<table>
<thead>
<tr>
<th><strong>Title</strong></th>
<th>The Evolution of the Iron Truss in the Work of John Rennie</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Authors(s)</strong></td>
<td>Shotton, Elizabeth</td>
</tr>
<tr>
<td><strong>Publication date</strong></td>
<td>2015-06-07</td>
</tr>
<tr>
<td><strong>Publication information</strong></td>
<td>5ICCH Proceedings</td>
</tr>
<tr>
<td><strong>Conference details</strong></td>
<td>5th International Congress on Construction History, Chicago, USA, 3 -7 June, 2015</td>
</tr>
<tr>
<td><strong>Publisher</strong></td>
<td>The Construction History Society of America</td>
</tr>
<tr>
<td><strong>Link to online version</strong></td>
<td><a href="http://www.5icch.org/">http://www.5icch.org/</a></td>
</tr>
<tr>
<td><strong>Item record/more information</strong></td>
<td><a href="http://hdl.handle.net/10197/6926">http://hdl.handle.net/10197/6926</a></td>
</tr>
</tbody>
</table>
THE EVOLUTION OF THE IRON TRUSS IN THE WORK OF JOHN RENNIE

Elizabeth Shotton

Keywords
John Rennie; history and construction of specific projects; iron truss evolution; truss connections building materials, their history, production and use

Abstract
Dublin's nineteenth-century Tobacco Store built by John Rennie (1761-1821) is considered significant due to its cast- and wrought-iron roof trusses. Though by no means the first to experiment with iron, Rennie had been a firm believer in the superiority of this material over timber in warehouse construction and used it extensively throughout his portfolio. Less acknowledged is that a similar, yet more advanced truss was used in the New West Stores (demolished 1988), also built as part of the Dublin Docks ensemble by Rennie. That this achievement was overlooked was a result of the roof structure being replaced with a less adventurous timber roof following its collapse in a fire in 1833, ten years after its completion.

Archival evidence suggests that the original cast- and wrought-iron truss designed by Rennie for the New West Stores mirrored that of the earlier Tobacco Store in profile consisting of queen-post truss, surmounted by a lantern structure and a smaller kingpost truss. However, this later truss far exceeded the earlier structure in span, being 52 foot 6 inches in comparison to the 38 foot 9 inch span of the Tobacco Store. As studies in the evolution of iron truss technology have suggested that the span of early trusses were limited to 40 feet, which was not exceeded until after the 1830s when such inventions as the Polonceau truss and various arched truss technologies were introduced, this early truss by Rennie was a significant achievement in the 1820s.

In addition to its span, it is probable that this truss also represented an evolution in Rennie's connection details. Prior to his work in Dublin Rennie had favoured connections made with slotted assemblies, using wedges and cotter pins to tighten and hold pieces together, which were often dependent on the structure's own self weight to provide stability – a strategy employed in the London Tobacco Dock, the West India Dock sheds and even the Southwark Bridge. The truss work in the Dublin Tobacco Store mirrored this tendency, until the connections were re-worked during a recent renovation. Evidence from Rennie's resident engineer John Aird (1760-1832) and later work by his sons at the Royal William Victualing Yard, suggest that the connections used in the New West Stores truss may have represented an evolution in this thinking, with the introduction of bolted connections to the assembly.

---

1 School of Architecture, University College Dublin, Belfield, Dublin 4, Ireland, elizabeth.shotton@ucd.ie
THE EVOLUTION OF THE IRON TRUSS

In Yeomans’ study on the evolution of trusses in 1992, he begins the discussion of iron trusses by recounting the introduction of iron fittings and fasteners into wooden trusses. It is an instructive way to illustrate the evolution of the truss from timber to iron as it makes evident the reliance on timber framing techniques for the early developers of the iron truss. Long before the divergent properties of wrought and cast iron were understood, or the casting and rolling processes perfected, the manner of jointing sections of an iron truss drew on these early timber models for inspiration. As identified by Swailes and Marsh (2005) this influence is apparent in the dovetailed joints of the first iron bridge at Coalbrookdale of 1779 and was to equally influenced how iron trusses were to develop. Though bolts and rivets would be common jointing techniques later in the nineteenth century, in the early trials with this new material slotted connections, as well as cotters and wedges were often used to join and tighten iron truss work assemblies (Swailes and Marsh 2005; Yeomans 1992).

