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Abstract

The collapse of the significant church of Holyrood Abbey in Edinburgh in December 1768 is discussed as the result of the ill-conceived repair of the roof in 1760, i.e. the substitution of the timber trusses with closely-spaced diaphragm masonry walls that aggravated the delicate equilibrium of the vaults and the poor state of a building being mutilated over 250 years. This study interprets these repairs by demonstrating the authorship and partnership of the architect John Douglas with the mason-developer James McPherson, who combined architectural ambition (the aesthetics of a flagstone roof) with the (cheaper) option of diaphragms, which would not involve a wright. The detailed examination of the procurement, the process of the intervention, the collapse and the limited impact of its aftermath, are framed in a wider technical and historical context in Edinburgh and Scotland, during a period marked by several failures of medieval churches, and reveals a poor understanding of a critical element in Gothic construction. Analysis of all public archive material available sheds light on key events of the case, and critical study of the work of the two partners' attempts to identify the intentions of their project, whose limitations were inevitable once the partnership was formed.

Keywords

John Douglas, stone vaulting, Gothic, Edinburgh, Holyrood, restoration

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INTRODUCTION

The collapse of the remaining nave of the church of Holyrood Abbey in Edinburgh in 1768 (Fig. 1) was the result of the inappropriate substitution of the main timber trusses with closely-spaced diaphragm rubble-masonry walls in 1760 (Scots Magazine 1768, Harrison 1919). This project was planned and carried out by the partnership of the architect John Douglas of Pinkerton (ca 1709-1778) (Kinnear 2001, Gow 1989, John Douglas 2015, John Douglas 2015b, Theodossopoulos 2015) with the stonemason James McPherson (McPherson 2015), both experienced with major private buildings and conversions.

Essentially the church had been mutilated in various stages since the 15th century during the transformation of the original abbey into the Palace of Holyroodhouse. By 1750's it was poorly maintained or even appreciated, prompting the 5th Duke of Hamilton (hereditary keeper of the Palace) to arrange repairs, in particular the roof and pavement. Douglas and McPherson submitted a proposal in 1757 to substitute the timber trusses with closely spaced stone walls, acting like diaphragms that could re-create a stone-tiled (flagstone) roof. This new roof was finished in 1760 and tripled the load on the vaults, bringing the strength of the buttresses to their limits and causing the collapse in 1768. The intervention, the collapse and its aftermath are discussed in detail using all available original documentation, confirming Douglas and McPherson as the authors and placing their experience and project in the wider technical and historical context in Edinburgh and Scotland

The discussion also offers a reflection on attitudes during the restoration and repair of complex structures like vaults at the time. The period is marked by several failures of stone roofs, but also

many restoration projects on major English cathedrals (Theodossopoulos 2015b). It reveals a poor understanding of a critical element in Gothic construction in a period of revival of Gothic aesthetics and right before the industrialisation of construction that would start later to support the rapid speculative housing construction during the Georgian period (especially the commissioning of Edinburgh's first New Town).

Several key aspects of the project and its limitations become evident from archive material and analytical understanding of the vaults' technical performance, showing the project was guided by recreation of a form rather than understanding of a construction process. The discussion highlights the joint responsibility of the rather experienced partners: Douglas chose to design a solid flagstone roof, possibly showing off in order to gain more Edinburgh projects; McPherson as a stone mason and later speculative builder, did not want to invest beyond his skills and no wright (carpenter) was involved to build a timber roof.

CONTEXT OF THE STUDY AND STRUCTURAL COMPLEXITY IN 18TH CENTURY EDINBURGH AND SCOTLAND

The choice of the collapse of the Holyrood Abbey church to highlight a limited understanding of vaulting technology started from earlier studies that assessed the structural performance of the vaults (Theodossopoulos 2001, Theodossopoulos et al 2003, Theodossopoulos et al 2001). Contemporary reports (Scots Magazine 1768) reveal public curiosity for the slowly collapsing church in 1766 but there is no impact on the profession or wider popular culture, in contrast with the regulations established for example after the major fires of London (London Building Act of 1667) or Edinburgh (Building Act 1698) or with modern attitudes to failure (Theodossopoulos 2014). Catastrophic failures of functioning monuments are usually followed by swift action (see North French cathedrals after World War One, the Cámara Santa in Oviedo after the Spanish Civil War, York Minster after the 1984 fire, St. Francis of Assisi in 1997, Warsaw after World War Two, the city

of Noto in Sicily etc). Even more controversial cases are characterised by extensive discussion, like the reconstruction or not of many churches in Barcelona after the Siege of 1714 or the Tragic Week of 1909, or even the ongoing (2015) debate and stalemate of the reconstruction of the cities of New Orleans and L'Aquila. Little happened however in the case of Holyrood, and mostly long after the events of 1760's, while today historiography treats the event as merely a footnote (Gifford et al 1984, Historic Scotland 2013).

There may have been cultural reasons behind this indifference. The Abbey was founded by David I in 1128 as an Austin Canons monastery and until the 16th century there was a history of continuous prosperity. The first collegiate church was replaced between 1195 and mid 14th c. Archaeological evidence and stylistic and historical affinities with Lincoln Cathedral suggest that the nave was roofed with sexpartite vaults, probably added after 1260. The status of the medieval church was consolidated by the gradual transformation of the abbey into the Palace of Holyroodhouse (Fig. 2), especially by James IV (1498-1501), but this also marked the start of its decay. In 1544 and 1547 the abbey was attacked by English troops, causing severe damage to the fabric that is still visible today (Historic Scotland 2013, RCAHMS 1951, Robertson et al 2005). Among the plundering acts, the precious lead of the roof was removed, initiating the crucial decay of the roof, and probably the exposed buttresses were damaged by this looting and gunfire (Fig. 3). During the Scottish Reformation the church was looted in 1559, and the monastery was left to decay and eventually was dissolved. These turbulent events and changes in the rite made the choir and transepts redundant, so eventually Adam Bothwell, the appointed commendator, pulled them down in 1570 (Oldrieve 1911) using the funds from the sale of the stone to repair the remaining nave and create the tracery infill of the window formed on the East gable, to enclose the building in 1573 when became a parish church.

Both ends of the church were strengthened as a preparation for Charles I Scottish coronation in 1633: structural movement of the west front had appeared earlier and by 1626 it had caused

detachment of the front from the stone vaulted roof (Laing 1854, Gallagher 1998), so its upper part was rebuilt, while the tracery infill window at the East gable was rebuilt. Also, various pews and lofts were inserted for the noblemen and the trade incorporations then and afterwards. Later in 1687, James VII inserted further elaborate furnishings when he transformed the church to Chapel Royal and Chapel of the Order of the Thistle. All this left profound marks on the fabric, but in turn they were violently destroyed by the mob during the political and religious riots around the Glorious Revolution in 1688 (Fig. 3). These events may have not been significant for the structural stability of the fabric, but together with the creation of the current Holyroodhouse Palace from 1671 and the move of parish worship to the new Canongate Kirk in 1691, it all meant the church was out of public life and with little importance for the city.

There are further questions regarding the 1760 intervention itself. The discussion later will demonstrate poor understanding of Gothic vaulting behaviour and lack of any engagement with the original design, questioning the intention of a repair versus conservation. In this case, it seems odd why such an experienced architect and stone mason did something that conservative, heavy-handed and disastrous. Beyond discussing the competence of these persons, it is more interesting to debate whether this incident reflects a wider oblivion of the technique (practicing instead what was called *Gothick* aesthetic) and lack of technical complexity in structures of the time. Is the intervention and failure representative of what was happening with historical buildings, especially those that architects could (or would) not understand?

The examination of the intervention through original documents (contract, correspondence with client, pre-failure survey and the legal dispute afterwards) and historical-critical analysis will shed light to the construction stages and the role of the added elements. This will be combined with a critique of the architecture of the intervention (which appears more suitable for barrel vaults), which will be framed within the work and expertise of John Douglas and the alterations culture of the time, questioning why conservation did not take place.

THE REPAIR PROJECT OF HOLYROOD ABBEY CHURCH IN 1758

The commissioning of the project

Various events around the middle of the 18th century show a slow renewal of interest for the Palace and the church. The author James Boswell (1758) lamented in May 1758 the abandonment of the church in his poem "An evening-walk in the Abbey-church of Holyrood-house" mentioning the state of the Royal Vaults as also the "venerable roof" which fell "a prey to the rude winds, and Winter's stormy blasts!". His correspondence with William Johnson Temple further indicates the church had a symbolic link for him with the Stewarts and Catholic medieval Scotland (Crawford 1997). This apparently moved Major Thomas Cochran, one of the Commissioners of Excise in Scotland, to make representations to the Exchequer Court which eventually pushed forward an earlier petition by the late Duke of Hamilton to carry out repairs as will be seen later.

The 5th Duke of Hamilton (1703-1743), the hereditary keeper of the Palace during the long absence of the monarchs from Scotland, was showing Mary Queen of Scots apartments to paying guests and had William Adam (1689-1748) to renovate his apartments (or the Queen's apartments) in 1740-41 - most of this work was demolished during the later restoration by Robert Reid. An event of some political significance is also that "Bonnie" Prince Charlie occupied the Palace and held court between September and October 1745 as part of his campaign to gain the Scottish throne.

