologies, such as terrestrial laser scanning, once the area of interest has been defined the instrument carries out the measurement process without supervision over a period of minutes to hours, providing the historian with ample opportunity to observe and consider. As regards errors, their removal or minimisation is a key skill for the surveyor with three types of errors being identifiable: gross, systematic, and random. Gross errors are typically errors in observational procedure and can be avoided through the use of correct procedures while systematic errors typically relate to instrumentation and can be avoided by using only calibrated equipment. Gross error avoidance measures include taking multiple observations and including check measurements at every available opportunity. Calibrated equipment is equipment which has been checked against higher order standards. Random errors, however, are the errors which remain despite using the best quality instrumentation and techniques. Fortunately, these faults tend to be smaller and less significant when measurements are made by experienced persons. If correct procedures in respect of the minimisation of errors are applied, as has been done throughout this study, then the concerns of tactile historians can be entirely allayed and researchers can have confidence in their results.

integrate with high quality imagery to assist in condition assessment. Thousands of examples of such work have been reported by the research communities active within the International Society for Photogrammetry and Remote Sensing and CIPA, the heritage documentation arm of ICOMOS, the International Commission on Monuments, as well as in conservation and remote sensing journals.[7] These technologies have now reached such a level of acceptance, particularly in relation to their accuracy potential, that current research in the remote sensing community has moved from proof-of-concept to automation and increased ease of use for non-remote sensing experts.

The other significant advantage of using remote sensing methods is that they remove much of the potential bias from the data collection phase. The reliability of some architectural historical studies has suffered as a result of the "strong *a priori* opinions" of individual researchers concerning the expected intentions of a mason at a particular location.[8] It is human nature to see certain measurements if they are the ones which were expected, perhaps as a result of having previously seen something similar or having made a predictive calculation.[9] The remote sensing methods used in this study, however, collect data in a disconnected manner where the three-dimensional position of a point is measured in order to generate the x, y, z co-ordinate but where the relationship of that point to significant neighbouring points (e.g. distance from) is unknown until a separate processing step has been carried out, away from the point of data capture. Thus preconceived ideas, even if they were present in the researcher, could not interfere with the data collection process, making the results of this study as reliable and independent as could possibly be achieved.

3.1 Empirical measurements at all sites

The choice of study regions will be explained below, but it is necessary here to mention that a total of sixty-seven sites were visited, as illustrated in Figure 3.1. At each site between one and sixteen windows with tracery were measured, resulting in 199 occasions

[7] ISPRS (International Society for Photogrammetry and Remote Sensing), 'ISPRS Commission V.' 2009. ISPRS. Viewed July 2009. <www.commission5.isprs.org>; ICOMOS (International Council on Monuments and Sites), 'ICOMOS (International Council on Monuments and Sites).' 2008. ICOMOS. Viewed July 2009. <http://www.international.icomos.org> and CIPA (The International Committee for Documentation of Cultural Heritage), 'CIPA Heritage Documentation.' 2009. CIPA. Viewed July 2009. <http://cipa.icomos.org/>. See, for example, the restoration work at Salem Cathedral: R. Strobel, 'Die Masswerkfenster der Klosterkirche Salem: Zur Erhaltung und Dokumentation von gotischem Masswerk', *Journal of Landesdenkmalpflege Baden-Wurttemberg*, 2003, 2, 160-7.
[8] S.L. Sanabria, 'Metrics & Geometry of Romanesque & Gothic St. Benigne, Dijon', *The Art Bulletin*, 1980, 62 (4), 518-32, p. 518.
[9] The effects of such preconceptions would be deemed by surveyors to be gross errors.

where the following data collection and processing steps were undertaken. However, on a number of occasions, due to survey access problems beyond the author's control it was not possible to process some windows to completion. Since revisiting the sites would not have corrected these problems, a reduced number of results appear in later sections of the thesis and in the inventory. The quantity and distribution of windows impacted on the choice of measurement method because combined accuracy and speed were important.
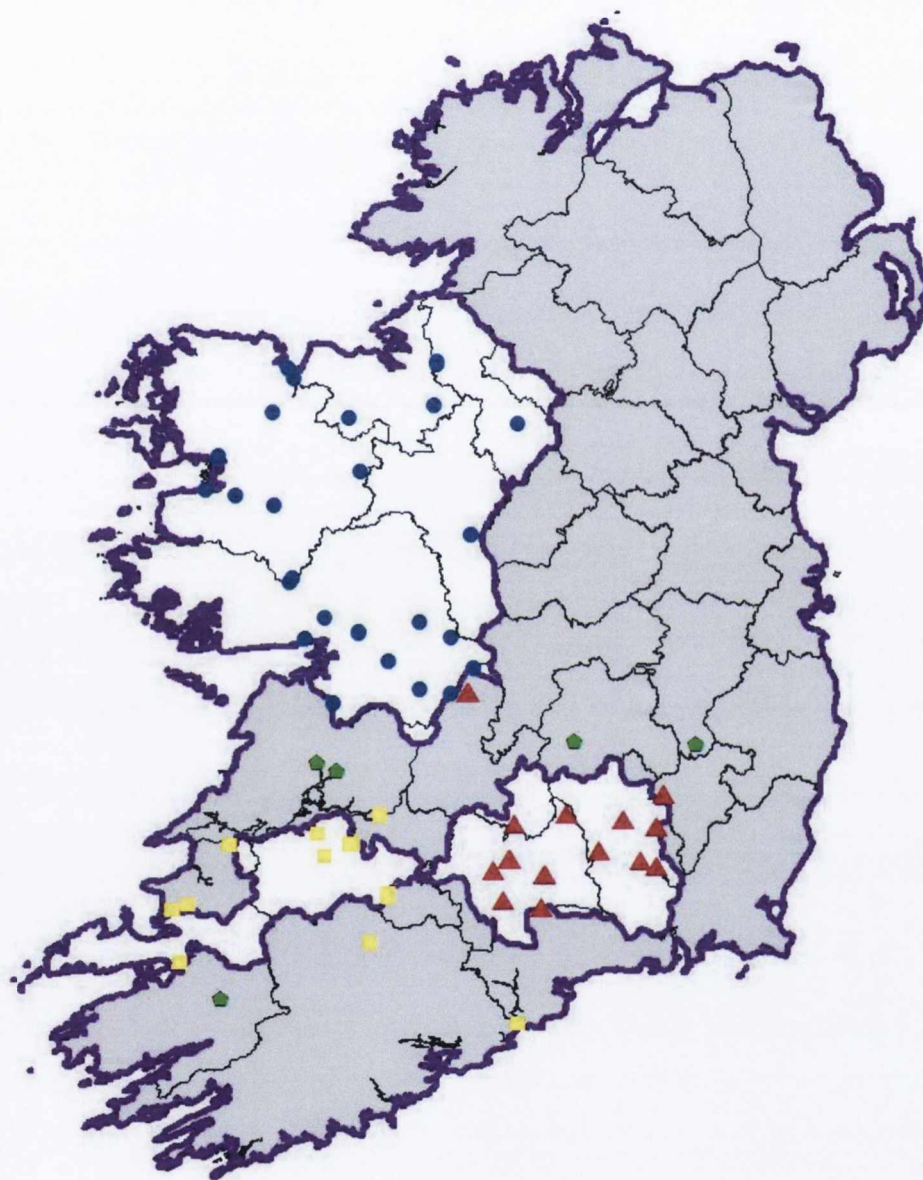
Figure 3.1 Distribution of measured sites in Connaught (blue circles), Ormond (red triangles), Desmond (yellow squares), and other locations (green pentagon) overlaid on modern county boundaries (black lines) and medieval kingdoms c.1534 after Nicholls (white shading).[10] The affiliations of each site are mapped in the following sections.

[10] K.W. Nicholls, 'Lordships of Ireland c.1534.' *A New History of Ireland, III: Early Modern Ireland 1534-1691.* Eds. T.W. Moody, F.X. Martin and F.J. Byrne. Oxford: Oxford University Press, 1976 (Hereafter 'Lordships *c.*1534').

3.1.1 Stereo photogrammetry

The aim of this research was to collect full three-dimensional (depth and elevation) information about each window and its tracery field at each site visited. Although a number of methods exist for the production of such models stereo photogrammetry was chosen.[11] Photogrammetry is defined as the science of generating measurements from imagery, and stereo photogrammetry uses two photographs captured and viewed in a simulation of the offset between the human eyes to achieve depth perception (Figure 3.2). When stereo images are combined with a small amount of reference or control information this converts two unscaled, planar images into a three-dimensional model where real-world measurements can be extracted from within a virtual environment.
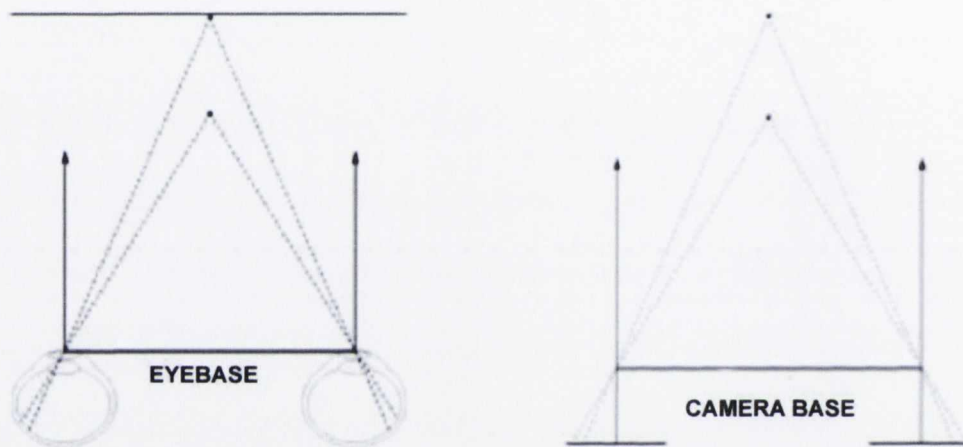
Figure 3.2 Depth perception generated by the human eyebase (left); camera reconstruction for simulation of eyebase (right)

The mathematical realisation of this 3D model relies on a physical law, called the collinearity principle, which describes standard frame camera geometry. This rule states that the line joining a point on an object with its image on a photograph must pass through the very centre of the camera lens, the principle point. The rule is valid for every point on the object and its image point. This allows us to use relatively simple trigonometric functions to transform measurements made on the imagery into real-world values via a set of equations called the collinearity equations:

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[11] Other options include terrestrial laser scanning and discrete point/line measurement using a reflectorless total station. The total station option was rejected because the required field time was prohibitive. However, one of these instruments was employed to acquire the reference measurements used to scale the imagery. Terrestrial laser scanning was not used again due to the amount of time required per window and the number of windows being evaluated in the study. The TLS instrument available would also not have achieved any higher accuracy than could be achieved in a shorter time using image-based methods. TLS was however, used for the case studies, as will be described later, because of the economy of scale when measuring a large amount of information on the same site. For a description of the integrated use of a range of technologies see, for example, F. Henze, U. Wulf-Rheidt, D. Schneider and A. Bienert, 'Photogrammetric And Geodetic Documentation Methods At St.Petri Cathedral, Bautzen', *CIPA Symposium Volume 20/IAPRS Volume 36-5/C34*, Turin, Italy, 26th September - 1st October 2005.

$$X_P - X_O = \left(Z_p - Z_O\right)\left[\frac{r_{11}\left(x-x_h\right)+r_{21}\left(y-y_h\right)+r_{31}\left(-c\right)}{r_{13}\left(x-x_h\right)+r_{23}\left(y-y_h\right)+r_{33}\left(-c\right)}\right]$$

$$Y_P - Y_O = \left(Z_p - Z_O\right)\left[\frac{r_{12}\left(x-x_h\right)+r_{22}\left(y-y_h\right)+r_{32}\left(-c\right)}{r_{13}\left(x-x_h\right)+r_{23}\left(y-y_h\right)+r_{33}\left(-c\right)}\right]$$

The simple scaled linear relationship between an image point and its object point must be adjusted to account for possible movements of the cameras relative to each other (about three axes, x, y, z, creating a rotation matrix represented by r_{11} to r_{33}) and for a known, manufacturing error within the camera lens, the principle point offset. In the equations above x, y is the image point, x_h, y_h is the principle point offset, r_{11} to r_{33} are the elements of the rotation matrix, X_0, Y_0, Z_0 is the position of the centre of the lens in the real-world co-ordinate system, and X_P, Y_P, Z_P is the position of the object point in the real-world co-ordinate system. Also c is the principle distance, which is the fixed distance between the centre of the camera lens and the image. It is a calibrated version of the focal length of the camera lens.

When two stereo images are captured by a camera all of the elements r_{11}-r_{33}, c, x_h, y_h and X_O, Y_O, Z_O in the above equations are unknown for both of the camera positions. If we selected a point x, y on either image we would have no idea of its real-world co-ordinate X_p, Y_p, Z_p. Therefore, field measurements of the real-world co-ordinates of at least four points are required and these must be visible on both photographs in the stereo pair. The co-ordinates of these four points are then also measured on the images, using specific computer software, and a pair of the above equations is written for each control point. The eight equations, two per point, are solved using simultaneous equation techniques to find values for each of the remaining unknown elements (r_{11}-r_{33}, c, x_h, y_h and X_O, Y_O, Z_O).[12] Once the values of these elements have been found the user can select any x, y point on a stereo image pair and the software will return the X_P, Y_P, Z_P real-world 3D co-ordinate.[13]

The application of stereo photogrammetric techniques also has the advantage of

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[12] The equations must then be linearized using Taylor's theorem, to remove higher order terms (squared, power of 3, etc.), after which they can be solved simultaneously using the least squares method. Through the use of the least squares best fit method variations in the quality of control points can be manually identified and controlled. Lower quality points can be given less influence over the solution of the equations making the final result more reliable. The use of least squares methods also facilitates the identification and removal of any gross errors without negatively influencing the final solution. One further advantage of this method is that it allows the user to introduce redundancy, which is the measurement of more than the minimum number of control points, thus increasing the robustness and reliability of the solution. B.D.F. Methley, *Computational Models in Surveying & Photogrammetry*. Bishopbriggs, Glasgow G64 2NZ: Blackie & Son Ltd, 1986.

[13] M. Kasser and Y. Egels, *Digital Photogrammetry*. London: Taylor & Francis, 2002. The output of the software is not limited to individual co-ordinates because lines, shapes and surfaces can also be measured and recorded making the results significantly more useful than if only isolated points could be extracted.

using relatively inexpensive field equipment: for this study photographs were taken using a Nikon D70 with 18-70mm Nikkor lens, while a Leica TPS 1205 reflectorless total station was used to collect the control (scale and orientation) information. The TPS 1205 has angular accuracy of 5 seconds of arc and distance measurement capability of 2mm ±2 parts per million. With this measurement technique the amount of error which could occur for any single point increases as the distance between the instrument and the target grows. When taking the reference measurements for this work the maximum distance between the total station and the window never exceeded 30m. At this range the maximum positional errors which could have occurred were 0.7mm, horizontally and vertically, and 2.06mm in direction away from the instrument.[14] These calculations demonstrate that the achievable accuracy of this instrument and method was sufficient for the requirements of this study.

3.1.2 On site activities

For each window one pair of photographs was taken in accordance with the following requirements. The plane of the camera sensor was aligned parallel to the main plane of the window.[15] The two photographs overlapped by between 70% and 80% through adherence to a rule of thumb which required use of a ratio of 1:10 between 'the distance between the two camera positions' and 'the distance between the camera and the window'.[16] The focus on the camera and the lens were manually fixed.[17] Once acquired, each image was checked to ensure that the radiometric quality was sufficient for measuring both the control and the details of the window tracery.[18]

The second requirement on site was the collection of control information to enable the stereo model to be scaled and orientated. In this project the relative positions of a minimum of four control points were measured in three dimensions using a reflectorless

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[14] The formula required to calculate the planimetric error is (Distance * tan(5")) and the distance away (depth) error is calculated by converting the distance to millimetres and multiplying that value by 2/1,000,000. However, for most of the windows the distance between target and instrument was significantly less than the maximum 30m meaning that the potential error were also significantly reduced.

[15] In as much as this was possible despite some access difficulties at some sites related to the slope of the ground and the positions of other buildings, sculpture and grave stones.

[16] For instance, if the photographer wished to take the images at a distance of 5m from the window, the two images would need to be acquired with a distance of 0.5m between the positions from which they were taken.

[17] This ensured that the calibrated focal length of the camera was not inadvertently changed as would happen through the use of automatic focussing.

[18] In particular, when working in sunny conditions the radiometric check served to ensure that no part of the image was either over- or under-exposed.

total station.[19] The selected control points were pre-existing features on the window and its surround.[20] All points were clearly identifiable in the photographs and could be measured unambiguously using the total station. Typically between six and twelve control points were actually measured to ensure that redundant points were available in case of visibility issues during processing.[21]

3.1.3 Photogrammetric processing and extraction

To generate a 3D model from the stereo imagery the software Leica Photogrammetric System version 9.3 (LPS) was used in combination with Autodesk Civil 3D 2007/2008.[22] The processing steps involved were as follows. The control points were checked using Autodesk Civil 3D to ensure that they contained no gross errors and that the x-y plane of the control co-ordinate system was parallel to the plane of the camera sensor.[23] In LPS the stereo model was established by recreating the exact relative geometries of the images at the time of capture and linking these to real-world measurements. This was achieved through identification and measurement of the same control points on both photographs in the pair. This process was the first stage of exterior orientation and resulted in the population of sets of collinearity equations, as detailed above, with image x, y and real-world X_p, Y_p, Z_p co-ordinates.[24] Once all points had been measured the software ran a bundle-block adjustment (simultaneous solution) in order to find values for each of the unknown elements (r_{11}-r_{33}, c, x_h, y_h and X_O, Y_O, Z_O) in the collinearity equations using a least-squares method.

The results of the orientation could be monitored after solution of the equations because the least-squares method also evaluates the overall quality of the result. Each

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[19] The positions of the control points were measured relative to each other rather than any external reference source. It would not have been feasible to relate the window tracery to details such as ground or gable heights at most sites, since these have been significantly altered by later burials and through deterioration of the building fabric, respectively.

[20] These control points either occurred naturally (e.g. sharp corners on stonework or patterns caused by lichens) or used existing man-made features (e.g. the centres of screws holding protective grilles or metal bars used to prevent unauthorised entry to sites).

[21] To generate the highest accuracy photogrammetric products it is advisable to use artificial targets, typically plastic cards or reflective stickers, but these could not be used in this survey because of the delicate nature of some of the sites (and the potential damage that the targets might cause) and the inaccessibility of the features (lifting or hoisting equipment could not have been used in many of the locations because of issues of topography and the position of the features in very close proximity to modern graves). Where such targets cannot be used in photogrammetric surveys increased redundancy is introduced by measure more pre-existing targets than the minimum number required.

[22] Autodesk Civil 3D is Computer Aided Drafting (CAD) software with a number of enhancements to better handle survey generated data, and for the manipulation and visualisation of three-dimensional models.

[23] This was a requirement of the LPS software in order to obtain full access to a range of functionalities.

[24] The previous two steps involve processing based on the collinearity equations and least squares solutions as previously described.

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processed window was monitored to ensure that all dimensions extracted from the model would be accurate to approximately 10mm. A total of 179 successful orientations resulted from this process. The final photogrammetric stage involved viewing each oriented stereo model and measuring the 3D points needed to extract the required dimensions as detailed in Table 3.1 and Figure 3.3. These measurements were recorded in a separate spreadsheet for each site and have been included in the site catalogue in appendix 8 and in the Site_Measurements_Units_Proportions folder on the accompanying DVD.

Table 3.1 lists the key dimensions extracted for each window. The choice of which dimensions to record was based on examination of medieval masons' design methods, ascertained through the study of evidence from tracing houses, pavements, small-scale drawings, etc. and from nineteenth- and twentieth-century text books for stone masons, as discussed in chapter 2. Particular attention was paid to the drawings at Roslyn chapel, Scotland and Corcomroe Cistercian abbey and using CAD these were analysed, as detailed previously, to better understand the mason's methods. The focus of both of these works was on the setting out of the arches. Detailed examination of the arches in this study, to discover which were Three- or Four-point gothic arches or some other shape, was considered, but to do justice to such work all windows would need to be measured internally and externally. The time required to carry out this work would have greatly reduced the number of sites that it was possible to visit, thus limiting the scope of the rest of the study. However, at both Roslyn and Corcomroe the ratio of tracery field span to tracery field height matched known ratios, 2:3 and 1:√2 for the former, and 1:√2 and 5:6/1:1 for the latter. This relationship was, therefore, analysed for all windows in the study.

With the exception of William Purchase's "Divide the span for small openings, and draw in the mullions", the exact method by which individual lights were set out, particularly in elevation, was not addressed by any of the sources mentioned above.[25] Therefore a number of variants of particular measures/ratios needed to be examined e.g. 'height to springing of the arch' or 'height to arch peak'. A list of all extracted dimensions is available for each window in the site catalogue.

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[25] W.R. Purchase, *Practical Masonry*. 5th ed. Powys: Attic Books, 1904, p. 109.

Table 3.1 Details of extracted dimensions – Roman numerals refer to locations in Figure 3.3

Item of Interest	Detail Description		
Full window	Overall width (i)	Overall height (ii)	Height to the springing of the arch (iii)
Per Light	Width (iv)	Overall height (v)	Height to springing of the arch (vi)
Arch	Span[26] (vii)	Height (viii)	
Per Mullion	Width (ix)		
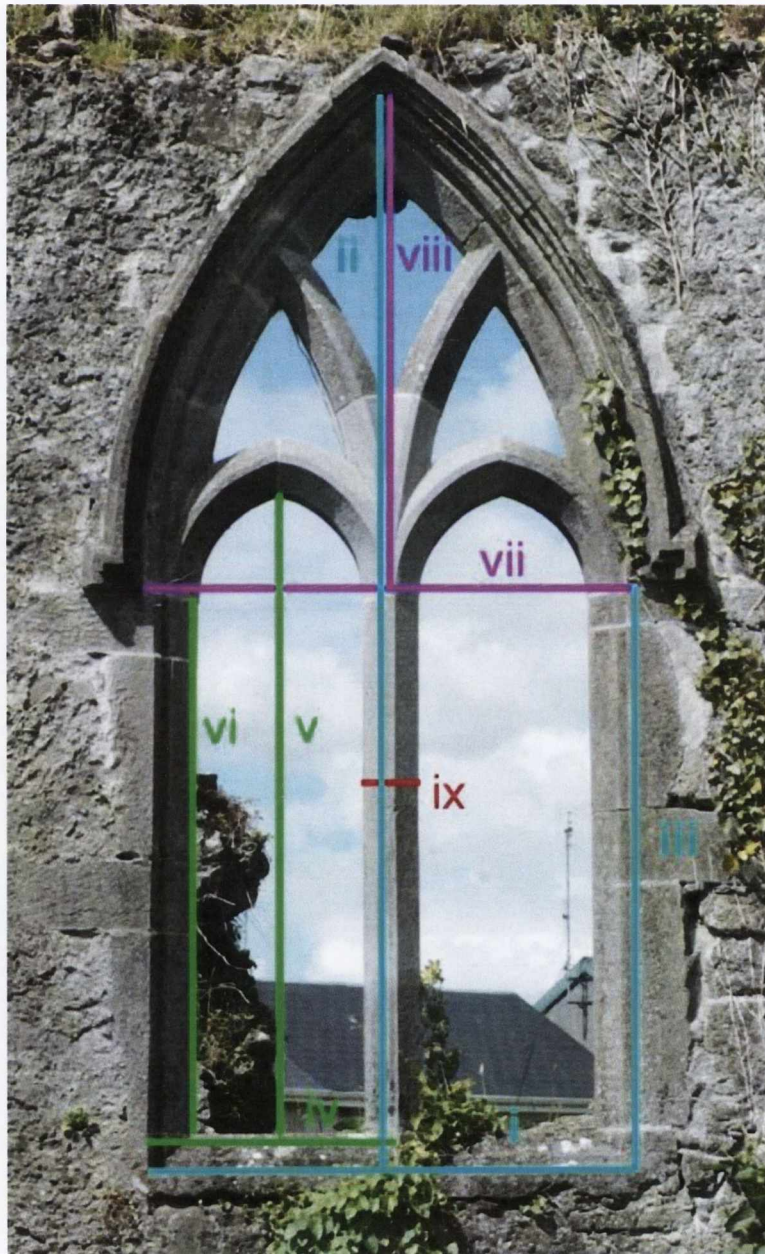
Figure 3.3 Diagram of the locations of extracted dimensions

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[26] The span is typically wider than the window width because it was measured relative to the hood stonework, where available.

Since measurement of the widths of the lower, rather than upper, portions of each window is more likely to represent the original intentions of the mason (less affected by settlement or plumb errors during building), the base measurements of the widths of lights and mullions were used, by preference. If, as occurred on a number of occasions, the base of the window was obscured then the upper measurements for the feature were utilised.

Establishing the exact point defining the overall width of the window is more difficult but, for this study, the width was measured between the widest points at the base of the window, where the moulded stonework bonded with the wall surface (see Figure 3.4). This is based on nineteenth-century masons' texts which, although not specifically addressing the lower portion of traceried windows, indicate that the arches of the upper tracery portion were set out using this stonework junction.
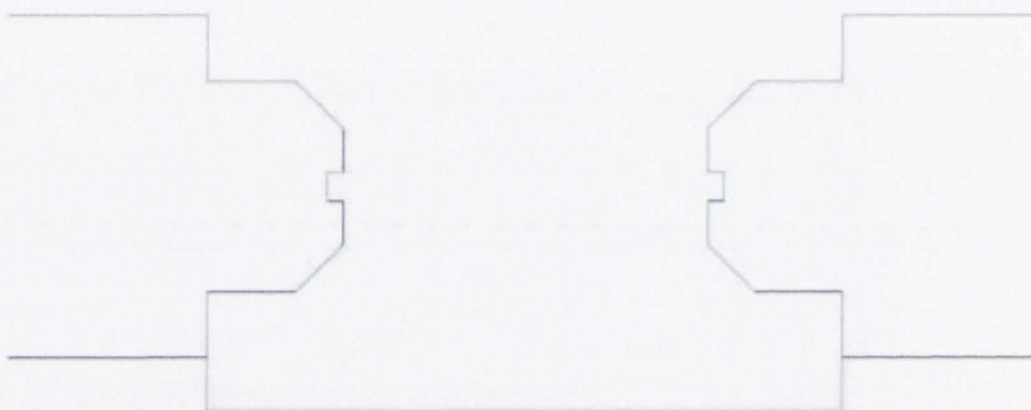
Figure 3.4 Plan view showing the points from which the overall window width dimension was measured on each window

For the heights of features, as there is no practical difference between the left or right side, the left side measurements were used unless they were obscured.

Measurements were also made of each light in a window because, in many cases, the dimensions of the lights were not consistent. This usually appeared to be a choice of the mason during the design phase and so merited separate investigation. In subsequent processing, to ensure that windows with higher numbers of lights did not exert undue influence on regional analysis, all regional totals were normalised by the 5 times the number of windows plus 3.5 times the number of lights per window.[27]

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[27] See Table 3.1 where 5 measurements are made for each window, 3 measurements are made for each light in that window and 1 measurement per mullion, where there is one mullion per pair of adjacent lights.

3.1.4 Proportion processing

The function of the proportional analysis was to identify if and where known ratios appeared in the major dimensions of medieval window tracery. As the review of Irish and European research has shown, no precedent exists for this type of analysis. Furthermore, examination of medieval masons' work practices and later instructive texts provided little information on methods used.

Therefore, the proportions selected for examination were based on the following reasoning. The tracery field provided an artistic space and its height relative to the overall window or to the lights might indicate the significance of artistry over light, or *vice versa*. The overall dimensions of the window were important in allowing light into the building and relative sizing was notable in emphasising more significant or sacred spaces, such as the east end of the choir or the south transept. How the overall width to height of each window was proportioned might have been mainly defined by the available wall and gable spaces, but it may also have been a conscious decision on the part of the designer. Another significant proportion may have been the overall height or the height to the division between the tracery and light field (springing or arch peak).

Róisín Mullin suggested that the number of lights was one of the decisions made by a designer as part of the process of creating window tracery, but many Irish medieval windows are not divided into lights of a standard width. Therefore, the proportions relating the width of each light to the overall window width and to the light height, at different levels, was also examined.[28] How the width of each mullion related to both the light width and the overall window width was also considered. This is because of the significance that standardisation of architectural practice through the use of templates might have had on mullion shape and size, as detailed from English and continental European studies, and because of possible copying of window designs between sites. Table 3.2 summarises the derived proportions examined in this study.

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[28] R. Mullin, 'A regional study of late medieval window tracery in Ireland', M.Phil. Queen's University, Belfast, 1999, pp. 15-48 (Hereafter 'A regional study').

Table 3.2 Details of proportions studied

Item of Interest	Proportion		
Tracery field	Tracery field height to overall window height	Tracery field height to light height (at springing point)	Tracery field height to light height (at arch peak)
Full window	Overall window width to overall window height	Overall window width to window height to spring	Overall window width to arch span
	Overall width to light height (at springing point)	Overall width to light height (at arch peak)	
Light	Light width to light height (at springing point)	Light width to light height (at arch peak)	Light width to overall window width
	Light width to overall window height	Light width to arch span	
Mullion	Mullion width to light width	Mullion width to overall window width	

These numeric values were then compared with the numeric equivalent values of a variety of ratios, as given in Table 3.3 and as known from literature related to the plans of Irish buildings or to architectural details from abroad. In the following and in site catalogue, the proportions calculated for each window are colour-coded according to the scheme illustrated in Table 3.3.

Table 3.3 Significant ratios extracted from the literature

Ratio	Numeric Value	1%		2%	
1 : 4	0.250	0.253	0.248	0.255	0.245
1 : 3	0.333	0.337	0.330	0.340	0.327
2 : 5	0.400	0.404	0.396	0.408	0.392
1 : root 5	0.447	0.452	0.443	0.456	0.438
1 : 2	0.500	0.505	0.495	0.510	0.490
13 : 23	0.565	0.571	0.560	0.577	0.554
1 : root 3	0.577	0.583	0.572	0.589	0.566
3 : 5	0.600	0.606	0.594		
377 : 610	0.618	0.624	0.612	0.630	0.606
2 : 3	0.667	0.673	0.660	0.680	0.653
1 : root 2	0.707	0.714	0.700	0.721	0.693
3 : 4	0.750	0.758	0.743	0.765	0.735
4 : 5	0.800	0.808	0.792	0.816	0.784
5 : 6	0.833	0.842	0.825	0.850	0.817
1 : 1	1.000	1.010	0.990	1.020	0.980

The frequency of occurrence of each ratio within a region was then calculated for comparison purposes. For these counts it was important to consider the potential influence of random errors within the measured data. Although all modern processes were carried out using the best available technologies and procedures, random errors could still have occurred due to the number of measurement and processing steps. Furthermore, by evaluating a number of results centred on the true value, this study also considered the possibility that the execution of design and construction was almost certainly not perfect. Therefore, the proportional results for each window were compared against numeric values within 1% and within 2% of the true values as shown in Table 3.3. At each site three counts were made of the number of occurrences of each proportion; one each for the 1% and 2% categories, as well as a total for both 1% and 2% combined. Each proportional result could only contribute to one of the two categories for a single ratio.[29] Following individual analysis of each window, the results from within each region were combined to enable identification of any patterns.

The results from application of this methodology are described in detail in the following chapters. These results of the proportional processing were recorded in a separate spreadsheet for each site and have been included in the Site_Measurements_Units_Proportions folder on the accompanying DVD. The Microsoft Excel Visual Basic for Application macros written to execute these procedures have been included in appendix 4.[30]

3.1.5 Metrology processing

The following metrological processing was used to extract the preferred unit of measurement for each window. The presented method was designed as an amalgam of the best aspects of previously employed techniques as outlined in the literature review in chapter 2. Processing was carried out on a building by building basis, but the data from each window was separately retained making it possible to analyse individual windows as well as entire buildings. The ability to comment on individual windows was essential due to the piecemeal construction of many of the buildings examined.

In steps of 1mm, test units between 0.212m to 0.372m, which covers the range of possible foot, shaftement and palm values derived from the literature review, were compared against each measurement extracted for the chosen window (Figure 3.3). The

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[29] This restriction was implemented in the Excel macro.
[30] All Microsoft Excel Macros used in this study were written by the author specifically for this use.

following processing sequence was carried out for each comparison in turn. Each extracted measurement was divided by the selected test unit. The whole numbers in the resultant answer were subtracted producing a remainder.[31] The remainder indicated the proportion of one full unit left over if measurement had been set out using the length being tested. The absolute difference between this remainder value and each of the numeric equivalents of the $\frac{1}{1}, \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \frac{2}{3}$ and $\frac{3}{4}$ fractions was calculated.[32] The smallest of the six results was retained.[33] The lower the numeric value of the retained difference, the more likely it was that the mason intended to use the particular test unit and fractions thereof. The evidence in favour of that unit was further strengthened if the minimum differences for all of the measurements from a single window averaged at a very low difference value. This process was repeated for each unit in the set. The average minimum differences for all test units were then compared to find the lowest value, thus indicating the test unit most likely to have been used for a particular window.

Then, in recognition of possible errors in construction and measurement as mentioned in the previous section, units which resulted in average minimum differences within 10% and 20% of the minimum value, termed highly probable units, were also extracted. When these tests had been carried out for all measurements at a building the probable units for each window and for the whole building were known.[34] The results of these analysis steps for each window have been included in the site catalogue.