Though the capacity to cast iron to the scale and finesse required for roof trusses existed in Europe as early as 1750 it remained prohibitively expensive in Britain, far exceeding that of equivalent options in timber (Addis 2008). It was not until the need arose for better fire-proofing technology in industrial mills in the late eighteenth century in tandem with the increasing cost of imported timber to Britain, that the benefits of this new material were to outweigh its apparent cost, resulting in a far greater use of iron in trusses in first half of the nineteenth century (Addis 2008; Yeoman 1992). Addis (2008) has suggested a date of 1802 for the earliest experiment in cast-iron roofing by Charles Bagg at Meadow Lane, where a 38 foot roof truss was used. In fact, the earliest reported iron roofs were within the foundries themselves, the first located at the Carron Works in Scotland and reported in 1770 (Swailes and March 2005).

These early trusses in Britain were typically constructed of cast-iron and had limited spans, in contrast to France and Russia where wrought-iron arched ribs were used rather than trusses, with ties of flat bar added for longer spans (James 2013). By the early nineteenth century wrought iron, though still expensive, became more available in Britain, leading to the composite truss assemblies in which wrought iron was used for tension members and cast iron for the struts and rafters (Swailes and Marsh 2005). Sutherland (1997) suggested that up to 1814 “long-span roofs of iron were still in their infancy” though he cites the Plymouth Theatre roof by John Foulston (1772-1841) which was a cast- and wrought-iron truss of 60 foot span built in 1813 (Jenkins 1968). Despite this early example, of which no details are available, early limitations in span were not overcome until after the 1830s when such inventions as the later named Polonceau truss was introduced, as well as the various arched truss technologies used in railway buildings from the 1850s onwards (Swailes and Marsh 2005).

RENNIE’S WORK IN IRON

Though generally remembered for his work on harbours, docks and bridges, John Rennie (1761-1821) was initially trained as a millwright and spent a considerable part of his career in developing machinery in addition to his major civic works (Boucher 1963). This background likely influenced his interest in iron, as Boucher (1963) credits Rennie for the innovations in the equipment supplied to Albion Mills in London, Rennie’s first project while working with Boulton and Watt, which was the first to be made almost entirely of iron and, in particular, the redesign of the previous wood gearing mechanism in cast-iron. This interest in iron extended to its use in buildings and, though by no means the first to experiment with this new technology, Rennie was a firm believer in the superiority of this material over timber in warehouse construction.
and used it extensively throughout his harbour and dock projects. The work on both the Tobacco Store and the New West Stores in the Dublin Custom House Docks project (1815-1824) were based on advances in construction methods made by Rennie and his collaborators for the London Docks and the West India Docks in London, before and during his commission in Dublin.

In the earlier work on the London Docks, Rennie had collaborated with the architect David Asher Alexander (1768-1846) on the well-known Tobacco Dock Warehouse, built between 1811 and 1814, as an extension to the original London Docks site in east London (Thorne and Cruickshank 1986). Of note were the eccentric bifurcated cast-iron stanchions and struts which support the timber framed queen-post trusses, creating a floor plan uninterrupted by intermediate walls (Thorne and Cruickshank 1986; Hamilton 1940). The eccentricity is the three-dimensional character of the struts, which stretch in both directions, offering direct support to the timber-trusses immediately above the column, as well as to the intermediate trusses and length of guttering spanning between them, resulting in a highly figured profile. The cast iron assembly is slotted together, rather than being fixed, and rests on the stonework below secured in place only by the weight of the timber above, which was considered a novelty. As Hamilton (1940) has suggested, based on a close study of the original drawings, “the essence of the scheme appears to have been the provision for correcting defects which might develop through uneven subsidence.”

Coincident with the Tobacco Dock warehouse, Rennie had won the commission to build the Southwark Bridge, and was also working on the provision of iron framed sheds at the West India docks, both of which had similar approaches to jointing the iron assemblies. At Southwark Rennie employed a system of dovetailed sockets and long cast-iron wedges to joint the assembly, thus the entire construction, built between 1813 and 1819, was assembled without the need for bolts. Though as a arch bridge this structure was in compression, thus these details could be confidently used, the West India shed roof structure, a wrought-iron truss assembly developed by Thomas Pearsall, was not subject to the same compressive action and failed shortly after its erection (Tucker 1989, Swailes and Marsh 2005), though this may have been due to deficiencies in its fabrication and assembly (Rennie 1815). Though Thorne’s attribution of credit to Alexander for the highly figured character of the stanchions and struts used on the Tobacco Dock roof system may have legitimacy, the clever jointing and bearing solutions may owe something to Rennie’s insights, given that he made use of this strategy in other projects.