William Adam had also carried out repair work on the lead roof of the Palace, worthy £2098 (Exchequer Court 1733). The young 6th Duke (1724-1758) was also living in Holyroodhouse and would not like the state of the Abbey church, heavily damaged and neglected, in contrast to the Palace and his refurbished apartments, where he was holding balls and social events. The archive research shows that on 20/2/1754 a petition by the Duke was discussed by the Exchequer Court (the then Scottish Treasury, responsible for the administration of government revenue) regarding repairs on the roof of the Abbey Church (Exchequer Court 1754) and a sum was allocated from the Vacant

Stipends (priest salaries that were not paid as the church had no priest for some time). This practice had been followed elsewhere, like the repairs of the East End of Elgin Cathedral in 1735. More funds could have also been available for the project from Jacobite estates forfeited after the 1745 uprising.

In a collection of letters at the National Library of Scotland dated generically 1757, estimates appear for the first time by John Douglas (architect from Leith) and James McPherson (stonemason) for the repair of the Church (Douglas and McPherson 1757). The first amount was for £ 1124-13-2 and a discount to £ 1003-4-10½ was finally offered, removing item 3 about the refurbishment of the roof of the aisles (Table 1). The timber and slates of the old roof were going to be re-used or fund scaffolding, nails and workmanship but if "Timber is found insufficient and will not answer the purpose then and in that Case there will be an additional artickle of £30".

On 28/6/1758 the Exchequer Court discussed the petition (Douglas and McPherson 1758) and ordered them to sign a contract with Andrew Stewart - trustee of the Will of the late Duke of Hamilton, who had died in January (Exchequer Court 1758). Unfortunately no copy of the contract could be found to date at the Register of Deeds around these dates, but possible dates are 5 to 7 August 1758, when the first payment to Douglas and McPherson of the sum of £ 307-10 was made. Later correspondence between Douglas and the Exchequer or the legal dispute following the collapse always refer to that final estimate of £ 1003-4-10½ so it is highly likely that the quantities in Table 1 describe the final project.

This is not a considerable amount, as it corresponds to approximately £157,000 in 2013 (Bank of England 2015) and compares with other projects in Edinburgh like St Cecilia Hall (£888 in 1763 but only for building work, no furnishings) (Rock 2009). A complete and furnished building like the Exchange (currently City Chambers) in 1754 had a budget of £19,707 (excluding the cost to buy the land and existing houses), almost £3M in 2013 (Contract 1754). A further payment of £100 was made on 22/6/1760 upon completion of the works (paper 2 in Exchequer Court 1760).

In any case, the contract would not provide any further specific technical details of the project, judging from similar documents John Douglas had signed for his projects in Archerfield or Finlaystone. An interesting clause mentions payment (Douglas and McPherson 1758): "As also is to be understood as a Condition of us agreeing to perform the work at the preceding Estimate that as the Artickles are all computed at ready money prices We are to be allowed interest for such part of price as shall remain unpaid at the conclusion of the work and that until payment".

There is no clear indication how the crucial appointment of Douglas and McPherson was made exactly. William Adam (the prominent architect, well connected to the Palace sit) had died in 1748 but his practice (by then at the hands of his experienced sons) was not considered, even if the project was within their business (they had charged the Exchequer Court (1733) £2098 for the repairs of the Palace roof). The reason may have been the dispute between W. Adam and the 5th Duke of Hamilton about the 1733 works, which resulted to a last direct payment in 1743 before settlement in 1762 and 1770, as also their bigger dispute around Chatelerhault. Douglas on the other hand may have been directly appointed (and his project not having to go through the Dean of Guild Court) after he made connections with the Palace and the Duke while he was working on the provision of fresh water to the Palace in June 1753 (Exchequer Court 1753). John Douglas, as will be seen later when his experience is discussed, would be expected to provide a good design, not too ambitious or expensive. Moreover, his Petition (1758) shows clear knowledge of the funding sources and his early engagement in the repairs, even before a contract was signed, both indications of familiarity with the site and ease with the client or the keepers. Douglas may as well have been very keen into getting projects in Edinburgh as he did not have any major commissions elsewhere at the time and might be reaching an age when he would like to reduce his travels (Douglas 2015 and 2015b, Theodossopoulos 2015).

It is important here to clarify the authorship of John Douglas, which is disputed by H. Colvin (2008) by considering there may have been on a different architect with the same name. As John Douglas

architect in Edinburgh, he is the same person who designed Archerfield for example and the contract from Archerfield (1747) and a receipt (1758) of the first fee instalment from Holyrood are signed by the same person (Fig. 5). He is also the same John Douglas of Pinkerton (a property "at the Burgh of Crail and in the Shire of Fife") whose will in 1773 was witnessed by the Earl of Dullhousie and his brother William (his wright in the Finlayston House project).

Reflecting on the administration of the project, it is peculiar why the Master of Works to the Crown of Scotland (responsible for the construction and upkeeping of royal property in Scotland) was never involved in the proceedings. It may have to do with the declining role of the post or the origin of the funding (vacant stipends). Throughout the intervention it was always Sir David Moncrieffe (1710-1790), the Deputy King's Remembrancer (deputy chief executive of the Treasury) who controlled not only the finances but also the professional aspects and quality of the works (Exchequer Court 1754 and 1760, Douglas and McPherson 1758).

The project

Very little from this intervention remains on the fabric, so the facts are discussed from the analysis of the estimate (Table 1) and correspondence recorded at the Exchequer Court. Firstly, it is important to clarify that the rood unit used here is actually 1 sq rod, i.e. 5.5 x 5.5 yards = 30.25 sq yards (or 25.3 m^2) and this verifies all the quantities. Yard is also intended as a surface unit, i.e. square yards (0.836 m^2), as also is feet.

The most relevant items, constituting the bulk of the budget (78%) are 1 (removal of the existing timber roof and preparation of wall heads for the new one), 2 (stone), 3 (construction of the diaphragm walls to support the roof coverings) and 8 (blocking the triforium openings). Crucially, items 2 and 3 specify the huge volume of rubble stone walls, essentially diaphragms at t= 1 ft 4'' (410mm) thick, spaced at 2ft (610 mm) to substitute the timber trusses of the main roof only ("Hewn Stone contain'd in the Main Roof). The trusses of the aisles were not substituted eventually as they

were probably deemed to be safe (Fig. 4) and this reduced the budget. No major replacement of the aisle roofs is mentioned in the 19th and 20th century and their condition is still quite good (Fig. 6).

The calculation of the total weight of the new walls is based on the geometry of the gable in Figure 7 and shows these walls added an enormous load on the nave vaults. The rough volume of each diaphragm wall V1 is

$$V_1 = A \cdot t = \left(\frac{2.9 \cdot 8.1 \cdot 0.5}{2} \cdot 2 + \frac{10.5 \cdot 4}{2}\right) \cdot 0.41 = 32.7 \cdot 0.41 = 13.4\, m^3$$

The total interior length of the nave of the church is 38.7 m (127 ft). Each diaphragm takes up a space of 1.02m (610 spacing + 410 width), so roughly 38 walls were built on top of the vaults, without an apparent choice to locate them on specific or less critical areas on the extrados. The total surface of the walls is 38* A= 38* 32.7 m^2 = 1242 m^2 = 1486 sq yards = 13,355 sqft , close to what is specified in the contract (12,060 sqft).

The resulting total volume is 1242 m^2*0.41m = 510 m^3 of new fabric and if the unit weight of stonework is 2.2 t/m^3 , then a total of 1122 t of stonework was added. The length of the transverse arch's extrados is about 9.7m (Fig. 7), therefore the nave vault's extrados surface is approximately 9.7m * 38.7m = 375 m^2. This results to a uniformly distributed load (UDL) of 1122/375 = 3t/m^2 = 30 kN/m^2 . If the thickness of the existing vault is t= 1 ft 4 in = 410 mm (the thickness of a typical stone block as specified in this contract), then UDL due to dead weight is 9 kN/m^2 , i.e. the diaphragm walls add on the structure 3 times its original weight! And the weight of the flagstones or covering is not included.

There is confusion whether flagstones were used as covering of the roof (Harrison 1919). Table 1 refers to "Stone Walls that is to carry the hewn Stone Roof" but no clear estimate for roofing flagstones is made in table 1 as item 4 refers to "laying the whole Church with pavement" while item

5 refers "To levelling the floor of the Church and furnishing dead sand for laying the pavement of (Ditto)". After the collapse however, William Mylne is asked to separate the flagstone tiles (Flaggs) from the debris and pile them carefully (see next section), while during the dispute about the payment of the remaining project costs in 1781, Douglas and McPherson, through their representatives claimed to have covered "the whole of the roof of the Church with brotched hewen stone of a proper thickness" (paper 4 in Exchequer court 1778).

If the roof was indeed covered in flagstones, it would justify that the spacing of the new diaphragm walls was chosen to carry the width of a stone flag (600 mm or 24''). The flagstones used earlier in Dirleton Aisle (East Lothian) for example were 25'' x 30'' (6.5'' thick) = 2 ft 1' x 2.5 ft = ca 5 sqft (or 640 x 760mm), so they would fit in Holyrood. The other justification would be that John Douglas was aiming to restore an archaic view for the church, like the 15th century barrel vault of St. Salvator's (see later Fig. 9) that he must have seen when he was building almost at the same time new student residences for the college with the same name in St. Andrews (Cant 1956, Grater 2000, Fawcett 2012 and 2013, Theodossopoulos 2014). This aspect needs a more extensive discussion under the question of whether this project was actually a restoration.