As with the proportional study, the results from each separate site were then collated to provide information which could be used to assess potential patterns of metrology usage. For each region, charts were generated to show the total number of times that each unit in the range 0.212m to 0.372m was identified as being either the most likely unit or a highly probable candidate unit. Where a unit was deemed the most likely candidate unit at a location it was given a weighting of 1 when added to the regional total. The highly probable units, within 10% and 20% of the most likely candidate, were also added to the regional total but with lower weightings of 0.9 and 0.5, respectively.

In a final step, cognisant of the tolerance of the study of ~1cm, which aligns well with medieval tolerance as previously discussed, the frequency counts were amalgamated

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[31] e.g. 5.281 produces a remainder of 0.281
[32] The literature has shown that subdivisions of units were most likely to have been achieved by folding a cord or using dividers meaning that for these short distances the chosen ratios should be representative of most typical setting out.
[33] For example: 0.281 − 0.500 = 0.291; 0.281 − 0.333 = 0.052; 0.281 − 0.250 = 0.031; 0.281 − 0.666 = 0.385; 0.281 − 0.750 = 0.469; 0.281 − 1.000 = 0.281. Minimum result is 0.031 for ¼ length.
[34] The whole site average would only be significant in the case of a single construction phase building.

into running totals for each 9mm of measurement.[35] This allowed identification of groups of high frequency units which suggested the probable units in use in a region and these could be analysed to find relationships between contributing windows and in comparison with known units from the literature. Since this method was experimental, no existing definition of "high frequency" was available; therefore both values higher than 75% of all value and, in some cases, higher than 50% of all values were considered in the analysis.[36]

Before creating the graphs all frequencies were normalised as described in the following to ensure the validity of comparisons made between the regions. These results of the metrological processing were recorded in a separate spreadsheet for each site and have been included in the Site_Measurements_Units_Proportions folder on the accompanying DVD. All of the Microsoft Excel Visual Basic for Application macros written in order to execute the above-described method are included in appendix 4.

3.1.6 Normalised results

In Connaught eighty-two windows were processed while in Ormond and Desmond the numbers were only fifty-eight and forty-nine, respectively. The number of measurements and proportions recorded for each window depended on the number of lights into which it was divided. Thus the total counts made for the occurrence of each unit and ratio were biased according to the size of the sample in each region making direct comparison unfeasible.[37] This imbalance was eliminated through normalisation of the data, i.e. division of the total frequency count in a region by 5 times the number of windows plus 3.5 times the number of lights.[38] Since the division process resulted in numbers that were typically well below one these values were made more manageable by multiplying each normalised result by 500. For example, if the Connaught total frequency count for a particular measurement unit was 3.8 it was divided by (5*82 + 3.5*242 i.e. 1257) and multiplied by 500 to give a normalised frequency result of 1.512. This value could then be

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[35] If the following set of data occurred: (unit followed by normalised frequency) 0.212 0.527, 0.213 0.527, 0.214 0.820, 0.215 0, 0.216 0.879, 0.217 1.757, 0.218 0.527, 0.219 0.527, 0.220 2.578 then the running total for the mid-value, 0.216 would be 8.143.

[36] Values higher than 50% were only considered in a few circumstances, as will be discussed in later chapters, where the results suggested notable correlations with existing units or across the boundaries of regions.

[37] In statistical terms this problem is referred to as a systematic error because its effect is uniform on particular groups of data.

[38] Such data normalisation procedures are commonplace when multiple dataset of different sizes need to be directly compared and are applied in fields as diverse as business, economics and science. 5 measurements were taken from the entire window (overall width, overall height, height to spring, arch width and tracery field height) while 3 measurements were made per light (width, height to arch peak and height to spring) and 1 measurements per mullion (width), where there was 1 mullion per 2 windows; thus 3.5.

directly compared with the normalised values for that same unit in the other regions without bias.

3.2 Case studies

The purpose of the case studies presented in chapters 4 and 5 is to evaluate whether proportional or metrological patterns found using a photogrammetric evaluation of window tracery could also be found in other details of the buildings where they occurred. As outlined in chapter 2, previous studies have found that in some medieval buildings standard measurements and sets of proportions were used throughout the design of the building. The identification of harmonious metrology and proportions in features other than tracery might therefore confirm identification of the units being used, and also shed light on the overall design processes engaged by Irish masons and, potentially, the building phases in specific monuments.

This examination was inspired by the work of previous investigators who found evidence for medieval geometrical design schemes constructed around specific base modules such as the width of a wall or an inter-column distance. These modules were reused in multiples or subdivisions in piers, arcades, chapel positions, and elements of the ground plan. Other researchers have found that some designers avoided base modules preferring instead to use squares, rectangles or combinations of the two, particularly when setting out ground plans. Given the variety of medieval systems one cannot be certain of the best approach to making sense of any given site, particularly in the absence of relevant documentation.[39] In some cases, although the work was executed with "a high degree of precision" this was accompanied by a surprising variation in the "range of dimensions".[40] Furthermore, there is significant difficulty in knowing from which points the medieval masons actually set out their work, and there is also a question of consistency as raised by Roger Stalley's study of Muckross abbey: "it is necessary on occasions to switch from internal to external measurement".[41]

To enable detailed examination of the case study locations, the first requirement was the collection of high accuracy spatial information about all possible indicators of geometry or metrology. These details included ground plans, arch spans and heights, pier

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[39] R. Fawcett, 'Later Gothic architecture in Norfolk: an examination of the work of some individual architects in the fourteenth and fifteenth centuries', Ph.D. East Anglia, 1975, p. 500-3.
[40] S. Murray and J. Addiss, 'Plan and Space at Amiens Cathedral: With a New Plan Drawn by James Addiss', *The Journal of the Society of Architectural Historians,* 1990, 49 (1), 44-66, p. 45.
[41] R. Stalley, 'Gaelic Friars & Gothic Design.' *Medieval Architecture & its Intellectual Context: Studies in Honour of Peter Kidson.* Eds. E. Fernie and P. Crossley. London, England: The Hambledon Press, 1990. 191-202, p. 202.

designs, doorways, ecclesiastical sculpture, and any other elements which were likely to have been designed by the same individual. Dimensions and proportions could then be extracted and analysed using similar methods to those previously described for the window tracery, thus providing a set of comparative data.

3.2.1 Fieldwork

The data collection method chosen for the case studies was terrestrial laser scanning (TLS). Laser scanning is probably the most significant development in building and general surveying in recent years and its application to architectural historical studies could be significant, a point which this study aims to evaluate.

The scanning instrument sends laser pulses to an object and records the bounced returned signals in order to build up a 3-dimensional model of the surface of the object. The movement of the beam is directed using computer-controlled servo-motors and the density of points can be selected to suit the application. In order to avoid confusion with other reported studies it is necessary to first differentiate between the three main types of terrestrial laser scanning technology:

- **Time-of-Flight**

  The principle of operation is that a highly accurate clock measures the time taken for a pulse to travel from the instrument to the object of interest and back again, divides that time by two and multiplies it by the speed of flight of the laser produced by the instrument thus converting the measurement into a distance. Simultaneously, a recording is made of both the horizontal and vertical angles from which this pulse was sent, relative to some fixed reference, thus fixing the location of the reflecting surface in three-dimensional space. This method allows long distances, up to 200m, to be measured with an accuracy of approximately 12mm at 100m, and at a rate of tens to hundreds of thousands of pulses per second.

- **Phase Difference Measurement**

  With this technology, one short wavelength signal is modulated over a longer wavelength signal and by measurement of the phase (position along) of these waves a conversion into a distance can be made. These systems are more accurate, typically approximately 10mm at 50m, than the time-of-flight systems and operate with a

significant speed advantage, almost one million points per second at time of writing. However, the maximum distance achievable is limited to approximately 100m.[42]

- **Triangulation**

  These are the most accurate systems measuring to 0.3mm at 2.5m. However this gain is achieved through a significant compromise in relation to time with these instruments typically measuring only some thousands of points per second. Triangulation scanners also require many more setups than either of the other two types of scanner because of the smaller coverage per setup.[43] A laser beam is directed towards the object of interest by a mirror at such an angle that it reflects onto a Charge Coupled Device (CCD) sensor and the distance to the object is triangulated by the instrument. Variations on this system use two cameras at either end of a fixed bar.[44]

All three systems produce data in a format called a "point cloud". These voluminous data sets contain a lot of valuable information which is only accessible following manipulation and handling in specific laser scanner software. For instance, it is rare that an entire object, such as a building, can be captured from a single set-up making it necessary to carry out multiple scans. These numerous scans must be co-registered in order to facilitate measurement between parts of objects which were separately observed. This registration process is carried out in the TLS software through surface matching techniques or, for higher accuracy results, through the use of targets at known locations within overlapping scans.[45]

In an ideal situation the scanner best suited to the task at hand would employ phase-based technology. This would enable rapid acquisition of data at 10mm accuracy or better and, although more setups may be needed than with a time of flight system, the set-up time would be negated by the more rapid data collection. However, a phase-based scanner was not available for this study. Therefore, a time-of-flight scanner, the

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[42] For example, Faro's latest phase-based scanner can measure 976,000 points per second with an accuracy of up to ±2mm at distances less than 120m. Faro Technologies UK Ltd, 'FARO Laser Scanner Focus 3D.' 2011. Viewed February 2011. <http://www.faro.com/>.

[43] T. Kersten, 'Digital Architectural Photogrammetry.' Hamburg: HafenCity University, 2004.

[44] W. Boehler and A. Marbs, '3D Scanning Instruments', *CIPA WG6 & Commission V - Close-Range Imaging, Long-Range Vision*, Corfu, Greece, Sept 1-6.

[45] Newer models of scanner are more consistent with typical survey instruments and allow the operator to set up over a point of known coordinates from which polars, distance and angle measurements, allow calculation of the reflecting point's 3D coordinates, thus making the process of scanning large objects from multiple setups easier and faster.

Trimble/Mensi GS200, was selected and an examination of the instrument's characteristics (Table 3.4) demonstrates that the accuracy requirements of the project were readily achieved.

Table 3.4 Trimble/Mensi GS200 Specifications

Scanner / Criterion	Trimble/Mensi GS200
3D scan precision	12mm/100m
Angular resolution	0.0017°
Scan method	Time-of-flight
Field of view [°]	360 x 60
Scan distance [m]	> 200
Scanning speed	≤ 5000 pts/s
Camera	Integrated video, 640 x 480

In each case study more than one setup of the instrument was required in order to achieve the necessary coverage.[46] To connect these setups spherical targets were positioned in highly visible locations which could be seen from numerous setups. The exact details of each case study are given in the relevant chapter.

One of the major concerns when using TLS systems is the indiscriminate nature of the point cloud.[47] While it is only possible to specify the density of the points and not the specific locations from which the laser beam will bounce, a prudent choice of point density ensured that the major details important to this study could be captured.[48] Very high density scans were executed for pier bases and capitals, windows, arch peaks and decorative features, such as sedilia and tomb niches, while a coarser resolution was used to acquire ground plans.

3.2.2 TLS point cloud processing and extraction

Once the field survey had been completed the first stage of processing was the co-registration of separate setups using the targets included in each scan for that specific purpose. The registration process in the TLS processing software Trimble Realworks (V. 6.4) used a least squares based solution to find the best match between the target positions

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[46] The laser beam requires line of sight access in order to make a measurement.

[47] The movement of the laser beam is specified in a grid format and the user cannot identify particular features for measurement, such as corners, mouldings, etc.

[48] Point density is specified in the format "1 point every Xmm at Y distance". This means that for objects closer to the scanner the point density is higher while for objects further away than Y distance the density is lower than the specified Xmm.

in one reference scan and their locations in the adjacent scan. A registration report was generated and these have been provided in the appendix 7.

Following registration all point coordinates were available in a single co-ordinate system thus allowing the extraction of any measurements of interest. Since different measurements were extracted for the different case studies this phase will be described more fully in the relevant chapters.

The acquisition of large and complex point clouds in these case studies facilitated the extraction of many similar measurements; for example, obtaining a range of heights for specific portions of features, such as piers, when it was unknown whether the original setting out would have measured to the base, top or middle of mortar joints. The rapid acquisition of many alternative measurements was an essential feature of this study since the original design intentions were entirely unknown.[49] These multiple measurements could be readily extracted from the TLS point cloud using the software tool rather than on site, making the data collection process very time-efficient and unbiased.

Another essential feature of the software was that distances did not need to be measured directly, but could be extracted after 3D lines had been drawn within the point cloud. The advantage of line drawing is that it sometimes makes measurement of particular inter-object distances easier to achieve than is possible in the general point cloud where snapping on an exact point is required.

3.3 Period of interest

The history of the medieval era in Ireland is extremely complex and the abbreviated version which follows can only highlight a very small number of key events and circumstances which affected ecclesiastical architecture. In later chapters some specific events will be mentioned in the context of particular sites, but for more comprehensive discussions of Ireland in the middle ages the reader is referred to other sources.[50] The

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[49] M.A. Cohen, 'How Much Brunelleschi? A Late Medieval Proportional System in the Basilica of San Lorenzo in Florence', *Journal of the Society of Architectural Historians,* 2008, 67 (1), 18-57, p. 19.

[50] The history of medieval Ireland has seen a significant reappraisal in the last few decades with many authors now contesting the previously long-held view of an island supporting a divided community of two nations. For the earlier perspective see J.A. Watt, *The Church and the Two Nations in Medieval Ireland.* Cambridge Studies in Medieval Life & Thought. Ed. W. Ullman. 1 ed. Vol. 3. Cambridge: Cambridge University Press, 1970. Current thinking suggests that Ireland was home to complex interrelations between Gaelic, Anglo-Norman, Cambro-Norman, English of Ireland and English of England and that throughout the high to late middle ages the boundaries between these groups ebbed and flowed as circumstances, in particular intervention from England, required. For a review of Ireland as a lordship see J. Lydon, *The Lordship of Ireland in the Middle Ages.* Dublin: Four Courts Press, 2003 (hereafter *Lordship of Ireland*) and

chronological convention utilised by Duffy, Edwards & Fitzpatrick in their examination of medieval Gaelic Ireland will be adhered to throughout the following description (Table 3.5).

Table 3.5 Convention of chronology used by Duffy, Edwards & Fitzpatrick in Gaelic Ireland [51]

Early medieval	Fifth century to c.1100
High medieval	c.1100 to c.1350
Late medieval	c.1350 to c.1600

Church reform and the introduction of the European monastic orders to Ireland heralded something of an architectural revolution in Ireland during the twelfth century. Surviving evidence suggests that the introduction of the Cistercian order in particular introduced new masonry skills into Ireland. The foundation of Mellifont abbey in 1142 brought new forms of masonry architecture and monastic layout to Ireland and the rapid expansion of the Cistercian order throughout the country ensured that these new methods were quickly embedded.[52] The subsequent decades of Anglo-Norman settlement influenced Irish architecture through secular building works but more importantly through the foundation and patronage of religious establishments across the new colony. This colonial expansion reached its peak in the first half of the thirteenth century when approximately three-quarters of the country had been feudalised.[53] This first phase of colonization is considered to have continued until the mid- to late-thirteenth century and its cessation roughly corresponded with the reduced interest shown in Ireland by the later Angevin kings and the absenteeism of many Anglo-Norman lords. Only a very small number of tracery windows from this period have survived to be recorded and evaluated in this study.

Building work in the fourteenth century, although not as rare as was once thought, did encounter a significant slow down.[54] Architecture suffered as a result of both political instability, particularly through the effects of the Bruce-led Scottish invasions from 1315,

for appraisals of aspects of the history of the Gaelic 'nation' during this era see P. J. Duffy, D. Edwards and E. FitzPatrick, eds. *Gaelic Ireland c.1250-c.1650: Land, Lordship & Settlement*. Dublin: Four Courts Press, 2004 (hereafter *Gaelic Ireland*).

[51] P.J. Duffy, D. Edwards and E. FitzPatrick, eds. *Gaelic Ireland*, p. 17.

[52] R. Stalley, *The Cistercian Monasteries of Ireland*. London & New Haven: Yale University Press, 1987, p. 239.

[53] J. Lydon, *Lordship of Ireland*, p. 86.

[54] H.G. Leask, *Irish Churches & Monastic Buildings*. Vol. II. Dundalk, Ireland: Dundalgan Press Ltd., 1960. 3rd, pp. 123-4 (hereafter *Irish Churches II*). For a reappraisal of building activity in the fourteenth century see R. Stalley, 'Irish Gothic and English Fashion.' *The English in Medieval Ireland*. Ed. J. Lydon. Dublin, 1984. 65-86; T.E. McNeill, 'Church Building in 14th Century Ireland and the 'Gaelic Revival'', *The Journal of Irish Archaeology*, 1985, 3, 61-4 and S. Mannion, 'A study of the physical remains of the medieval friaries of Connacht', Ph.D. Queen's University, Belfast, 1997 (hereafter 'Medieval friaries').

and environmental conditions, such as the recurrence of the plague from 1348 throughout the 1350s. The nobility of the country, both Anglo-Norman and Gaelic, were too often occupied with war to spare the financial support needed for architectural patronage. The situation was further aggravated by the issue of massive depopulation which affected the religious communities, who might otherwise have needed to expand, and the masons and labourers who might have carried out these building works.[55] However, a small but important number of architectural endowments were made to some buildings such as the Dominican friary at Athenry and St. Nicholas' collegiate church, Galway. These donations are particularly worthy of examination in relation to an investigation into how the political and economic landscape of the time may have affected contemporary architecture, particularly in comparison with later periods.

Most important for this study, however, are the architectural remains of the late medieval era. Buildings and traceried windows from this period constitute the main body of the architectural record which has survived to modern times. The available evidence includes a good record of window tracery but the researcher must also be cognisant of the amount of material which has been lost or altered, and must reflect this in any conclusions. Any information which this research can reveal about post-medieval alterations will also be examined and considered.

The relatively large amount of building work undertaken at this time can be attributed to a period of general prosperity in the country. James Lydon described the fifteenth century as an era when the fighting between Anglo-Irish and Gaelic societies abated allowing trade to flourish. This came about partly as a result of greater Irish political and governmental independence from the crown, a situation created by the Lancastrian kings' need to focus on affairs in England and in France. In Ireland these events produced increased wealth which ruling families increasingly directed towards architectural patronage, frequently in the form of ecclesiastical endowments.[56]

About this time a major change was also taking place in church doctrine with emphasis being placed on the need to speed a soul's path from purgatory to heaven; a process which could be assisted through prayer and benefaction to the church. The Council of Florence, which began in 1439, drew up the Decree of Union between the Greek and Roman churches and included agreement on purgatory which it defined as "a place or condition of temporal punishment for those who, departing this life in God's grace, are, not entirely free from venial faults, or have not fully paid the satisfaction due to

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[55] J. Lydon, *Lordship of Ireland*, pp. 121-76.
[56] J. Lydon, *Lordship of Ireland*, p. 180.

their transgressions." Developing this, in the ecumenical Council of Trent from 13 December, 1545 to 4 December, 1563, a decree enjoined "on the Bishops that they diligently endeavour to have the sound doctrine of the Fathers in Councils regarding purgatory everywhere taught and preached, held and believed by the faithful" a statement, which although later than many of the windows in this study, demonstrates the continued focus of the idea of purgatory throughout the 15th and 16th centuries.[57] To receive prayers after their death donors paid for visible elements of the church, in particular, windows which could also display images and heraldry. Prayers for passage through purgatory were also often directed towards saints and their relics, which links with the importance of the medieval pilgrimage. In Ireland, Holycross Cistercian abbey benefited from generous patronage which resulted, at least partially, from ownership of a relic of "the one true cross". The impact of this belief system on the sponsorship of glass and the tracery that supported it remains to be examined in an Irish context.

Rachel Moss, among others, has suggested that "scarcely a standing church was left unaltered" during this time, while there was also significant activity in the refurbishment of many existing monasteries and the founding of religious houses with, for example, sixty-seven Franciscan friaries established between 1400 and 1508.[58] In the examination which follows, this enquiry into the potential influences at play in the design of Irish architecture is further examined through an empirical evaluation of late Irish medieval tracery.

In summary, the period of study for this investigation is primarily late medieval but, where appropriate, works from the twelfth, thirteenth and early fourteenth centuries will also be considered, with the aim of examining how the political and environmental conditions of the period impacted on its architecture, if at all.

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[57] E. Hanna, *The Catholic Encyclopedia.* New Advent Online Edition ed. Vol. 12. New York: Robert Appleton Company, 1911.
[58] R. Moss, 'Revivalist tendencies in the Irish Late Gothic: defining a national identity?' *Reading Gothic architecture: Studies in the visual cultures of the Middle Ages.* Ed. M.M. Reeve. Vol. 1. Turnhout, Belgium: Brepols, 2008, p. 125.

3.4 Choice of study area

The final element of methodology to discuss is the selection of regions selected for study. The most critical factor in this regard was that a sufficient quantity of surviving window tracery would be available in order to give credibility to any conclusions drawn. This rules out the modern province of Ulster because the more volatile nature of the region, particularly following the Ulster plantation of the seventeenth century, ensured that fewer medieval buildings survived intact than in other regions of the country. A second factor which affected the survival of medieval buildings was subsequent development, particularly between the seventeenth and twentieth centuries, and locations where population increases were limited generally endured less damage. In this respect a significant number of sites documented in Dissolution records and antiquarian drawings of the eighteenth and nineteenth centuries in the eastern part of the country, contiguous with the medieval Pale are now lost.[59] Since the nature of the topography combined with the absence of suitable building materials in west Munster limited the amount of architectural activity there during the middle ages the remaining potential study areas are south-west Leinster, Connaught and north-east Munster. In medieval times these territories were roughly equivalent to the kingdoms of Ormond, Connaught and Desmond, respectively.

While any one of these regions might provide a useful focus for study, little comparative work has been carried out on the regional nature of architecture in these areas, or if indeed such distinctions exist at all. The political affiliations of the ruling families as well as the geographical, economic and religious characteristics of the region could all have influenced the local ecclesiastical architecture.

The following is a brief description of the characteristics of each of the selected regions during the medieval era, particularly in the fifteenth and early sixteenth centuries, in respect of the known patronage of ruling families and ecclesiastical powers, the local geographical and economic conditions, and the types of buildings that contain tracery.

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[59] See, for instance, N.B. White, *Irish Monastic and Episcopal Deeds, A.D. 1200-1600. Transcribed from the originals preserved at Kilkenny Castle. With an appendix of documents of the sixteenth and seventeenth centuries relating to monastic property after the dissolution.* Ormond Deeds. Dublin: Stationery Office, 1936; G. Beranger and P. Harbison, *A collection of drawings of the principal antique buildings of Ireland.* Dublin: Royal Irish Academy, 1991; P. Harbison, 'Barralet and Beranger's antiquarian sketching tour through Wicklow and Wexford in the autumn of 1780', *PRIA,* 2004, 104 (6 Section C), p. 132-90 and P. Harbison and A. Cooper, *Cooper's Ireland: drawings and notes from an eighteenth-century gentleman.* Dublin: O'Brien Press in association with the National Library of Ireland, 2000.

3.4.1 Kingdom of Ormond
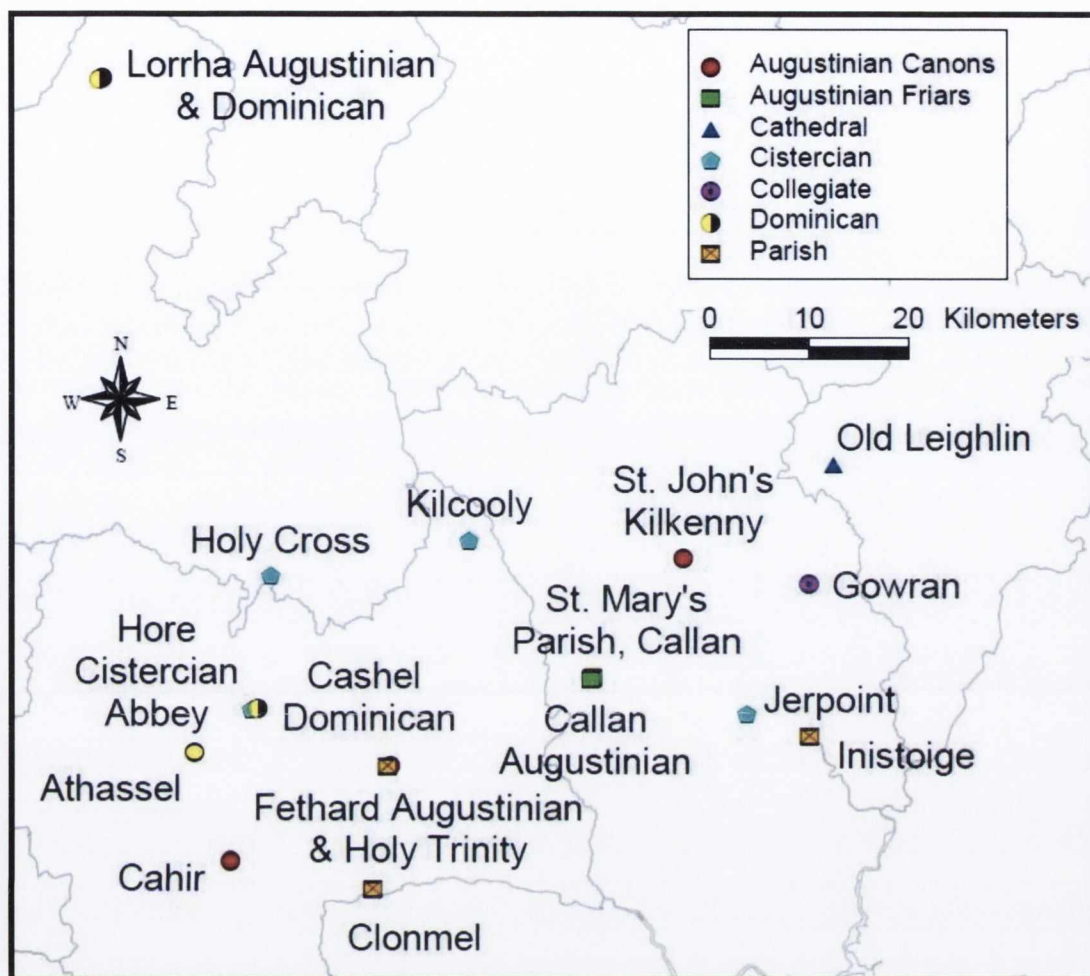
Figure 3.5 Medieval Ormond: distribution of ecclesiastical sites examined in this study

The borders of the kingdom of Ormond varied throughout the Middle Ages, but by the later medieval period they corresponded roughly with the territories in south east Munster and Leinster under the control of the Butler Earls of Ormond.[60]

The title 'Butler of Ireland' was first issued to Theobald FitzWalter after he had accompanied King John on his visit to Ireland in 1184, and from this line descended James Butler, first Earl of Ormond, created in 1328.[61] With the exception of a two-year period between 1527 and 1529 when Thomas Boleyn, also a relative, was incumbent, the title was held in the Butler family name, creating a political dynasty more stable than most in medieval Ireland. The fourth or 'white' earl, James Butler, for example, ruled for

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[60] For the history of the Lordship see for example E. Curtis, *Calendar of Ormond Deeds [1172-1603]*. 6 vols. Dublin: Irish Manuscripts Commission, 1932 with the original deeds retained at Kilkenny Castle; C.A. Empey, 'The Butler lordship in Ireland', PhD. Trinity College Dublin, Dublin, 1970; D. Edwards, *The Ormond lordship in County Kilkenny, 1515-1642: the rise and fall of Butler feudal power*. Dublin: Four Courts Press, 2000 and D. O'Donovan, 'Building the Butler Lordship 1405–c. 1552', Ph.D. Trinity College, Dublin, 2007 (hereafter 'Building Butler').

[61] A.L. Poole, *From Domesday Book to Magna Carta, 1087-1216* Oxford History of England. 2nd ed. Oxford: Clarendon Press, 1955, p. 313.

almost half a century from 1405 to his death in 1452. This is not to say that the borders of the kingdom were equally constant since family feuding and incursions from neighbouring Anglo-Norman and Gaelic lords lead to frequent redrawing of the physical limits of the territory.[62]

During the fifteenth century members of the Butler family held roles such as Deputy of Ireland, Lord Lieutenant in Ireland, Lord High Treasurer of England, and Lord Chamberlain to the Queen of England.[63] As well as their Irish estates, at various periods the earls held significant territories in England, [64] and maintained close connections with the English court. However, like most of the English of Ireland, the family were not immune to the influences of their Gaelic neighbours and by the late fifteenth century the Butler earls exhibited distinctively cross-cultural tastes.

For a family with such high-level connections to the English crown and to England's leading individuals, the ability to demonstrate both their wealth and sophistication would have been important. Architectural patronage provided one very visible medium by which this could be achieved. Danielle O'Donovan's examination of the nature and extent of Butler patronage in the fifteenth and early sixteenth centuries has shown that stylistic influence from abroad was brought to bear on many of their architectural achievements.[65] On the other hand, it is clear that some of the earls demonstrated more than a passing interest in Gaelic culture. For example James, the White Earl, commissioned books from both Gaelic and English scribes – so to what extent did this cross-cultural patronage extend to architecture?[66]

Although medieval Ormond was geographically close to the English administration in Dublin, communication between the two regions was frequently conducted by sea in order to avoid the hostile MacMurrough territory of modern west Wicklow. The region's ports, in particular at Waterford, were also an essential

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[62] J. Lydon, *Lordship of Ireland*, p. 197.

[63] J.W.E. Doyle, *The Official Baronage of England, showing the succession, dignities, and offices of every peer from 1066 to 1885, with Sixteen Hundred illustrations*. London: Longmans & Green, 1885 and A. Fraser, *The six wives of Henry VIII*. Illustrated ed. London: Weidenfeld & Nicolson, 1996, p. 59.

[64] The 7th earl was said to have owned 72 manors in England and been one of its richest men. M.L. Bruce, *Anne Boleyn*: London: Pan Books, 1975, p. 11.

[65] See in particular chapter 4: Butler patronage: local and national context. D. O'Donovan, 'Building Butler', pp. 132-88.

[66] In 1422, from the Dublin notary James Yonge, he commissioned a copy of *The Governaunce of Prynces*, a free translation of the *Secreta Secretorum*: A. Bliss and J. Long, 'Literature in Norman French and English to 1534.' *A New History of Ireland. 2, Medieval Ireland 1169-1534*. Ed. A. Cosgrove. Vol. 2. Oxford: Clarendon Press, 1987, p. 735. He also commissioned a praise poem from Tadhg O'Higgin and a book in Irish containing some of the highest quality Insular illumination of the 15th century: K. Simms, 'Bards and Barons: The Anglo-Irish Aristocracy and the Native Culture.' *Medieval Frontier Societies*. Eds. R. Bartlett and A. MacKay. Oxford: Clarendon Press, 1992, pp. 186-7 and F. Henry and G. Marsh-Micheli, 'Manuscripts and Illuminations, 1169-1603.' *A New History of Ireland. 2, Medieval Ireland 1169-1534*. Ed. A. Cosgrove. Vol. 2. Oxford: Clarendon Press, 1987, pp. 801-2.

thoroughfare for trade with England, often through Bristol, and with continental Europe. Waterford had been declared a city by Henry II in 1171 and its rights were frequently confirmed by statute of the king, such as recorded in 1458 by Henry VI who proclaimed Waterford free to "enjoy all their goods customs, liberties, franchises, privileges and usages, as they have had and used heretofore".[67] Along with the towns of Kilkenny, Wexford and Ross, Waterford nominated "worthy and lawful citizens" to attend Irish parliament, as given in an example from 1380, validating its importance to the English administration.[68]

As well as importing luxury goods via a wide network of trading links the Earls of Ormond also mobilised people, as recorded in 1525 where Margret Fitzgerald, Countess of Ormond, brought craftsmen from Flanders to instruct local weavers in the making of "diapers, tapestries, Turkey carpets, cushions and other like works".[69] This evidence also demonstrates that the relative political and economic stability of the era made the purchase of expensive luxury items and the employment of craftsmen for purely decorative purposes possible.

Although funds were made available for building works, these were still relatively restricted and most building resources were sourced locally. Unlike many of the larger building projects of the thirteenth century, such as Waterford Cathedral, where oolitic limestone was imported from Dundry, near Bristol, fifteenth and sixteenth century works tended to use local stone.[70] While the purchase of foreign stone may have been within the means of architectural patrons it was the transport of materials which made its use unfeasible. Unless water transport was possible in the middle ages the carriage of heavy materials, such as building stone, was significantly more costly than the materials themselves or even the craftsmen who worked them.[71]

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[67] 36 Henry VI. A.D. 1458.

[68] E. Curtis and R.B. McDowell, *Irish historical documents, 1172-1922*. London: Methuen, 1968, p. 64.

[69] Historical Manuscripts Commission, Manuscripts of O'Conor Don in Appendix to 2nd Report. MS, pp. 224-5.

[70] For information on Waterford cathedral see R. Stalley, 'Three Irish Buildings with West Country Origins.' *Medieval Art & Architecture at Wells and Glastonbury*. Eds. N. Coldstream and P. Draper: British Archaeological Association Conference Transactions, 1981. 62-80, p. 69. For information about the use of imported stone at the Dublin cathedrals see M. O'Neill, 'St Patrick's Cathedral in Dublin and its place in the history of Irish medieval architecture', Ph.D. Trinity College, Dublin, 1995; M. O'Neill, 'Design sources for St. Patrick's Cathedral, Dublin, and its relationship to Christ Church Cathedral', *Proceedings of the Royal Irish Academy*, 2000, 100C (6), 207-56; R. Stalley, 'The construction of the medieval cathedral, c.1030-1250.' *Christ Church Cathedral, Dublin: a history*. Ed. K. Milne. Dublin: Four Courts Press, 2000; R. Stalley, 'The architecture of the cathedral and priory buildings, 1250-1530.' *Christ Church Cathedral, Dublin: a history*. Ed. K. Milne. Dublin: Four Courts Press, 2000 and R. Moss, 'Tales from the crypt: the medieval stonework of Christ Church cathedral, Dublin.' *Medieval Dublin III: proceedings of the Friends of Medieval Dublin Symposium 2001*. Ed. S. Duffy. Dublin: Four Courts Press, 2002. 95-114.