Despite the early failure at the West India docks, Rennie continued to promote the use of iron for roofing warehouses, though with limited success among the Board of the West India Dock Company, who were by now wary of this new material. Though he proposed the use of iron truss-work again to this Board for new Rum Warehouses in 1816, it was dismissed, and instead timber-framed queen-post trusses, very similar to those at the Tobacco Dock, were used. These warehouses are nevertheless revealing for the lineage in Rennie’s thinking on structural ironwork, as well as for other elements in the design of warehousing (Fig. 1). Though the section of the warehouses bears an uncanny resemblance to that of the Tobacco Dock the differences are most telling. Rather than reusing the three-dimensionally complex stanchions of Tobacco Dock, Rennie forgoes this complication in favour of a single girder of cast-iron to carry the timber trusses, reminiscent of Pearsall’s early piece-work wrought-iron truss, resting on circular cast-iron columns which Renni was to use in future works. The castings of columns and girders for these buildings (1817-18), were supplied by Butterley Ironworks, which was to prove critical in the work undertaken in Dublin, since Rennie had, by 1814, been commissioned by the Commissioners of Excise and Customs to build the new Docks and Stores east of the Dublin Custom House and its original dock (Cox 2009) and Butterley Ironworks was to supply the ironwork for the first of the two warehouses, the Tobacco Store.
The Tobacco Store in Dublin

Though the project in Dublin was commissioned in 1814, due to difficulties in the land transactions the excavation work of Georges dock did not start until 1815, prior to the building of the two warehouses east and west of the dock. Eastward of the dock was the Tobacco Store, the building of which started once the dock is nearly complete in 1817 (Rennie 1817). Rennie borrows heavily from the Tobacco Dock project in London, as well as advances he made in the vaults at the West India docks, to design the Tobacco Store from Dublin, but in this case the queen post structure, surmounted by a lantern to provide light and a king post structure above, is rendered in cast- and wrought-iron sections and achieved a clear span of 38 feet, 9 inches (Fig 1). Identical to the West India works, the trusses are carried by an arched girder of cast iron supported on cast iron columns, though the trusses are offset from the columns and given further support by struts originating from the column capitals, not unlike the configuration at the London Tobacco Dock. In a further evolution of the larger assembly by Rennie, the secondary rafters and purlins are also displaced to separate the bearing points of the transverse and longitudinal members to simplify the connections (Tucker 2008).

The joints and single castings are of interest here, as a sketch for a truss for the Dublin Excise Roof dated 1818 exists in the Rennie archive at the Institution of Civil Engineers (Fig. 2). The sketch book in which the drawing is found has been attributed to George Rennie (1791-1866), the eldest son of John Rennie, who was known to accompany his father to project sites (Tucker 2008). The assembly on site varies from the drawing in notable ways. Most significantly the lantern structure and central bracing frame, shown as piece work in the drawing, appear to be cast as a single pieces in the truss as built. Given the work lately completed on the Rum Warehouses, where Butterley also cast the girders as single pieces, it may be that the foundry suggested these single castings in this project, which would have simplified the assembly process.

The very precise use of wrought-iron rods for the tension members in the built truss, as opposed to more generalized use of cast-iron, with its lesser tensile properties, for the remainder of the assembly could likewise suggest the intervention of a knowledgeable iron-maker who would better understand the differential between the properties and costs of cast versus wrought-iron. However, George Rennie was known by this date to have an interest in the properties of materials, and had undertaken tests into the compressive and tensile characteristics of cast and wrought iron in 1817, likely at the workshop his father kept in London, the results of which were published in the *Philosophical Transactions of the Royal Society of London* in the same year this drawing was made. The intelligence by which the characteristic strengths between cast- and wrought-iron are exploited in this truss may well be due to the younger Rennie’s contemporaneous study.
The difference between the detailing on the connections of the wrought-iron tie rods between drawing and as built is also noteworthy. In the sketch the tie member at the bottom of the truss is drawn as a flat bar, similar to the continental fashion, rather than a rod. This makes a considerable difference in how the joints between members can be affected, as the drawing illustrates. Use of a bar allows for screw-threaded rod connections to be developed between members, which can be tightened as required. As built, with rods rather than a bar, these connections are resolved with complex overlapping cast-iron joints through which the bars are threaded and pinned in place with wedges (Fig. 3). This solution resonates with the sensibilities of Butterley Ironworks and the senior Rennie’s previous assemblies and suggests some, but not all of the younger Rennie’s ambitious ideas were used in this first Dublin truss.
The New West Store

The insights gathered regarding the lineage of thinking underlying the Tobacco Store in Dublin is enlightening for what it can illustrate about the New West Stores, which, as a result of the roof structure being replaced with a single timber king-post roof following its collapse in a fire in 1833, followed by its demolition in the late 1980s, is far more difficult to assess independently from its nearest relation. Though the Tobacco Store was Ireland’s first completely iron-roofed warehouse (Cox 2009) it was the New West Stores which may have represented Rennie’s most advanced building work. The design work on the New West Store, west of the new dock, began following the completion of the Tobacco Store in late 1820, though construction was not complete until 1823, following the elder Rennie’s death in 1821.