The area of the roof expected to be covered is reasonably approximated as follows, as it is difficult to evaluate the surface of the vaults' extrados due to the curved geometry: the interior length of the nave is 38.7 m, its width is 10.84m and the length of the pend of the roof is 6.4m (Fig. 7), resulting to a total area of roof = 38.7 * 6.4 * 2 = (127 x 21 ft x 2) = 495 m2 = 585 sq yards = 5264 sqft = 0.484 rood , which is well below the estimate of 7,500 sqft, unless waste is factored in. The corresponding weight (if the flags are 6.5"= 165mm thick) is (495 m^2 x 0.165m)x 2.2t/m^3 = 180 t or 0.36 t/m^2, i.e. it was still the weight of the new walls that essentially increased the thrust of the vault.

If the hewn stone was ordered for the floor, the area to be paved is assessed as 38.69 x 10.84 = 419.4 m^2 = 4,572 sqft = 55.7 sq yards (nave) and (38.69 *4.5) x2 = 348.3 m^2 = 3,749 sqft (aisles),

giving a total of 768 m2 = 8,255 sq ft, which is not far from the 7,500 ft area at the estimate, if the bases of the pillars are discounted.

In addition to these estimates, an inspection of the roof of the remaining S aisle shows the covering is stone tiles (Fig. 5). It is highly probable the nave roof had originally the same covering (Fig. 4), which could have been simply re-located after the repair. If flagstones were used on the other hand, no mention is made in any of the Exchequer minutes that the stone tiles were carefully stored, although they could have been re-used in Edinburgh Castle (the Great Hall, for example).

Following the collapse, few remains survive from the repair project. The triforium windows (" where the Stone Roof of the Isles is to join to the side walls of the Main Body of the Church") were blocked with "Rubble Building" (Fig. 8) during that project (item 8 in table 1). If the estimated area of the openings is 60% of the corresponding band of the triforium, this is then (38.7 * 2.2)*2*0.6 = 102m^2 =127 sq yards = 4 roods and 6 yards, which is close enough to 4 Roods 26 yards mentioned in Table 1. Coping stones are still fixed along the W gable which together with the obelisks at the base of the gable may have been an attempt to visually tidy up the edge of the renovated roof, especially when seen against the original pinnacles over the piers of the flying buttresses.

THE COLLAPSE OF 1768

The progress of the collapse

It is very interesting to follow the events around the collapse through the minutes of the Exchequer Court. On 28 November 1766, the dangerous condition of the roof is discussed at the Court (1766) and William Mylne (1734-90) was asked on 2/12/1766 to examine the condition of the roof and report to the Barons (NRS, E310/1/2/58). Mylne reports (1766) on 10 December 1766 that the walls and pillars of the church are 2-3'' (50 to 75mm or 1/70 of transverse aisle span) out of plumb at ten feet (3m) height to the North, i.e. possibly the S arcade moving inwards (see Appendix for the full letter). He further observed the East gable/ window inclined outwards to the East from 3-4'' (75 to

100 mm) at ten feet high (3m) and he estimated the inclination would be 7-8'' (175-200mm) at the top of the gable. Several voussoirs ("Coins of the Arches") have fallen down or were loose, many of the shafts of the piers were also loose and the walls had visibly bent. The whole building was giving clearly an impression it was slowly failing and he considered the excessive load added over the walls, "a load the walls and pillars were never intended to carry".

Following discussion at the Court, D.S. Moncrieff asks W. Mylne the next day for an estimate for repairs (NRS, E310/1/2/59), in particular in line with his recommendations to remove the damaging diaphragm arches, strengthen the E gable with pier buttresses and put on a (new) slate roof. Fig. 9 shows the church presumably at this period and since there is no distinctive appearance of a flagstone roof, Mylne probably refers to removing further weight due to the stone tiles. There is no record whether such an estimate was given to the Exchequer Court and certainly no action was taken, except from possibly closing down the church on Mylne's recommendation as it had become a dangerous attraction for the public. Indication of the lack of action is that payment to W. Mylne for his survey of the roof was not made until much later, on 21/6/1768 (NRS, E305/7/319).

On Friday 2 December 1768 the roof of the church collapses. Scots Magazine (1768) and the Edinburgh Advertiser newspaper report a two stage failure.

"On the 2nd of December, about noon, part of the walls and roof of the church of the Abbey of Holyroodhouse, Edinburgh, gave way and fell in; and in the night following a great part of the remainder fell also. This is said to be owing to the enormous weight of a new stone roof laid over the church some years ago, which the walls were unable to support. The pillars and ornaments of this edifice, though for many years waste, and almost ruinous, were greatly admired, as one of the finest Gothic remains in the Island. The vaults, where the bodies of some of the royal family, several of the nobility, and a great number of the gentry, were deposited, were by this accident laid in ruins. – The church however, is, it is said, to be speedily rebuilt."

W. Mylne is asked on 7 December to examine the collapse (NRS, E305/7/352) and after he reports, he is asked *"to take that part of the Arch or roof which is still standing and to raise the plain stone below the same and to take down the two Stairs and top of the Tower and to take down the two Bells that are there hanging"* (NRS, E306/3/308). He completes the demolition in March 1769 (NRS, E310/1/2/67), he clears the debris, takes down the steeples and puts the bells in a safe place. He is also allowed to sell the lead from the roof of the stairs and the steeple as payment in part (NRS, E306/3/316 and E310/1/2/67).

In August 1769 W. Mylne's estimate for repairs is discussed (Exchequer Court 1769), which appear as a temporary measure for the security of the church rather than a restoration. He builds up the windows (of the aisles) and stair door of the church, but not the E gable, he puts new doors and locks on the gates to the North and (probably the Royal) Vaults and he collects the tiles (flags) from the debris into piles.

Dispute between DS Moncrieff and John Douglas & James McPherson

Possibly in 1771, D. S. Moncrieff orders any further payment to John Douglas and James McPherson for the repairs of 1760 to be withheld, i.e. after receiving payment of £457-10 in 3 instalments. This was challenged by Douglas and McPherson and much later, on 3/7/1778, settlement of the remaining payment for the repairs of 1760 (*Abbey Debt*) was considered after petition by James Rutherford (representing the trustees of the Will of J. Douglas) and James Gray (representing those trustees for J. McPherson) (Exchequer Court 1778).

On 7 December 1781, thirteen years after the collapse, His Majesty's Advocate Henry Dundas (1742-1811), a very influential figure in Scotland, ordered the Exchequer Court to pay the remaining sum with interest based on the following argument, which challenges the excessive intervention as the sole cause of the collapse:

"In the first place. The Roof remained for several years after the work was finished and I see a discrepance of opinion amongst Tradesmen as to the immediate cause of its fall. And therefore under these circumstances I find no such conclusive evidence as could authorise me to find that the cause of the ruin of this Fabrick was the nature of the Roof put upon it by the Claimants in term of the Contract; and if this position is held to be a doubtfull one the objection to the payment of the Covenanted Sum of course falls to the ground." (Exchequer Court 1760, paper 3)

He further supported his judgement by considering that "*although it is very probable there may have been a misjudgement as to the nature of the roof which ought to have been placed upon the Abbay Church I see no reason to impute that error particularly to the Claimants. It seems to be an opinion universally prevalent among all parties interested in this transaction, and the error only discovered after the work had been precisely and accurately executed in terms of the Contract. All the Objections now made are against the plan, not the execution of the work and therefore I see no ground in law or justice for withholding the price of the execution from the Tradesmen who have faithfully performed it."* Rutherford and Gray however had to make a final petition to the Barons to settle payment on 9th October 1798…

Aftermath

No reference survives on the impact of the collapse, either towards the strengthening of other similar monuments or guidance about practices that should be avoided in projects of this kind. Apart from the Scots Magazine, other newspapers of the time like the Edinburgh Advertiser or the Edinburgh Evening Courant mention the events and subsequent clearances of the "beautiful fabrick of the Church of Holyroodhouse", while the Caledonian Mercury makes no reference. The Courant goes on even reporting a mistaken interest by W. Mylne (referred to as Deacon Mill) to reconstruct the church, which he denies later in the month, indicating lack of interest by the Barons of Exchequer or even by himself.

Hugo Arnot (1816) describes in 1780 that *"These walls [vaults], which could withstand the fury of a mob, have since been brought to the ground, through the extreme avarice or stupidity of an architect"*. He carries on to mention that the site had been since looted for any valuables it may have contained, especially the royal burial vaults (which were restored later). Moreover, the surrounding area of the almost abandoned Palace was considered as an asylum for debtors, so it was like a buffer zone to the city.

There will not be a restoration proposal made until 1835, by Gillespie Graham and Augustus Pugin to create a home for the General Assembly of the Church of Scotland (later building the Highland Tolbooth for the scope), around the time when Robert Reid refurbished the Palace (1824-34). A further major proposal was made in 1906 by Robert Lorimer to re-establish the chapel for the Order of the Knights of the Thistle (which eventually was built next to St. Giles in 1911). They were both rejected in terms of the excessive amount of new material that would be added, compromising the authenticity and integrity of the remains, while the last proposal produced a very lively debate for alternatives in the Scotsman newspaper.