[71] For examples of the costs related to the carriage of materials see L.F. Salzman, *Building in England down to 1540: A Documentary History*. Oxford: Oxford University Press, 1952, pp. 349-354.

In Ormond quality building stone was available locally. An examination of the geology of the area shows that both limestone and sandstone were present. The limestone is shown in Figure 3.6 as pale blue, representing marine shelf facies, while the dark blue areas indicate marine shelf and ramp facies resulting in argillaveous dark-grey bioclastic limestone; a type of stone containing significant amounts of clay-like materials producing a silvery appearance. These geological features encircle areas of sandstone with deltaic and basinal marine origins (green in Figure 3.6) and with deltaic and shallow marine origins (grey in Figure 3.6).[72] Although no definite information survives about the location of medieval quarries throughout the region, an examination of the positions of working quarries in 2001 as mapped by the Geological Survey of Ireland could give an indication of locations where stone extraction occurs. In Figure 3.6 these quarry sites are shown as pink circles, with the positions of pits shown as orange circles. Both types of extraction feature strongly in the limestone and sandstone areas of north Kilkenny and west Carlow.
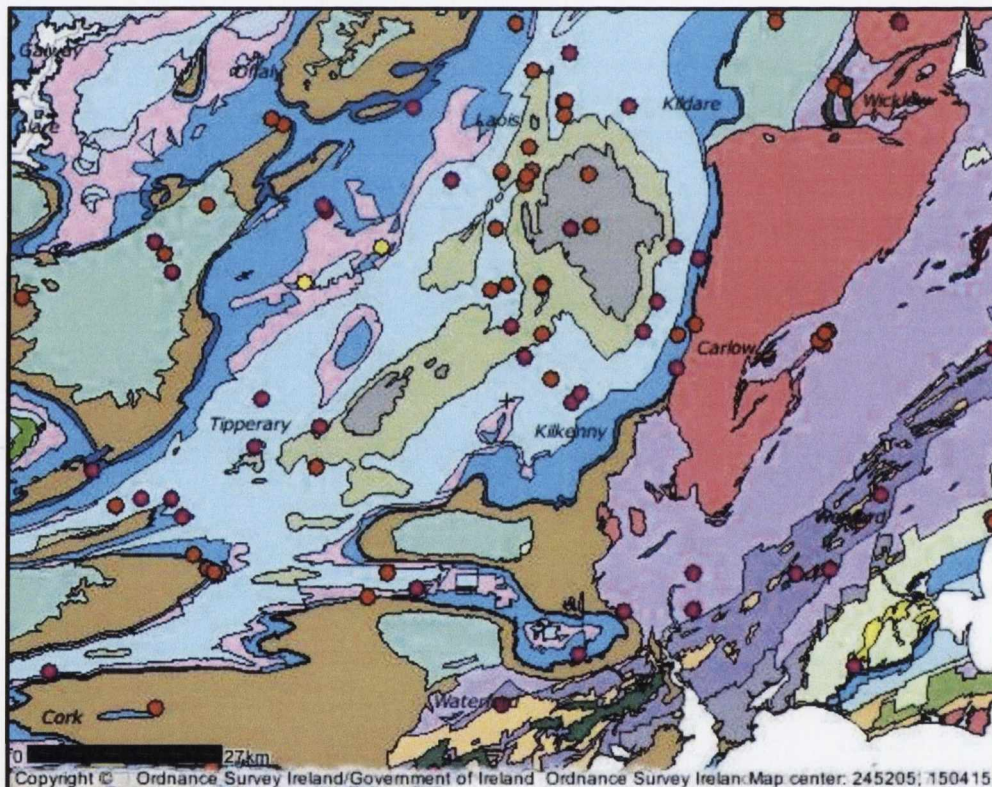
Figure 3.6 Geological map of the Ormond region overlaid with quarries (pink circles) and pits (orange circles) from 2001. Pale blue areas represent limestone while the green area on the Kilkenny, Carlow, Kildare, Laois border represents sandstone. A full interpretation of all of the geological information is included in appendix 5. Data courtesy of Geological Survey Ireland and Ordnance Survey Ireland.[73]

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[72] Geological Survey of Ireland, 'GSI Datasets Public Viewer.' Dublin, 2009. Government of Ireland. Viewed September 2009. <http://spatial.dcenr.gov.ie/imf/imf.jsp?site=GSI_Simple>.

[73] Geological Survey of Ireland, 'GSI Datasets Public Viewer.' Dublin, 2009. Government of Ireland. Viewed September 2009. <http://spatial.dcenr.gov.ie/imf/imf.jsp?site=GSI_Simple>.

Daniel Tietzsch-Tyler's work on the building stones of St. Canice's cathedral, Kilkenny shows that ~45 modern or closed quarries of lower carboniferous fossiliferous limestone are known within an approximately 10km radius of Kilkenny city (Figure 3.7). However, given the scale and importance of Kilkenny cathedral, stone was also sourced from throughout Ireland as well as imported from Wales, England, Italy, Spain and France.[74] This indicates the density of locations from which stone of sufficient quality for building could be extracted.
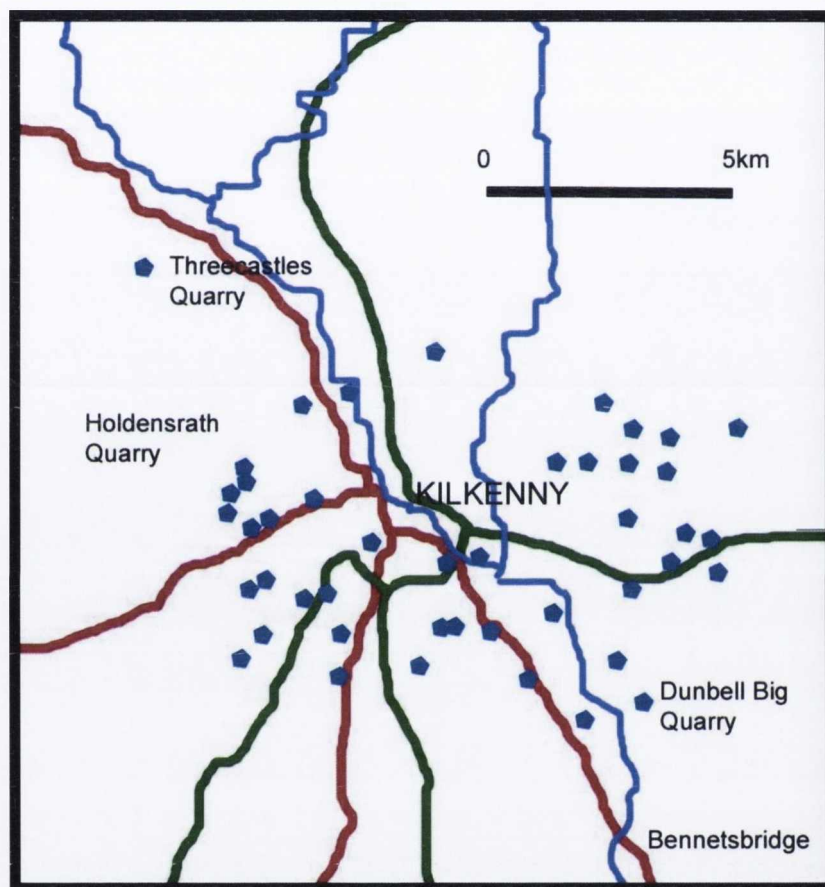
Figure 3.7 Map of past or presently active quarries in the vicinity of Kilkenny city shown with national primary routes (green), national secondary routes (red) and main rivers (blue). Quarry locations are marked by blue pentagons.

The evidence from these two sources shows that distances between most ecclesiastical sites and their nearest quarry would have been less than 50 kilometres and that at least some transport could have been undertaken using local rivers, thus reducing overall costs. With reduced costs, more projects and works of greater ambition could be undertaken, as is reflected in the density of ecclesiastical sites in the region.

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[74] D. Tietzsch-Tyler and Geological Survey of Ireland., *Building stones of St Canice's Cathedral, Kilkenny: an introduction to the rocks of the Kilkenny region.* Dublin: Geological Survey of Ireland, 1995.

As was typical of the whole country, ecclesiastical buildings of various types were distributed throughout the Ormond region. Houses of Cistercian monks, Augustinian canons and friars, and Dominican friars were established in the area and examples of window tracery from each are included in this study. However, although six first order and two third order Franciscan houses were founded within Ormond, none have retained any measurable tracery.[75] Of tracery from cathedral buildings, Waterford Cathedral has been lost, having been demolished in the eighteenth century, and St. Canice's Cathedral, Kilkenny, unlike many buildings in the region, did not update its windows with bar tracery in the later middle ages, retaining its thirteenth-century groups of lights and very simple plate tracery (Figure 3.8).
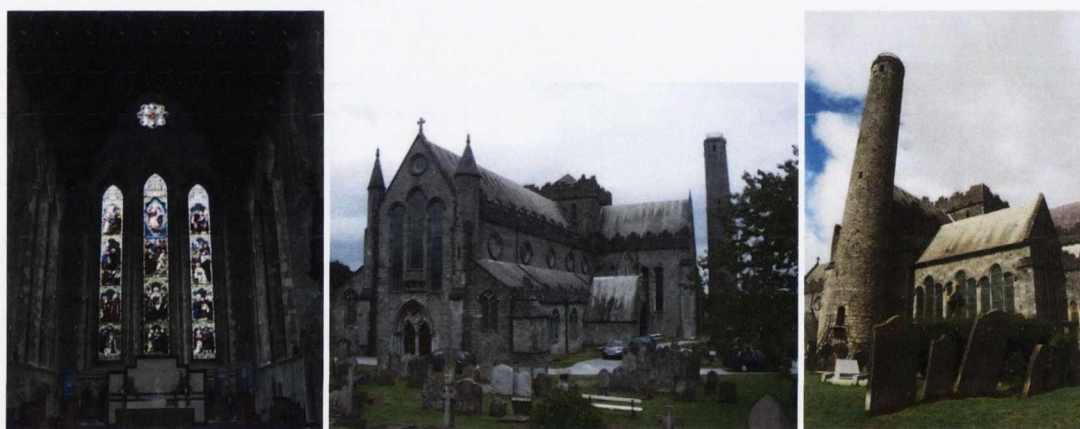
Figure 3.8 St. Canice's cathedral, Kilkenny, Ormond. Chancel east window interior, exterior from the south west and exterior from the south east (left to right).

This study included eighteen ecclesiastical sites in Ormond where window tracery has survived and the analysis which follows investigates their similarities, differences and relationships to the political, geographical and economic conditions of this region.

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[75] A. Gwynn and R.N. Hadcock, *Medieval Religious Houses: Ireland.* 2nd ed. Blackrock, Co. Dublin: Irish Academic Press, 1988. pp. 238-9 and p. 267-8 (hereafter *Medieval Religious Houses*).

3.4.2 Kingdom of Connaught
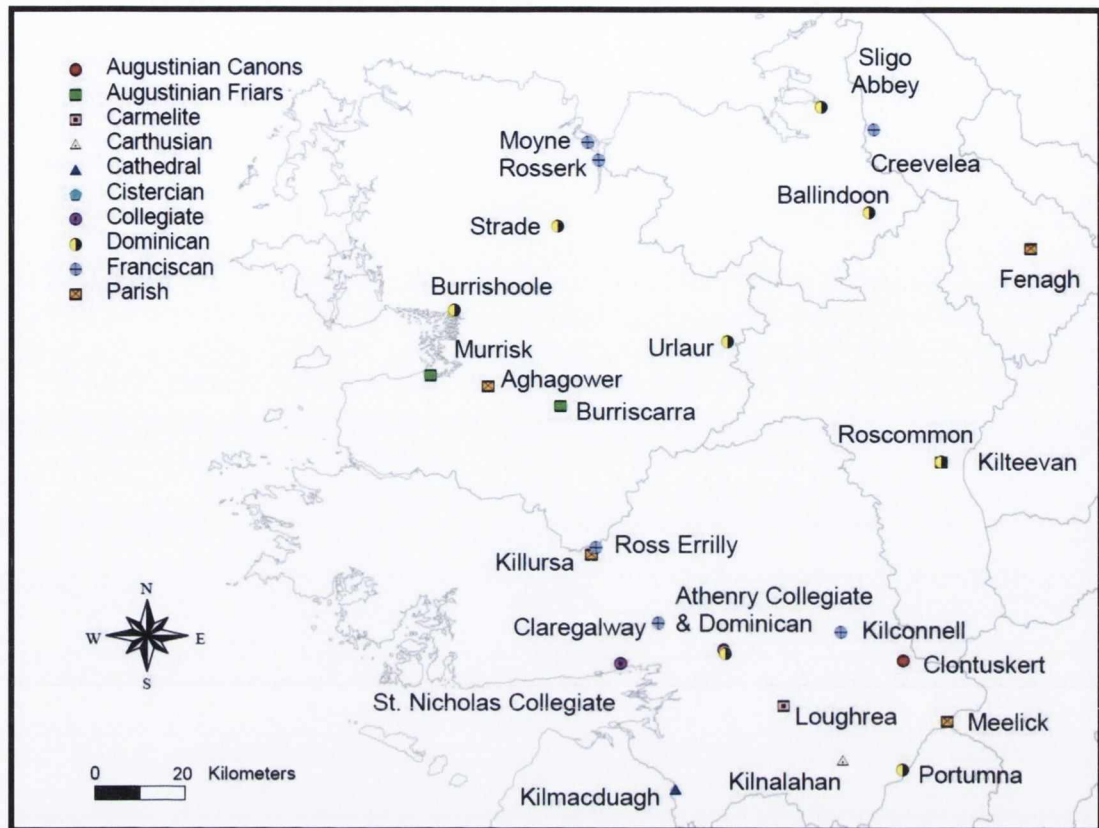
Figure 3.9 Medieval Connaught: distribution of ecclesiastical sites examined in this study

The Connaught region encompassed the lands west of the Shannon as far south as the border with the kingdom of Thomond, modern county Clare, and north to the border of Ulster, counties Donegal, Fermanagh and Monaghan.[76]

Having first been granted to Richard de Burgh in 1215, the early intention for the province seems to have been governance by an Irish king, of the O'Connor clan, in subjugation to the English Crown.[77] However, following twenty years of infighting amongst the O'Connors, and with their neighbours, the Anglo-Normans felt it necessary to undertake a major campaign to bring the entire province under direct control, leading to a record in the Annals of Connaught from 1237 which read "The Irish Barons came into

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[76] For the medieval history of the area see for example H.T. Knox, 'Occupation of Connaught by the Anglo-Normans after A.D. 1237', *Journal of the Royal Society of Antiquaries of Ireland*, 1902, 32 (2), 132-8; 1902, 32 (4), 393-406; 1903, 33 (1), 58-74; 1903, 33 (2), 179-89; 1903, 33 (3), 284-94; B.J. Graham, *Anglo-Norman Settlement in Ireland*. Irish Settlement Studies. Vol. 1. Belfast: Group for the Study of Irish Historic Settlement, 1985; and J. Lydon, *Lordship of Ireland*. For the early relations of Connaught with the Anglo-Normans see H. Perros, 'Crossing the Shannon Frontier: Connacht and the Anglo-Normans, 1170-1224.' *Colony and frontier in medieval Ireland: essays presented to J.F. Lydon*. Eds. T.B. Barry, R. Frame and K. Simms. London: The Hambledon Press, 1995.

[77] P. Holland, 'The Anglo-Normans in Co. Galway: The Process of Colonization', *Journal of the Galway Archaeological and Historical Society*, 1987, 41, 73-89, p. 73.

Connaught and began the building of castles therein".[78] While de Burgh remained the overlord, taking direct control of areas related to the pre-Norman territories of Meanmagh, Síl Anmchadha and Cineal Aedha, the Anglo-Norman tradition of subinfeudation meant that other ancient cantreds were granted to tenants such as the Maurice FitzGerald, John de Cogan and Walter de Ridelsford.[79] At the peak of colonisation, towards the end of the thirteenth century, the Connaught region was considered an Anglo-Norman territory since the local Gaelic lords had not successfully rebutted the English advances, as had been achieved in areas such as Ulster and parts of Thomond.

However, the problems affecting the entire Anglo-Norman territory in Ireland in the fourteenth century were particularly strongly felt in Connaught, resulting in the area obedient to England contracting to small regions, such as the areas surrounding Galway city and the town of Athenry. While descendants of original Anglo-Norman families still retained territories in Connaught, they were often surrounded by Gaelic lands, a pattern which continued until the middle of the sixteenth century (Figure 3.10).

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[78] 'Annala Connacht.' The Annals of Connaught. Ed. P. Bambury: CELT online at University College, Cork, Ireland, 2001.
[79] P. Holland, 'The Anglo-Norman Landscape in County Galway; Land-Holdings, Castles and Settlements', *Journal of the Galway Archaeological and Historical Society,* 1997, 49, 159-93, pp. 164-5.

Figure 3.10 Lordships in Ireland *c.*1534 from K.W. Nicholls [80]

Separated from English control as these colonists were, they adopted many Irish traditions, such as the use of hereditary assembly and inauguration place.[81] In relation to the patronage of religious establishments, this practice was a feature of late medieval lordship for Anglo-Norman and Gaelic nobility alike. For both traditions the foundation

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[80] K.W. Nicholls, 'Lordships *c.*1534'.
[81] See for instance E. FitzPatrick, 'Assembly and Inauguration Places of the Burkes in Late Medieval Connaught.' *Gaelic Ireland c.1250-c.1650: Land, Lordship & Settlement.* Eds. P.J. Duffy, D. Edwards and E. FitzPatrick. Dublin: Four Courts Press, 2004. 357-74.

and endowment of ecclesiastical sites were regarded as important religious activities, as well as being indicators of status. In some cases, such as the Dominican friary at Athenry, patronage came from both sides of the political divide.[82]

The effect that these political circumstances had on the ecclesiastic architecture of the region and, in particular, its similarity to, or distinction from, other regions has been little studied. Religious architecture in Connaught has been examined in isolation, such as by Susan Mannion, but comparative studies have usually focussed on areas of Munster and Leinster, such as those by Colum Hourihane, Róisín Mullin and, to an extent, by Danielle O'Donovan.[83] The following investigations, based on empirical measurement, will add to this limited body of knowledge and, hopefully, serve as a basis for further discussion.

Although Connaught's physical distance from England and continental Europe was greater than the other regions in this study, her ports actively traded with both locations during the period of interest. There are a number of records of vessels from Galway trading with Bristol but the percentage, relative to vessels from Ormond and Desmond is surprisingly small.[84] For example, of the 171 Irish ship movements recorded at Bristol between 1376 and 1404, only 1 came from Galway with other west coast towns of Limerick and Dingle registering 2 and 1, respectively. The Ormond ports of Waterford, Ross, and Wexford accounted for 64 entries while Desmond's south coast ports of Youghal, Kinsale, and Cork registered 92 ship movements. In a later fifteenth century record between 1460 and 1497, no ships from Galway were included in the register of 381 trades between Irish ships and Bristol or Bridgwater.[85] Only a few Connaught individuals have been recorded as being involved in trade through Bristol: Geoffrey Blake of Galway exported cloth in 1389; Nicholas Skeret of Galway did so in 1437; and Dennis Galway was employed as a Bristol shipmaster in the 1470s."[86] In respect of trade links with other

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[82] A. Coleman, 'Regestum monasterii fratum praedicatorum de Athenry', *Archivium Hibernicum,* 1912, 1, 201-21.

[83] C. Hourihane, *The Mason and His Mark: Masons' Marks in the Medieval Irish Archbishoprics of Cashel and Dublin.* British Archaeological Reports. Eds. J. Hedges and E. Hedges. Vol. BAR 294. Oxford: British Archaeological Reports, 2002; R. Mullin, 'A regional study' and D. O'Donovan, 'Building Butler'.

[84] H. Bush, 'Origins of the grant of the town of Bristol.' *Bristol Town Duties: A collection of original and interesting documents [etc.].* British History Online ed: Bristol Record Society, 1828. 5-42 (Hereafter *Bristol Town Duties*; S. Flavin, E.T. Jones and Bristol Record Society., *Bristol's trade with Ireland and the continent, 1503-1601 : the evidence of the Exchequer customs accounts.* Dublin: Four Courts Press, 2009 and Department of History University of Bristol, 'Ireland-Bristol Trade in the Sixteenth Century.' Bristol, 2009. University of Bristol. Viewed April 2011.
<http://www.bristol.ac.uk/Depts/History/Ireland/datasets.htm>.

[85] W.R. Childs, 'Irish Merchants and Seamen in Late Medieval England', *Irish Historical Studies,* 2000, 32 (125), 22-43, pp. 24-5 (Hereafter 'Irish Merchants and Seamen').

[86] W.R. Childs, 'Irish Merchants and Seamen', p. 26 quoting: Cal. pat. rolls, 1391-6, p. 594; H. Bush, *Bristol Town Duties,* pp 17-25; P.R.O., E 122/19/13,14, 20/1,5,7.

Connaught locations Wendy Childs could only find "one clear reference to direct shipping contact with Sligo" for the transport of herring. However, Bristol had a proverb that "'Herring of Sligo and salmon of Bamme [*recte* Bann] have made in Bristol many a rich man" implying that "the fish must have been transhipped on boats of the south-east".[87]

Examples of trade between Galway and French Aquitaine have also been reported through port records from the early fourteenth through to the early sixteenth centuries with the Irish importing essentials such as corn and salt, commodities such as wine and honey, and raw materials such as iron and lead.[88] Records of a Special Custom placed on wine imports in 1570 as preparation for the arrival of the Spanish Armada recorded the following returns: "Dublin, £711 1s. 4d., Drougheda, £134 5s. 4d., Waterforde, £700 10s. 8d., Rosse, £8 8s. 8d., Cork, £340, Wexford, £30, Lymerick, £400, Galwaye, £127 16s. 8d. £2,472 2s. 8d. summa in compoto Thesauri."[89] Galway's share was only about 2% while the combined Ormond ports of Waterford, New Ross, and Wexford accounted for ~30%. Thus, while Connaught's international trade may have increased significantly during the late middle ages, its opportunities for contact with foreign influence were still not as great as Ormond's or Desmond's.

In relation to the availability of building materials, an examination of the geological map of Connaught (Figure 3.11) clearly shows that access to workable stone here was as easy as in Ormond, if not easier, since the pale blue colour which dominates the province represents marine shelf facies-based limestone. Overlaying the locations of quarries and pits from 2001 on the geology of the region and extrapolating back to the middle ages suggests that few masons working at ecclesiastical sites would have needed to travel far to find suitable resources.

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[87] W.R. Childs, 'Irish Merchants and Seamen', p. 26 quoting P.R.O., E122/16/2.

[88] A. O'Brien, 'Commercial relations between Aquitaine and Ireland c.1000 to c.1550.' *Aquitaine and Ireland in the Middle Ages*. Ed. J.-M. Picard. Dublin: Four Courts Press, 1995. 31-80, pp. 59-60 and p. 64.

[89] A. Longfield, 'Anglo-Irish Trade in the Sixteenth Century as Illustrated by the English Customs Accounts and Port Books', *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature*, 1921, 36, 317-32, p. 329 quoting St. P. Irel., Eliz., vol. xxxii, No. 14.
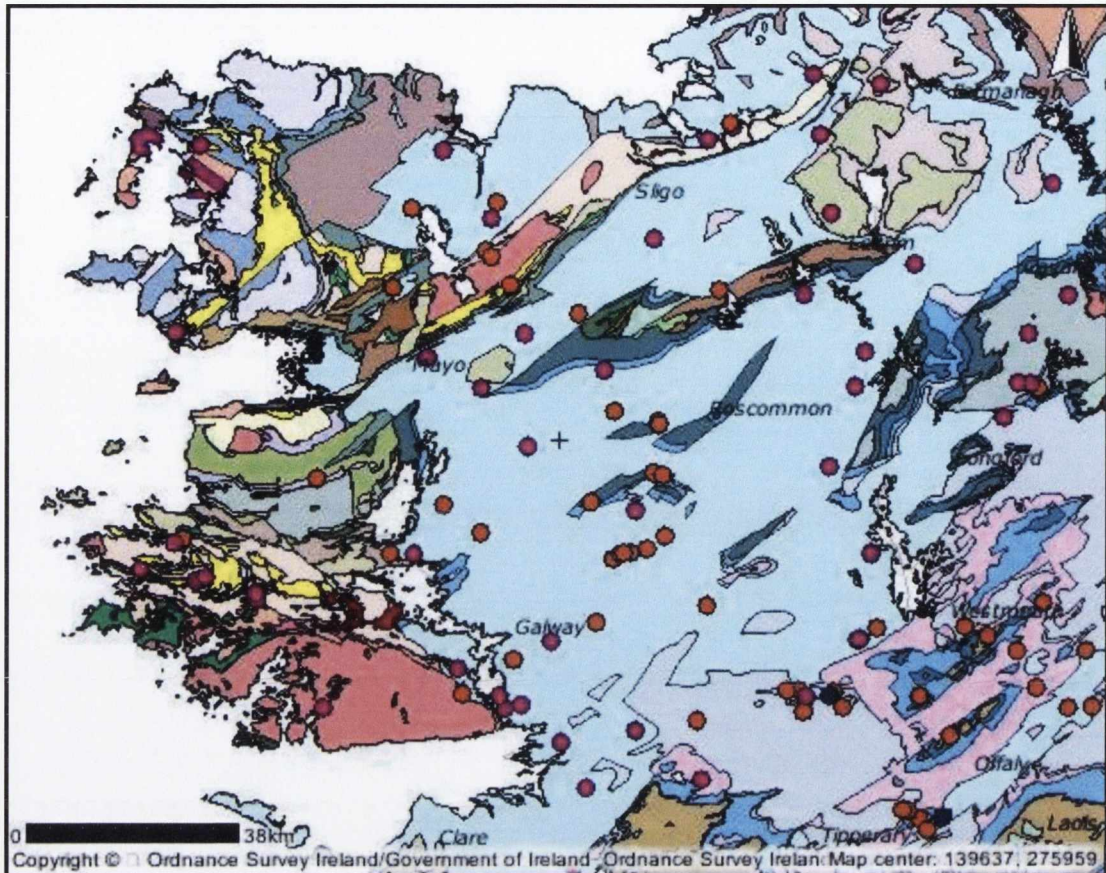
Figure 3.11 Geological map of the Connaught region overlaid with pits (orange circles) and quarries (pink circles) from 2001. Pale blue areas represent limestone. Interpretation and credits as for Figure 3.6.[90]

Many of the monastic foundations in Connaught survived the initial onslaught of Henry VIII's 1536 dissolution order only to succumb to Elizabeth I's new legislation for an Anglican state church in 1560. The survival of these sites for an extra twenty-five years is evidence of two key characteristics for Connaught: that its administration was not under the direct influence of the English crown, and that many of the religious houses were too poor to make the task of dissolution worth the effort. A number of sites were only briefly or never fully suppressed, typically because of support received from the families to whom the houses were granted.[91]

The selection of ecclesiastical establishments covered by this study is typically varied, including a cathedral at Kilmacduagh, a number of parish and collegiate churches, and monasteries of most of the major religious orders. Neither of the two remaining Cistercian abbeys, at Abbeyknockmoy and Boyle, nor the Cistercian cell on Clare Island

[90] Geological Survey of Ireland, 'GSI Datasets Public Viewer.' Dublin, 2009. Government of Ireland. Viewed September 2009. <http://spatial.dcenr.gov.ie/imf/imf.jsp?site=GSI_Simple>.
[91] J.S. Brewer and W. Bullen, eds. *Calendar of Carew MSS 1515-1624*. Vol. 5. 6 vols. London, 1867-1873, pp 471-6.

retain any window tracery.[92] Both abbey churches remained relatively untouched during the later middle ages, although a new cloister constructed at Abbeyknockmoy at this time. A significant number of mendicant friaries were founded in Connaught, particularly during the fifteenth century when thirty-nine were established, and a detailed history and description of each is given by Susan Mannion.[93] However, the remains of only eighteen sites contain bar tracery. These, and another ten sites in the other ecclesiastical categories, were examined in this study.

3.4.3 Kingdom of Desmond
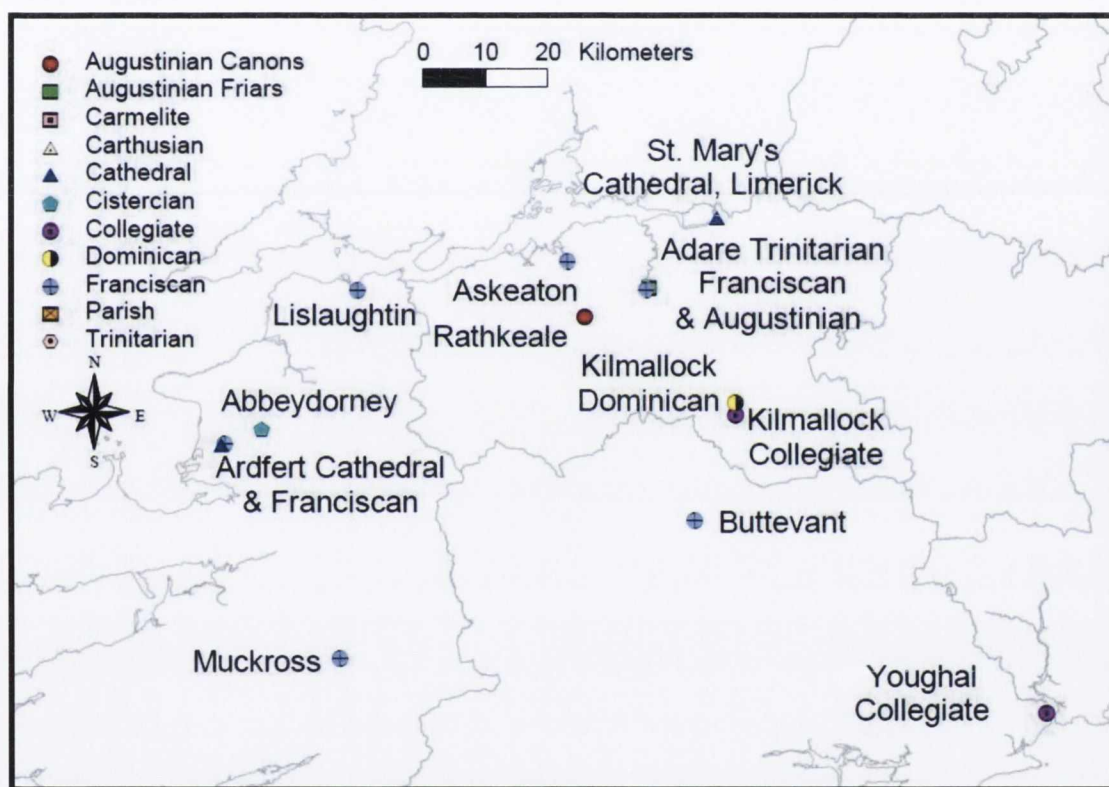
Figure 3.12 Medieval Desmond: distribution of ecclesiastical sites examined in the study

Rather than being subjected to the same level of investigation as Ormond and Connaught, the kingdom of Desmond was chosen as a reference or limited type of control. This choice was made because, although the first Earl of Desmond, Maurice fitzThomas, was a descendant of the Anglo-Norman FitzGerald family, he is reported as having frequently adopted Gaelic traditions where they were favourable to his personal gain, particularly

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[92] Although on Clare Island the cell contains a traceried tomb.
[93] S.E. Mannion, 'Medieval friaries'.

during the period 1330 to 1345.[94] While the Earls of Ormond were also involved in the general Hibernicisation of the Anglo-Normans which lead to, among other commands, the Statutes of Kilkenny, their allegiance to the Crown was less wavering than that of Desmond.[95] The first Earl was found guilty in 1326 of assembling a significant number of Anglo-Norman and Gaelic chiefs in a meeting intended to organise the wresting of control over Ireland from the king of England.[96] Ultimately, the revolt never materialized because of Maurice's local quarrels with the Powers and Burkes. However, in 1344 Desmond again made a similar attempt at uprising. Although outlawed as a result, by 1351 Desmond had been promoted to the position of justiciar of Ireland.[97] This episode was an early occurrence of a trend that repeated itself throughout the later middle ages where the king, often through lack of resources for a territory not deemed a priority, was forced to depend upon and make concessions to men such as Desmond in order to control the lordship of Ireland. This in turn meant that the English of Ireland could, and frequently did, wield a significant amount of unfettered power.

During the fifteenth century the kingdom of Desmond, like Ormond, enjoyed a long period of political stability, particularly during the rule of the sixth earl who held the title from 1420 to 1462, a period of more than forty years.[98] However, with the exception of a relatively brief period of temporary alliance between 1422 and 1444, the earls of Desmond and Ormond and their families were almost continuous engaged in wars and border skirmishes.[99] The amount of influence that this had on the movement of craftsmen or ideas is unknown but some level of distinctiveness might be expected between the two territories.

Administrative constancy led to increased economic prosperity, encouraging an increase in existing trading routes with Britain and across Europe through the regions ports.[100] Closeness to the sea ensured that, despite its land-measured distance from the administrative centres at Dublin and in the Pale, Desmond kept up-to-date with current

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[94] G.O. Sayles, 'The rebellious first earl of Desmond.' *Medieval Studies presented to Aubrey Gwynn, S. J.* Eds. F.X. Martin, J.B. Morrall and J.A. Watt. Dublin: Colm O Lochlainn, 1961. 203-29.