In a letter to the Commissioners of Customs and Excise in early 1820, Rennie described his intention to design the store as two long ranges running parallel to the docks, the east to serve Georges Dock and the west to serve the original dock, separated by a solid masonry wall, with a third smaller store to the south to create an L-shaped building and to roof the entire store with cast-iron truss work similar to that used in the Tobacco Store (Rennie 1820a), though just what the span of the intended trusses was to have been is not mentioned in any documentation. As the store has two floors above the vaults, Rennie adds that the cast-iron columns should have iron caps to support timber girders, but that they would be constructed in such a manner as to connect the iron columns from one floor to the next, making clear that his preference is for the primary structure to be iron, and possibly that these columns would be supporting a roof (Rennie 1920a). Given the configuration of the vaults, and hence the foundations below, there are only two probable means of roofing the main block of New West Stores: with two roofs, one each over the east and west ranges which would bear on the walls alone; or three roofs covering the width of the main block of the building, which would require the placement of columns.

Evidence as to the roof profile of the New West Stores comes from an early nineteenth century illustration of Dublin originally published in London (Fig. 4) etched prior to the collapse of Rennie’s iron roof. The roofs described over the stores in the lower right corner make this clear, because this is not a representation of the single-span king-post truss roof built in 1834, but something much closer to the Tobacco Store roof, complete with lantern structure and a hipped structure at its south end. This is a fair representation of the descriptions provided by both Rennie and Rennie’s resident engineer John Aird (1760-1832) in their various correspondences with the Commissioners between 1820 and 1824. The configuration of the internal wall, in its height, girth and foundation, suggests that there were two roofs over the main building, one over each range, which were entirely supported on these load-bearing masonry walls. Further evidence of the intermediate wall’s role in supporting this roof is the existence of the stone coping at its top. Though much of this appears to have been thrown off during the collapse of the roof, as well as one or two courses of brickwork, the remaining coping is at a height that would bring it into alignment with the bearing surface on the external walls, and conforms to Rennie’s prescription for stone to underlie all truss-bearing conditions. When compared to the survey of the building by Ove Arup in 1988, prior to its demolition, which gives a dimension in excess of 105 foot to the north elevation of the block, it suggests that the iron roofs originally constructed over the main block of the New West Stores spanned 52 foot 6 inches, which may be Rennie’s most significant design achievement in this form of technology, since spans in iron roofs were not to commonly exceed 50 feet until a decade or more later (Swail & Marsh, 322).
As to the continuous iron connection between the columns and roof, which Rennie alluded to in his first description of the project to the Commissioner, the south wing of the main building may be the location of this particular feature in the project. For if 52 feet, 6 inches was a significant increase in span over the lately completed Tobacco Store, attempting to span the 63 foot width of the wing may well have proved too great. It is conceivable that it is here where one would have found a range of two roofs supported by a line of columns and girders, comparable to those found in the Tobacco Store, running down the middle of the building (Fig. 5).

Of the detailed connections of this truss nothing is known with certainty. However, from his own correspondence it is clear that Rennie had only provided schematic drawings and models for the tender process but that Aird had prodded him to provide more specific drawings of the ironwork from which the contractors could develop quotes more accurately. Rennie complies in July 1820, though begrudgingly as in his estimation the details should not be required for the tender but “sent in the order in which the works required their execution” (Rennie 1820b). This suggests that Rennie’s habit would not have been to supply details for iron work of this kind, but to negotiate these with the iron foundry once the contracts were signed, but that in the case of the New West Stores the detail connections were provided by Rennie’s office.