THE QUALITY OF THE PROJECT

The critical appraisal of the architectural aspects of the project and its technical merits will examine some hypotheses on the respective roles of Douglas and McPherson, aiming to clarify the main driver of the intervention, revealing at the same time some interesting things on the conservation culture of the period.

Architectural intentions

The study of the archive material and site evidence provides very few clues of any architectural intention for the entire project. The most obvious is the notion that Douglas and McPherson had to "*paint and harle the whole outside of the said Church"* (Abbey Debt paper 4 in Exchequer Court 1778). The estimate (item 7) mentions 1,750 (square) yards or 1463m^2 of pan-cratch, a lime-type by-

product from saltpans. This is a considerable surface, having in mind that the perimeter of the church is (19+38.6)x2= 114m, so it is highly likely the whole exterior was white-washed. However, there is no physical evidence from that work remaining today or ever mentioned in later repairs (Harrison 1919, RCAHMS 1951, Robertson et al 2005). This was done at 6% of the budget (Table 1), which possibly meant a very light whitewash.

Returning to the roof, although non-conclusive, the hypothesis for flagstone covering brings a further architectural dimension to the project and can make this a central aspect of the intervention, as essentially it may have been the reason for the heavy diaphragms underneath. Earlier, pre-1760 engravings do not show a strong materiality in flagstone roof on Holyrood and this roof type was not encountered in John Douglas' vocabulary before or after this project. The hypothesis of a characteristic flagstone roof makes the project an architectural intervention rather than a mere refurbishment, which could even be discussed in the context of conservation.

Although precedent does not always drive architectural projects, it has to be mentioned that such roofs were not standard any more, but Douglas may have found a meaning in this type, which was not communicated in any of the documentation (Douglas and McPherson 1758). A direct inspiration could have been St. Salvator's roof (Fig. 10) as John Douglas was building new halls of residence within the college, when the barrel vault roof of the ex-collegiate church was still standing (before James Craig had it pulled down in 1773) (Cant 1956, Grater 2000). Dirleton Aisle (built from 1664), could have been another connection as the Nisbet family, who owned the nearby Archerfield House that was designed by Douglas, were the patrons of the church.

These examples make reference to a more plain architectural treatment of stone-vaulted space that had been developed earlier in the significant group of mainly private churches built in Scotland during the 15th century (Fawcett 2012 and 2013, Theodossopoulos 2014), which were roofed with exposed ashlar stone barrel vaults and covered with flagstones (the cases of Bothwell in 1398,

Dunglass Collegiate Church in 1423, Corstorphine in 1429, St. Salvator's Chapel in St. Andrews in 1450 (Fig. 10), Seton Collegiate Church in 1492, Ladykirk in 1500). These churches had their origin in earlier vaults in castles and tower-houses (Dundonald, Borthwick, Neidpath etc) which provided strong and fire-proof major domestic spaces, without compromising the integrity and defence capacity of the tower. Similar vaults also characterise later votive or burial aisles in existing churches (Cockburnspath parish church in 15C, Wardlaw Vault in Dunfermline in 1617, Dirleton Aisle in 1664 (Fig. 10), Abercorn in 1727 etc), designed in the spirit of restrained classicism that characterises post-reformation church architecture in Scotland (Glendinning et al 1996).

The covering of the roof with flagstones could also be interpreted as an attempt to shed past memories of decoration and uses associated with controversial moments of Scotland's political history (Charles I, James VII), returning to a purity of forms that characterised the largely peaceful 15C. Moreover, the lofty aspect of barrel vaults is in line with the simplicity of the Presbyterian treatment of church space, ignoring or misunderstanding the articulated impression of the pre-reformation interiors, especially visually stressed here by the ribs of the (possibly) sexpartite vaults. The other two major churches in Edinburgh, St Giles and Trinity, have either lead or slate roofs, with the latter combining a flagstone roof over a chapel, making therefore the addition of such a roof in Holyrood more "appropriate" for the current ethos.

To highlight the architectural context in Scotland further, earlier ca. 1621 in Melrose Abbey a new barrel vault was built to roof the nave, then serving as the parish church, with clearly no intention to repair or restore the ribbed vault of the pre-Reformation church (Fig. 10). In a period when no major vaults are being built any more, these examples can make the vaults in Holyrood to be misinterpreted as barrel vaults. Their strength would then be overestimated, exacerbated by the lack of interest in the role of buttresses and understanding of the containment of thrusts (as a complex structural system). A further indication of this misunderstanding of function can be seen in

the very poor representation of the cross section of a nave vault and roof that James Craig did later in 1768 for his design of the King's Seat in St Giles (Fig. 11).

Finally, the obelisks that survive today at the gable (Fig. 8) could not have been part of the project and architectural intentions of Douglas and McPherson as they were already illustrated by John Elphinstone in his view of Holyrood Palace and Abbey in 1740.

Construction and structural qualities

It is worthy now to examine the technical aspects of the project, inquiring once again why a contemporary timber roof was not built and what were the structural performance and context of the intervention, instead of simply dismissing the whole project as a quick job.

Scarcity of timber towards a full replacement of the rotting roof trusses has been put forward but it will be shown it was not a significant reason, supporting furthermore the argument that a flagstone roof (and the necessary diaphragm walls) was the architectural intention of a project rather than a quick repair. Continuous warfare like the contemporary Seven Years' War (1754-1763) meant that quality timber would be diverted into shipbuilding and the forests around Spey River, where they would usually come from, would be dedicated to this trade. However, good, seasoned timber could have been recycled from the decommissioning of old ships and the timber truss roof was fully developed in the 18th century (Yeomans 1999), which means shorter lengths could have been used to create a truss that would be further supported half-span on the longitudinal ridge of the vault.

A king post would have been the original design since access to the ridge of the stone vault of the nave would not be required as much as in major cathedrals like Lincoln or Durham, where queen post roofs were built. Even though during the period of the repairs many Gothic cathedrals were re-roofed in Britain (e.g. East end of Ely by James Essex in 1757-62) in queen post trusses (more effective than king posts for their steep pitches as the principal rafters were easier to strut, Yeomans

1999), it is highly probable a king post roof, supported on the ridge of the vault to minimise use of long beams, would have been the design for a new roof (Fig. 12).

Although the Holyrood church was not very tall and the gable shows the roof was not too steep to be exposed to the elements, a significant amount of timber could have been required for a new roof. For a span L = 10.5m and rise F=4m, the main rafter, at 45^{o}, is 6.6m. The structure of each truss needed 2 x 5.2m for the tie and also 1 x 4m for the king post, 2 x 3.3m for struts, 2 x 6.6m for rafters. Roofing required not only these structural timbers (rafters, collar beams and ashlar posts), but also sarking (deals) and lathes to support slates, tiles, and plaster ceilings. Each process requires different techniques and eventually more carpenters (wrights).

There was an established trade network with Norway and primarily the Baltic after 1750's (Russia or Memel in Sweden) which was not affected by the warfare and could have enabled the procurement of any quality and type of timber for such projects (Newland 2010, Crone et al 2013). Longer span timbers from Norway allowed for buildings with wider and larger rooms. In ells, the unit used for Norwegian baulk timber (63cm or 2ft 1in), each truss would require 3 x 12 ells and 3 x 9 ells, a TOTAL of 38 x 3 x 12 + 38 x 3 x 9 = 114 x 12 ells+ 114 x 9 ells for an entire new roof. A medium sized ship of 15 lasts (30 tons) would be suitable to ship the entire load, so it was possible to get the quantity, if an order was properly made (by a wright).

In the absence of precise data on roof trusses costs, an idea about the cost of a new roof can be given by comparing with the price listed for two dwelling houses in the W wing of the new Royal Exchange building in Edinburgh (1754): on p. 101 of the contract, 336 (square) yards (281 m^2) of roofing and sarking are cost at £100 to which should be possibly added £116 for 1,164 ft (349m) of joisting, a total of £226. In Holyrood, if the roof area is 7,500 sqft (or 750 m^2), by analogy 3 times this amount would be spent, i.e. £678, while £889 was eventually spent for the roof only (table 1). Once

again, the difference in cost is in favour of a timber roof and justifies the architectural intention of a flagstone roof for the project.

McPherson was not a carpenter (wright) and the budget does not seem sufficient enough to leave him a profit if he employed one. These post Union and post 1745 Jacobite Rebellion years were not yet prosperous times for Scotland and only £1,000 were allocated for the project's budget. This was a very large timber roof and the need for a wright and large quantities of timber should not be underestimated. Kate Newland (2010) shows that ordering timber for a large roof (cf. Panmure House in Angus, of 8.2m span) required significant organisation and no trace of similar skills can be found in this project.

A substantial fee for a wright could then have been saved, with direct profit for Douglas and McPherson, a possible further reason for the preferred solution. There is however an interesting fact, that John Douglas' brother William was a wright, who he employed in Finlaystone in 1746-7 for example (Court of Session 1762). Only speculation can be made why he did not use him, but reduced expenses and a possible origin of the proposal on a stone mason like McPherson could be plausible reasons.