[95] 'Statutes of Kilkenny.' Parliament before Lionel Duke of Clarence, Lord Lieutenant of Ireland. Ireland, 1366. Published online by The Corpus of Electronic Texts < http://www.ucc.ie/celt/published/T300001-001/>.

[96] J. Lydon, *Lordship of Ireland*, p. 128.

[97] J. Lydon, *Lordship of Ireland*, p. 130.

[98] J. Lydon, *Lordship of Ireland*, p. 197.

[99] Ormond deeds, 1413-1509, no. 51; D. Mac Firbis, 'The annals of Ireland.' *The miscellany of the Irish Archaeological Society.* Ed. J. O'Donovan. Vol. 1. Dublin: Irish Archaeological Society, 1846, p. 205 and Public Records Office E.101/248/15.

[100] As recorded, for example, in the exchequer rolls of the period: H. S. Sweetman, *Calendar of Documents Relating to Ireland, Preserved in Her Majesty's Public Record Office, London.* Vol. 1. 5 vols. London: Longman: Trübner, 1875.

fashions from England and continental Europe. As was happening throughout medieval Ireland, patronage of ecclesiastic architecture flourished during this era with cathedrals, monasteries, and parish churches sharing in the bounty.

Only in the western extents of the kingdom could any notable geographical distinctions be made between Desmond and neighbouring Ormond. Here the reduced amount of quality land for farming produced a lower population and resulted in fewer ecclesiastical foundations vying for the patronage of the local nobility. Also in the west of Desmond, the available building stone was different, and tended to be less easily carved than the limestones of either Ormond (Figure 3.6) or Connaught (Figure 3.11). As demonstrated in Figure 3.13, much of this region shared a bedrock of shale or sandstone with little limestone. The different materials possibly had an effect on ecclesiastical design and on the detailing of buildings.

Figure 3.13 Geological map of the Desmond region overlaid with pits (orange circles) and quarries (pink circles) from 2001. The dominant green areas show the presence of sandstone while the pale blue areas represent limestone. Interpretation and credits as for Figure 3.6.[101]

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[101] Geological Survey of Ireland, 'GSI Datasets Public Viewer.' Dublin, 2009. Government of Ireland. Viewed September 2009. <http://spatial.dcenr.gov.ie/imf/imf.jsp?site=GSI_Simple>.

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Thus, Desmond as a region, and some of its key sites in particular, provide valuable comparative information for this study. By exhibiting some similarities to and some differences from one or both of the main study regions of Connaught and Ormond, the sites in this area will help to develop our understanding of a number of influences, in particular political, economic and geographical, on Irish medieval ecclesiastical building.

4 Metrology and proportion in medieval Ormond

Research into the systems of proportion and metrology used in tracery design in Ormond involved an empirical study of fifty-eight windows at eighteen sites throughout the region. It included parish and collegiate churches, and the churches of the Franciscan, Dominican, Augustinian (canons and friars) and Cistercian orders. All of these windows contain bar tracery and the total number shown represents an almost complete record of the remaining medieval tracery in Ormond.

Initially, this chapter will set out the general patterns of metrology and proportion in the region. A subset of windows will be sampled as an exercise in aligning the results of this investigation with the existence of a specific school or schools of masons active in the area, identified by a number of authors. Further samples will be extracted from the overall dataset to examine the sources of the most prominent medieval units and/or proportions in the region. A comprehensive case study will then be presented for St. Mary's collegiate church, Gowran. This examination will facilitate an appraisal of the relationship between window tracery and architectural details as regards metrology and proportion.

The results of these examinations will be further analysed in conjunction with the outcomes from Connaught in chapters 6 and 7 in order to address the remaining aims of this thesis.

4.1 Ormond metrology results

Two types of analysis were carried out for all fifty-eight windows measured in the Ormond region; metrological and proportional. The detailed methodologies of these analyses have been previously described but the key elements are reiterated here.

Irrespective of whether Irish masons' chosen unit of measurement was the shaftement, foot, rod or perch, a review of relevant medieval sources indicated that its metric value would most likely fall between 0.212m and 0.372m, or subdivisions thereof, making these the potential units for this investigation. A set of measurements was extracted from each window and these were compared with each potential unit, in steps of 1mm. This comparison process produced for each window at least one, and sometimes a number of, candidate units with associated statistical reliability. Following normalisation of these results to allow for unbiased comparison between the regions, as previously described, the information from all of the windows was combined to produce Figure 4.1,

which illustrates the number of times that each unit in the range 0.212m to 0.372m was identified in the data from Ormond.[1] The chart was created using a weighting of 1 for the most likely candidate unit, with 0.9 and 0.5 used for units within 10% and 20% of the most likely candidate unit, respectively (see appendix 6 on the DVD). The results for each measured location within the Ormond data set from which this chart was compiled are individually presented in Appendix 8, the site catalogue, and in the Site_Measurements_Units_Proportions folder on the accompanying DVD.
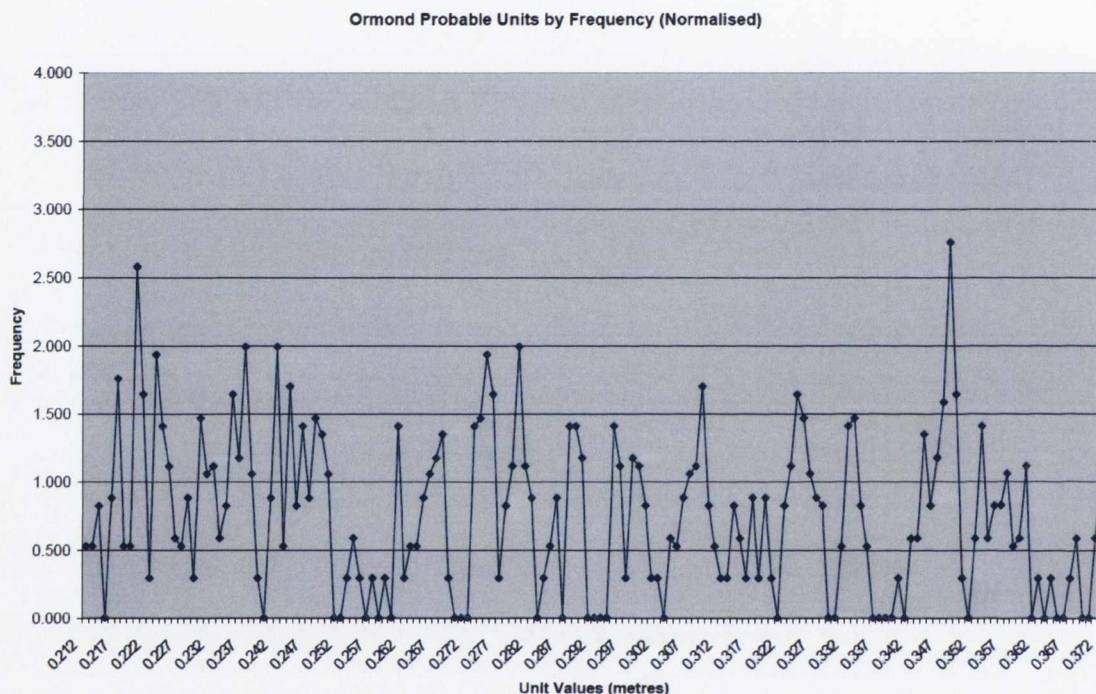
Figure 4.1 Ormond - Frequency of occurrence of all units between 0.212 and 0.372m

The data for Ormond shows two sharp peaks at 0.220m and 0.348m. However, the likelihood of a unit being deliberately used depends not on finding a single high-frequency unit but on locating a group of units within a number of millimetres of each other, all having relatively high frequencies. Since the tolerance for this study is ~1cm groups of high frequencies within 1cm of each other have been identified in the frequency data.

Figure 4.2 depicts such groupings as totalled frequency bars. The lower portion of each bar (in blue where the total count was within 25% of the maximum count for the region and in yellow when within 50%) represents the normalised, grouped frequency of one most probable candidate unit, while the smaller red portion on top of the frequency bar represents a measure of the difference between the probable unit as calculated from the

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[1] All similar charts in chapters 4, 5 and 6 were graphed using the same scales to facilitate comparison.

tracery data and the closest known or documented unit as evidenced from the literature.[2] It is acknowledged that some units may have been in use although no reference was made to their existence in contemporary medieval documentation, or no such documentation survives.[3] Therefore, the significance of the upper, red portion of the graph is, in some cases, limited.

Ormond Probable Units

Unit (m)	0.221	0.234	0.246	0.265	0.277	0.298	0.310	0.323	0.346
Normalised Frequency	11.775	10.896	11.189	7.499	11.775	6.503	7.499	8.143	10.779
Known Unit Name	Long Palm	Dodrans	Natural Foot	French/Welsh Foot	Bettess's Foot	Standard Roman Foot	Irish Foot	French Pied du Roi	Ped Manualis
Known Unit Value (m)	0.2230	0.2250	0.2490	0.2516	0.2800	0.2960	0.3048	0.3250	0.3540
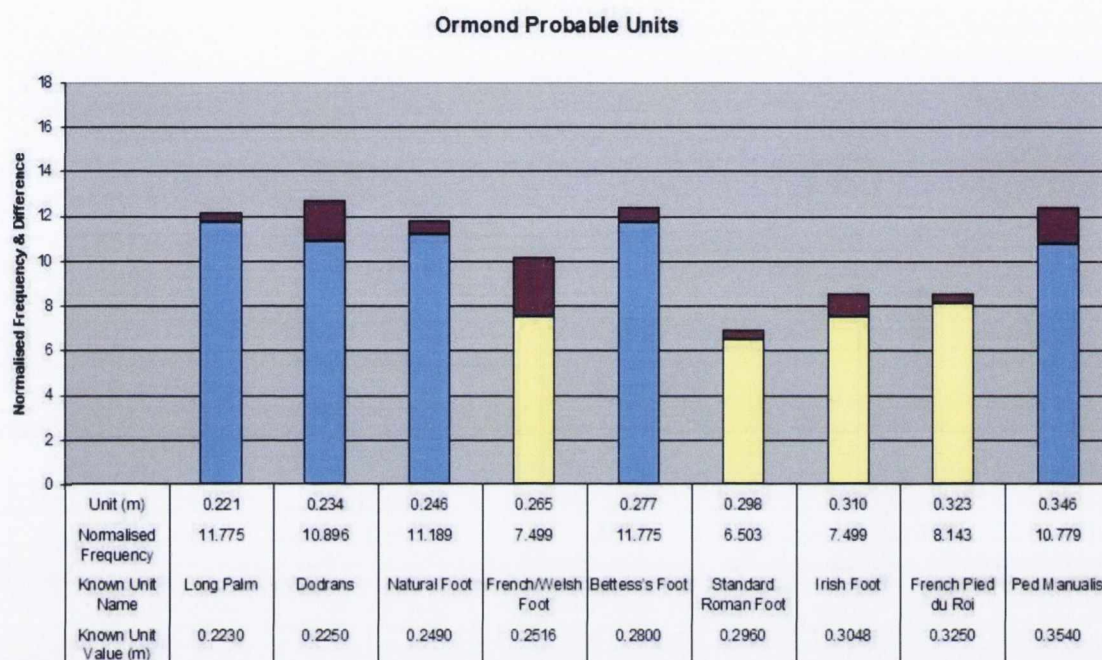
Figure 4.2 Ormond probable candidate units: frequency of occurrence (blue where frequency is within 25% of the maximum value and yellow within 50%) and similarity to known units (red)

Table 4.1 demonstrates the method used to derive each unit's total (9mm Total) as the sum of its own normalised frequency count plus the counts for the preceding four units and the following four units (sequentially shown as Contributing Normalised Counts). Table 4.1 also includes the value and name of the closest medieval unit found in the literature.

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[2] Since the values that resulted from the difference calculation were very small relative to the frequency counts they were multiplied by 200 in order to make them visible in the graph.

[3] The need to align results from building measurements with documentary evidence is highlighted by E. Fernie, 'A Beginners Guide to the Study of Architectural Proportions and Systems of Length.' *Medieval Architecture & its Intellectual Context: Studies in Honour of Peter Kidson.* Eds. E. Fernie and P. Crossley. London, England: The Hambledon Press, 1990. 229-37. This is discussed in detail in Chapter 2.

Table 4.1 Ormond probable units with totalled frequencies

Unit	Contributing Normalised Counts					9mm Total	Closest Medieval Unit Value & Name	
Units within 25% of the maximum count								
0.221	1.757	0.527	0.527	2.578	1.640	11.775	0.223	Long Palm
	0.293	1.933		1.406	1.113			
0.234	1.465	1.054	1.113	0.586	0.820	10.896	0.225	Dodrans
	1.640	1.172		1.992	1.054			
0.246	1.992	0.527	1.699	0.820	1.406	11.189	0.249	Natural Foot
	0.879	1.465		1.347	1.054			
0.277	1.406	1.465	1.933	1.640	0.293	11.775	0.280	Bettess's Anglo-Saxon Foot
	0.820	1.113		1.992	1.113			
0.346	0.586	0.586	1.347	0.820	1.172	10.779	0.354	*Ped Manualis*
	1.582	2.753		1.640	0.293			
Units within 50% of the maximum count								
0.265	1.406	0.293	0.527	0.527	0.879	7.499	0.2516	Welsh/French Foot
	1.054	1.172		1.347	0.293			
0.298	0.000	1.406	1.113	0.293	1.172	6.503	0.296	Standard Roman Foot
	1.113	0.820		0.293	0.293			
0.310	0.879	1.054	1.113	1.699	0.820	7.499	0.3048	Irish Foot
	0.527	0.293		0.293	0.820			
0.323	0.879	0.293	0.000	0.820	1.113	8.143	0.325	French *Pied du Roi*
	1.640	1.465		1.054	0.879			

The differences between calculated and known values for each of the higher probability units are, in millimetres, 2, 9, 3, 3 and 8 for 0.221m, 0.234m, 0.246m, 0.277m, and 0.346m, respectively. Considering the range of possible influences on accuracy and on build versus intention these deviations are very small and, certainly in the cases of 0.223m, 0.249m, and 0.280m, probably negligible. The significance and origin of all of the frequently-occurring units, either as unique to this region or also important in Connaught and/or Desmond, will be analysed in detail in chapter 6.

While the evidence gathered in the metrological investigation could be examined in isolation, the results of previous studies have shown that a holistic approach to a combined examination of metrology and geometric design could be more valuable. The approach of this chapter therefore, will be to first examine groups of windows that have previously been identified as products of the same school. Following on from this a purely empirical study will be carried out and the results of analysis of the two studies will be compared with data from the rest of the study in chapters 6 and 7.

4.2 Ormond proportion results

Evidence for the use of proportional design was extracted, as described previously, through the identification of known ratios between measurements of specific elements of the elevation of each window (widths and heights of lights, the full window, and the tracery fields). In order to identify the presence of any patterns within the ratio data, counts were made of the number of times that ratios were achieved within the full Ormond dataset. The criteria for selecting the ratios of interest was given in chapter 3 and margins of error were included through the use of 1% and 2% ranges (Table 4.2) about the true numeric value of each ratio. Values within the 1% and 2% ranges are shown separately and as a summation.

All of the same data was analysed in the proportional study as in the metrological one, fifty-eight windows from eighteen sites; a sufficiently large sample to provide a reliable basis for statistical analysis. Table 4.2 shows a list of the amalgamated and ranked results from the Ormond sites. For a full breakdown of which windows and which elements contributed to each ratio count see the site catalogue, appendix 8, and the Site_Measurements_Units_Proportions folder on the accompanying DVD

Table 4.2 Ormond ratios from normalised data - ranked by occurrence

Ratios	Numeric Value	All	1%	2%
1:2	0.500	55.3	34.8	20.5
1:3	0.333	37.9	20.5	17.4
4:5	0.800	29.8	18.6	11.2
1:1	1.000	29.8	14.9	14.9
5:6	0.833	28.6	13.7	14.9
1:4	0.250	19.9	7.5	12.4
2:3	0.667	19.9	9.3	10.6
3:4	0.750	19.9	10.6	9.3
1:√3	0.577	16.8	9.9	6.8
13:23	0.565	14.9	6.8	8.1
2:5	0.400	13.0	5.0	8.1
1:√2	0.707	12.4	7.5	5.0
377:610 Golden Section	0.618	11.2	3.7	7.5
3:5	0.600	6.2	6.2	0.0
1:√5	0.447	5.0	1.9	3.1

The most frequently occurring ratio, by a significant distance, is that of 1:2, which is one of the easiest proportions to execute. Next most frequent was 1:3 followed by 4:5, 1:1 and 5:6, which occurred an almost equal number of times. The similarity between the

numeric values for 4:5 and 5:6 (i.e. 0.800 and 0.833, respectively; a difference of only 4% in absolute terms) makes it difficult to definitively distinguish the intentions of the mason. If all of the occasions where these two ratios occurred were actually intended to be the same then this ratio would be the most frequently occurring of the data set with a normalised total of 58.4. That 1:4 and 2:3 are the next most prominent ratios is also significant. If a mason proportioned elements of a window using the halving of a particular unit, then it stands to reason that a smaller element could be derived by again halving that unit, thus resulting in the 1:4 ratio; similar arguments could be made for using 1:3 and 2:3 in combination.

4.3 Site analysis

The Ormond region provides a unique opportunity to examine how metrology and proportion may have aligned with other medieval masonic practices. In recent years studies that include late medieval sites in Ormond have been made through Colum Hourihane's investigation of masons' marks and Danielle O'Donovan's examination of moulding profiles.[4] The former found evidence for a school of masons centred on Holycross Cistercian abbey, while the latter developed this theory and presented an argument that a pattern book used by the Holycross masons later circulated within the region. In order to establish whether similar patterns can be detected in the metrology and proportions used, window tracery in buildings that provided evidence for these two investigations will be examined as a group in the following as a sample based on *a priori* knowledge. Then groupings of sites where the most prominent ratios and/or metrology in the region occurred will be presented representing a sample based on *a posteriori* or empirical knowledge from this study.

4.3.1 The Holycross 'school' and 'pattern book'

When describing the School of the West, Harold Leask defined a school of masons as "a body of tradition" but not as "an indication of the existence of one guild of masons".[5] The masons involved at least in the early stages of the Holycross 'tradition' were based there

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[4] C. Hourihane, *The Mason and His Mark: Masons' Marks in the Medieval Irish Archbishoprics of Cashel and Dublin*. British Archaeological Reports. Eds. J. Hedges and E. Hedges. Vol. BAR 294. Oxford: British Archaeological Reports, 2002 (hereafter *Masons' Marks*) and D. O'Donovan, 'Building the Butler Lordship 1405–c. 1552', Ph.D. Trinity College, Dublin, 2007 (hereafter 'Building Butler').

[5] H.G. Leask, *Irish Churches & Monastic Buildings*. Vol. II. Dundalk, Ireland: Dundalgan Press Ltd., 1960. 3rd, p. 53 (hereafter *Irish Churches II*).

during fifteenth-century works, which probably started as early as 1432 and continued until as late as 1484, with funds having been collected between 1429 and the 1450s.[6] While the original abbey was founded as a daughter house of Monasteranenagh, co. Limerick c.1182 by Donal Mór O'Brien, by the fifteenth century Holycross came under the protection of the Butler earls of Ormond.[7] The Butlers were the major patrons of this phase of building, as shown by heraldry on site and by the granting of land to the monastery by associates of the family.[8]

Through his examination of masons' marks at Holycross, Colum Hourihane suggested that forty-nine different masons worked on site, although not necessarily contemporaneously.[9] Using the same type of evidence, 'by their marks', Hourihane identified two phases of the Holycross 'school', with the first phase in the mid-fifteenth century and the second of slightly later date. Marks from both phases at Holycross were also identified at Hore abbey, Quin friary, Ennis friary, Fethard priory, Kilcooly abbey and Cashel cathedral. However, as discussed in the literature review, a note of caution about this theory was sounded by Jennifer Alexander, in her review of Hourihane's work, as some of the connections were suggested based on only a single mark, for example, the comparisons between Holycross, Quin and Ennis.[10] The later grouping of marks were more stylised than the earlier inscribed lines and Hourihane defined them as personal signatures of more Irish than English style. Danielle O'Donovan argued that these marks should not be defined as masons' banker marks, which could have been part of a system of payment or quality control, but rather as "status symbols" which reflected the rank of the mason and allowed them to advertise their identities in prominent locations, with the blessing of their patrons.[11] Regardless of their use however, superficially at least, they do appear to suggest a link between the structures in which they are found.

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[6] R. Stalley, *The Cistercian Monasteries of Ireland*. London & New Haven: Yale University Press, 1987, p. 115 (hereafter *Cistercian* Monasteries) and N.B. White, *Irish Monastic and Episcopal Deeds, A.D. 1200-1600. Transcribed from the originals preserved at Kilkenny Castle. With an appendix of documents of the sixteenth and seventeenth centuries relating to monastic property after the dissolution.* Ormond Deeds. Dublin: Stationery Office, 1936, nos. 27, 28, 29, 32, 34 and 41.

[7] A. Gwynn and R.N. Hadcock, *Medieval Religious Houses: Ireland*. 2nd ed. Blackrock, Co. Dublin: Irish Academic Press, 1988, p. 134 (hereafter *Medieval Religious Houses)* and C.A. Empey and K. Simms, 'The Ordinances of the White Earl and the Problem of Coign in the Later Middle Ages', *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature*, 1975, 75, 161-87, p. 170.

[8] In the 1480s, Gerald, eighth earl of Kildare, foster father of Piers MacRichard Butler, granted lands to Holycross to aid the building campaign. The full charter is published in G. MacNiocaill, *Na manaigh liatha in Eirinn, 1142-c.1600*. Baile Átha Cliath: Morainn, 1959, pp. 202-3.

[9] However, the short timescale for building suggests that a large number of masons were present on site at the same time, an idea mirrored in the variety of designs of the window tracery.

[10] J.S. Alexander, 'The Mason and his Mark, Review', *Journal of the British Archaeological Association*, 2002, 155, pp. 321-2.

[11] D. O'Donovan, 'Building Butler', pp. 235-6.

Adopting a less minute approach to the study of late medieval architecture, O'Donovan focussed on the wide range of window tracery designs at Holycross and the moulding profiles used to create them. Partly based on continental European evidence and partly based on the difficulty of assigning acceptable chronology to the designs at Holycross, O'Donovan suggested that the tracery patterns could have been "derived from a collection of architectural pattern drawings brought together specifically for the construction of the Abbey".[12] She suggested that these drawings could have originated from a range of sources and dates, some possibilities for which will be discussed in later chapters. The result was that tracery designs of what seem like widely varying dates were found together in a building constructed over a short period of time. She supported her argument by drawing attention to the presence of a number architectural 'drawings' found on tombs and fonts in the area that can be directly related to extant tracery and rib vaults. She also noted that the moulding profiles do not appear to have been conveyed with the drawings. The quadrant and hollow chamfer, was particularly common, although the exact forms used varied significantly even on works that were coeval and, possibly, by the same hand.[13] Very few measured moulding profiles for windows referenced in the following were available. Therefore, where such evidence is important, photographs of the mullions or jambs are included, providing sufficient information given the simplicity of most Irish medieval mouldings.

O'Donovan suggested that the impact of Holycross on its region and on successive generations of masons was "remarkably strong" and argued that the reason for this went beyond the principles of a "school of masons" and instead reflected the importance of both the Holycross site, as a destination for pilgrimages to visit the relic of the True Cross, and of its major patrons, the Butlers.

In addition to the architectural studies conducted by Hourihane and O'Donovan at least two distinctive 'schools' of sculptors have been identified as working in Ormond during the late Middle Ages. Roughly coeval with one another the so-called Ormond School and O'Tunny atelier also enjoyed the patronage of the Ormonds and their supporters. Although associated primarily with tomb sculpture, Edwin Rae highlighted the

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[12] D. O'Donovan, 'Building Butler', p. 229 and M. Carpo, 'How Do You Imitate a Building That You Have Never Seen? Printed Images, Ancient Models, and Handmade Drawings in Renaissance Architectural Theory', *Zeitschrift für Kunstgeschichte*, 2001, 64 (2), 223-33, p. 229: "Given the organisation of Renaissance and late-medieval artistic workshops, some of these sketchbooks may in fact have been designed with an eye to semi-private circulation. They might have been used collectively or freely within the same workshop, and sometimes they actually were a workshop product – a collective work supervised by one master".

[13] D. O'Donovan, 'Building Butler', p. 244.

architectural nature of the O'Tunney tombs in particular, and posited their involvement in some church buildings, a point also developed by O'Donovan.[14]

Taking these studies collectively, what begins to emerge is the presence of a small number of 'schools' working in a specific area over a defined period of time. Some of the issues dealt with in chapter 2, such as the transmission of designs through pattern books, are hinted at, but to date there has been some divergence in opinion as to how such 'schools' should be defined. This section will examine the systems of metrology and proportion across the Ormond region to see whether any further light can be shed on the matter.[15]

O'Donovan argued that at least some of the contents of the Holycross pattern book can be found in two-dimensional form on two tombs, one at St. Mary's parish church, Callan (Figure 4.3) and the other the MacGillapatrick tomb at Fertagh parish church (Figure 4.4), and one font, formerly also from Fertagh parish church but now located at the Roman Catholic church in Johnstown (Figure 4.5 and Figure 4.6), to which a number of Fertagh's medieval tracery windows and a doorway have also been relocated. The Fertagh tomb, font and windows were commissioned by the MacGillapatrick family in the early sixteenth century.[16] The architectural details depicted on the Fertagh tomb and font, and the Callan tomb will now be cross-referenced against the results of this study.
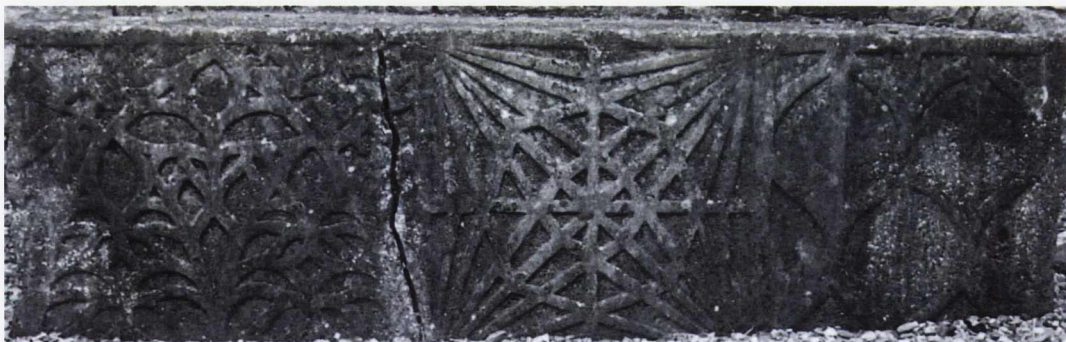
Figure 4.3 Tomb frontal, St. Mary's parish church, Callan, Kilkenny (photo credit Danielle O'Donovan)

[14] E.C. Rae, 'Irish Sepulchral Monuments of the Later Middle Ages. Part I the Ormond Group', *The Journal of the Royal Society of Antiquaries of Ireland,* 1970, 100 (1), 1-38; E.C. Rae, 'Irish Sepulchral Monuments of the Later Middle Ages. Part II the O'Tunney Atelier', *The Journal of the Royal Society of Antiquaries of Ireland,* 1971, 101 (1), 1-39; J. Hunt, 'Rory O'Tunney and the Ossory tomb sculptures', *Journal of the Royal Society of Antiquaries of Ireland,* 1950, 80, 22-8 (hereafter 'Rory O'Tunney').

[15] D. O'Donovan, 'Building Butler', p. 232.

[16] W. Carrigan, *The history and antiquities of the diocese of Ossory.* Vol. 2. 4 vols. Dublin: Sealy, Bryers & Walker, 1905, p. 294.

Figure 4.4 MacGillapatrick tomb frontal, parish church Fertagh (photo credit Rachel Moss)

Figure 4.5 Johnstown Roman Catholic church: Fertagh font, side 1 (photo credit Danielle O'Donovan)

Figure 4.6 Johnstown Roman Catholic church: Fertagh font, side 2 (photo credit Danielle O'Donovan)

Of the three panels on the tomb frontal at Callan (Figure 4.3) the middle one is unimportant to this study because it represents a vaulting pattern.[17] The right panel resembles the north aisle west window in the same building (Figure 4.7). This window was not measured as part of this investigation due to access issues.

Figure 4.7 North aisle west window, St. Mary's parish church, Callan

The left panel displays tracery that is found in three-dimensional form in the chancel east window at Kilcooly Cistercian abbey (Figure 4.8 left). The window tracery is

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[17] This vault is to be found at Old Leighlin cathedral.

more elongated than the tomb frontal but, within the accepted definition of a medieval copy, this is a replica and the height of the tomb may have restricted the space available for the sculpting work.[18] Five-light variants of this window are found in the south transept of the Dominican friary in Cashel (Figure 4.8 right) and in the chancel east window at St. Mary's parish church, Clonmel (Figure 4.9). A three-light version was also inserted into the south chapel of the south transept at Holycross while the west window at Kilcooly could be regarded as a very debased copy of the east window from the same building (Figure 4.10).
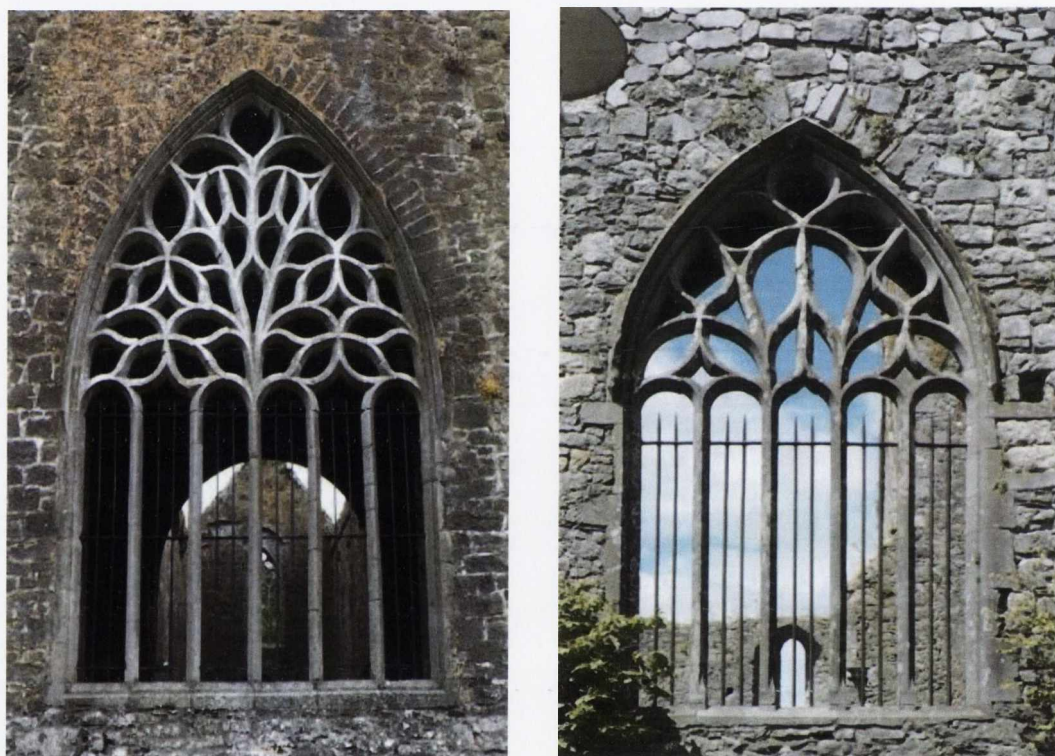
Figure 4.8 Chancel east, Kilcooly Cistercian abbey (left) and south transept south, Dominican friary, Cashel (right)

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[18] See examples from L.F. Salzman, *Building in England Down to 1540: A Documentary History*. Oxford, England: Oxford University Press, 1952, pp. 499-500 and pp. 547-9.
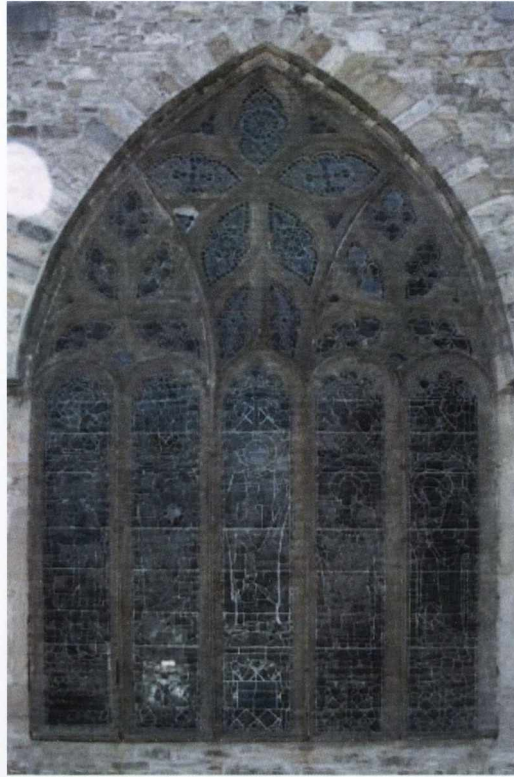
Figure 4.9 Chancel east, St. Mary's parish church, Clonmel
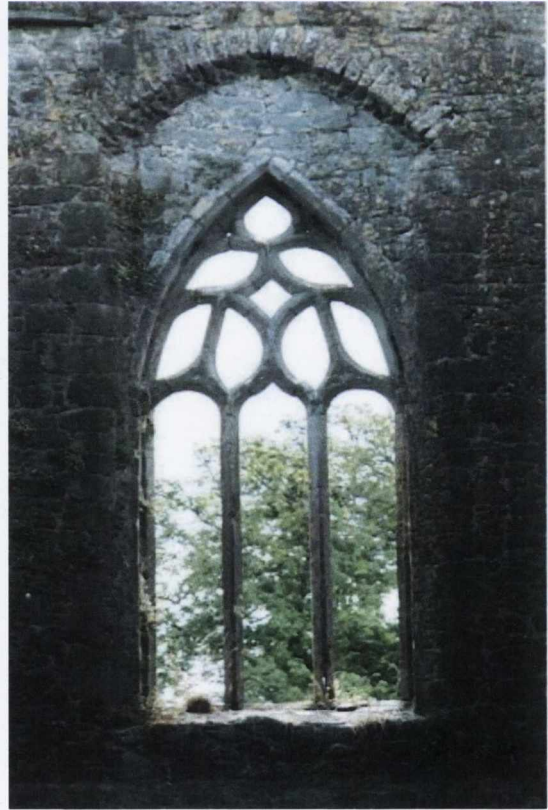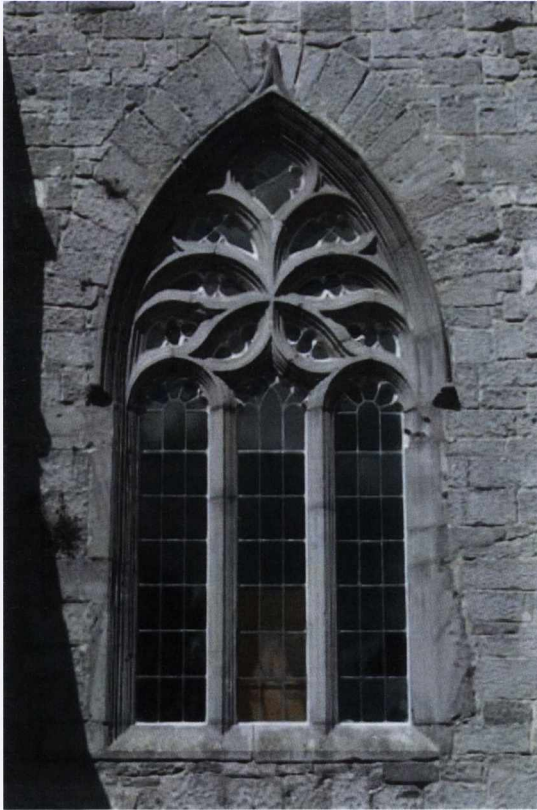
Figure 4.10 East window south chapel south transept, Holycross Cistercian abbey (left) and west window, Kilcooly Cistercian abbey (right)

If one assumes the same pattern book was used by masons working at these different churches, then the question arises as to the manner in which it was translated from page to stone. For example, if used by the same mason or group of masons one might expect the same set of proportions and metrology to be used from site to site. The east window of the chancel at Kilcooly (Figure 4.8), as would be expected from the intricate design, was most likely designed according to specific principles of proportionality. The overall width of the window relates to the height of the lights at arch peak by the ratio of 2:3 while the tracery field height to the same light height at arch peak relates by 4:5. The other ratios shown in Table 4.3 are considered unintended by-products. 4:5 is typical of Ormond while 2:3 was used much less frequently.