From later correspondence between Aird and the Commissioners is clear that, despite the significant span of the truss, Aird had an unusual degree of confidence in the roof of the New West Store, far exceeding that of the Tobacco Store, which suggests that its detailing most have differed significantly. In the case of the Tobacco Store, Aird insisted on the need for duplicate roof members to be saved at the termination of the work for use as patterns should any part of the

Figure 4: Dublin, Samuel Davenport c. 1825 (Kelly’s New and Universal English Dictionary)

Figure 5: Conjectural Transverse Section new West Stores (Author 2012)
roof fail and had recommended storing 30 tons of ironwork, representing a complete set of roof members (Revenue 1823). By the completion of the New West Stores, Aird makes a similar plea to lay up, for future use, a number of duplicates of the roof members. But in this instance he suggests that “the structure of the roof is altogether so substantial that in my opinion there is no assignable period to its [destruction]. What I want beg to recommend therefore in case of an accident to any of the small scantling of the roof would be to retain a small portion of each to serve as patterns to cast from if it should ever become necessary” (Revenue 1823). In the end, what Aird puts away for future reference are all small members, the whole of which amounts to approximately 4 tons of ironwork, in contrast to the 30 tons stored up for the Tobacco Store (Revenue 1823; Telford 1823). There is a measure of confidence here, which suggests that the roof is far more robust than that of the Tobacco Store, despite its similar profile. It may be that its support on masonry rather than cast-iron girders and columns is what convinced Aird that a failure was so unlikely. Or perhaps it was something in the jointing of its members that assured Aird about its worthiness.

The Rennie Brothers and the Royal William Yard

There are considerable similarities between the work at the Royal William Yard and that of the portfolio of the elder Rennie, indicating, as Miele (2006) alludes, that George and his brother John (1794-1874), borrowed heavily from their father’s work. Later drawings by Sir John Rennie from 1849 illustrate continuous cast iron column work, with the pillars standing in sockets of the pillars below no rigid fixing, so as to allow the pillars to readjust to slight changes in level without risk of fracture, also similar to construction techniques of Rennie senior (Hamilton 1940). This is advantageous to the current attempt to reconstruct the New West Stores because these buildings have survived so well, and thus provide insight into the possible configurations used in Dublin. The truss work of the Melville building at the Yard (Fig. 5), constructed 1829-32, is very similar to that found in the Tobacco Store in Dublin according to Miele (2006), being a queen-post truss, though exceeds its span, being 46 foot. However, these trusses are spanning between masonry walls, so the assembly lacks the girders and struts of the Tobacco Store configuration and are likely more similar to the trusses roofing the New West Stores.

Figure 1: Cremill Point (Melville) Roof Trusses, Sir John Rennie c. 1834 (National Archives Work 41/17 and detail)
The connection details of these trusses are nearly identical to those first sketched by George Rennie in 1818 for the ‘Dublin Excise Roof’, consisting of a flat bar for the bottom tension member with connections to screw-threaded vertical rods, while the complex joints where cast struts are jointed are figured in a very similar manner to the earlier Tobacco Store roof truss. These details suggest that George was likely the author of the Melville truss, but may equally hint at the detailing of the New West Store truss. Given the senior Rennie’s misgivings to provide Aird with the details for the truss in Dublin, as they were ultimately supplied as requested it is possible that George, who had such an interest in the properties of cast- and wrought-iron and was working in his father’s office at that date, may well have been the one to accommodate Aird with the requested drawings.

CONCLUSIONS

Though the precise configuration of the roof connections and detailing may never be known, there is evidence within these documents, when assembled with information gleaned from the records of the fire in 1833 and the surveys of the 1980s, that the New West Stores incorporated and expanded on the previous work Rennie had undertaken and may have represented one of the most significant buildings of his career. The roof span, though conjectural, represents not only the most considerable roof built in Rennie’s career but may well have been the largest span yet achieved in iron at the time of its building. Unfortunately it was Rennie’s attention to the variation between the new and the old docks, leading to the treatment of the main building as two separate stores, which may well have led to its demise. For, in offering this potential for divided occupation in the building, the way was made clear for the operation a “free store” in its western range, the ill-governed management of which led to the great fire of 1833 and the failure of Rennie’s most significant iron roof. George Rennie’s participation on the roof’s design is also conjectural, but his interest in the use of iron is well documented and as he suggested "..whoever has had occasion to investigate the principles upon which any edifice is constructed, where the combination of its parts are more the result of uncertain rules than sound principle, will soon find how scanty is our knowledge on a subject so highly important" (Rennie, 1818).

REFERENCES


The Evolution of the Iron Truss in the Work of John Rennie


Rennie, John. 1815. Chairman of Court of Directors of West India dock. The Rennie Reports. London: Institution of Civil Engineers. REN/RB/08/118.


Rennie, John. 1820a. Rennie, John to Customs, Dublin. The Rennie Reports. London: Institution of Civil Engineers. REN/RB/11/93

Rennie, John. 1820b. Rennie, John to Customs, Dublin. The Rennie Reports. London: Institution of Civil Engineers. REN/RB/11/221