John Douglas and James McPherson: their experience and professional status

On hindsight of course the intervention was disastrous, which prompts why such an experienced architect and mason could not foresee it. Clearly the hypothesis of the flagstone roof is not encountered in any of John Douglas' known or assumed designs (Kinnear 2001, Gow 1989, Theodossopoulos 2015), but he had long experience in reforming and extending existing buildings. Up until that point, he had several major projects, some quite prestigious, like Archerfield (1745-47), Kilmahew (1744?), Wardhouse (1757?), and carried out designs for Blair Castle or Inveraray. Many of his projects however are usually extensions and regularisations of medieval towers, including occasionally the insertion of new staircases. Technically these works do not seem to be challenging,

as no critical temporary works, delicate underpinnings or wall shorings are required (Fig. 13). Accordingly, any roofs would be new and mounted upon a rectangular plan and the junction with an existing one would require simply a good joiner.

Although because of this simplicity there is not much point to discuss the design of his roofs, it may be worthy to include some aspects of his professional practice. There are a few uncertainties about the buildings attributed to him and incomplete contemporary documentation or contracts have been found in archives, which may indicate something about the way he was operating and the set-up of his business. During the dispute over the retained fees for the Holyrood disaster (Abbey Debt) no architect colleagues or patrons came to testify for him, as he did for William Adam during his dispute with Lord Braco over Duff House, and only few of his proposals materialised eventually, which does not show the building up of a client basis.

The proceedings from the 1762 Lybell against him by George Paterson, Wright at Newmills, employed as his "Overseer and Director of the Severall Buildings and Works" carried on between 1744-49 (Court of Session 1762), confirm he had buildings sites all across Scotland (Woodhall Dirleton, Finlayson, Taymouth, Newmills, Edmonston – see map in John Douglas 2015). This is a very useful document as it enlists the flow of these projects and presents aspects of professional practice that are worthy investigated further elsewhere (Theodossopoulos 2015).

The development however of a contemporary new build, the new halls of residence at St. Leonard's College in St Andrews University (1754-57) reveal not very competent technical knowledge (Cant 1956, Grater 2000). Many service problems appeared soon after completion, especially the roof was leaking so heavily that had to be re-slated in 1769. The leakage however had penetrated the walls, and damaged them structurally, so eventually the building was demolished in mid-19C, although the replacement maintained some of Douglas' architectural features (like the pronounced bay of the entrance). This failure can be an indication of lack of confidence in roofing skills.

More specific observations can be made by an architectural reading of the project, within John Douglas' work which is characterised by compactness and economy in design (Gow 1989, John Douglas 2015b) and a continuous approach of concealment (Glendinning et al 1996). The stylistic features of Archerfield House (1745-46), which can be considered as his most mature and intact work, frame well the affirmative texture of the volcanic porphyrytic trachyte used for the elevation, within an otherwise restrained eclectic design and, as often in his work, its horizontality is signposted by a centrally placed vertical element, the bay entrance.

In Holyrood, the new textured roof brings a castellated aspect to the building (a vocabulary he explored in his designs for Inveraray and Blair – see Gow 1989), which is visible however from around the park and Calton Hill rather than Canongate (a view which is ultimately dominated by the rich W façade). Although not exactly le Corbusier's "fifth façade", the flagstone roof becomes from certain view points (N and SE) an element that aligns with the flying buttresses of the nave (now gone) and underlines the axis leading to the E gable window (Figs. 7, 8).

This is certainly a subtle treatment, in line with a minor Gothic revivalism of the time (see a later discussion) and distinct from the exuberant neoclassicism of W. Adam, the dominant figure of his generation, yet it is the design of an architect and not just a repair. The design will be further analysed later within the context of contemporary interventions to existing and medieval building.

Finally, James McPherson was not registered in Edinburgh as mason or a freeman of the Incorporation of Mary's Chapel so he could not be allowed to work in the city of Edinburgh (Rock 2015). Architects however would employ any experienced mason, even outside the burgh, risking penalties, and Holyrood was outside the jurisdiction of Edinburgh's city council then. This seems one more reason why a partnership initiated by McPherson has driven the project.

McPherson however does not appear as a particularly skilful mason: in 1773 during work on a tenement he damaged a neighbouring property (see 3 September 1773 in the Dean of Guild record

by Joe Rock 2015b); his most famous work, the Botanic Cottage of 1764 had a problem with the stair, which had to be rebuilt (Joe Rock 2015).

THE NEW ROOF DESIGN

Structural performance of the vault and the collapse

The performance and strength of the roof may have been equally influenced by the process of applying the repairs (8 August 1758 to 28 June 1760), rather than the design itself. The ageing roof had to be removed first, but was the execution careful enough to remove the tie beams that may have been embedded on the walls heads? Subsequently, the vaults were exposed, but for how long and during which seasons? What was the weather like during the winters of 1758 and 1759, and later in December 1768 (gloomy and cold as the Edinburgh Advertiser reports)? Once exposed, were the vaults cleaned and maintained or more rain water penetrated eventually? Regarding the building of diaphragms itself, it is not certain at all it was done with proper attention, in particular around the tight pockets at the spandrels (especially if the hypothesis for sex-partite vaults stands), in which case the sequence of the execution of the main tasks was crucial. Temporary shoring of the vaults during construction probably did not happen (cost of scaffolding was not included in the budget in Table 1 and can be significant), neither scaffolding was added around the church.

The design of the existing roof is also an interesting question: was it the original Gothic one or it was remodelled from 1564 as the church was refurbished following its reduction in size? Also, in the Exchequer minutes, there is no mention what happened with the timber of the trusses and whether Douglas and McPherson profited from selling it or re-using it.

Even if the original trusses were as closely spaced as the diaphragm walls, their weight would be far less than the stone walls built in 1760. The huge new weight and the state of the lateral walls still appear as the main reasons of the collapse and the distribution of the forces during and after the construction of the diaphragm walls will be further investigated in a specific work, through

numerical analysis of the vaults and comparison of the performance of quadripartite vs sexpartite configuration (Fig. 14).

Earlier experimental and numerical analysis of the collapse mechanism of the aisle vaults due to lateral support spread (Theodossopoulos 2001, 2003, 2008) indicated the limits of this instability (135mm or 1/28 of the transverse span 3.8m). The ensuing failure pattern of the aisle (Fig. 15) is caused by the development of a mechanism formed by three hinge lines along the wall, longitudinal axis and back ribs, and the base of the nave arch. A similar pattern characterises the nave vaults (longitudinal and nave arch cracks), as the simulation of the ones in Durham (Theodossopoulos 2008) indicate they can fail numerically at 330mm symmetric spread (or 1/34 of 11.2m span).

The examination of the remains (Fig. 1, 2 and 16) and the report by W. Mylne immediately before the collapse (see appendix and Mylne 1766) may offer more clues on the dynamic of the collapse. The study of the surviving piers shows a few distortions that are remnants from the collapse but their cross section was not weakened from the 1633 and 1687 fittings any more particularly compared to the South arcade (certainly, these are the piers that survived the collapse). It is not certain whether the demolished ones are those that gave way or where most of debris fell. The damage appears to have occurred closer to the West façade (which as seen later had to be strengthened in 1626), and at higher level as the towers had to be removed by Mylne, while the East gable (much less robust than the West front, but also rebuilt in 1626) was not damaged much. Most probably all loose fabric was removed immediately after the collapse as there were no funds for consolidation. It is also probable some damage must have happened during demolition as well.

It is difficult to trace the dynamic of the collapse from the condition of the floor as most of the slate slabs (measuring about 3 x 4 ft) were removed (Fig. 16) and only a few survive towards the East window (confirming potentially that the primary damage happened away from that delicate area). Eventually however the un-braced and exposed East window would be blown down during a storm

in 1795 and was rebuilt in 1816 (Robertson and Crae 2005). Damages on the internal face of the North walls (Figs 1, 2) are spread across the upper levels (around the windows mainly), and a few more severe ones can be detected closer to the W end, like some missing shafts on the piers and lower blind decorative arcades.

W. Mylne had warned of the heavy inclination of the church to the North, where the collapse eventually happened, and at the height he could reach (10 feet or 3 meters) he measured a spread of 50 to 70 mm. At the springing of the aisle vaults then (5m) this would be proportionally 80-120mm, around 1/40 of the span, and he made clear that such a deformation was becoming a (dangerous) spectacle for visitors – an indication of public perception of imminent disproportionate collapse. Curiously, John Douglas' opinion does not appear anywhere: he was not asked to survey the impeding failure of his intervention and his defence during the Abbey Debt dispute was mainly on legal and contractual rather than technical terms (Exchequer Court 1778).

Most of the debris was cleared afterwards by W. Mylne, while this probably continued until 1856 (Robertson and Crae 2005). In the discussion about the necessary works (Exchequer Court 1769), he is asked to build up most of the windows and the stair door, for safety reasons, while he was allowed to sell any valuable remaining dressed stone. Special mention is also made on the flagstones that survived the fall of the roof to be put carefully aside. No mention is made on structural repairs, but all loose vaults are taken down, including the entire North aisle, but the outer wall survives to the height of the lancet windows (Figs. 1, 2, 16).