The south window of the south transept at Cashel (Figure 4.8 right) also uses the 4:5 ratio for tracery field height to light height (at arch peak) ratio (Table 4.4). A 1:1 ratio occurs between the overall window width and the light height, but at the springing point. I think it unlikely that a mason would use the light's arch peak as the reference for some work and the springing point for others but, since no other ratios are used in this window, it is possible. The east window at St. Mary's parish church, Clonmel is very similar to the Cashel window, although with the addition of cusps and a more detailed moulding profile. Since the base of this window was obscured a full height measurement could not be taken photogrammetrically. An estimation of its height suggested that the 4:5 ratio between tracery field height and light height found in the other two windows was not used here and that, instead, the ratio was between 5:6 and 1:1.

Sufficient measurements could be made at all three sites to establish that the ratio of mullion width to light width was typically 1:4. However, the actually widths of the lights and mullions varied considerably (Kilcooly: 0.613m, 0.145m; Cashel: 0.388m, 0.123m; Clonmel: 0.749m, 0.177m). Kilcooly's window height was 5.343m while Cashel's was 5.041m, thus narrower mullions were appropriately used for a smaller window. The Clonmel window's height was estimated at ~7.3m, making the width of the mullions and lights appropriate to its overall scale. In relation to metrology, three entirely different units were found: Kilcooly 0.217m, Cashel 0.348m and Clonmel 0.280m.

For the similar east window of the south chapel of the south transept at Holycross the mullion width to light width ratio again equates to 1:4 on a number of occasions but the tracery field is taller relative to the light height (ratio 1:1) than used for the larger windows just described. The unit of 0.368m introduces another metrological unit for this sample. The results of proportional examination for the west window of the nave at Kilcooly (Figure 4.10 right) suggest that the mason designed the rest of the window about

the significant measure of the light height at arch peak since this related to the tracery field height by 1:√2 and to the overall window width by 2:3 (Table 4.6). Despite a possible use of significant proportions the mason lacked the skill to execute the tracery design in imitation of the east window or some other source of inspiration.

In summary, where this pattern was used there are some proportional correspondences, in particular the 1:4 mullion width to light width. However, these are not sufficiently consistent to suggest that a standard 'formula' for laying out the pattern was used. Equally systems of metrology are defined more by their difference than their similarity with four different units apparent. It is noteworthy too that even though the pattern is comparable in elevation, the moulding profiles used differ between the various windows.

Table 4.3 Kilcooly Cistercian abbey: proportional investigation

| | | Kilcooly | | | | | |
| | | East External | | | | | |
Proportions	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3	Light/ Mullion4	Light/ Mullion5	Light/ Mullion6
Tracery field height to light height (at springing point)		0.724	1.209	0.724	0.721	0.722	0.727
Tracery field height to light height (at arch peak)		0.797	0.827	0.796	0.794	0.834	0.797
Tracery field height to overall window height	0.580						
Overall window width to overall window height	0.688						
Overall window width to window height to spring	0.420						
Overall window width to arch span	0.991						
Light width to light height (at springing point)		0.289	0.268	0.263	0.266	0.274	0.280
Light width to light height (at arch peak)		0.262	0.235	0.240	0.241	0.238	0.256
Light width to overall window width		0.176	0.164	0.161	0.162	0.167	0.172
Light width to overall window height		0.121	0.112	0.111	0.111	0.115	0.118
Light width to arch span		0.175	0.162	0.159	0.160	0.166	0.170
Overall window width to light height (at springing point)		0.611	0.610	0.610	0.607	0.609	0.613
Overall window width to light height (at arch peak)		0.672	0.697	0.671	0.669	0.703	0.672
Mullion width to overall window width		0.039	0.039	0.039	0.039	0.040	
Mullion width to light width		0.223	0.241	0.238	0.242	**0.246**	0.244
Mullion width to light width		0.242	0.234	0.240	0.234		

Table 4.4 Cashel Dominican friary: proportional investigation[19]

| | | Cashel Dominican | | | | |
| | | South External | | | | |
Proportions	Single	Light/ Mullion 1	Light/ Mullion 2	Light/ Mullion 3	Light/ Mullion 4	Light/ Mullion 5
Tracery field height to light height (at springing point)			0.888	0.889	0.891	0.890
Tracery field height to light height (at arch peak)			0.813	0.785	0.814	0.812
Tracery field height to overall window height	0.470					
Overall window width to overall window height	0.537					
Overall window width to window height to spring	0.530					
Overall window width to arch span	1.008					
Light width to light height (at springing point)			0.194	0.194	0.195	0.220
Light width to light height (at arch peak)			0.177	0.172	0.178	0.200
Light width to overall window width			0.191	0.191	0.191	0.216
Light width to overall window height			0.103	0.103	0.103	0.116
Light width to arch span			0.192	0.193	0.193	0.218
Overall window width to light height (at springing point)			0.985	0.984	0.982	0.983
Overall window width to light height (at arch peak)			0.929	0.897	0.930	0.928
Mullion width to overall window width			0.045	0.046	0.044	
Mullion width to light width				0.238	0.238	
Mullion width to light width		0.243	0.243	0.232	0.206	

Table 4.5 St. Mary's parish church, Clonmel: proportional investigation[20]

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[19] Some items are missing from this table because it was not possible to measure the overall window width due to the presence of foliage.

	St. Mary's parish church, Clonmel					
	Chancel East					
Proportions	Single	Light/ Mullion 1	Light/ Mullion 2	Light/ Mullion 3	Light/ Mullion 4	Light/ Mullion 5
Tracery field height to overall window width	0.945					
Overall window width to arch span	0.890					
Light width to overall window width		0.200	0.204	0.205	0.198	0.195
Light width to arch span		0.178	0.182	0.182	0.176	0.173
Mullion width to overall window width		0.049	0.047	0.044	0.048	
Mullion width to light width		**0.247**	0.242	0.233	0.232	
Mullion width to light width		0.215	0.223	0.243	**0.247**	

Table 4.6 Holycross Cistercian abbey and Kilcooly Cistercian abbey: proportional investigation

	Holycross				Kilcooly			
	South Transept East Southern				Kilcooly West Internal			
Proportions	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3
Tracery field height to light height (at springing point)		0.999	0.998	0.995		0.766	0.779	0.777
Tracery field height to light height (at arch peak)		0.889	0.859	0.885		0.708	0.686	0.698
Tracery field height to overall window height	0.501				0.432			
Overall window width to overall window height	0.532				0.406			
Overall window width to window height to spring	0.939				0.704			
Overall window width to arch span	0.979				0.971			
Light width to light height (at springing point)		0.372	0.336	0.361		0.237	0.256	0.235
Light width to light height (at arch peak)		0.331	0.288	0.318		0.220	0.226	0.211
Light width to overall window width		0.351	0.316	0.339		0.330	0.350	0.322
Light width to overall window height		0.187	0.168	0.180		0.134	0.142	0.131
Light width to arch span		0.344	0.309	0.332		0.320	0.340	0.313
Overall window width to light height (at springing point)		0.944	0.941	0.938		0.720	0.732	0.731
Overall window width to light height (at arch peak)		0.943	0.912	0.939		0.866	0.644	0.656
Mullion width to overall window width		0.085	0.089			0.072	0.072	
Mullion width to light width		0.243	0.270	0.252		0.218	0.205	0.223
Mullion width to light width		**0.253**	0.281	0.262		0.218	0.205	0.223

Ratio	Numeric Value	1%		2%	
1 : 4	0.250	0.253	0.248	0.255	0.245
1 : 3	0.333	0.337	0.330	0.340	0.327
2 : 5	0.400	0.404	0.396	0.408	0.392
1 : root 5	0.447	0.452	0.443	0.456	0.438
1 : 2	0.500	0.505	0.495	0.510	0.490
13 : 23	0.565	0.571	0.560	0.577	0.554
1 : root 3	0.577	0.583	0.572	0.589	0.566
3 : 5	0.600	0.606	0.594		
377 : 610	0.618	0.624	0.612	0.630	0.606
2 : 3	0.667	0.673	0.660	0.680	0.653
1 : root 2	0.707	0.714	0.700	0.721	0.693
3 : 4	0.750	0.758	0.743	0.765	0.735
4 : 5	0.800	0.808	0.792	0.816	0.784
5 : 6	0.833	0.842	0.825	0.850	0.817
1 : 1	1.000	1.010	0.990	1.020	0.980

The MacGiallapatrick tomb frontal from Fertagh (Figure 4.4) also features three panels with the one on the right representing the same vaulting pattern as found on the Callan tomb and, thus, at Old Leighlin cathedral. The left panel is a very close copy of the tracery pattern in the windows of the south wall of the nave of the Augustinian friary, Callan (not measured) and also in the north wall of the Carmelite friary at Loughrea in Connaught, where cusps and a more intricate moulding profile was used. This similarity will be discussed in relation to masons' movements in the following.

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[20] External measurement was not possible because of a very dense protective grill and some of the interior lower details were obscured by the altar.

Figure 4.11 Nave south wall, Augustinan friary, Callan

Figure 4.12 Nave north wall, Carmelite friary, Loughrea

The central panel of the MacGillapatrick tomb frontal is the most interesting since it is replicated exactly, including the slight tilt on the angle of the supermullions, in window tracery in the church where the tomb is located (although now reset in Johnstown RC church) and in the east window of the north transept at Kilcooly (Figure 4.14). Variants on this window which feature the upper portion of the pattern of a vesica surrounded by two mouchettes but without the supermullions between the ogee and round-headed arches at the top of each light are found at a range of Ormond sites and beyond. The latter category will be considered in the discussion of masons' mobility which follows

but the Ormond examples that feature in this study are: Fethard Holy Trinity church; Fethard Augustinian friary; St. Mary's parish church, Callan; Kilcooly Cistercian abbey; and Holycross Cistercian abbey.[21]

A four-light version of this window can be found at the west end of the Holy Trinity church in Fethard (Figure 4.13). This window has been completely rebuilt, and so was not measured in this study. However, it is useful to consider here because of some dating evidence that survives. William Carrigan noted two inscriptions from the church which recorded restoration of the church fabric by the Hackett family with one inscription stating that Edmund Hackett and his wife Anna Rockel died during restoration works in 1508.[22] A later examination by H.G. Leask dated the belfry where the west window is located as "later fifteenth century". Leask's date was assigned partly because "the flowing tracery of some complication" "affords a stylistic clue to the approximate dating of the whole structure", possibly because of stylistic similarity to Kilcooly's east window.[23] Tadhg O'Keeffe suggested that the tower may have been built in 1450 but without any specific evidence and that "late medieval" additions were made to the church.[24] He may have been referring to Leask's assigned date.

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[21] Another window in this style was located at Thurles Townparks, Tipperary, but was not examined in this study. Danielle O'Donovan also suggested a stylistic link between this panel and the east window of Aghaboe Dominican friary, partly because of the MacGillapatrick family founded both Aghaboe and Fertagh churches. However, I think that the north transept north window from Holycross is a much more likely inspiration and the two will be compared in the following.

[22] W. Carrigan, 'Fethard', *Journal of the Society of the Preservation of Memorials to the Dead in Ireland*, 1901-3, 5, 450-1.

[23] H.G. Leask, *Irish Churches & Monastic Buildings*. Vol. III. Dundalk, Ireland: Dundalgan Press Ltd., 1960. 5th, p. 56 (hereafter *Irish Churches III*).

[24] T. O'Keeffe, 'Fethard: Irish Historic Town Atlas.' Dublin: Royal Irish Academy, 2003. Vol. 13, p. 3 and T. O'Keeffe, *Fethard, Co. Tipperary: a guide to the medieval town*. Fethard, Co. Tipperary: Fethard Historical Society, 1997, p. 20-1.

Figure 4.13 West window, Fethard Holy Trinity church

The window at Johnstown (Figure 4.14 left) was not measured in this study because it had been relocated from its original setting. The east window in the north transept at Kilcooly (Figure 4.14 right) appears to make use of proportional principles through the application of 1:2 light width to light height (at arch peak), light width to overall window width, and overall window width to overall window height; 1:4 for light width to overall window height; and 5:6 for tracery field height to light height at springing point (Table 4.7).
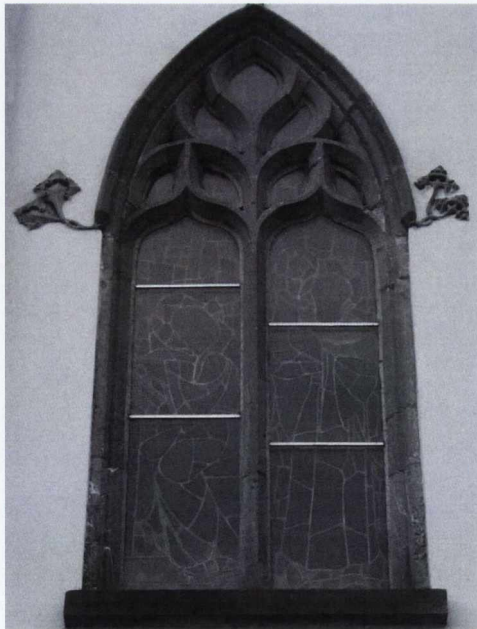
Figure 4.14 West window, Johnstown RC church, transferred from Fertagh parish church (left) and north transept east, Kilcooly Cistercian abbey (right)

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Table 4.7 Kilcooly Cistercian abbey: proportional investigation

Proportions	Single	Kilcooly North Transept East Light/ Mullion1	Light/ Mullion2
Tracery field height to light height (at springing point)		0.832	0.841
Tracery field height to light height (at arch peak)		0.968	0.969
Tracery field height to overall window height	0.529		
Overall window width to overall window height	0.497		
Overall window width to window height to spring	0.981		
Overall window width to arch span	0.728		
Light width to light height (at springing point)		0.573	0.551
Light width to light height (at arch peak)		0.493	0.478
Light width to overall window width		0.507	0.493
Light width to overall window height		0.252	0.252
Light width to arch span		0.369	0.359
Overall window width to light height (at springing point)		0.885	0.895
Overall window width to light height (at arch peak)		0.971	0.970
Mullion width to overall window width		0.096	
Mullion width to light width		0.189	0.194

Both the Kilcooly south transept south chapel east window and the Holycross north transept north chapel east window (Figure 4.15) share a number of proportions with the Kilcooly north transept window (Table 4.8). Despite the presence of cusps at Holycross but not at Kilcooly, the expected similarity between light width and overall window width is achieved with repetition of the 1:2 proportion for all three windows. The Holycross window uses the same proportions as Kilcooly north for the tracery field height to light height (at springing point) (5:6), overall window width to overall window height (1:2) and light width to overall window height (1:4).[25] Variation occurs in the relationship between the mullion width and the light width with the Kilcooly south transept window using 1:4 while no known ratio occurs for the other two windows. The mullions vary in width from 0.125m (Kilcooly north) to 0.135m (Holycross north) to 0.150m (Kilcooly south) with light widths of ~0.633m, ~0.599m, and ~0.630m, respectively.

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[25] Proportions are taken as being the same if they fall within either the 1% or 2% bands.

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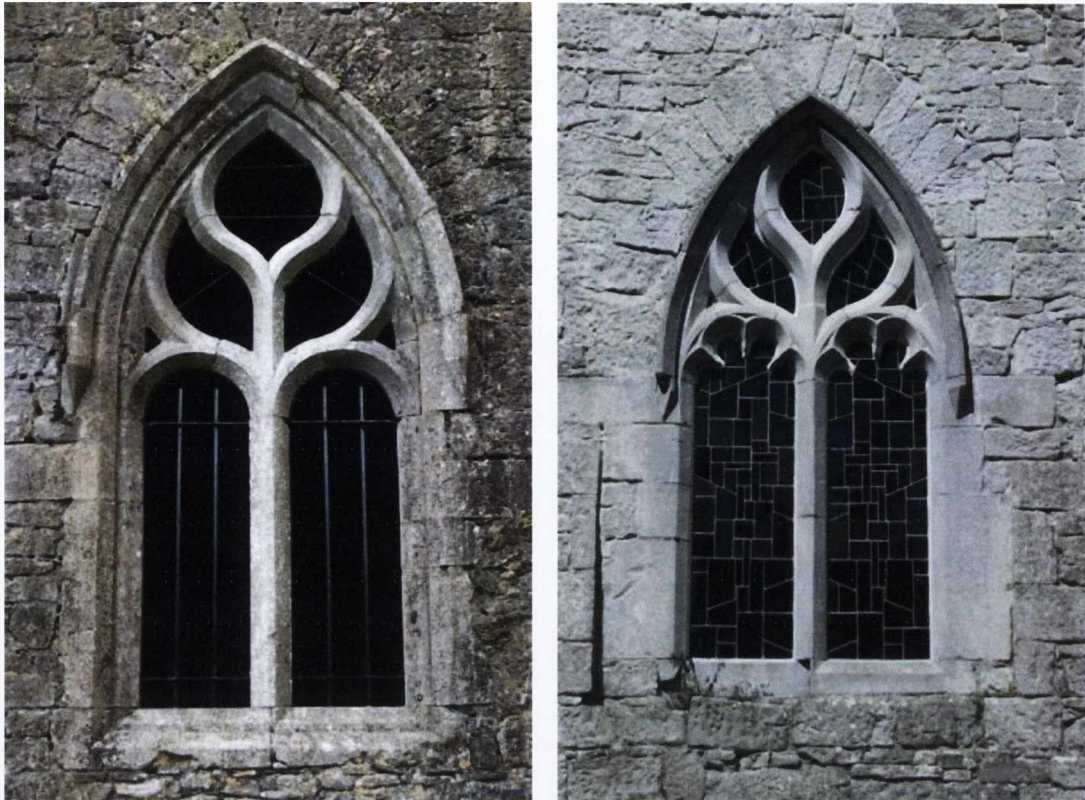
Figure 4.15 South transept south chapel east window, Kilcooly Cistercian abbey (left) and north transept north chapel east window, Holycross Cistercian abbey

Table 4.8 Kilcooly Cistercian abbey and Holycross Cistercian abbey: proportional investigation

| | Kilcooly | | | Holycross | | |
| | South Transept East Southern | | | North Transept East Northern | | |
Proportions	Single	Light/ Mullion1	Light/ Mullion2	Single	Light/ Mullion1	Light/ Mullion2
Tracery field height to light height (at springing point)		0.925	0.928		0.844	0.854
Tracery field height to light height (at arch peak)		0.781	0.775		0.946	0.955
Tracery field height to overall window height	0.427			0.564		
Overall window width to overall window height	0.460			0.493		
Overall window width to window height to spring	0.791			0.974		
Overall window width to arch span	0.795			0.962		
Light width to light height (at springing point)		0.502	0.497		0.519	0.517
Light width to light height (at arch peak)		0.424	0.415		0.463	0.463
Light width to overall window width		0.503	0.497		0.501	0.505
Light width to overall window height		0.232	0.232		0.247	0.247
Light width to arch span		0.400	0.395		0.482	0.486
Overall window width to light height (at springing point)		0.997	1.000		0.965	0.976
Overall window width to light height (at arch peak)		0.842	0.835		0.924	0.916
Mullion width to overall window width		0.126			0.107	
Mullion width to light width		0.251	0.254		0.214	0.212

The east window of the south transept at Fethard Augustinian friary (Figure 4.16) matches the light width to overall window width and overall window height proportions of the Kilcooly north and Holycross north windows (Table 4.9). The light width is exactly the same as at Holycross but the mullions are narrower at 0.115m. These mullions also have a more complex moulding profile which suits the more complex hood design with its sculpted keystone and hood stops.

Figure 4.16 South transept east window, Fethard Augustinian priory

Table 4.9 Fethard Augustinian friary: proportional investigation

Proportions	Single	Fethard Augustinian South Transept East Lower Light/ Mullion1	Light/ Mullion2
Tracery field height to light height (at springing point)		0.896	0.889
Tracery field height to light height (at arch peak)		0.783	0.782
Tracery field height to overall window height	0.470		
Overall window width to overall window height	0.495		
Overall window width to window height to spring	0.934		
Overall window width to arch span	0.967		
Light width to light height (at springing point)		0.480	0.475
Light width to light height (at arch peak)		0.420	0.418
Light width to overall window width		0.509	0.507
Light width to overall window height		0.252	0.252
Light width to arch span		0.492	0.490
Overall window width to light height (at springing point)		0.943	0.936
Overall window width to light height (at arch peak)		0.825	0.824
Mullion width to overall window width		0.093	
Mullion width to light width		0.183	0.184

While the tracery field of the windows at the two sites in Callan (Figure 4.17) copy the upper portion to the Kilcooly north transept design, they are both significantly taller with the Augustinian friary's west window, having the additional support of a horizontal transom at about half the light height. Despite the extra height the lights are only marginally wider (1-3cm) than those of the other windows and the mullion widths fall within the existing range. The mullions of both Callan windows meet the sill in a different way to the other windows in this group. At St. Mary's church the chamfer of the mullion stops a few centimetres above the sill allowing the mullion to sit squarely on it. At the Augustinian friary a section of stonework that is significantly wider than the rest of the mullion is used where the mullion meets the sill. Using only the upper portion of the Callan Augustinian window the same 5:6 ratio is found for tracery field height to light height at springing point as was used at Kilcooly north. At Callan church the tracery field

height is half the height of the lights, measured to the peak of the arch. The light widths are again half the overall window width for both windows but although some other proportional systems were found, as can be seen in Table 4.10, the lack of repetition in this window and their infrequent use in Ormond makes their appearance seem more random than planned.

Figure 4.17 West window, Augustinian friary, Callan (left) and south aisle west window, St. Mary's parish church, Callan

Table 4.10 Callan Augustinian friary and St. Mary's collegiate church, Callan: proportional investigation

Proportions		Callan Augustinian				St. Mary's Church, Callan	
		Nave West				South Aisle West	
	Single	Light/ Mullion1	Light/ Mullion2		Single	Light/ Mullion1	Light/ Mullion2
Tracery field height to light height (at springing point)		0.834	0.831			0.570	0.569
Tracery field height to light height (at arch peak)		0.753	0.754			0.502	0.504
Tracery field height to overall window height	0.526				0.362		
Overall window width to overall window height	0.290				0.432		
Overall window width to window height to spring	0.453				0.678		
Overall window width to arch span	0.441				0.990		
Light width to light height (at springing point)		0.233	0.226			0.343	0.340
Light width to light height (at arch peak)		0.211	0.205			0.301	0.301
Light width to overall window width		0.508	0.494			0.504	0.501
Light width to overall window height		0.147	0.147			0.218	0.218
Light width to arch span		0.224	0.218			0.498	0.496
Overall window width to light height (at springing point)		0.460	0.458			0.680	0.678
Overall window width to light height (at arch peak)		0.415	0.416			0.598	0.601
Mullion width to overall window width		0.238				0.107	
Mullion width to light width		0.469	0.482			0.212	0.213

Ratio	Numeric Value	1%		2%	
1 : 4	0.250	0.253	0.248	0.255	0.245
1 : 3	0.333	0.337	0.330	0.340	0.327
2 : 5	0.400	0.404	0.396	0.408	0.392
1 : root 5	0.447	0.452	0.443	0.456	0.438
1 : 2	0.500	0.505	0.495	0.510	0.490
13 : 23	0.565	0.571	0.560	0.577	0.554
1 : root 3	0.577	0.583	0.572	0.589	0.566
3 : 5	0.600	0.606	0.594		
377 : 610	0.618	0.624	0.612	0.630	0.606
2 : 3	0.667	0.673	0.660	0.680	0.653
1 : root 2	0.707	0.714	0.700	0.721	0.693
3 : 4	0.750	0.758	0.743	0.765	0.735
4 : 5	0.800	0.808	0.792	0.816	0.784
5 : 6	0.833	0.842	0.825	0.850	0.817
1 : 1	1.000	1.010	0.990	1.020	0.980

The units of measurement for this group of windows is given in Table 4.11. The two Kilcooly windows were probably designed using the same unit ~0.240m while the Holycross and Callan Augustinian windows may have similar units close to ~0.280m. Overall, the choice of metrology does not seem to be linked to the design of the window tracery.

Table 4.11 Metrology of MacGillapatrick tomb left panel windows[26]

Window	Unit (m)
Kilcooly Cistercian abbey north transept east	**0.244**
Kilcooly Cistercian abbey south transept east southern	**0.237**, 0.299
Holycross Cistercian abbey north transept north chapel east	**0.273**
Fethard Augustinian friary south transept east (lower)	**0.353**
Callan Augustinian friary west	**0.281**, 0.232, 0.223, 0.250, 0.331
St. Mary's collegiate church, Callan south aisle west	**0.304**, 0.276

This group of Ormond windows, which share the same tracery design, show a significant degree of similarity in the use of proportions (with 1:2, 1:4 and 5:6 predominating) but do not display any relationship in the use of a metrological system.

Three window tracery panels are carved on the font from Fertagh (Figure 4.18) which Danielle O'Donovan suggested could have acted like "the folios of an architectural model book" that a mason might use to illustrate his designs to his patron.[27]

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[26] The bold text indicates the most probable unit while numbers in standard font demonstrate that the measures fall within 10-20% of the most probable unit.

[27] D. O'Donovan, 'Holycross and the Language of Irish Late Gothic.' *Limerick and South-West Ireland: Medieval Art and Architecture.* Ed. R. Stalley. Vol. 34. *British Archaeological Association (BAA) Conference Transaction Series.* Limerick, Ireland: British Archaeological Association, 2011, p. 151 (hereafter 'Language of Irish Late Gothic').

Figure 4.18 Johnstown Roman Catholic church: Fertagh font, side 1 (top) and side 2 (bottom) (photo credits Danielle O'Donovan)

Although O'Donovan identified one of these plates as "directly" relating to the south aisle east window at St. Mary's collegiate church in Callan, this is not correct since both of Callan's switchline windows have round heads while the lights in the font tracery extend into the tracery field without the addition of round or ogee heads.[28]

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[28] D. O'Donovan, 'Building Butler', p. 230.

Figure 4.19 St. Mary's collegiate church, Callan: south aisle east (left) and south extension south (right)

Neither of the window tracery patterns shown on the second side of the font (Figure 4.18) is actually feasible as a switchline pattern, if the structural function is to be obeyed, and no examples matching this design remain, if they ever existed, in this study area. Both patterns have an extra row of kite/diamond shapes in the tracery field. This has been achieved because the window jamb, when extended into the tracery field, was tilted inwards and downwards and an extra line of stonework was used to form the surrounding arch. In actual window tracery the window jamb normally extends upwards to form the arch surrounding the tracery field. This suggests that the font design was executed by someone who did not know how to execute switchline tracery.

The closest examples to the four-light tracery design 'intended' on the first side of the Fertagh font all occur outside the Ormond region and will, therefore, be discussed in a future chapter.[29] The occurrences are at Rathkeale Augustinian priory, Muckross Franciscan friary, Adare Franciscan friary, Adare Trinitarian priory, and St. Mary's cathedral, Limerick. The only three-light switchline window where the lights extend fully into the tracery field occur in the south wall of the nave of St. Laserian's cathedral, Old Leighlin. Both 4:5 and 5:6 were used in a typical Ormond manner but it is also possible

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[29] By 'intended' I mean if the tracery was executed with the mullions extending into the tracery field such that they are approximately parallel with the surrounding arch as would be normal for switchline or intersecting tracery.

that the window's overall dimensions were intended to fit with the unusual golden ratio proportions found for overall width to overall height (Table 4.12).

Figure 4.20 Three-light version: nave south, eastern window, St. Laserian's cathedral, Old Leighlin

Table 4.12 Old Leighlin cathedral: proportional investigation

	Old Leighlin			
	Nave South Eastern External			
Proportions	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3
Tracery field height to light height (at springing point)		0.851	0.846	0.845
Tracery field height to light height (at arch peak)		0.583	0.584	0.586
Tracery field height to overall window height	0.456			
Overall window width to overall window height	0.617			
Overall window width to window height to spring	0.882			
Overall window width to arch span	0.879			
Light width to light height (at springing point)		0.376	0.393	0.377
Light width to light height (at arch peak)		0.258	0.271	0.261
Light width to overall window width		0.327	0.344	0.330
Light width to overall window height		0.202	0.212	0.203
Light width to arch span		0.288	0.302	0.290
Overall window width to light height (at springing point)		0.869	0.875	0.875
Overall window width to light height (at arch peak)		0.787	0.789	0.793
Mullion width to overall window width		0.090	0.099	
Mullion width to light width		0.276	0.263	0.274
Mullion width to light width		0.301	0.287	0.299

Table 4.13 Significant ratios extracted from the literature

Ratio	Numeric Value	1%		2%	
1 : 4	0.250	0.253	0.248	0.255	0.245
1 : 3	0.333	0.337	0.330	0.340	0.327
2 : 5	0.400	0.404	0.396	0.408	0.392
1 : root 5	0.447	0.452	0.443	0.456	0.438
1 : 2	0.500	0.505	0.495	0.510	0.490
13 : 23	0.565	0.571	0.560	0.577	0.554
1 : root 3	0.577	0.583	0.572	0.589	0.566
3 : 5	0.600	0.606	0.594		
377 : 610	0.618	0.624	0.612	0.630	0.606
2 : 3	0.667	0.673	0.660	0.680	0.653
1 : root 2	0.707	0.714	0.700	0.721	0.693
3 : 4	0.750	0.758	0.743	0.765	0.735
4 : 5	0.800	0.808	0.792	0.816	0.784
5 : 6	0.833	0.842	0.825	0.850	0.817
1 : 1	1.000	1.010	0.990	1.020	0.980

It is notable that the tracery panel on side one (Figure 4.18 top) of the Fertagh font depicted switchline tracery with a range of misshapen kite and diamond forms. Prompted by the exact duplication of the tracery with curiously tilted supermullions between the MacGillapatrick tomb front and the north transept east window at Kilcooly, an examination was made into Ormond's switchline tracery to see if its unusual treatment on the font was replicated in actual window tracery.

Two examples of this type occurred in Ormond, both at St. Laserian's cathedral, Old Leighlin (Figure 4.21). Two further occurrences are found at Kilnalahan Carthusian abbey in south Connaught and one each at Burrishoole Dominican friary and Aghagower parish church Co. Mayo. The Connaught examples will be examined in a later discussion. The chancel east window at Old Leighlin is also remarkable because of the inclusion of horizontal transoms. In Ireland such transoms are seldom used with the only other occurrences in this study being the west windows of St. Mary's church, Cailan and Callan Augustinian friary.[30] Both Callan windows are tall narrow structures and the support given by the transom to the glass would have been essential. There would have been no such requirement at Old Leighlin. However, the window's mason may not have been so confident in this or other elements of the window design, an argument supported by the unusual execution of the switchline pattern.