It is likely a part of the North aisles could have remained standing, as the South ones still do today, but this is the equivalent of a modern Class 3 structure, i.e. due to the first damage and the long term decay or the insertion of the diaphragm walls, the structural components (vaults, buttresses, walls) were not linked together sufficiently any more to give adequate overall robustness. The second stage and the eventual collapse of the North aisle were probably caused by the instability of

the heavily deformed piers and falling debris of the extraordinary combined weight of the roof and diaphragm walls (Scots Magazine 1768). The collapse therefore lasted a day and the case of the slow deformation of Beauvais cathedral (Taupin 1993), possibly from the failing tas-de-charge junctions over the aisles, shows that even very slender cases in Gothic architecture can have significant redundancies.

Douglas is known to possess a copy of James Gibbs 1728 "A Book of Architecture" (Kinnear 2001, Gow 1989), which would essentially serve him as pattern book for architectural elements and compositions. As far as professional practice is concerned, there were no contemporary design codes (like the 1698 Edinburgh building regulations) dealing with the subject of vaults, let alone their repairs, neither architectural and construction authors attempted to consolidate such knowledge in treatises or other pattern books (like Pain 1794, P. Nicholson etc). The context of established practice of the period regarding stone vaults repair will be discussed in the next section in more detail.

Vaults performance and repairs in the 18th century

A closer look at the contemporary technical context when Douglas and McPherson operated, it can show that very little of vaults construction was taking place and there was a poor understanding of their complexity. Outside Britain, there was still great interest in the design of vaults. In France for example new vaults would be geometrically complex, eclectic in the form and precise in their construction, as in the case of Saint Sulpice in Paris (1660-1760). In today's Belgium, architectural drawings from Jesuit churches in the 17th and early 18th century suggest that vault, roof structure and anchoring system constituted one structure conceptually and constructionally (de Jonge and Snaet 2009) – an approach possibly echoed in Craig's drawing for St Giles (Fig. 10)? The same period marks the birth of the scientific understanding of vaults and arches behaviour as presented in the texts of La Hire (1712), Couplet (1729) or Coulomb (1773). In a broader context, technical

sophistication already characterised strengthening and repairs of existing buildings during the 18th century in the Continent, regarding foundations (de Voght and de Jonge 2012), bridges, towers etc.

This is in a clear contrast to British empiricism. No similar spatial or structural complexity is observed in British architecture of the time, with vaults even being misunderstood (Fig. 10) and mostly new barrel vaults would be built for bridges as Piranesi's engravings for the construction of Robert Mylne's Blackfriars Bridge during construction in 1764 show.

On the other hand, 17th and 18th century in Scotland sees a definite transition from medieval to early modern practices in church architecture alongside the establishment of Reformation rituals. This renovation was also triggered by failure of existing churches due to inappropriate interventions or accidents, for example St. Machar in Aberdeen, which did not recover the loss of fabric from the Civil War and a storm in 1688 until 1953; a strong vision sustained a continuity of radical transformations in neighbouring St. Nicholas, from the failure of the West Church in 1732 onwards; the fatal collapse of Fearn Abbey (1742) produced a succession of reconstructions that highlighted the parishioners perseverance with their antique church. Instead, as was seen earlier, St. Salvator's roof was demolished after a diagnosis in 1773.

In the broader context, it would be worthy to investigate how far designers and contractors became more sensitive to possible failures of their work and their consequences following news of the devastating Lisbon earthquake in 1755 that had a groundbreaking effect on the administration of natural disasters from then on. Transmission of knowledge and exchanges would happen at a different scale, emphasis and times in Scotland in that period, mainly through architects learning from Rome (James Smith, James Gibbs, Robert Adam) or France. John Douglas apparently was not part of that circuit and therefore not a communicant of the latest innovations. His copy of Gibbs' treatise may have educated his architectural vocabulary but not his awareness of vaulting or really advanced technologies. J. McPherson on the other hand would get his knowledge up to date

through a different type of pattern books, more contractor-oriented, and he is known for example as a subscriber of George Jameson's book "Thirty Three Designs with the Orders of Architecture according to Palladio" (Lewis 2014).

CONSERVATION OR REPAIR?

The initial impression of the intervention, that John Douglas, as an experienced architect, set up a (conservation) project seems to be outweighed by his partnership with McPherson as more oriented to repair. There was no understanding of Gothic vault behaviour (despite some popular Gothick aesthetic) and they over-estimated the remaining strength or stability of the flying buttresses, as their construction strategy would have been different.

The intervention can be further framed in the conservation context of the period, exploring whether it was representative of what was happening with historic buildings at the time. Regarding church buildings (Cocke 1975), the 18th century church establishment, even in England, was less interested in the rituals and many medieval buildings and cathedrals were seen as having a lot of space surplus. The austerity and functionality of a flagstone roof would be therefore welcome in a church, which also was not a parish any more.

In the broader British context, many major churches needed repairs and restoration, and much started after 1770 (Jokilehto 1999) as it is well documented: James Wyatt for example worked in Durham cathedral and Hereford, damaged by the West tower collapse in 1786; James Essex restored Lincoln and Ely (1757-62); N. Hawksmoor had earlier in 1716 shown ingenuity and understanding of complex behaviours in his consolidation of the leaning North transept in Beverley Minster (a timber structure that he returned to the vertical).This sensitivity and understanding for the structural behaviour of Gothic buildings in England unfortunately was not followed in Scotland, so no true model of good practice existed for architects at the period there.

CONCLUSION

The reader may find the discussion too extensive for a relative minor event, a mistaken repair. But it is this curiosity that drove this work, why an intervention which in a different context would have been a source of wide debate, went largely unnoticeable.

Was it "extreme avarice or stupidity of an architect" as Hugo Arnot put it? This study showed there was ignorance, but it was essentially the result of a partnership between an architect focused on tectonics (the aesthetics of a flagstone roof) and a stone mason, rather than a wright (carpenter), working on a context with no interest or experience any more on vaults, for a building that was not particularly part of any community's life.

This paper aims to contribute into the interpretation of those events by confirming authorship of the project by John Douglas and James McPherson; identifying John Douglas with the fashionable designer of country houses like Archerfield and Finlaystone; laying down all available facts of the intervention and discussing the application process; reporting on the aftermath; and reflecting on the technical and cultural context of vaulted structures, failures and repairs.

The in-depth analysis of its technical and architectural aspects treats the project as a conscious and planned effort, not a quick repair, offering at the same time a critique of the project within its cultural context. The key question behind the choice of a flagstone roof and the associated diaphragm walls is not fully answered but tectonic connections appear as the main driver of the proposal, rather than understanding of a complex structural behaviour. The project was guided by appreciation of form rather than construction process and from the moment the partnership between Douglas and McPherson was formed the fate of the nave was sealed.

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APPENDIX

Letter from Mr. Wm. Mylne Architect to Mr. Moncrieffe (p. 58)

Edinburgh 10th December 1766

Sir

I received your letter of the 2nd Current and in obedience to the commands of the Right Honourable the Barons of his Majesty's Court of Exchequer I examined the Abbay church, the walls and pillars of which are from two to three Inches out of the perpendicular, each ten feet high inclining to the North. The East gable in which is the East Window inclines to the East being from 3 to

4 inches out of the perpendicular, each ten feet high, so that I imagine the walls & pillars will incline seven or eight Inches from the perpendicular that is at the greatest height. There is one of the Coins of the Arches fallen down another just ready to drop away, several of the small columns on the Pillars come away, others fast following; the walls much [*bent*] in several places and the whole building approaching ruin at swift pace; all this is owing to the great load of building later laid above the Arches; a load the walls and pillars were never intended to carry.

I am desired by your letter to make out an Estimate of the Expense necessary to repair what is wrong. There would be a great deal of guess work in this. I mean what is required for repairing the injuries the Arches and Pillars have sustained: therefore must be excused as to that part. If the Right Honourable the Barons will consent to take off the present stone covering (which in my opinion is absolutely necessary for the preservation of the building) and cause put on a slate roof, the expense of that part may be ascertained. I am likeways of opinion that if the burthen above is taken off and a slate roof put on and the East gable strengthened by Counter fort, the building may be rendered usefull.

And now Sir before I conclude, I cannot help taking notice of a practice which should be put a stop to: Strangers daily resort to view the Abby Church. They walk about not knowing their danger from the loose stones hanging over their heads. This is concealed by the person that keeps the keys that more Customers may come: an accident may happen even to a person of rank; As it is thought it incumbent on me to mention this, I hope you will excuse me And I am Sir

your most obedient and most humble Servant

signed William Mylne

Figure 1. The current state of the abbey church of Holyrood (2010) following no major interventions after the collapse of 1768

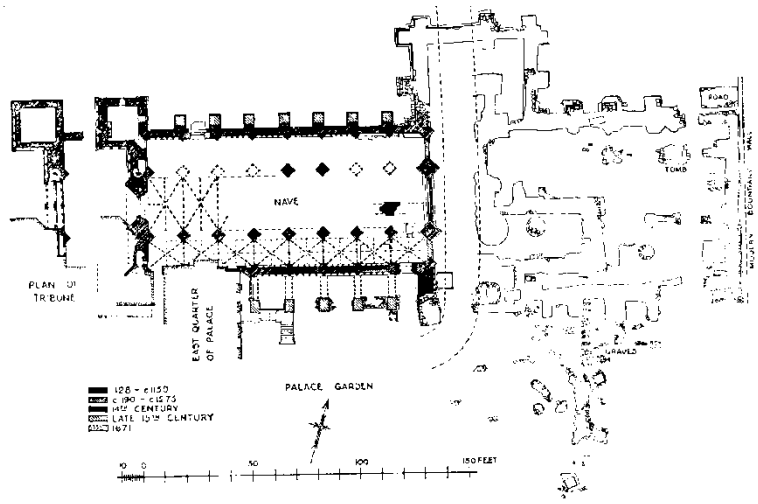

Figure 2. Plan of the development of the abbey (Oldrieve 1911)

Figure 3. Evidence of gunfire damage at the exterior (from the 1544 invasion) and deep cuts on the shafts of the piers for the insertion of pews at the interior during the extensive refurbishments of 1633 and 1670.

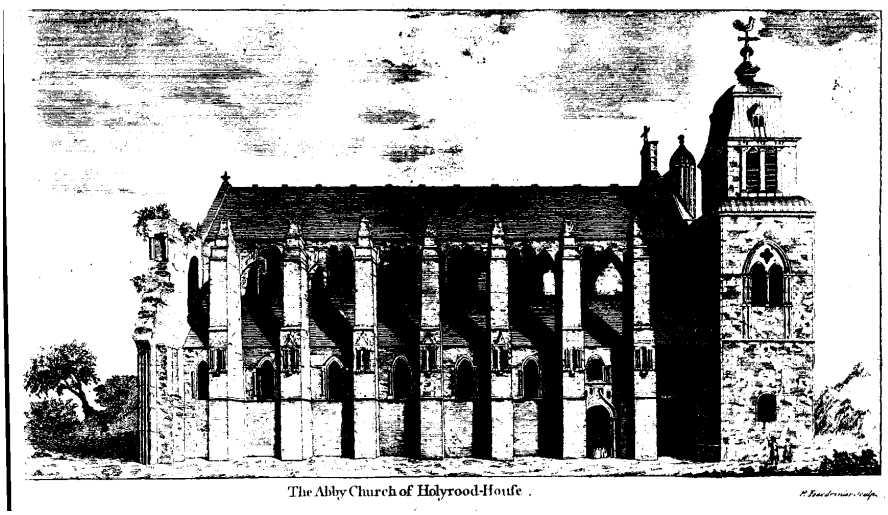

Figure 4. The abbey church in 1753, showing some of the decay that required the intervention in 1760 (Maitland 1753)

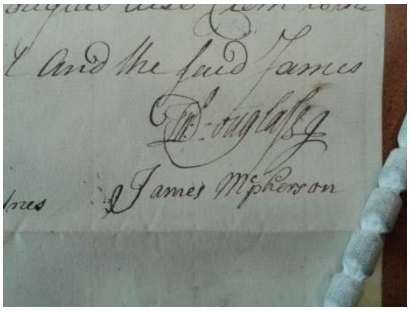

Figure 5. The signatures of John Douglas and James McPherson (Receipt 1758)

Figure 6. Aisle roof: Covering with stone tiles, similar to what probably used to cover the nave, and internal view of the intrados space (taken in Summer 2013).

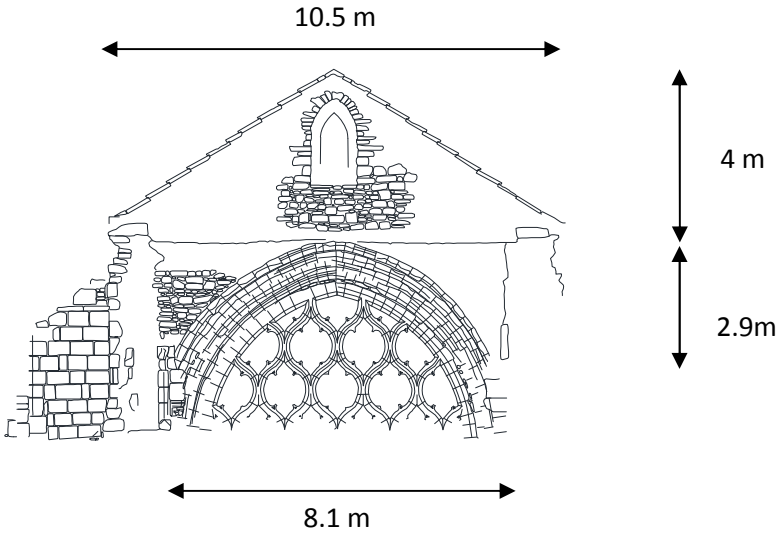

Figure 7. Survey of the East gable (Robertson and Crae 2005) and dimensions of the nave vault

Figure 8. Remains of the Douglas and McPherson project at the rubble stonework blocking the openings of the triforium (item 8 in Table 1) and possibly the coping stones at the W gable window (but not the obelisks and fleur-de-lis finial).

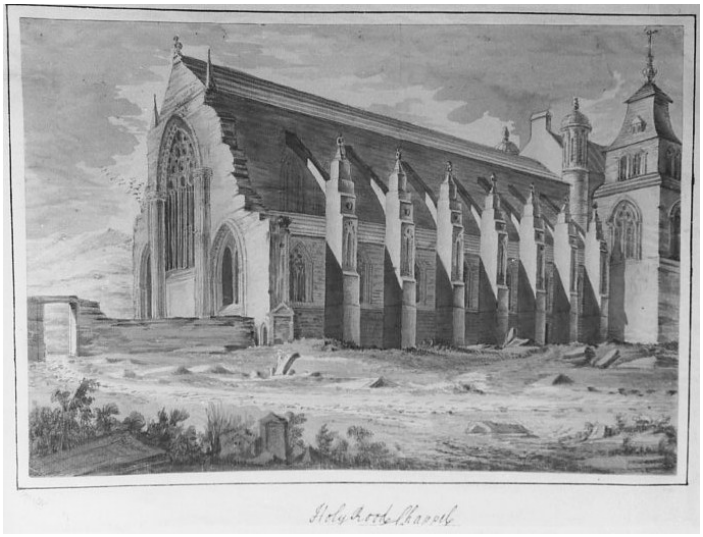

Figure 9. The Abbey Church in 1765 ("View of Holyrood Chapel") in an engraving by Richard Cooper jun. (Richard Cooper 2015)

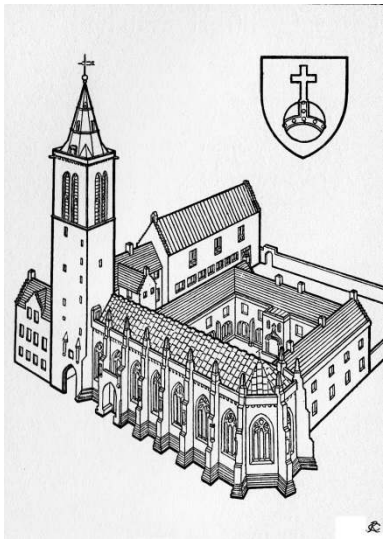

Figure 10. St. Salvator's Chapel in St. Andrews University before the forced collapse of the roof in 1773 (Cant 1956) and Dirleton Aisle (East Lothian), built in 1664.

Figure 11. Misinterpretations of vault design in post-reformation Scotland: the barrel vault that replaced the nave cross vaults in Melrose ca 1621 and James Craig's design of the King's Seat in St. Giles, Edinburgh in 1777 (NMR catalogue number C 96508 PO)

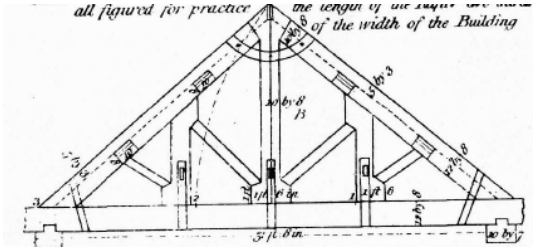

Figure 12. Form of 18C king post trusses from William Pain (1794)

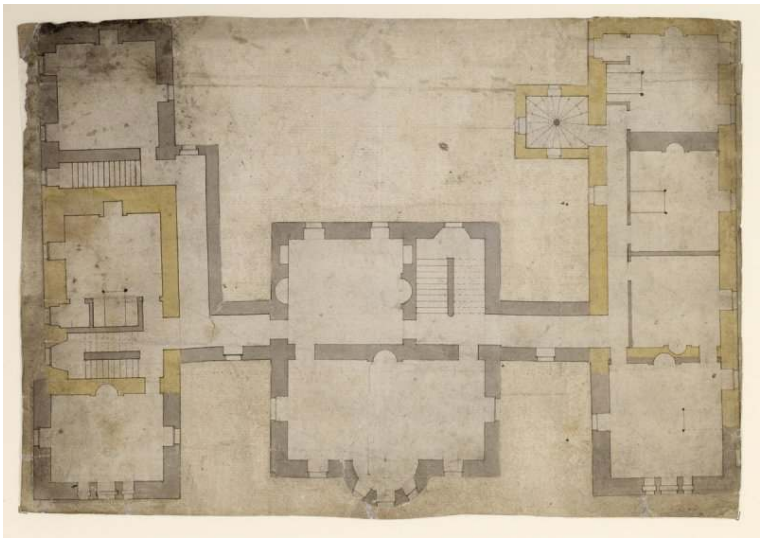

Figure 13. John Douglas' assumed design for Finlaystone House, Port Glasgow (1746-47). Lighter shades indicate the original parts of the site (RCAHMS DP057863).