The east window could not be measured photogrammetrically because of obscuring foliage, but the treatment and design of the western window of the nave south wall at the cathedral is so similar that some information on the preferences of the designing mason may be garnered. The probable unit of measurement for the nave south window was 0.220m, which did not agree with the other measurable windows on site. The other switchline windows of the eastern end of the nave south wall and above the west

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[30] One of the original medieval windows from Fertagh also featured a horizontal transom but it was not measured in the study because it had been repositioned.

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doorway fit the standard expectations of the pattern suggesting that a different mason was involved. The north aisle east and north windows are of entirely different design so it is even less likely that their mason was the same as for the nave south western. The use of simple proportions in the nave south western window is remarkable with 1:1 overall window width to light height at springing point, 1:2 overall window width to overall window height and tracery field height to overall window height; 1:3 for light width to light height at springing point and 1:4 for mullion width to light width (Table 4.14). This is a clear demonstration of a mason's ability to execute a proportioned design but less concern to produce a standard switchwork tracery design.
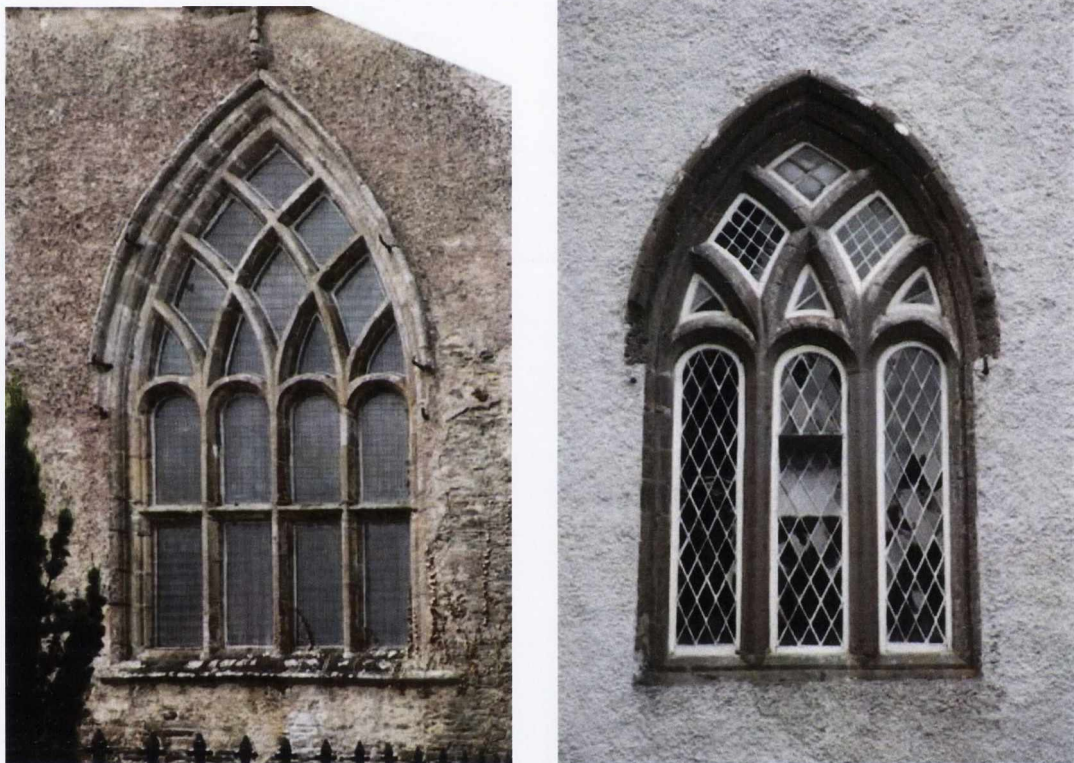
Figure 4.21 Chancel east and nave south (western) windows, St. Laserian's cathedral, Old Leighlin

Table 4.14 St. Laserian's cathedral, Old Leighlin: proportion investigation

	Old Leighlin			
		Nave South Western External		
Proportions	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3
Tracery field height to light height (at springing point)		0.970	0.970	0.974
Tracery field height to light height (at arch peak)		0.893	0.904	0.891
Tracery field height to overall window height	0.507			
Overall window width to overall window height	0.492			
Overall window width to window height to spring	0.997			
Overall window width to arch span	0.865			
Light width to light height (at springing point)		0.318	0.353	0.328
Light width to light height (at arch peak)		0.275	0.309	0.285
Light width to overall window width		0.318	0.353	0.330
Light width to overall window height		0.156	0.174	0.162
Light width to arch span		0.275	0.305	0.285
Overall window width to light height (at springing point)		1.000	1.000	0.996
Overall window width to light height (at arch peak)		0.866	0.877	0.864
Mullion width to overall window width		0.094	0.088	
Mullion width to light width		0.295	0.266	0.285
Mullion width to light width		0.276	0.248	0.266

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Ratio	Numeric Value	1%		2%	
1 : 4	0.250	0.253	0.248	0.255	0.245
1 : 3	0.333	0.337	0.330	0.340	0.327
2 : 5	0.400	0.404	0.396	0.408	0.392
1 : root 5	0.447	0.452	0.443	0.456	0.438
1 : 2	0.500	0.505	0.495	0.510	0.490
13 : 23	0.565	0.571	0.560	0.577	0.554
1 : root 3	0.577	0.583	0.572	0.589	0.566
3 : 5	0.600	0.606	0.594		
377 : 610	0.618	0.624	0.612	0.630	0.606
2 : 3	0.667	0.673	0.660	0.680	0.653
1 : root 2	0.707	0.714	0.700	0.721	0.693
3 : 4	0.750	0.758	0.743	0.765	0.735
4 : 5	0.800	0.808	0.792	0.816	0.784
5 : 6	0.833	0.842	0.825	0.850	0.817
1 : 1	1.000	1.010	0.990	1.020	0.980

Taking Danielle O'Donovan's assertion that the pattern book circulating in Ormond was collated for the reconstruction of Holycross in the fifteenth century, and subsequently circulated around the region, two further examinations were carried out: first of the Holycross windows as a group and second of other windows in Ormond which may have been inspired by Holycross tracery.[31]

At Holycross abbey no clear metrological pattern emerged; in fact the results were almost as diverse as could have been imagined. However, for all but two windows (north aisle north eastern and south transept south chapel east) the probable units fell within the major Ormond groupings.

Table 4.15 Holycross Cistercian abbey: metrology results[32]

Window	Unit (m)
Nave west	0.221
Chancel east	0.309
North aisle north eastern	0.289
North transept north chapel east	0.273
North transept south chapel east	0.346
North transept north	0.342
South transept north chapel east	0.276
South transept south chapel east	0.368

In relation to proportional analysis, there is evidence of an aspiration by the Holycross masons to design window tracery in accordance with particular geometric principles, irrespective of what the metrological unit might be. 1:1, 1:2, 1:3, 4:5 and 5:6, all the dominant Ormond proportions, were displayed in this building.

Observation of the windows of the east end of the church at Holycross, including the two transepts, shows a great variety in tracery design, but some harmony is also

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[31] Of course it is possible that these designs were also executed in sculpted form on tombs or architectural features but they are now lost to us.

[32] For all of these windows no other possible units were found within the 20% tolerance set for this study.

evident in the use of proportions (Figure 4.22). As noted by Roger Stalley, the main patron of Holycross's rebuilding, James, the fourth earl, was widely travelled, particularly in England, and could have been expected to have been aware of, and interested in, the latest architectural fashions. However, it appears that local considerations were more important.[33] Stalley also suggested that a "series of master masons followed each other in quick succession, each leaving his own imprint on the building" but this related to the building as a whole and not just to the east end, which is hardly likely to have been thus affected.[34]

The variety of styles in Holycross's east end is numerically verified in Table 4.16 where a number of different ratios are used. The similarities that occur include how, in all five cases, the tracery field height is very close to half the overall window height and the light width to height at arch peak approximates to 1:3 in three of the four transept windows. For the east end windows the ratio between tracery field height and light height (at one of the two significant points) is either 1:1 or 5:6 in each case and this pattern is also found in the nave west and north aisle north window. Only the north transept north window employs a different ratio but since that ratio is 4:5 it is possible that 5:6 was actually intended. Therefore, for all of the commentary on the diversity of window tracery design, at least one parameter was consistent, suggesting, at the very least, a degree of coherent planning from the outset.

Figure 4.22 East windows of the chancel and transepts, Holycross Cistercian abbey (relative scaling approximate)

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[33] R. Stalley, *Cistercian Monasteries*, p. 113.
[34] R. Stalley, 'Irish Gothic and English Fashion.' *The English in Medieval Ireland.* Ed. J. Lydon. Dublin, 1984. 65-86.

Table 4.16 Holycross Cistercian abbey: proportional investigation

North Transept East Northern

Ormond — Holycross — Proportions	Single	Light/Mullion1	Light/Mullion2
Tracery field height to light height (at springing point)		0.844	0.854
Tracery field height to light height (at arch peak)		0.946	0.865
Tracery field height to overall window height	0.564		
Overall window width to overall window height	0.493		
Overall window width to window height to spring	0.974		
Overall window width to arch span	0.962		
Light width to light height (at springing point)		0.519	0.517
Light width to light height (at arch peak)		0.463	0.463
Light width to overall window width		0.501	0.505
Light width to arch span		0.247	0.247
Overall window width to light height (at springing point)		0.482	0.486
Overall window width to light height (at arch peak)		0.985	0.976
Mullion width to overall window width		0.924	0.916
Mullion width to light width	0.107		
Mullion width to light width		0.214	0.212

North Transept East Southern

Ormond — Holycross — Proportions	Single	Light/Mullion1	Light/Mullion2
Tracery field height to light height (at springing point)		0.959	0.964
Tracery field height to light height (at arch peak)		0.851	0.848
Tracery field height to overall window height	0.507		
Overall window width to overall window height	0.393		
Overall window width to window height to spring	0.797		
Overall window width to arch span	0.938		
Light width to light height (at springing point)		0.407	0.400
Light width to light height (at arch peak)		0.332	0.327
Light width to overall window width		0.504	0.497
Light width to arch span		0.198	0.198
Overall window width to light height (at springing point)		0.472	0.466
Overall window width to light height (at arch peak)		0.808	0.804
Mullion width to overall window width		0.660	0.657
Mullion width to light width	0.131		
Mullion width to light width		0.260	0.264

South Transept East Northern

Ormond — Holycross — Proportions	Single	Light/Mullion1	Light/Mullion2	Light/Mullion3
Tracery field height to light height (at springing point)		0.968	0.985	0.966
Tracery field height to light height (at arch peak)		0.917	0.841	0.915
Tracery field height to overall window height	0.504			
Overall window width to overall window height	0.525			
Overall window width to window height to spring	0.944			
Overall window width to arch span	0.971			
Light width to light height (at springing point)		0.376	0.334	0.376
Light width to light height (at arch peak)		0.334	0.271	0.333
Light width to overall window width		0.349	0.309	0.349
Light width to arch span		0.183	0.162	0.183
Overall window width to light height (at springing point)		0.339	0.300	0.339
Overall window width to light height (at arch peak)		0.929	0.926	1.078
Mullion width to overall window width		0.956	0.877	0.954
Mullion width to light width	0.084			
Mullion width to light width	0.085	0.240	0.272	0.240
Mullion width to light width		0.244	0.276	0.244

South Transept East Southern

Ormond — Holycross — Proportions	Single	Light/Mullion1	Light/Mullion2	Light/Mullion3
Tracery field height to light height (at springing point)		0.999	0.993	0.995
Tracery field height to light height (at arch peak)		0.889	0.859	0.885
Tracery field height to overall window height	0.501			
Overall window width to overall window height	0.532			
Overall window width to window height to spring	0.939			
Overall window width to arch span	0.979			
Light width to light height (at springing point)		0.372	0.336	0.361
Light width to light height (at arch peak)		0.331	0.288	0.318
Light width to overall window width		0.351	0.316	0.330
Light width to arch span		0.187	0.168	0.180
Overall window width to light height (at springing point)		0.344	0.309	0.332
Overall window width to light height (at arch peak)		0.944	0.941	0.938
Mullion width to overall window width		0.943	0.912	0.939
Mullion width to light width	0.085			
Mullion width to light width	0.089	0.243	0.270	0.252
Mullion width to light width		0.253	0.281	0.262

Chancel West

Ormond — Holycross — Proportions	Single	Light/Mullion1	Light/Mullion2	Light/Mullion3	Light/Mullion4	Light/Mullion5	Light/Mullion6
Tracery field height to light height (at springing point)		0.845	1.079	0.843	0.845	0.837	0.835
Tracery field height to light height (at arch peak)		0.930	0.926	0.930	0.927	0.925	0.925
Tracery field height to overall window height	0.544						
Overall window width to overall window height	0.599						
Overall window width to window height to spring	0.456						
Overall window width to arch span	0.952						
Light width to light height (at springing point)		0.214	0.222	0.219	0.219	0.220	0.216
Light width to light height (at arch peak)		0.195	0.202	0.199	0.200	0.199	0.195
Light width to overall window width		0.164	0.170	0.168	0.168	0.167	0.164
Light width to arch span		0.098	0.102	0.101	0.101	0.100	0.098
Overall window width to light height (at springing point)		0.156	0.162	0.160	0.160	0.159	0.156
Overall window width to light height (at arch peak)		0.768	0.764	0.766	0.767	0.760	0.759
Mullion width to overall window width		0.845	0.842	0.845	0.842	0.840	0.841
Mullion width to overall window width		0.046	0.047	0.047	0.046	0.050	
Mullion width to light width		0.282	0.273	0.274	0.278	0.278	0.278
Mullion width to light width		0.273	0.274	0.297	0.303	0.278	

Chancel East

Ormond — Holycross — Proportions	Single	Light/Mullion1	Light/Mullion2	Light/Mullion3	Light/Mullion4	Light/Mullion5	Light/Mullion6
Tracery field height to light height (at springing point)		0.925	0.985	0.922	0.924	0.923	0.925
Tracery field height to light height (at arch peak)		0.990	0.985	0.990	0.984	0.987	0.985
Tracery field height to overall window height	0.520						
Overall window width to overall window height	0.564						
Overall window width to window height to spring	0.480						
Overall window width to arch span	0.971						
Light width to light height (at springing point)		0.190	0.198	0.197	0.197	0.199	0.194
Light width to light height (at arch peak)		0.174	0.179	0.180	0.179	0.181	0.177
Light width to overall window width		0.162	0.168	0.167	0.168	0.169	0.166
Light width to arch span		0.091	0.095	0.094	0.095	0.095	0.093
Overall window width to light height (at springing point)		0.157	0.163	0.162	0.163	0.164	0.161
Overall window width to light height (at arch peak)		0.853	0.847	0.851	0.852	0.851	0.853
Mullion width to overall window width		0.932	0.937	0.932	0.937	0.935	0.937
Mullion width to overall window width		0.048	0.048	0.049	0.049	0.049	
Mullion width to light width		0.299	0.288	0.286	0.287	0.291	0.289
Mullion width to light width		0.293	0.292	0.288	0.293		

Table 4.17 Holycross Cistercian abbey: proportional investigation

Ormond Holycross Proportions	North Aisle North Eastern				North Transept North			
	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3
Tracery field height to light height (at springing point)		0.835	0.846	0.853		0.801	0.801	0.802
Tracery field height to light height (at arch peak)		0.774	0.734	0.755		0.690	0.650	0.687
Tracery field height to overall window height	0.501				0.445			
Overall window width to overall window height	0.477				0.477			
Overall window width to window height to spring	0.838				0.859			
Overall window width to arch span	0.543				0.949			
Light width to light height (at springing point)		0.330	0.253	0.377		0.282	0.289	0.288
Light width to light height (at arch peak)		0.306	0.219	0.334		0.243	0.234	0.246
Light width to overall window width		0.415	0.314	0.465		0.329	0.337	0.335
Light width to overall window height		0.198	0.150	0.222		0.157	0.161	0.160
Light width to arch span		0.225	0.170	0.252		0.312	0.320	0.318
Overall window width to light height (at springing point)		0.795	0.806	0.812		0.858	0.858	0.859
Overall window width to light height (at arch peak)		0.737	0.699	0.718		0.739	0.696	0.735
Mullion width to overall window width		0.108	0.088			0.071	0.074	
Mullion width to light width		0.260	0.344	0.233		0.217	0.212	0.213
Mullion width to light width		0.212	0.280	0.189		0.225	0.220	0.221

Ratio	Numeric Value	1%		2%	
1 : 4	0.250	0.253	0.248	0.255	0.245
1 : 3	0.333	0.337	0.330	0.340	0.327
2 : 5	0.400	0.404	0.396	0.408	0.392
1 : root 5	0.447	0.452	0.443	0.456	0.438
1 : 2	0.500	0.505	0.495	0.510	0.490
13 : 23	0.565	0.571	0.560	0.577	0.554
1 : root 3	0.577	0.583	0.572	0.589	0.566
3 : 5	0.600	0.606	0.594	0.606	0.566
377 : 610	0.618	0.624	0.612	0.630	0.606
2 : 3	0.667	0.673	0.660	0.680	0.653
1 : root 2	0.707	0.714	0.700	0.721	0.693
3 : 4	0.750	0.758	0.743	0.765	0.735
4 : 5	0.800	0.808	0.792	0.816	0.784
5 : 6	0.833	0.842	0.825	0.850	0.817
1 : 1	1.000	1.010	0.990	1.020	0.980

A number of windows inspired by or sharing common inspiration with Holycross survive across Ormond.

The north window of the north transept at Holycross shares its design with an uncusped version at Aghaboe Dominican friary on the borders of Ormond territory (Figure 4.23). The friary was founded by Finghin MacGillapatrick in 1382 and his family continued patronage through the fourteenth and fifteenth centuries, despite increased association with Fertagh parish church, where the previously-described font and one of the tombs were located.[35] Danielle O'Donovan argued that such is the similarity between works at Fertagh and Aghaboe that it suggests that "the same team of craftsmen was employed."

Analysis of the north window of the north transept at Holycross produced a unit of measurement of 0.342m and the most significant proportional relationships are 4:5 for tracery field height to light height at springing point, 3:4 for overall window width to light height (at arch peak), and 1:3 for light width to overall window width. The use of these ratios, combined with mullions that are slender relative to the window's height in comparison with the tracery of Holycross's east end, is very effective in emphasising the flame tracery.

At Aghaboe the probable unit used for the east window was 0.307m although 0.343m and 0.344m were found to be within 20% of the minimum value. The proportional investigation found a match between the tracery field height to overall window height ($1:\sqrt{5}$) of this window and Holycross's north transept north window as well as close similarity between the overall window width to light height at arch peak and tracery field height to light height (4:5 and 3:4 in both cases). The difference in the overall height, 3.281 for Holycross and 3.783 for Aghaboe, and overall width, 1.567 and 1.827m, respectively, of the two windows, account for most of the variations between the two sets of proportions since the mullions all measure ~0.154m and the light widths only vary by 1cm. This could suggest that one of the windows needed to be fitted into an existing space but neither wall shows any clear signs of previous work.

These results hint that the Holycross and Aghaboe windows were designed by the same masons and if, as suggested by Danielle O'Donovan, these same masons also worked at Fertagh, it would reiterate the connections between these three sites and the possible use of a shared pattern book.

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[35] W. Carrigan, *The history and antiquities of the diocese of Ossory*. Vol 2. 4 vols. Dublin: Sealy, Bryers & Walker, 1905, p. 41 and D. O'Donovan, 'Language of Irish Late Gothic', p. 149.

Figure 4.23 North transept north, Holycross Cistercian abbey (left) and chancel east, Aghaboe Dominican friary (right)

Table 4.18 Holycross Cistercian abbey and Aghaboe Dominican friary: proportional investigation

Proportions	Holycross North Transept North				Aghaboe Chancel East			
	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3
Tracery field height to light height (at springing point)		0.801	0.801	0.802		0.860	0.858	0.859
Tracery field height to light height (at arch peak)		0.690	0.650	0.687		0.749	0.709	0.754
Tracery field height to overall window height	0.445				0.448			
Overall window width to overall window height	0.477				0.483			
Overall window width to window height to spring	0.859				0.847			
Overall window width to arch span	0.949				0.680			
Light width to light height (at springing point)		0.282	0.289	0.288		0.307	0.310	0.309
Light width to light height (at arch peak)		0.243	0.234	0.246		0.267	0.256	0.272
Light width to overall window width		0.329	0.337	0.335		0.331	0.336	0.334
Light width to overall window height		0.157	0.161	0.160		0.160	0.162	0.161
Light width to arch span		0.312	0.320	0.318		0.225	0.228	0.227
Overall window width to light height (at springing point)		0.858	0.858	0.859		0.928	0.925	0.926
Overall window width to light height (at arch peak)		0.739	0.696	0.735		0.808	0.764	0.814
Mullion width to overall window width		0.071	0.074			0.085	0.085	
Mullion width to light width		0.217	0.212	0.213		0.258	0.254	0.256
Mullion width to light width		0.225	0.220	0.221		0.256	0.252	0.253

Ratio	Numeric Value	1%		2%	
1 : 4	0.250	0.253	0.248	0.255	0.245
1 : 3	0.333	0.337	0.330	0.340	0.327
2 : 5	0.400	0.404	0.396	0.408	0.392
1 : root 5	0.447	0.452	0.443	0.456	0.438
1 : 2	0.500	0.505	0.495	0.510	0.490
13 : 23	0.565	0.571	0.560	0.577	0.554
1 : root 3	0.577	0.583	0.572	0.589	0.566
3 : 5	0.600	0.606	0.594		
377 : 610	0.618	0.624	0.612	0.630	0.606
2 : 3	0.667	0.673	0.660	0.680	0.653
1 : root 2	0.707	0.714	0.700	0.721	0.693
3 : 4	0.750	0.758	0.743	0.765	0.735
4 : 5	0.800	0.808	0.792	0.816	0.784
5 : 6	0.833	0.842	0.825	0.850	0.817
1 : 1	1.000	1.010	0.990	1.020	0.980

The north aisle window at Holycross (Figure 4.24 left) produced a unit of 0.289m, not an Ormond preference, and the tracery field height is half the overall window height. Furthermore, 5:6 and 4:5 have been used to relate widths to heights and between different height elements (Table 4.19). Caution must, however, be exercised with these findings because this window has been restored, which may have affected the measured results. Also, the style of the tracery does not suggest that the designer of this piece was geometrically conscious, although symmetry has been maintained.

A similar tracery design at St. Laserian's cathedral, Old Leighlin, contains the same subdivided circular shapes (Figure 4.24 right). However, at Old Leighlin the arch surrounding the tracery field is approximately tangential to the two circles while at Holycross the circle is flattened on one side to make the shape fit. The cross-like divider of the circle is aligned vertically at Old Leighlin rather than at the jaunty angle as at Holycross. It seems that the Holycross mason's focus was more on the decoration of the tracery than its specific pattern, a feat achieved by the introduction of an unusually complex moulding, in an Irish context, and through the use of the billet ornament on the stonework outlining each light.[36] Unfortunately, no measurements were available for the Old Leighlin window because the correct angle could not be obtained for photography.[37] The possible inspirations for these two windows will be discussed further in chapter 6.

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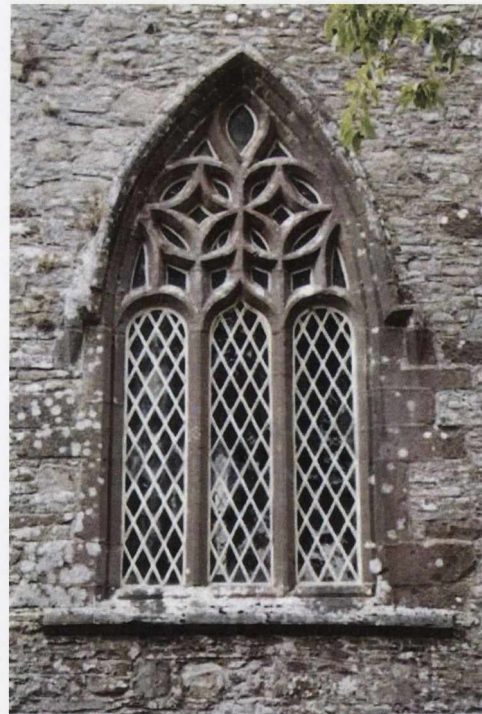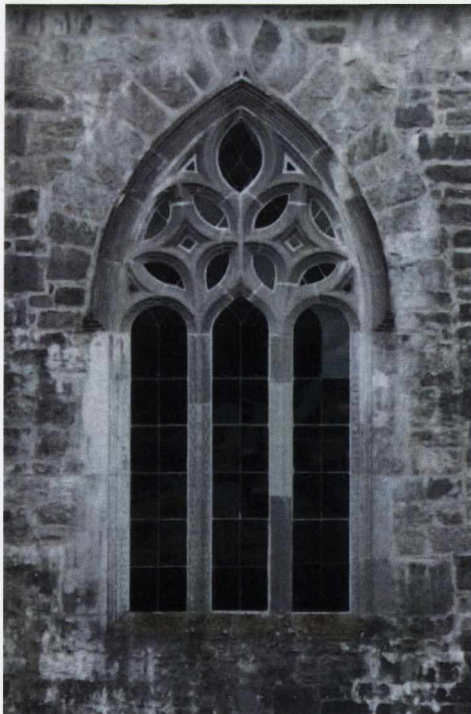
[36] R. Moss, 'Revivalist tendencies in the Irish Late Gothic: defining a national identity?' *Reading Gothic architecture: Studies in the visual cultures of the Middle Ages.* Ed. M.M. Reeve. Vol. 1. Turnhout, Belgium: Brepols, 2008.
[37] See chapter 3 for a discussion of situations where photogrammetric measurement could not be successfully completed.

Figure 4.24 North aisle north, Holycross Cistercian abbey (left) and north aisle east, Old Leighlin cathedral (right)

Table 4.19 Holycross Cistercian abbey: proportional investigation

		Holycross		
		North Aisle North Eastern		
Proportions	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3
Tracery field height to light height (at springing point)		0.835	0.846	0.853
Tracery field height to light height (at arch peak)		0.774	0.734	0.755
Tracery field height to overall window height	0.501			
Overall window width to overall window height	0.477			
Overall window width to window height to spring	0.838			
Overall window width to arch span	0.543			
Light width to light height (at springing point)		0.330	0.253	0.377
Light width to light height (at arch peak)		0.306	0.219	0.334
Light width to overall window width		0.415	0.314	0.465
Light width to overall window height		0.198	0.150	0.222
Light width to arch span		0.225	0.170	0.252
Overall window width to light height (at springing point)		0.795	0.806	0.812
Overall window width to light height (at arch peak)		0.737	0.699	0.718
Mullion width to overall window width		0.108	0.088	
Mullion width to light width		0.260	0.344	0.233
Mullion width to light width		0.212	0.280	0.189

Ratio	Numeric Value	1%		2%	
1 : 4	0.250	0.253	0.248	0.255	0.245
1 : 3	0.333	0.337	0.330	0.340	0.327
2 : 5	0.400	0.404	0.396	0.408	0.392
1 : root 5	0.447	0.452	0.443	0.456	0.438
1 : 2	0.500	0.505	0.495	0.510	0.490
13 : 23	0.565	0.571	0.560	0.577	0.554
1 : root 3	0.577	0.583	0.572	0.589	0.566
3 : 5	0.600	0.606	0.594		
377 : 610	0.618	0.624	0.612	0.630	0.606
2 : 3	0.667	0.673	0.660	0.680	0.653
1 : root 2	0.707	0.714	0.700	0.721	0.693
3 : 4	0.750	0.758	0.743	0.765	0.735
4 : 5	0.800	0.808	0.792	0.816	0.784
5 : 6	0.833	0.842	0.825	0.850	0.817
1 : 1	1.000	1.010	0.990	1.020	0.980

Another "late window" of similar tracery design but with a horizontal transom originated from the afore-mentioned Aghaboe Dominican friary. It was removed from Aghadoe and set up as a folly at Heywood house in the eighteenth century (Figure 4.25 right).[38] Notably, when H.G. Leask drew the window in his 1960 work he showed the light heads and the lower portion of the tracery as cusped (Figure 4.25 left). This must have been an error in transcribing a sketch. It was, therefore, not measured for this study. A fourth window with similar circles divided in four by a diamond shape is now found as the east window of St. Mary's Church of Ireland, Johnstown having been relocated there from Fertagh parish church (Figure 4.26). Because it too had been relocated it was also not measured in this study. The design was quite different from the others in this group because the window has four lights rather than three. The resulting tracery has lots of space for glass, which benefits the interior lighting of the church, but its shape

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[38] H.G. Leask, *Irish Churches III*, p. 131.

completely ignores the other function that tracery should fulfil, i.e. to provide structural support for the glass.[39]

A final window in this group was found in the east wall of Strade Dominican friary's north transept in north Connaught. This will be examined in the discussion that follows in chapter 7.

Figure 4.25 Aghaboe Dominican friary window: drawing H.G. Leask (left) and reinserted in a 'folly' at Heywood (right) (photo credit Rachel Moss)[40]

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[39] F. Bond, *Gothic architecture in England: an analysis of the origin and development of English church architecture from the Norman Conquest to the dissolution of the monasteries*. London: Batsford, 1905, p. 505 (hereafter *Gothic architecture*).

[40] H.G. Leask, *Irish Churches III*, p. 131.
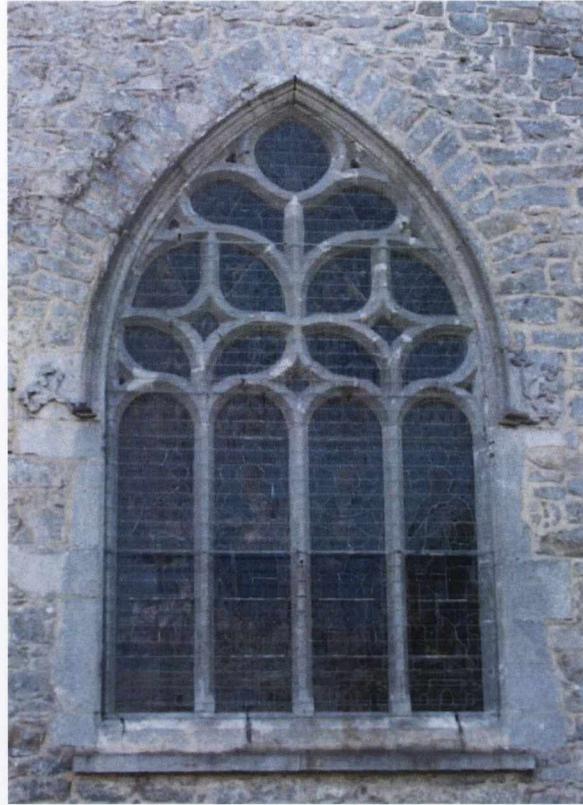
Figure 4.26 St. Mary's Church of Ireland, Johnstown east window from Fertagh (photo credit Rachel Moss)

Holycross's east window (Figure 4.27) of six lights with cusped ogee heads and a reticulated pattern without cusps is similar to a number of windows in Ormond and Desmond.[41] At St. Mary's collegiate church, Callan, which also received some Butler patronage, the chancel east window has a five-light, cusped, reticulated design. The presence of ivy, wood and a metal grille explains why there are a number of gaps in Table 4.21 but sufficient measurements were available to indicate that few proportional principles had been applied to the window's design. Only the mullion width related by 1:4 to the width of the light while the tracery field height to overall window height was almost 1:2 and the tracery field height to light height at arch peak almost equated to 5:6. There is no proportional similarity between the Holycross and Callan windows, except that neither window seems to have been designed using many of these principles. The probable unit of measurement for Holycross was 0.309m, possibly because of its reconstruction in the 1970s, while at Callan the unit was 0.230m.

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[41] Roger Stalley suggested that a fourteenth-century window at Kilmallock Dominican priory may have served as inspiration for the Holycross window: R. Stalley, *Cistercian Monasteries*, p. 120. It should be noted that Holycross's east window was rebuilt using the original stone in the 1970s.

Another similar window of four-light design is the east window (Figure 4.28) at the Dominican friary in Cashel which was probably installed *c*.1450.[42] The tracery here combines flame and reticulation designs and displays use of the ratio 4:5 for two elements: overall window width to light height (at arch peak) and tracery field height to light height (at arch peak) (Table 4.22). The whole impression, therefore, is of a neatly proportioned design, but the mixture of cusped and uncusped elements in the tracery is both unusual and visually confusing. Probably because it is so narrow relative to the windows at Holycross and Callan, this window shares no proportional design principals. The Cashel window was probably designed using the Irish foot of 0.3048m, although there is a possibility that the unit was 0.288m, close to the 0.290m found in the west window of the nave of the same building. Neither 0.288 nor 0.290 fall within any of the identified unit groupings in the region, although their lengths are within the 1cm medieval tolerance of the 0.280m standard. The match between the metrology at Cashel and at Holycross may only be the result of the twentieth-century reconstruction at Holycross and so will not be speculated upon.
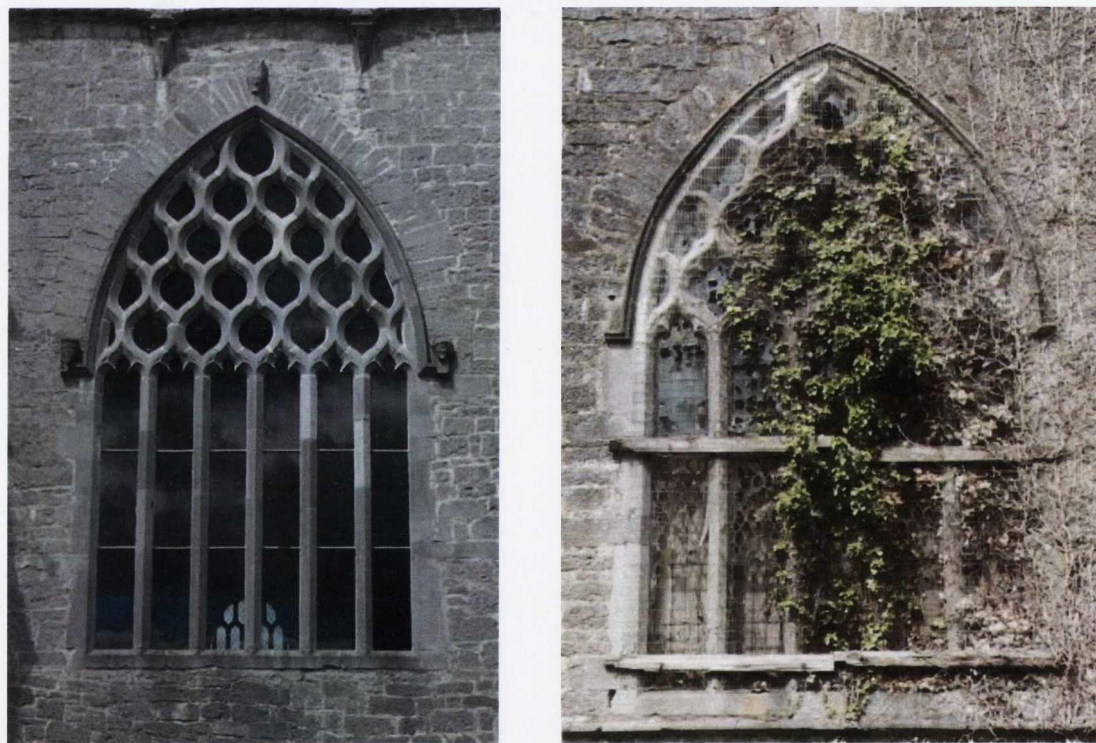

Figure 4.27 Chancel east window, Holycross Cistercian abbey (left) and chancel east window, St. Mary's parish church, Callan (right)

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[42] H.G. Leask, *Irish Churches III*, p. 93.

Figure 4.28 Chancel east, Cashel Dominican friary

Table 4.20 Holycross Cistercian abbey: proportional investigation

Proportions	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3	Light/ Mullion4	Light/ Mullion5	Light/ Mullion6
				Holycross Chancel East			
Tracery field height to light height (at springing point)		0.925	0.985	0.922	0.924	0.923	0.925
Tracery field height to light height (at arch peak)		0.990	0.985	0.990	0.984	0.987	0.985
Tracery field height to overall window height	0.520						
Overall window width to overall window height	0.564						
Overall window width to window height to spring	0.480						
Overall window width to arch span	0.971						
Light width to light height (at springing point)		0.190	0.198	0.197	0.197	0.199	0.194
Light width to light height (at arch peak)		0.174	0.179	0.180	0.179	0.181	0.177
Light width to overall window width		0.162	0.168	0.167	0.168	0.169	0.166
Light width to overall window height		0.091	0.095	0.094	0.095	0.095	0.093
Light width to arch span		0.157	0.163	0.162	0.163	0.164	0.161
Overall window width to light height (at springing point)		0.853	0.847	0.851	0.852	0.851	0.853
Overall window width to light height (at arch peak)		0.932	0.937	0.932	0.937	0.935	0.937
Mullion width to overall window width		0.048	0.048	0.049	0.049	0.049	
Mullion width to light width		0.299	0.288	0.286	0.287	0.291	0.289
Mullion width to light width		0.293	0.292	0.288	0.293		

Table 4.21 St. Mary's collegiate church, Callan: proportional investigation

Proportions	Single	Light/ Mullion1	Light/ Mullion2	Light/ Mullion3	Light/ Mullion4	Light/ Mullion5
			St. Mary's church, Callan East External			
Tracery field height to light height (at springing point)		0.958	0.955			
Tracery field height to light height (at arch peak)		0.861	0.870			
Tracery field height to overall window height	0.485					
Overall window width to overall window height	0.540					
Overall window width to window height to spring	0.515					
Overall window width to arch span	0.917					
Light width to light height (at springing point)		0.209	0.213			
Light width to light height (at arch peak)		0.188	0.194			
Light width to overall window width		0.196	0.200	0.211	0.202	0.190
Light width to overall window height		0.106	0.108	0.114	0.109	0.103
Light width to arch span		0.180	0.184	0.194	0.186	0.174
Overall window width to light height (at springing point)		0.937	0.940			
Overall window width to light height (at arch peak)		0.960	0.969			
Mullion width to overall window width		0.050	0.051	0.047	0.045	
Mullion width to light width		0.257	0.252	0.256	0.242	
Mullion width to light width		0.223	0.233	0.220	0.235	

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Table 4.22 Cashel Dominican friary: proportional investigation

Proportions	Single	Light/ Mullion 1	Light/ Mullion 2	Light/ Mullion 3	Light/ Mullion 4
			St. Dominic's, Cashel		
			East External		
Tracery field height to light height (at springing point)		0.860	0.862	0.859	0.859
Tracery field height to light height (at arch peak)		0.787	0.788	0.787	0.787
Tracery field height to overall window height	0.447				
Overall window width to overall window height	0.453				
Overall window width to window height to spring	0.819				
Overall window width to arch span	0.973				
Light width to light height (at springing point)		0.232	0.208	0.207	0.230
Light width to light height (at arch peak)		0.213	0.190	0.189	0.211
Light width to overall window width		0.267	0.239	0.238	0.265
Light width to overall window height		0.121	0.108	0.108	0.120
Light width to arch span		0.260	0.232	0.231	0.258
Overall window width to light height (at springing point)		0.870	0.870	0.869	0.869
Overall window width to light height (at arch peak)		0.797	0.797	0.797	0.796
Mullion width to overall window width		0.073	0.074	0.074	
Mullion width to light width		0.275	0.307	0.311	
Mullion width to light width		0.312	0.312	0.280	

Ratio	Numeric Value	1%		2%	
1 : 4	0.250	0.253	0.248	0.255	0.245
1 : 3	0.333	0.337	0.330	0.340	0.327
2 : 5	0.400	0.404	0.396	0.408	0.392
1 : root 5	0.447	0.452	0.443	0.456	0.438
1 : 2	0.500	0.505	0.495	0.510	0.490
13 : 23	0.565	0.571	0.560	0.577	0.554
1 : root 3	0.577	0.583	0.572	0.589	0.566
3 : 5	0.600	0.606	0.594		
377 : 610	0.618	0.624	0.612	0.630	0.606
2 : 3	0.667	0.673	0.660	0.680	0.653
1 : root 2	0.707	0.714	0.700	0.721	0.693
3 : 4	0.750	0.758	0.743	0.765	0.735
4 : 5	0.800	0.808	0.792	0.816	0.784
5 : 6	0.833	0.842	0.825	0.850	0.817
1 : 1	1.000	1.010	0.990	1.020	0.980

The final group of similarities between Holycross windows and those at other sites is found between the Holycross north transept windows and the south transept equivalents at nearby Kilcooly Cistercian abbey. The two sites being located at very close proximity to each other, they are both monasteries of the same order, significantly rebuilt at similar times, and both shared patronage from the Butler earls of Ormond. It is not surprising that other studies, such as of masons' marks, of moulding profiles, and of stylistic elements, have concluded that some of the same masons worked on both sites.[43]

Both south transept east windows of Kilcooly abbey have tracery fields that contain a vesica, with the northern one surrounded by downward pointing mouchettes, while the southern window contains a more leaf-like pattern (Figure 4.29). These two windows display significant similarity in proportional systems as evidenced in Table 4.23; the numeric values of most of the ratios are within 1-2% of each other. The probable units calculated for the two south transept east windows were 0.237m (southern) and 0.242m (northern).

Stylistically one could certainly argue that the south transept windows at Kilcooly were inspired by the north transept windows at Holycross. This would be in

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[43] C. Hourihane, *Masons' Marks*; D. O'Donovan, 'Building Butler' and R. Stalley, *Cistercian Monasteries*.

agreement with the documentary evidence which shows that Kilcooly abbey was refurbished after it was "completely destroyed by armed men" in 1444. Partial rebuilding took place during the time that Malachy Omulrian (d. 1463), a monk from Holycross, was abbot.[44] Furthermore, the cost of rebuilding was, at least in part, financed by the Butler family, as indicated by the inclusion of the family crest in a number of locations. Thus the dates for this work fall within the period of reconstruction of nearby Holycross. Potentially masons associated with the 'school' at Holycross, as suggested by Roger Stalley, Danielle O'Donovan, and Column Hourihane, could have carried out this rebuilding work.[45]

Whether these were the same masons, or simply masons who were inspired by the Holycross designs, they did not use the same metrology (Holycross 0.273m and 0.346m, Kilcooly 0.237m and 0.244m) or the same proportions (compare Table 4.23 and Table 4.24). The Kilcooly windows omit cusping and the moulding profiles are simple chamfers rather than detailed works. These windows also have a squatter tracery field than those at Holycross; the east window of the northern chapel of the north transept at Holycross has a tracery field height of 1.439m while that at the southern window at Kilcooly is only 1.105m. The mullion at Holycross was 0.135m wide while at Kilcooly the measurement was 0.150m, so although the designs share inspiration, we can certainly conclude that the same templates were not used at both sites. The walls into which both sets of windows were inserted were new builds so window heights were not constrained by existing fabric. However, the presence of a bedroom or dormitory above the south transept at Kilcooly may have placed some restrictions on the window height.[46] Of course, if proportions were of paramount importance then a mason could have adapted the dimensions of particular features to suit. The fact that this was not done suggests that, in the Kilcooly case at least, the proportions of a window's elevation were not a consideration.

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[44] A. Gwynn and R.N. Hadcock, *Medieval Religious Houses*, pp. 137-8.
[45] D. O'Donovan, 'Building Butler'; R. Stalley, *Cistercian Monasteries*; and C. Hourihane, *Masons' Marks*.
[46] R. Stalley, *Cistercian Monasteries*, p. 167.

Figure 4.29 (Left to right) South transept east northern window and south transept east southern window, Kilcooly Cistercian abbey and north transept north chapel east window and north transept south chapel east window, Holycross Cistercian abbey

Table 4.23 Kilcooly Cistercian abbey: proportional investigation

	Kilcooly				Kilcooly	
	South Transept East Northern				South Transept East Southern	
		Light/	Light/		Light/	Light/
Proportions	Single	Mullion1	Mullion2	Single	Mullion1	Mullion2
Tracery field height to light height (at springing point)		0.890	0.890		0.925	0.928
Tracery field height to light height (at arch peak)		0.747	0.748		0.781	0.775
Tracery field height to overall window height	0.430			0.427		
Overall window width to overall window height	0.478			0.460		
Overall window width to window height to spring	0.823			0.791		
Overall window width to arch span	0.794			0.795		
Light width to light height (at springing point)		0.497	0.492		0.502	0.497
Light width to light height (at arch peak)		0.417	0.413		0.424	0.415
Light width to overall window width		0.503	0.497		0.503	0.497
Light width to overall window height		0.240	0.240		0.232	0.232
Light width to arch span		0.399	0.395		0.400	0.395
Overall window width to light height (at springing point)		0.989	0.989		0.997	1.000
Overall window width to light height (at arch peak)		0.890	0.830		0.842	0.838
Mullion width to overall window width		0.131			0.126	
Mullion width to light width		0.261	0.263		0.251	0.254

Table 4.24 Holycross Cistercian abbey: proportional investigation

	Holycross				Holycross	
	North Transept East Northern				North Transept East Southern	
		Light/	Light/		Light/	Light/
Proportions	Single	Mullion1	Mullion2	Single	Mullion1	Mullion2
Tracery field height to light height (at springing point)		0.844	0.854		0.959	0.964
Tracery field height to light height (at arch peak)		0.946	0.955		0.851	0.848
Tracery field height to overall window height	0.564			0.507		
Overall window width to overall window height	0.493			0.393		
Overall window width to window height to spring	0.974			0.797		
Overall window width to arch span	0.962			0.938		
Light width to light height (at springing point)		0.519	0.517		0.407	0.400
Light width to light height (at arch peak)		0.463	0.463		0.332	0.327
Light width to overall window width		0.501	0.505		0.504	0.497
Light width to overall window height		0.247	0.247		0.198	0.198
Light width to arch span		0.482	0.486		0.472	0.466
Overall window width to light height (at springing point)		0.965	0.976		0.808	0.804
Overall window width to light height (at arch peak)		0.924	0.916		0.660	0.657
Mullion width to overall window width		0.107			0.131	
Mullion width to light width		0.214	0.212		0.260	0.264

4.3.2 Empirical Investigation

Having presented an analysis of groups of windows which are traditionally associated with the same school of masons, this section uses only the *a posteriori* knowledge from proportional and metrological investigation to create groups of windows. The groups to be presented represent the most popular ratios and units in this region. In the discussion that follows, an attempt will be made to investigate the possible meaning of these groupings.

Proportions

1:2 Ratio

This ratio was used at 9 of the 18 sites in Ormond.[47] As can be seen from Table 4.25 the ratio has been used in the proportioning of lights and the overall dimensions of the window as well as to relate the lights and tracery fields to the windows in which they are found.

Table 4.25 Occurrences of 1:2 ratio in Ormond[48]

St. Mary's, Callan south extension south	Light width to light height (at springing point)
Kilcooly south transept east southern **and** northern	Light width to light height (at springing point)
Fethard Augustinian nave north western	Overall window width to light height (at arch peak)
Fethard Augustinian south transept east (lower)	Overall window width to overall window height
Holycross north transept north chapel east	Overall window width to overall window height
Kilcooly north transept east	Overall window width to overall window height
Old Leighlin nave south western	Overall window width to overall window height
Old Leighlin west	Overall window width to overall window height
Fethard Holy Trinity south aisle east	Overall window width to overall window height[49]
Gowran south aisle east	Overall window width to overall window height[50]
Old Leighlin nave north eastern	Overall window width to window height to spring
Athassel east	Tracery field height to light height (at arch peak)
St. Mary's, Callan south aisle west	Tracery field height to light height (at arch peak)
Old Leighlin nave north eastern	Tracery field height to light height (at arch peak)
St. Mary's, Callan west	Tracery field height to light height (at springing point)
Cahir east	Tracery field height to overall window height
Holycross north aisle north	Tracery field height to overall window height
Holycross north transept south chapel east	Tracery field height to overall window height
Holycross south transept north chapel east	Tracery field height to overall window height
Holycross south transept south chapel east	Tracery field height to overall window height
Lorrha Dominican west	Tracery field height to overall window height
Old Leighlin nave south western	Tracery field height to overall window height

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[47] I want to reiterate that the high frequency of occurrence of this ratio is not caused by the large number of two-light windows in the region because all results were normalised to remove the impact of the number of lights.

[48] This list excludes any occasions where two-light windows measured half of the overall window width.

[49] The east window at Fethard Holy Trinity was within 1% of repeating this proportional relationship.

[50] The south aisle west window was within 1% of repeating this proportional relationship.

1:3 Ratio

This ratio has been used predominantly in the proportioning of lights with a few occurrences relating the tracery field to other elements (Table 4.26). On a single occasion, at Lorrha Dominican friary's east window, this represents the relationship between mullion width and light width. This window was exceptionally large with an overall width of some 4.8m and a height to springing point of 5.3m. Therefore mullions of ~0.349m were required to support the glass in the lights. Three of the eighteen sites in Ormond dominate this grouping: Callan collegiate church, Old Leighlin cathedral and Holycross Cistercian abbey. As has been shown above, these sites have been linked through a common school of masons or the possible use of a shared pattern book. Even though the use of 1:3 is far from universal within this group, it appears to be a tool that these masons had in their arsenal, but which was not generally used within the region.

Table 4.26 Occurrences of 1:3 ratio in Ormond[51]

Gowran south aisle east **and** west	Light width to light height (at arch peak)
Holycross north aisle north	Light width to light height (at arch peak)
Holycross north transept south chapel east	Light width to light height (at arch peak)
Holycross south transept north chapel east	Light width to light height (at arch peak)
Holycross south transept south chapel east	Light width to light height (at arch peak)
Old Leighlin nave north western	Light width to light height (at arch peak)
St. Mary's, Callan north aisle east	Light width to light height (at springing point)
St. Mary's, Callan nave south western	Light width to light height (at springing point)
St. Mary's, Callan south aisle east	Light width to light height (at springing point)
Old Leighlin nave south western	Light width to light height (at springing point)
Old Leighlin west	Light width to light height (at springing point)
Lorrha Dominican east	Mullion width to light width
Old Leighlin nave north eastern	Overall window width to overall window height
Fethard Augustinian nave north eastern (upper)	Tracery field height to light height (at arch peak)
St. Mary's, Callan north mid	Tracery field height to light height (at springing point)
St. Mary's, Callan west	Tracery field height to overall window height
Old Leighlin nave north eastern	Tracery field height to overall window height

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[51] This list excludes any occasions where three-light windows measured one third of the overall window width.

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4:5 Ratio

This ratio occurred at 10 of Ormond's 18 sites and, with only two exceptions, it was used to relate the height of the lights to the overall window width or to the tracery field height, or to relate the overall window width to its height to spring. This pattern seems to be very deliberate. Also, with the early thirteenth-century windows from Gowran appearing twice in the list alongside a range of mid to late fifteenth century windows from throughout the region, this suggests a continuity of use for this proportion (Table 4.27).

Table 4.27 Occurrences of 4:5 ratio in Ormond

Kilcooly south transept east southern **and** northern	Overall window width to arch span
St. Mary's, Callan south extension south	Overall window width to light height (at arch peak)
Cashel Dominican east	Overall window width to light height (at arch peak)
Old Leighlin nave south eastern	Overall window width to light height (at arch peak)
St. Mary's, Callan nave north western	Overall window width to light height (at springing point)
Gowran south aisle east **and** west	Overall window width to light height (at springing point)
Holycross west	Overall window width to light height (at springing point)
Holycross north transept south chapel east	Overall window width to light height (at springing point)
Holycross north aisle north	Overall window width to light height (at springing point)
Jerpoint north aisle east northern	Overall window width to light height (at springing point)
Gowran south aisle east **and** west	Overall window width to window height to spring
Holycross north transept south chapel east	Overall window width to window height to spring
Kilcooly south transept east southern	Overall window width to window height to spring
Athassel east	Tracery field height to light height (at arch peak)
St. Mary's, Callan north aisle east	Tracery field height to light height (at arch peak)
Cashel Dominican east	Tracery field height to light height (at arch peak)
Cashel Dominican south transept south	Tracery field height to light height (at arch peak)
Kilcooly east	Tracery field height to light height (at arch peak)
St. Mary's, Callan west	Tracery field height to light height (at springing point)
Fethard Augustinian east	Tracery field height to light height (at springing point)
Holycross north transept north	Tracery field height to light height (at springing point)
Cahir east	Tracery field height to overall window height

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1:1 Ratio

The 1:1 ratio has been used on an almost-equal basis to either divide the window vertically or to relate the overall window width to the height at which either the window arch or the light arches spring (Table 4.28).

Table 4.28 Occurrences of 1:1 ratio in Ormond[52]

Cashel Dominican south transept south	Overall window width to light height (at springing point)
Jerpoint east	Overall window width to light height (at springing point)
Kilcooly south transept east southern **and** northern	Overall window width to light height (at springing point)
Old Leighlin nave south western	Overall window width to light height (at springing point)
Old Leighlin west	Overall window width to light height (at springing point)
Callan Augustinian east	Overall window width to window height to spring
Kilcooly north transept north	Overall window width to window height to spring
Old Leighlin nave south western	Overall window width to window height to spring
St. Mary's, Callan south extension south	Tracery field height to light height (at arch peak)
Holycross east	Tracery field height to light height (at arch peak)
Cahir east	Tracery field height to light height (at springing point)
Holycross south transept south chapel east	Tracery field height to light height (at springing point)
Lorrha Dominican west	Tracery field height to light height (at springing point)

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[52] This list excludes any occasions where the overall window width to arch width was 1:1 because this frequently occurred when it was only possible to make internal measurements and no hood arch was available for measurement.

5:6 Ratio

The 5:6 ratio has been used in a very similar way to the 1:1 ratio for window proportioning (compare Table 4.29 to Table 4.28). This group is, however, dominated by occurrences at Holycross, with significant representation from nearby Kilcooly, while use of most of the other ratios has been relatively evenly distributed throughout the region. This possibly indicates an expressed preference by the designer(s) at Holycross, an idea which is somewhat at odds with Roger Stalley's description of the design of the Holycross windows as "a fairly hit-or-miss affair" partly because the masons lacked the "geometrical expertise to produce outstanding results".[53] This will be further examined in chapter 7.

Table 4.29 Occurrences of 5:6 ratio in Ormond

Cahir east	Overall window width to light height (at arch peak)
Holycross west	Overall window width to light height (at arch peak)
Kilcooly south transept east southern **and** northern	Overall window width to light height (at arch peak)
Holycross east	Overall window width to light height (at springing point)
Fethard Holy Trinity east	Overall window width to window height to spring[54]
Holycross north aisle north	Overall window width to window height to spring
Kilcooly south transept east northern	Overall window width to window height to spring
Cahir east	Tracery field height to light height (at arch peak)
Holycross north transept south chapel east	Tracery field height to light height (at arch peak)
Holycross south transept north chapel east	Tracery field height to light height (at arch peak)
Callan Augustinian west	Tracery field height to light height (at springing point)
St. Mary's, Callan south extension south	Tracery field height to light height (at springing point)
Holycross west	Tracery field height to light height (at springing point)
Holycross north aisle north	Tracery field height to light height (at springing point)
Holycross north transept north chapel east	Tracery field height to light height (at springing point)
Kilcooly north transept east	Tracery field height to light height (at springing point)
Old Leighlin nave south eastern	Tracery field height to light height (at springing point)

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[53] R. Stalley, *Cistercian Monasteries*, p.121.
[54] Because of the loss of most of the bar tracery from this window the exact same ratio resulted for the light height at springing point because it could not be distinguished from the springing point of the window arch.

Metrology

As previously described, the frequency counts used to ascertain patterns of metrology were calculated by totalling the number of times that each unit was identified as a probable unit, or to be within 10% or 20% of that most probable unit. Due to the nature of such numerical methods some of the results produced are unlikely by-products. An example would be where the units suggested for a particular window were: 0.230m within 20%, 0.341m within 20%, 0.342m within 10%, 0.343m probable unit, 0.344m within 10%. In this case, the most likely unit is 0.343m and, while a window may have contributed to the overall frequency count for the 0.230m unit, it is very unlikely to have been designed using that unit. However, in another case the results might be: 0.245m within 10%, 0.246m within 10%, 0.247m within 10%, 0.364m probable unit but an adjacent window in the same building with the same style of tracery might have a probable unit of 0.246m.[55] In this case the first window's probable unit of 0.364m would be rejected in favour of the 0.246m unit. This means that for each unit that occurred with high frequency in a particular region there is one list of contributing windows and another identifying the windows which were most probably designed using that unit.

0.221m unit

Full list of contributing windows: Callan Augustinian east and west; Callan church nave south western and south extension south; Fethard Augustinian north eastern (upper); Fethard Holy Trinity east; Holycross west and north transept north; Jerpoint chancel east, north aisle east northern and southern; Kilcooly east and south transept east southern; Old Leighlin nave south western, nave north eastern and western.

Windows where 0.221m was probably used: Callan Augustinian east and west; Fethard Augustinian north eastern (upper); Fethard Holy Trinity east; Holycross west; Kilcooly east; Old Leighlin nave south western.

0.234m unit

Full list of contributing windows: Cahir east; Callan Augustinian west; Callan church east, nave south western, south aisle east, and south extension south; Fethard Augustinian nave north western; Gowran south aisle east; Jerpoint north aisle east northern and southern; Kilcooly east, west and south transept east southern; Lorrha Augustinian east; Old Leighlin west.

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[55] This example also demonstrates why it was necessary to examine possible units with within 10-20% of the most probable unit and not just the probable units in isolation.

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Windows where 0.234m was probably used: Callan church east and south extension south; Fethard Augustinian nave north western; Kilcooly west and south transept east southern (and northern at 0.244 not far away).

0.246m unit

Full list of contributing windows: Cahir east; Callan Augustinian west, east and nave north; Callan church east, north aisle east nave north western and south extension south; Fethard Augustinian nave north mid; Holycross north transept south chapel east; Hore east; Jerpoint east; Kilcooly north transept east, south transept east northern and west; St. John's Kilkenny north western; Lorrha Augustinian east.

Windows where 0.246m was probably used: Callan church north aisle east and nave north western; Fethard Augustinian nave north mid; Hore east; Kilcooly north transept east, south transept east northern and west.

0.277m unit

Full list of contributing windows: Callan Augustinian west and north; Callan church west and south aisle west; Clonmel east; Fethard Holy Trinity east; Gowran north aisle east and south aisle east; Holycross north transept east northern and south transept east northern; Lorrha Dominican east; Old Leighlin nave north eastern and western.

Windows where 0.277m was probably used: Callan Augustinian west and north; Clonmel east; Gowran north aisle east and south aisle east; Holycross north transept east northern and south transept east northern; Lorrha Dominican east; Old Leighlin nave north eastern and western.

0.346m unit

Full list of contributing windows: Callan church south extension south; Cashel south transept south; Fethard Augustinian east and nave north western; Holycross north transept east southern and north; Inistioge north; Old Leighlin west.

Windows where 0.346m was probably used: Cashel south transept south; Fethard Augustinian east; Holycross north transept east southern and north; Inistioge north.

The possible origin of each of these units is examined in the discussion in chapter 6 and the windows within these groupings will be re-examined in that context.

4.4 Ormond Case Study – St. Mary's collegiate church, Gowran, County Kilkenny

Figure 4.30 St. Mary's collegiate church, Gowran between 1880 and 1914 (Lawrence Collection)

Having established potential patterns in the use of systems of proportion and metrology across Ormond, it now remains to examine whether such systems extended beyond tracery design and were used as a coherent means of designing an entire building. St. Mary's collegiate church, Gowran, also known as Ballygavern, county Kilkenny presents an opportunity to study early Irish medieval architecture executed by an English master who Roger Stalley described as "perhaps the most gifted craftsman to work in Ireland during the thirteenth century".[56] Stalley considered that the same individual was in charge of both the architecture and the sculpture at Gowran, such is "the close relationship" between all of the architectural detailing.[57] Only three windows, with two distinctive styles, fit within the description of traceried windows; the west windows of the nave aisles and the east window of the south nave aisle (Figure 4.31 and Figure 4.40). The mouldings of the west windows of both aisles comprise of simple chamfers. The east window of the south aisle is treated in a similar way, but elaborated internally

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[56] Although Stalley limited this statement by relating it specifically to the quality of the sculptural work in the building.

[57] R. Stalley, *Architecture and sculpture in Ireland 1150-1350*. Dublin: Gill and Macmillan, 1971, pp. 79-80 (hereafter *Architecture and sculpture*). Arnold Pacey also found evidence for sculptors/master masons in England identifying individuals such as Adam Lock and William de Malton: A. Pacey, *Medieval architectural drawing: English craftsmen's methods and their later persistence (c.1200-1700)*. Stroud: Tempus, 2007, p. 31.

by the addition of a rear arch, richly articulated with roll mouldings, dog tooth and foliate capitals.[58]

Despite only having three tracery windows, the state of preservation of other details such as the piers, arcade arches, wall niches, and hood decorations is very good, and thus the site is suitable for detailed examination. Also, with the exception of the loss of the south arcade, there has been little alteration to the nave since its construction, providing an opportunity to examine late thirteenth-century design in a way rarely possible at Irish religious sites.[59]

The exact date of foundation of the church at Gowran is uncertain but Harold Leask suggested 1275. Roger Stalley showed that much work at Gowran was carried out by the same master as was employed for the building of the nave of St. Canice's cathedral, Kilkenny under Hugh de Mapilton *c.*1251-6. This would give Gowran an earlier date than Leask proposed, probably between 1255 and 1260. Certainly the church had been established by the start of the fourteenth century, a fact evidenced by a document from *c.*1300 collected in the Ormond Deeds where Richard, son of William Gerard of Ballygaveran, gave a grant of land to "John de Thamurth, chaplain" "extending from the highway in length to *'campum Dominici'* towards the north, as divided by a fosse such as bounds grantor's burgage in the same part of the vill (except the religious house)."[60]

The church at Gowran was elevated to collegiate status in the early fourteenth century, and a college of priests continued to serve a chantry function for the Butler family into the early modern period. The role of the church as one of the mausolea of the Butler family (together with St Canice's cathedral Kilkenny) may have helped to preserve its original form. By the later medieval period, when so many other churches were undergoing radical renovation, the Butlers were apparently keen to demonstrate their long lineage in the area – something that would have been explicit in the architecture of the church.[61]

Theobald Walter and his descendents, including Edmund le Botiller, held land, including a manor house, at Gowran since the first land grants by William Marshall in

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[58] Francis Bond described this style of window as "a still more delightful way of turning the plain splay into a thing of beauty; [ ] to construct minor arches beneath the rear arch". F. Bond, *Gothic architecture*, p. 513.

[59] H.G. Leask, *Irish Churches II*, p. 116 and P. Harbison, *Guide to the National & Historic Monuments of Ireland*. 3rd ed. Dublin 12, Ireland Gill & Macmillan Ltd., 1992, p. 196.

[60] E. Curtis, *Calendar of Ormond Deeds*. Vol. III - 1413-1509. Dublin: The Stationary Office, 1935, p. 143 (hereafter *Calendar*).

[61] E. Curtis, *Calendar*, pp. 182-3 and J. Hunt, 'Rory O'Tunney', p. 25.

the early thirteenth century.[62] Therefore, as commented on by Roger Stalley, among others, it was entirely appropriate that an English style of architecture would have been employed in this enclave in Kilkenny, and this would have been emphasised by the employment of an architectural master of English origins for the building of the church.[63] The continuing 'foreignness' of the town to the native Irish, and its association with the Butler family and the Anglo-Normans in general, was confirmed by a murage charter from Henry V in 1387 which described "Balygaveran" as "situate[d] far from the aid of the English and surrounded by Irish enemies, who had lately burned it".[64]

The architecture of the building has been examined to try to understand the design methods utilised by the Gowran master. In the first stage of study, the two west windows of the north and south aisles of the nave were analysed using the same photogrammetric techniques as employed for the rest of the windows in this study (Figure 4.31). The probable metrological units for Gowran registered as 0.281m/0.282m for the south and north aisle west windows, respectively.[65]

The similarity of the windows was confirmed by an examination of the use of proportion and the minor variations in extracted ratios in Table 4.30 were mainly caused by very small differences in contemporary execution or modern measurement. Although use of the golden ratio is indicated by the comparison of tracery field height to light height at springing point, this is most likely an unintended result. This conclusion is reached because the numeric value of the tracery field height to light height at arch peak is only 0.002 outside the band for the 1:2 ratio. The 1:2 ratio was also used to relate the overall window width to its height and the light width to overall window width.

The use of the 4:5 ratio between the window width and the light/window height to the springing point of the arches is also in line with the preferences found throughout Ormond. I therefore suggest that the occurrence of the 2:3 ratio is an interesting, but unintended, by-product of the intentional design using ratios typical of the region. The 1:3 ratio between the light width and the light height (at arch peak) can also be interpreted as the intention of the mason, being so precise in both windows. At this point, there is already sufficient evidence to suggest that the mason in charge of the

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[62] E.S.J. Brooks, 'Machtalewi, a Leinster chieftain', *Journal of the Royal Society of Antiquaries of Ireland*, 1941, LXXI (11 Part 2), 53-5.

[63] R. Stalley, *Architecture and Sculpture*, pp. 75-80.

[64] Corporations Ireland, *Reports from Commissioners: the South Eastern Circuit*. Vol. 8. 16 vols: Corporations, Ireland, 1835, p. 517.

[65] The metrological analysis of the south aisle west window actually suggested 0.281m as being within 10% of the most probable value, with 0.280m and 0.279m registering as within 20%. The most probable value was actually 0.359m, and this was supported by high probability values within a few mm either side of this value, but there was no agreement from the north aisle window, as there was for the 0.281m value.

design of the west end aisle windows had a good knowledge of proportional design principles and executed these designs efficiently.