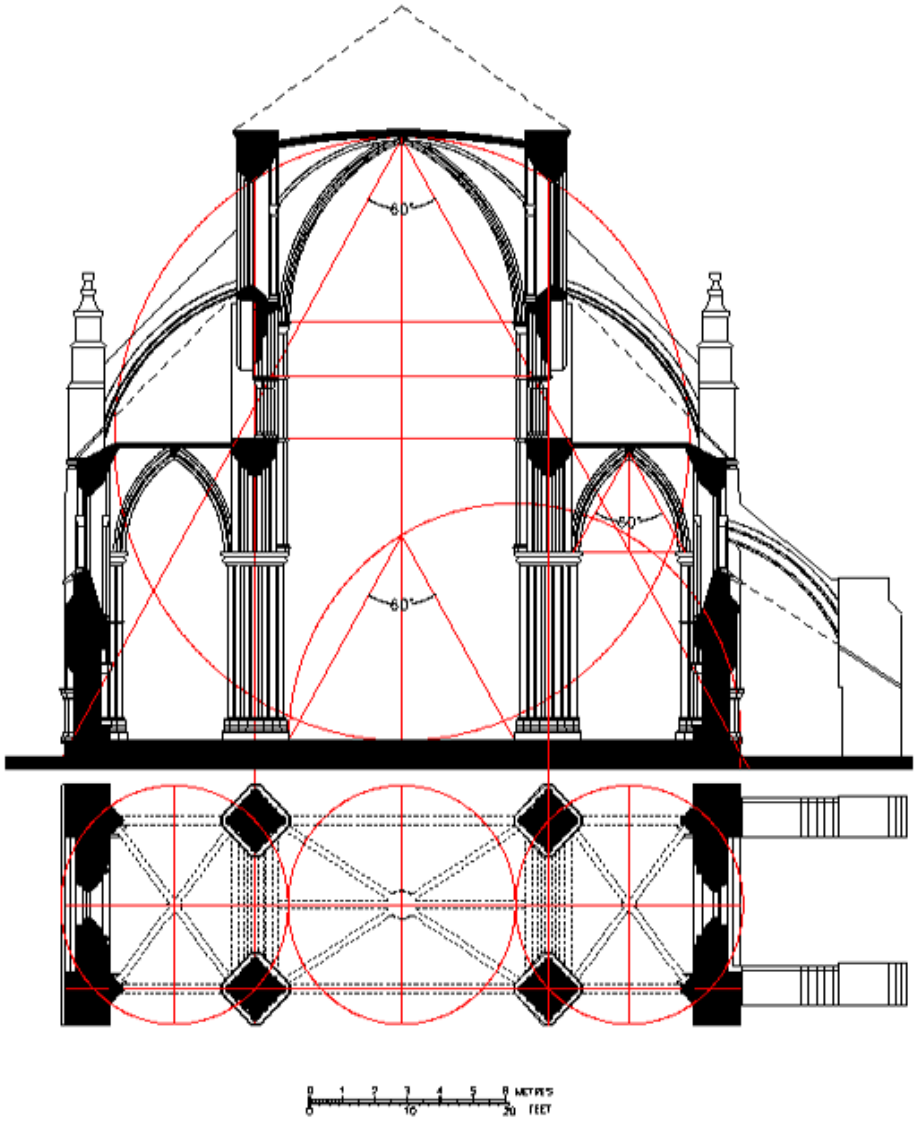

Figure 14. Hypothesis on the original configuration of the nave, considering a *sexpartite one for the high vaults (Theodossopoulos et al 2003)*

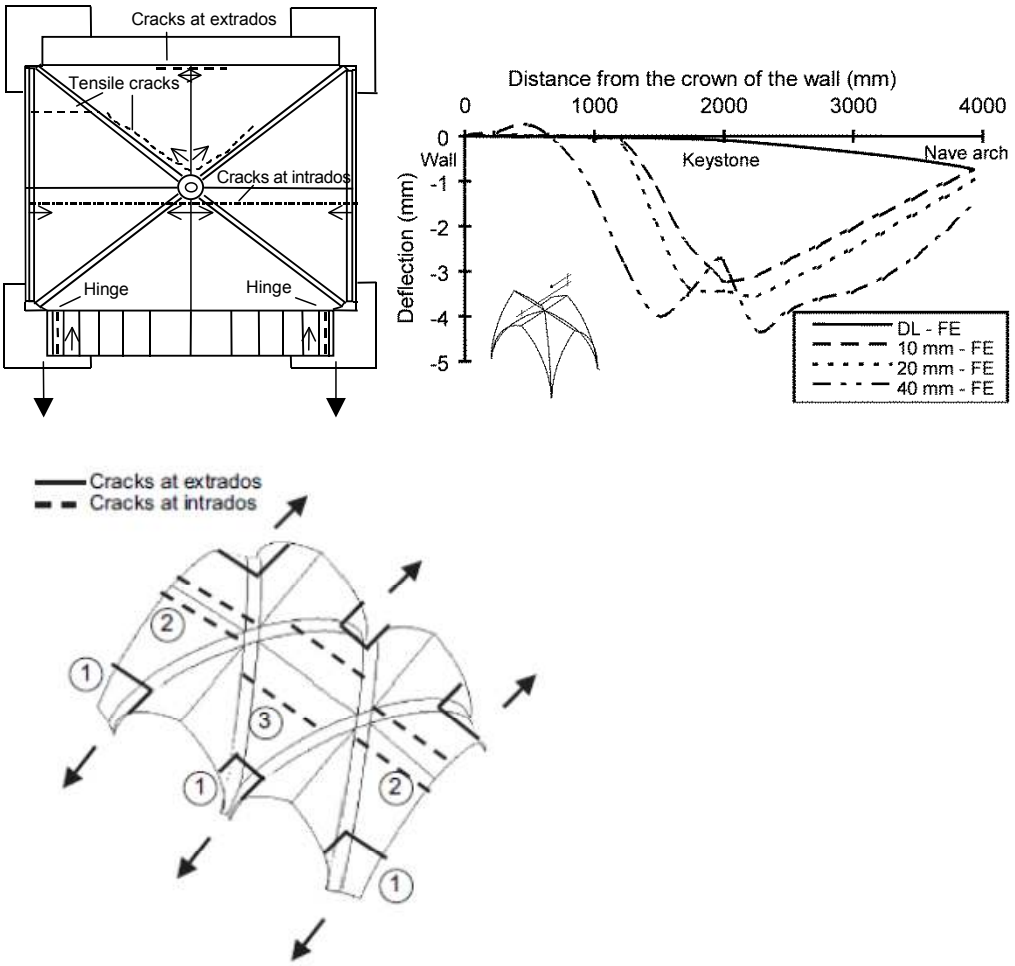

Figure 15. The crack pattern of an experimental model simulating the aisle vaults in Holyrood at 30mm support spread; the deflections of the symmetry axis of a FE model of the aisle (Theodossopoulos et al 2003); and crack pattern on a typical nave vault from Durham Cathedral (Theodossopoulos 2008)

Figure 16. The Abbey church ruins today (2010), showing the two surviving piers of the North arcade.

Table 1. The 1757 estimate by Douglas and McPherson that apparently informed the project. Costs are in British pounds (L), shillings (s) and dimes (d). Item 3 discounts the inclusion of diaphragm walls for the aisles (Douglas and McPherson 1757)

	"Estimate for Repairing the Abby Church of Holy Rood house by taking off the whole of the Slait Roofs and Building Walls one Foot four inches thick, at Two Feet distance from one another, so as to Raise and Frame the Reverse of the Arch, for to admit a proper Pitch, so as to cover the whole of the Roofs with hewn Stone And to pave the Floor & point & Harl the Outside of the Church ----------"	L	s	d	Cost %
1	To taking off all the Old Roof and clearing of the Rubbish of the Tops of the Pends so as to get a clear foundation for the Stone Walls that is to carry the hewn Stone Roof and for supporting the Stone Roof	35			4
2	To 54 Rood 18 yards of Rubble Building at £5 .. 3 p Rood	280	13	6	28
3	To 12060 Feet of Hewn Stone contain'd in the Main Roof ~~and Isles adjoining to (*it*)~~ at 8d per foot	402			40
4	To laying the whole Church with pavement Measuring 7500 feet at 6d per Foot	187	10		19
5	To levelling the floor of the Church and furnishing dead sand for laying the pavement of (Ditto)	10			1
6	To furnishing pan Cratch for jointing and laying the whole of the hewn stone of the Roofs	20			2
7	To pointing the whole of the Ashler round the Outside of the Church & Steeple with Pan-cratch and Harling the Rubble Building where there is no Ashler; the Measure being 1750 Yards at 6d per yard	43	15		4
8	To 4 Roods 26 yards of Rubble Building in making up the Windows, where the Stone Roof of the Isles is to join to the side walls of the Main Body of the Church at £5 .. 3 per Rood	24	6	4½	2
	Total £	1003	4	10½	100