Figure 4.31 North aisle west (left) and south aisle west (right), St. Mary's collegiate church, Gowran

Table 4.30 St. Mary's collegiate church, Gowran: proportional investigation

Ormond	North Aisle West External			South Aisle West External		
Gowran		Light/	Light/		Light/	Light/
Proportions	Single	Mullion1	Mullion2	Single	Mullion1	Mullion2
Tracery field height to light height (at springing point)		0.639	0.639		0.620	0.621
Tracery field height to light height (at arch peak)		0.529	0.527		0.512	0.516
Tracery field height to overall window height	0.390			0.384		
Overall window width to overall window height	0.486			0.498		
Overall window width to window height to spring	0.795			0.808		
Overall window width to arch span	0.918			0.909		
Light width to light height (at springing point)		0.397	0.400		0.409	0.397
Light width to light height (at arch peak)		0.329	0.329		0.338	0.330
Light width to overall window width		0.499	0.502		0.508	0.492
Light width to overall window height		0.242	0.242		0.253	0.253
Light width to arch span		0.458	0.461		0.462	0.447
Overall window width to light height (at springing point)		0.797	0.797		0.804	0.806
Overall window width to light height (at arch peak)		0.659	0.657		0.665	0.670
Mullion width to overall window width		0.182			0.179	
Mullion width to light width		0.365	0.363		0.352	0.363

To facilitate the full scale examination of Gowran collegiate church, a terrestrial laser scan was carried out of the interior of the building as generally described in the methodology chapter.[66] The Mensi GS200 time-of-flight laser scanner from Dublin Institute of Technology was utilised and two set ups of the instrument were required. The first setup was in the western chapel of the north aisle to allow for a detailed

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[66] The original intention had been to carry out a full internal and external scan but weather and equipment restrictions made this impossible to complete.

examination of the north aisle west window and the piers of that chapel (Figure 4.32). The second setup was in the centre of the south aisle and enabled the generation of an overall 360° scan of the building, as well as high-resolution scans of the pier bases, capitals and arch peaks of the arcades, and the windows and wall niches of the south aisle. The high resolution scan created a grid of approximately 5mm point spacing.[67]
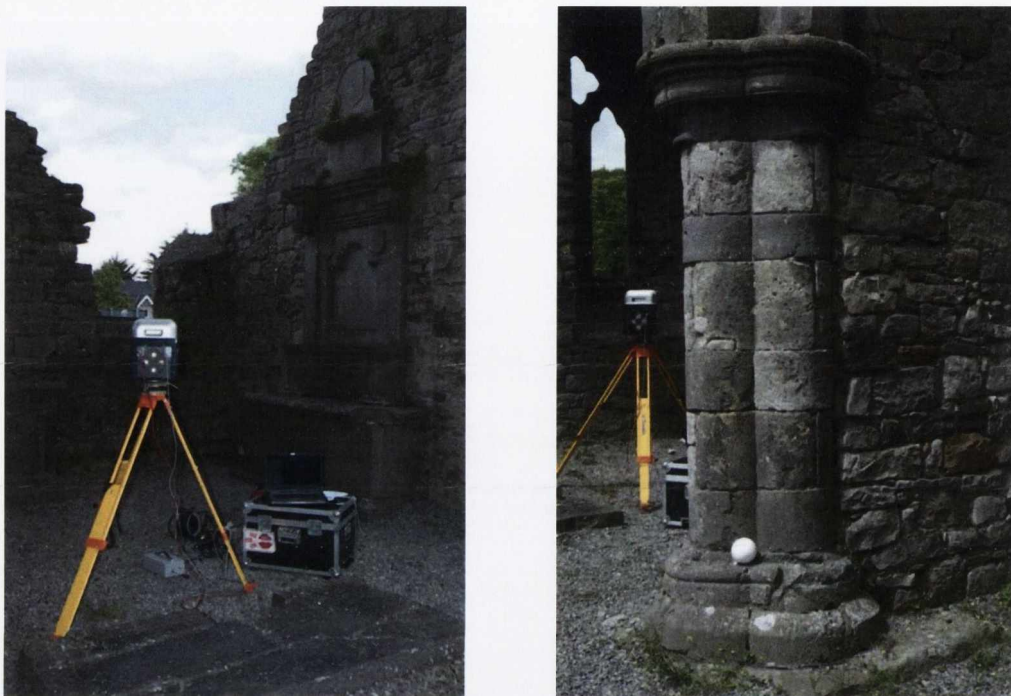

Figure 4.32 Mensi GS200 terrestrial laser scanner first setup location, St. Mary's collegiate church, Gowran

Since two setups were required this necessitated registration of the two scan locations in the Realworks software using spherical targets such as the one visible in Figure 4.32 right. The results of the least squares adjustment of one scan onto the other are summarised in Table 4.31. The residual error is an amalgamation of the three delta values and estimates the precision with which the two scans matched together at a particular target; in this case no error was higher than 1.3cm which is sufficient for this work.

Table 4.31 St. Mary's collegiate church, Gowran: scan registration results

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[67] The exact density is variable because point cloud density is a function of the distance from the scanner to the object of interest.

Target Number	Residual Error (mm)	Delta X (mm)	Delta Y (mm)	Delta Z (mm)	Fitting Error[68] (mm)
13	12.57	11.91	3.93	-0.83	0.96
5	12.53	-11.94	3.58	1.32	1.70
14	9.48	2.93	-7.70	4.70	0.59
7	3.86	-2.90	0.19	2.55	1.35

An outline ground plan of the nave and the aisles is shown in Figure 4.33.[69] The ratio between the width of the nave and its length is 4:5 or 3:4, with both being very close numerically. The ratio between the depth of the aisles and the length of the nave is in the region of 1:5, while the ratio between the depth of the aisles and the width of the nave is 1:4. The distance between the piers is ¼ of the total length of the nave. While it seems that the setting out of the nave was made with some conscious effort towards including some standard ratios, particularly 1:4 and 3:4, the argument cannot be made with any more certainty than this. As with most Irish buildings of this era, there is difficulty in ascertaining the exact intentions of the mason/architect because, with the exception of the pier bases, the walls were generally built of rough rubble and variations of up to 5cm in length are not uncommon, depending on the exact position along a wall where a measurement is taken. However, within the constraints imposed by the available building materials and possibly the skills of the local labourers, the Gowran master executed a ground plan that demonstrated knowledge of geometry.

Through extraction of a range of measurements from the ground plan the preferred unit of measurement was found to be 0.277m. This aligns well with the results from the photogrammetric analysis of the aisle west windows. Furthermore, it is interesting to link an English mason with this unit – a point that will be expanded upon in chapter 6.

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[68] This figure represents a measure of how well a spherical shape could be fitted into the point cloud which represented the scan of the spherical target. Where there is no mis-identification of the target spheres this value should be below 2mm, as is the case here.

[69] The plan is incomplete because only those elements which could be directly measured in the point cloud were extracted. Since TLS require line-of-sight access, gaps will always occur in the data unless significant numbers of setups of the instrument made. This, of course, has a temporal implication.

North Aisle West Window Location

North Aisle Arcade

South Aisle West Window Location

Tomb Niches and Piscina Locations

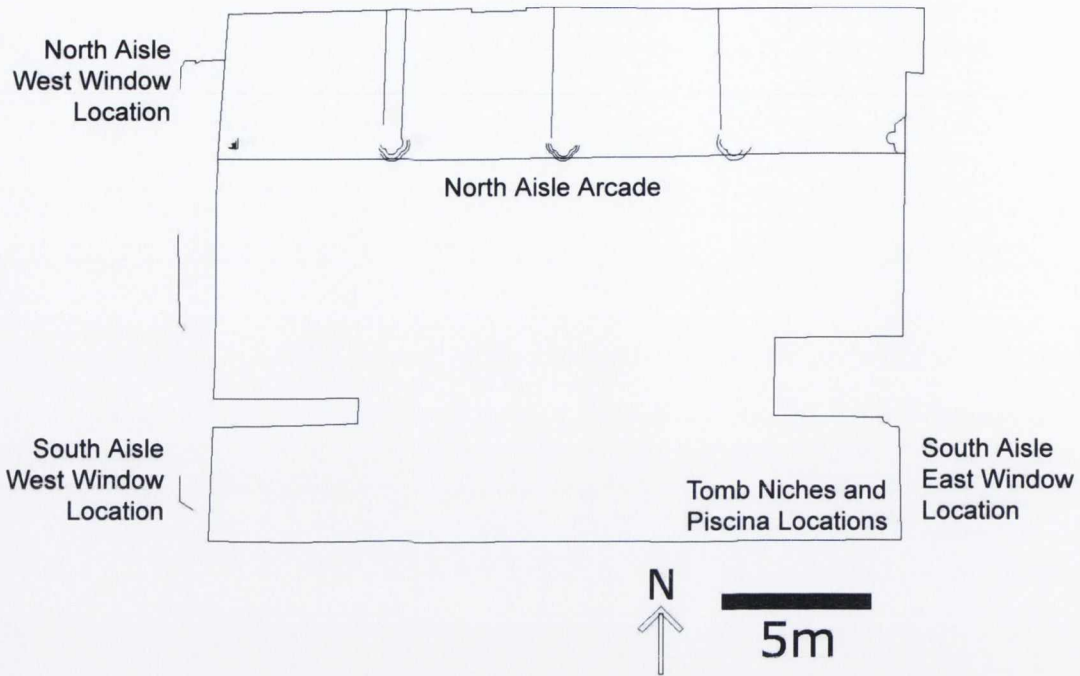South Aisle East Window Location

N

5m

Figure 4.33 St. Mary's collegiate church, Gowran: outline ground plan from terrestrial laser scan. Only a set of interior scans were carried out so all linework shown represents the interior faces of walls and features, with the exception of elements of the recessed windows at the west end.

Profiles of the three full piers of the north aisle arcade (Figure 4.34) were created in the Realworks software by cutting along the central axis of each pier.
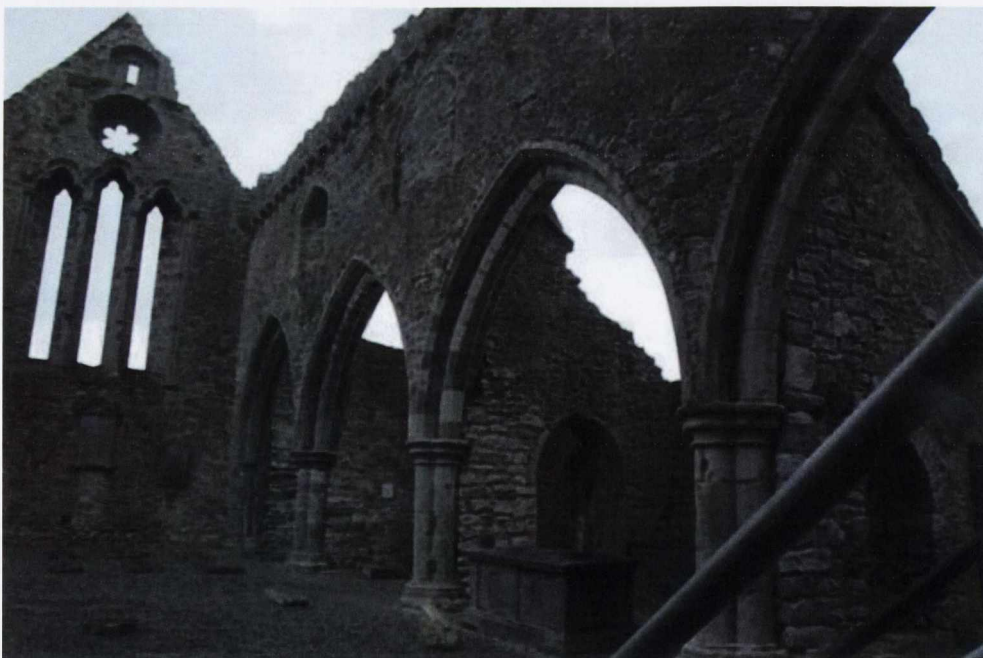

Figure 4.34 North aisle arcade, St. Mary's collegiate church, Gowran

Figure 4.35 left graphically compares the profiles of these three piers. Figure 4.35 right shows the measurements extracted for pier two and these were analysed using the same Excel VBA macros as were used for the photogrammetric assessments. Each of the other piers was also analysed using the same technique.

Pier 2   Pier 3   Pier 4

0.118
0.087
0.039   0.019
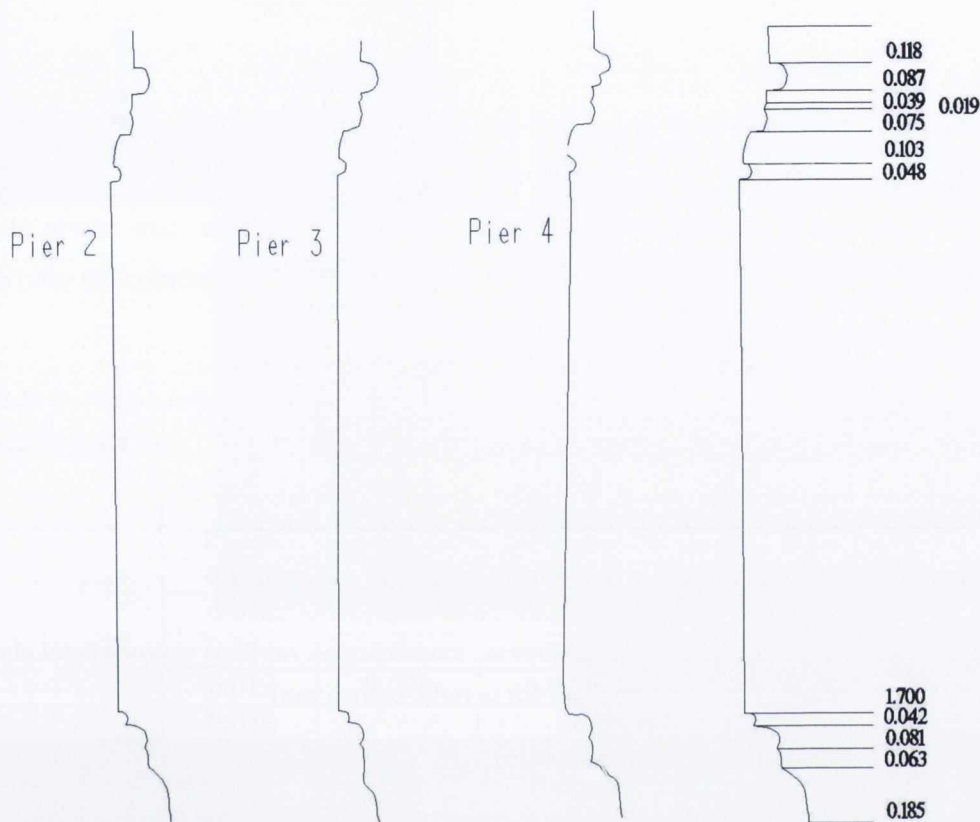0.075
0.103
0.048

1.700
0.042
0.081
0.063

0.185

Figure 4.35 St. Mary's collegiate church, Gowran: north aisle arcade pier profiles (2 – 4 represents the piers from west to east of the aisle) with measurements of moulding details (in metres)

However, the difficulty for comparison is that none of the three piers are absolutely identical, as demonstrated by the captures from the raw, uninterpreted laser point cloud shown in Figure 4.36, capitals, and in Figure 4.37, bases. The capital of the westernmost pier is much more delicately carved than the other two, although its base is more roughly shaped, perhaps as a result of some damage over time.
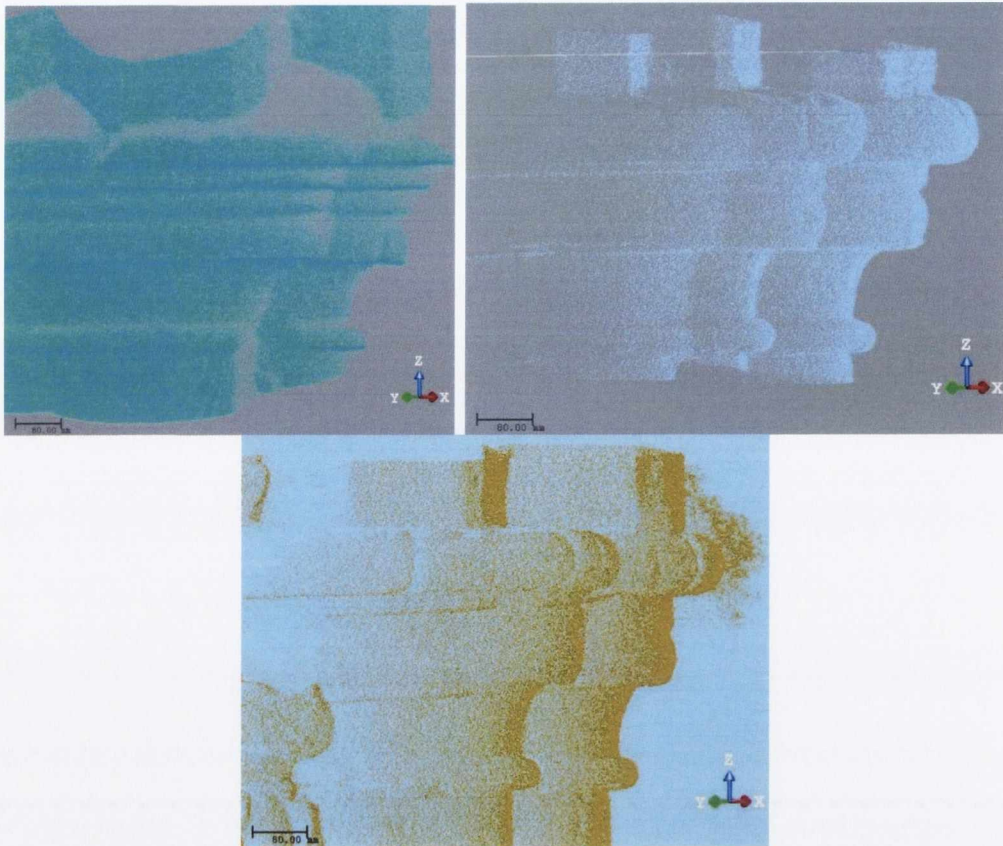
Figure 4.36 St. Mary's collegiate church, Gowran: uninterpreted, raw laser scanned point clouds of the north aisle capitals west to east (top row left to right, bottom row)
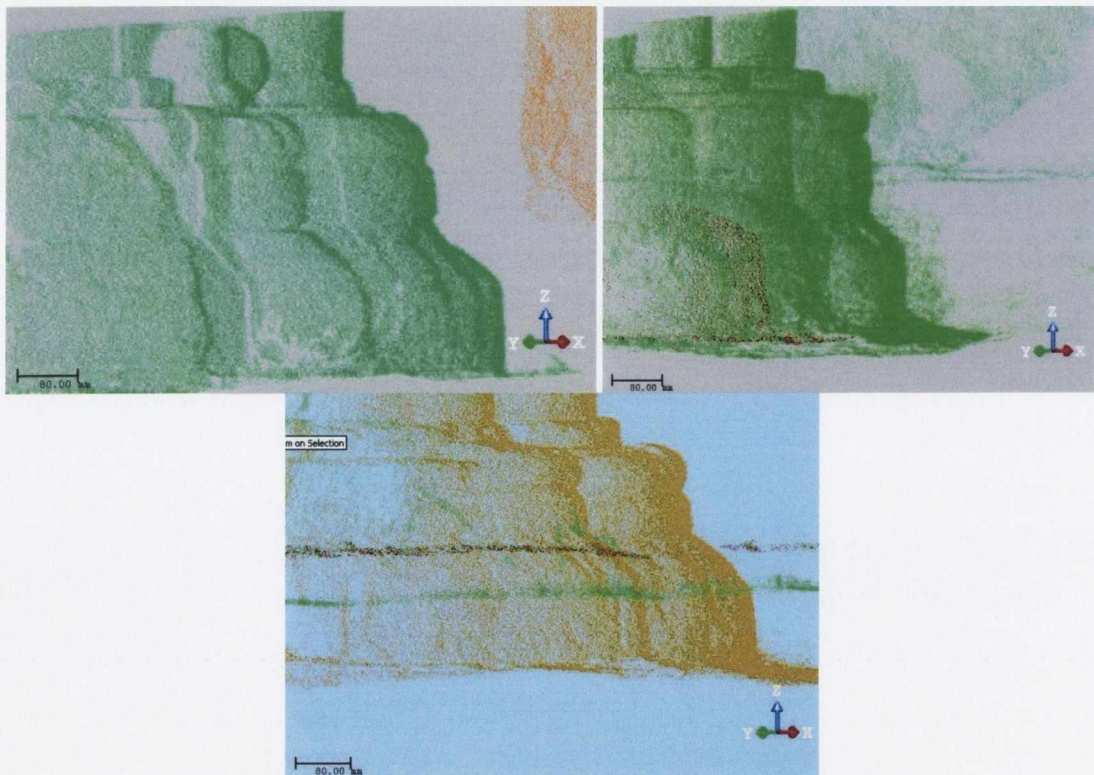

Figure 4.37 St. Mary's collegiate church, Gowran: uninterpreted, raw laser scanned point clouds of the north aisle bases west to east (top row left to right, bottom row)

Table 4.32 shows the actual measurements extracted for each of the three piers. Since piers 3 and 4 should actually share the same dimensions, based on a visual comparison, the final column of the table compares the extracted measurements. The capital measurements agree to better than 1cm, as do the measurements from the upper part of the base. The differences between the lower portions of the base could be influenced by damage to the stonework over time, particularly likely given the presence of a number of burials within the church building. The larger difference between the main sections of the column can be explained because these are composed of five separate stones and, with an error of 5mm in each stone this could easily equate to 20mm over the column height.

Table 4.32 St. Mary's collegiate church, Gowran: extracted pier section measurements (in metres) as shown in Figure 4.35

Pier 2	Pier 3	Pier 4	Piers 3-4 difference
0.055			
0.038	0.097	0.098	0.001
0.044	0.04	0.049	0.004
0.019	0.078	0.074	0.004
0.059			
0.108	0.1	0.094	0.006
0.036	0.048	0.058	0.010
1.700	1.716	1.695	0.021
0.03	0.041	0.043	0.002
0.07	0.062	0.068	0.006
0.086	0.128	0.058	0.070
0.198	0.168	0.187	0.019

The profile dimensions were analysed using both the metrology and proportional examination methods previously described. Probably because of the very short lengths of most of the dimensions extracted from the profiles, the results of the metrology investigation could not be interpreted in any meaningful way because for each pier over forty candidate units were suggested.

The proportional examination was more successful, although the measurements certainly do not indicate that all details of the building were executed with the "singular vision" often attributed to the master masons of the great gothic edifices of England and continental Europe. Another problem is that without a known relationship between the design of the pier profile and some recognised form, such as is possible in Renaissance

architecture or when relating features to classical pattern books, it is very difficult to separate the intentions of the designer from random effects.

Each measurement must therefore be compared with all other measurements and a pattern sought in the multiple results. The only possible trend which might be present in the proportions of the profiles of these piers relates to the proportions 377:610 (golden ratio), 3:4 and 1:2, as shown in Table 4.33. Piers 3 and 4 were almost identical, as was expected, while pier 2's proportions were very similar. While it is not possible to definitively say that the masons of Gowran intended the use of one or more of these ratios, the 3:4 ratio also occurs in the ground plan of the building while the other two ratios, the golden ratio and the proportion of halves, are both found in the dimensions extracted for the west windows of the north and south aisle.

I would argue that this indicates, at least, that the Gowran master understood that the use of proportional design was useful in building, perhaps for aesthetic motivations, perhaps for reasons of structural stability, but that he did not necessarily need to follow a rigorous pattern. This finding aligns well with L.R. Shelby's conclusion that Gothic methods were "certainly prescriptive" but "not rigidly restrictive".[70]

Table 4.33 St. Mary's collegiate church, Gowran: count of occurrences of particular ratios in the profiles of the north nave aisle piers

	Pier2	Pier3	Pier4	Total
1:2	4	4	4	12
3:4	2	5	7	14
377:610	6	5	5	16

Before leaving the piers it is important to mention the quatrefoil plan of the capitals and bases and how this relates to the profiles as well as to the overall building layout. The design of the piers of the north arcade of Gowran church is very simple, consisting of four foils distributed evenly about the circumference of a large circle. The same design is utilised for both the capital and the base of each of the three full piers. The fourth foil is difficult to measure because of its absorption into the later walls which have been inserted in order to divide the north aisle into separate chapels (Figure 4.38).

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[70] L.R. Shelby, 'The Geometrical Knowledge of Mediaeval Master Masons', *Speculum,* 1972, 47, 395-421, p. 420.
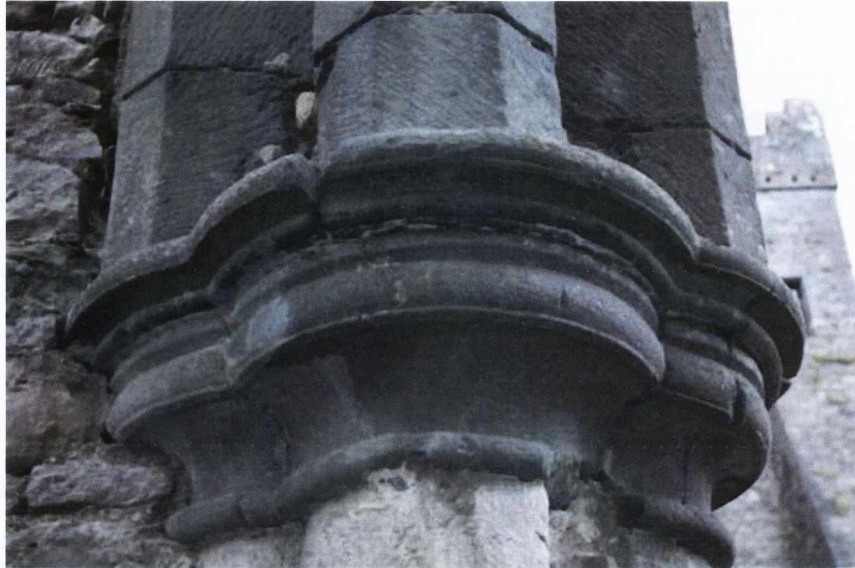
Figure 4.38 St. Mary's collegiate church, Gowran: pier capital north aisle arcade with later chapel wall visible to the left

In terms of setting out this design no detailed geometrical knowledge would have been needed, except the ability to create concentric circles of differing radii.[71] This design is set out in Figure 4.39. My conjecture is that the full design was set out at life-scale on either a prepared surface, or on a very large block, or a number of standard sized ashlar blocks assembled for cutting the design. On the large surface a circle, with radius C-A, was set out. The centre point, C, was joined to each quadrant point of the circle creating three lines of length C-B. The centre point of each quadrant line was found using a compass, e.g. point D, and a number of circles were drawn from this point with varying radii in order to produce the pier bases and capital designs.

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[71] For examples of setting out of geometric designs see, for a pier with "three concentric figures: a circle, an inscribed hexafoil, and a smaller hexafoil with the same orientation", P.J. Fergusson, 'Notes on Two Cistercian Engraved Designs', *Speculum,* 1979, 54 (1), 1-17 and for very complex plinths at Durham cathedral see J. Bony, 'The Stonework Planning of the First Durham Master.' *Medieval Architecture & its Intellectual Context: Studies in Honour of Peter Kidson.* Eds. E. Fernie and P. Crossley. London, England: The Hambledon Press, 1990. 19-34, pp. 30-3.
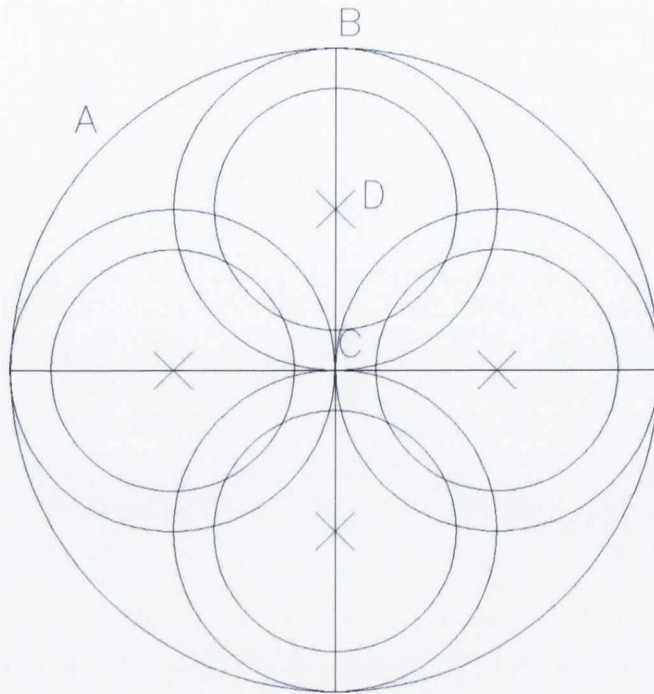
Figure 4.39 St. Mary's collegiate church, Gowran: conjecture of pier setting out design (not to scale)

Although the proposed setting out method fits with all three piers, the measurements do not entirely agree. At the bases of the piers the measurements for the radius of the large, encompassing circle vary between 0.573m and 0.586m. For the capitals the variation is even more significant ranging from 0.542m for pier 2 to 0.563m for pier 3 and 0.586m for pier 4. The variation between pier 2 and the others could be accounted for because of the previously mentioned difference in design but the expectation would be that piers 3 and 4 would have more similarity.

Individual measurements were then taken of the radii of each of the foils of the base and capital designs in order to identify other measures of similarity between the piers or, at least, to search for consistency within an individual design. From the figures contained in Table 4.34, I would conclude that the Gowran mason intended to use the same measurements for all three piers but that small variations occurred during execution, either because of the limited accuracy of available measurement methods, or because the work was handed over to another mason or apprentice who exercised a little less care.

Table 4.34 St. Mary's collegiate church, Gowran: pier capital and base plan measurements

	Pier 4 Capital/Base	Pier 3 Capital	Pier 3 Base	Pier 2 Capital	Pier 2 Base
Foil 1				0.193	0.193
	0.222	0.224		0.208	0.227
	0.327	0.268			
		0.289		0.288	0.288
	0.385	0.385		0.407	0.386
Foil 2	0.205	0.193		0.188	0.207
		0.239		0.242	0.235
	0.308	0.307		0.315	0.316
	0.389	0.381		0.401	0.37
Foil 3	0.171	0.182			
	0.202	0.238	0.204		
	0.311	0.347	0.231		
	0.364	0.351	0.316		

Using the same tests as previously applied to the photogrammetrically extracted values, the measurements in Table 4.34 were compared to extract any geometrical design pattern and the results are presented in Table 4.35. As was found in the evaluation of the profiles of the piers, the ratio of 3:4 occurred frequently for the plans of piers 2 and 3. In pier 4 the dominant ratios are 5:6 and 2:3, which do not occur in the other figures extracted on site.

Table 4.35 St. Mary's collegiate church, Gowran: proportional comparison of pier plan measurements

	Pier 4 Capital/Base		Pier 3 Capital		Pier 3 Base		Pier 2 Capital		Pier 2 Base	
Foil 1	0.679	2:3	0.836	5:6			0.928		0.850	5:6
	0.849	5:6	0.927				0.722	3:4	0.788	3:4
			0.751	3:4			0.708	1:root2	0.746	3:4
			0.501	1:2			0.462		0.536	
Foil 2	0.666	2:3	0.808	4:5			0.777	3:4	0.881	
			0.779	3:4			0.768	3:4	0.744	3:4
	0.792	4:5	0.806	4:5			0.786	3:4	0.854	5:6
	0.440	1:root5	0.478	1:2						
Foil 3	0.847	5:6	0.765	3:4						
	0.650		0.686	1:root2	0.883					
	0.854	5:6	0.989	1:1	0.731	3:4				

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My conclusion regarding the north aisle piers is that they were designed in accordance with a simple geometric scheme, and that it was intended that all three would be identical; however, due to circumstances related to the construction process and to the modern measurement of slightly damaged stonework, the measurements display some variations.

The south aisle east window was measured using the laser scanner rather than by photogrammetry. As part of the analysis of that window, a profile was extracted for the central mullion, measured from inside the building. Each measurement in the profile was compared against all others to try to identify specific relationships related to proportions. Although no perfect pattern appeared, the most prominent proportion is that of 3:4 and it also occurred in the relationship between the radii of the inner and outer foils of the window lights and the central quatrefoil.

0.070
0.029
0.030

0.084

0.040
0.033

1.820
0.030

0.068

0.052

Figure 4.40 St. Mary's collegiate church, Gowran: south aisle east window (left) and left pier profile with extracted measurements from laser scan (right)

In terms of metrology, both through an examination of the profile measurements represented in Figure 4.40, and through measurements of the window and light widths and heights, the probable unit used for this window was found to be close to 0.227m. This is 6mm different from the Ormond unit grouped about 0.221m and 4mm from the medieval measure, the Long Palm. This window is so much in keeping with the rest of the detail of the building, including the dogtooth design which is also used on the north doorway, that it is probably contemporary with the rest of the building. As has been

shown in the examples throughout Ormond, medieval metrology does not seem to have been fixed between windows that were inserted in the same building and even between windows that were coeval. Therefore it is quite feasible that different metrology was used for different architectural features or for features versus ground plans.

The measurement unit used for the design of the tomb niches and piscine could not be reliably extracted because of the very short distances available for measurement. Similarly, the use of specific ratios could not be derived from the measured laser scanned data.

Figure 4.41 Tomb niches and piscina, south aisle south wall, St. Mary's collegiate church, Gowran

Figure 4.42 Tomb niches on the south aisle wall, St. Mary's collegiate church, Gowran

4.5 Ormond Conclusions

This investigation of Ormond's medieval window tracery has demonstrated that masons working in this region understood the application of proportion to medieval architecture. They applied this knowledge effectively and, although relatively indiscriminate in their choices of proportions, displayed a tendency to prefer the ratios 1:2, 1:3, 1:1 and 4:5 or 5:6. The dominance of the 1:2 and 1:3 ratios suggests the importance of simplicity and ease of execution to Ormond's medieval masons. Unlike the manner in which proportions were used in some European contexts, the ratios applied in Ormond do not seem to have been employed as a means of ensuring structural stability. This is probably because the scale of the works was too small to require such consideration.

Evidence in favour of the use of a significant number of 'preferred' medieval units of measurement was found. These are represented by the metric values 0.221m, 0.234m, 0.246m, 0.277m, and 0.346m. If a broader definition of 'preferred' is taken then the units 0.265m, 0.298m, 0.310m, and 0.323m were also used on a noticeable number of occasions. While 0.298m, and possibly 0.310m, link to the official standard foot of England and Ireland after 1305, no documentary basis can be given to any of the other units. The reason why so many units seem to have been popular is unclear, but from this preliminary study it does not appear to bear any meaningful relation to the activities of individual or groups of individual masons. It also demonstrates how well units could co-exist in the absence of strict regulation. These issues will be considered further in the comparison with other regions which follows in chapters 6 and 7.