Cones, Not Domes: John Nash and Regency Structural Innovation

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The Museum of Artillery in the Rotunda is a little known building within John Nash's (1752 -1835) considerable oeuvre, but it is perhaps his most structurally ambitious. Situated on the edge of Woolwich Common in southeast London, where it has stood since 1820, its distinctive tented roof is immediately recognisable, evoking both battlefield and festival (fig. 1). Inside, the tent-like feel of the building is even more pronounced, with canvas lining seemingly draped from a huge Doric column. This post, analogous to the central pole of a military bell tent, helps support an elegant, yet fully concealed timber-framed roof structure whose outer ends rest on a circular colonnade enclosed by polygonal brick walls (fig. 2). The roof structure, 116ft in diameter and described in 1830 as having "no equal but the dome of St. Paul's Cathedral", is all the more remarkable for the fact that both the brick walls and the central post are secondary features (Hunt 1830, p. 97). Originally clad in boards and oilcloth, not lead, and encircled by timber-framed walls, the Rotunda roof and colonnade were, for the first few years, an entirely self-supporting spatial enclosure. The Rotunda was designedly unlike St Paul's and other domical roof structures, and its catenoidal form demanded innovation in structural technique. It was an extraordinary building born of unusual circumstance. It is the aim of this paper to examine the Rotunda's structural design and influences, as well as to look at how, in turn, its structural form influenced one of Nash's better known works, the Brighton Pavilion.

Figures 1 and 2. The Woolwich Rotunda (Jonathan Clarke; PSA Rotunda G (CN) 21156 1).

THE POLYGON ROOM: BUILDING HISTORY

Festive beginnings: Carlton House, 1814

Nash's Rotunda began life as a huge polygonal ballroom erected in the grounds of Carlton House, London, in June 1814. It was originally the centrepiece of a suite of temporary buildings erected for a grand fête held in honour of the Duke of Wellington, and is the sole surviving structure of the whole Carlton House complex (Crook & Port 1973, p. 317). The Prince Regent delighted in staging celebratory events in the gardens of his house, and over the previous 30 years tents and marquees had become familiar sights in the summer months. The scale of these celebrations increased, and to maintain some control over the costs of annually acquiring tents, the Prince had begun commissioning temporary, demountable buildings that had greater longevity and more scope for architectural character. Such buildings were abundant, "immense, and admirably contrived" in 1811 when they were designed under the direction of James Wyatt, following whose death in 1813, responsibility for Carlton House and its stock of semi-permanent marquees transferred to Nash (Berry 1865, p. 481). The fêtes of 1813 were relatively low-key, but the abdication of Napoleon in April 1814 gave the Prince enormous cause for celebration, and Nash, then his favoured architect, scope to impress. He expedited the design and erection of as many as 15 to 20 new temporary rooms intended for three celebrations in June, July and August (Carlton House 1991, p. 31). The full panoply was ready for the Duke of Wellington's fête on 21 July, the most extravagant ever staged by the Prince at Carlton House (Cole 2006).

The Polygon Room described

The Rotunda, or 'Polygon Room' as it was originally called, was the showpiece of the ensemble of interconnecting temporary structures which were designed collectively to accommodate 2,500 guests, including royalty, nobility, foreign ambassadors, ministers and officers of state. The temporary buildings were laid out in an H formation to the south of Carlton House, and included refreshment rooms, promenades, giant supper rooms, a botanical arbour and a Corinthian temple to Wellington. At the centre of the whole arrangement was the Polygon Room, with three apartments to the east, west and north (Crook & Port 1973, p. 317). The recent discovery of the original designs for the Polygon Room testify to the skill and ingenuity that went into their design and rapid construction (fig. 3); no drawings survive detailing the form or construction of the other temporary buildings. The drawings are dated May 1814, suggesting that the Polygon Room was assembled and erected in ten weeks or less. Nash was responsible for the overall design, but on structural matters it seems certain that William Nixon (d.1826), his chief carpenter, aided him considerably, as will be shown.

The drawings show a twenty-four sided structure in the form of a huge bell-tent, 120 feet across and 80ft high with a distinctive concave roof and match-boarded walls pierced by doors and large windows on alternate faces. The timber roof structure, carrying outer and inner sheets of canvas, is formed from an array of 24 tapering half-ribs that fan downwards and outwards from the apex.

Each half-rib is a trussed assembly of members with curvilinear laminated timber upper and lower chords shaped as catenary curves. They are strapped together at the crown, their bevelled upright members - analogous to king posts – combining to form a cylinder rather like the staves of a barrel. This hollow timber cylinder carried a louvered turret, which helped ventilate the building, and may have improved the acoustics. The lower ends of the ribs rested on two concentric circular wall plates joined together in the horizontal plane by double-diagonal timber braces. The outer wall plate was carried on and braced to 24 timber posts, which also framed the panel walls. The inner wall plate was carried on reeded timber columns set slightly inside the outer posts. The ground plan denotes these as having cast-iron cores, and photographs taken in the 1970s when the Woolwich Rotunda was restored substantiate this (PSA G (CN) 21156 11). Cast-iron arched braces with open-work spandrels link these posts circumferentially, and similar but shorter braces span between inner and outer posts. The plan of the ground floor clearly indicates members connecting the bases of the inner posts, as well as radial and diagonal members linking them to the outer wall or foundations. Corresponding to those above, these elements were presumably sited beneath the floorboards. However, unlike those braces at higher level, it is unclear whether they were made of timber or iron, or meant to be acting in tension or compression. This drawing also shows an innermost ring of twelve posts set at the centre of the building, each of lesser diameter than those already described, but still with an iron core. According to a description of the fête in *The Times*, this circular array 'supported a garland of artificial flowers in the shape of a temple … used as an orchestra for two bands' (Times 1814). *The Times* also gives us some idea of how impressive this structure must have looked on the day of the ball, with decorative groins formed between the inner and outer posts 'from which arose an elegant umbrella roof … decorated with large gilt cords … painted to imitate white muslin, which produced a very light effect'(Times 1814).

The Polygon Room was a huge success. Nash had succeeded in creating an illusionistic set-piece, one that from the outside looked familiar, like a huge tent, but whose sumptuously decorated interior, without the expected central pole, must have occasioned feelings of surprise and awe. That mere cloth could seemingly sustain itself overhead in a funnel-like contour must have bamboozled even the more sober guests, and appealed to their notions of the sublime. Certainly it found favour with the Prince Regent, who retained it and the three adjoining apartments until 1818, when negotiations were set in train for its removal to Woolwich. Almost all the other temporary rooms had been dismantled in 1815. Before considering the structural design of the Rotunda in more detail, it is worth recounting its dismantling at Carlton House and subsequent re-erection at Woolwich, not only because the records present an unusually detailed insight into this early instance of prefabrication and portability, but also because it tells us much about how Nash thought about the structure.

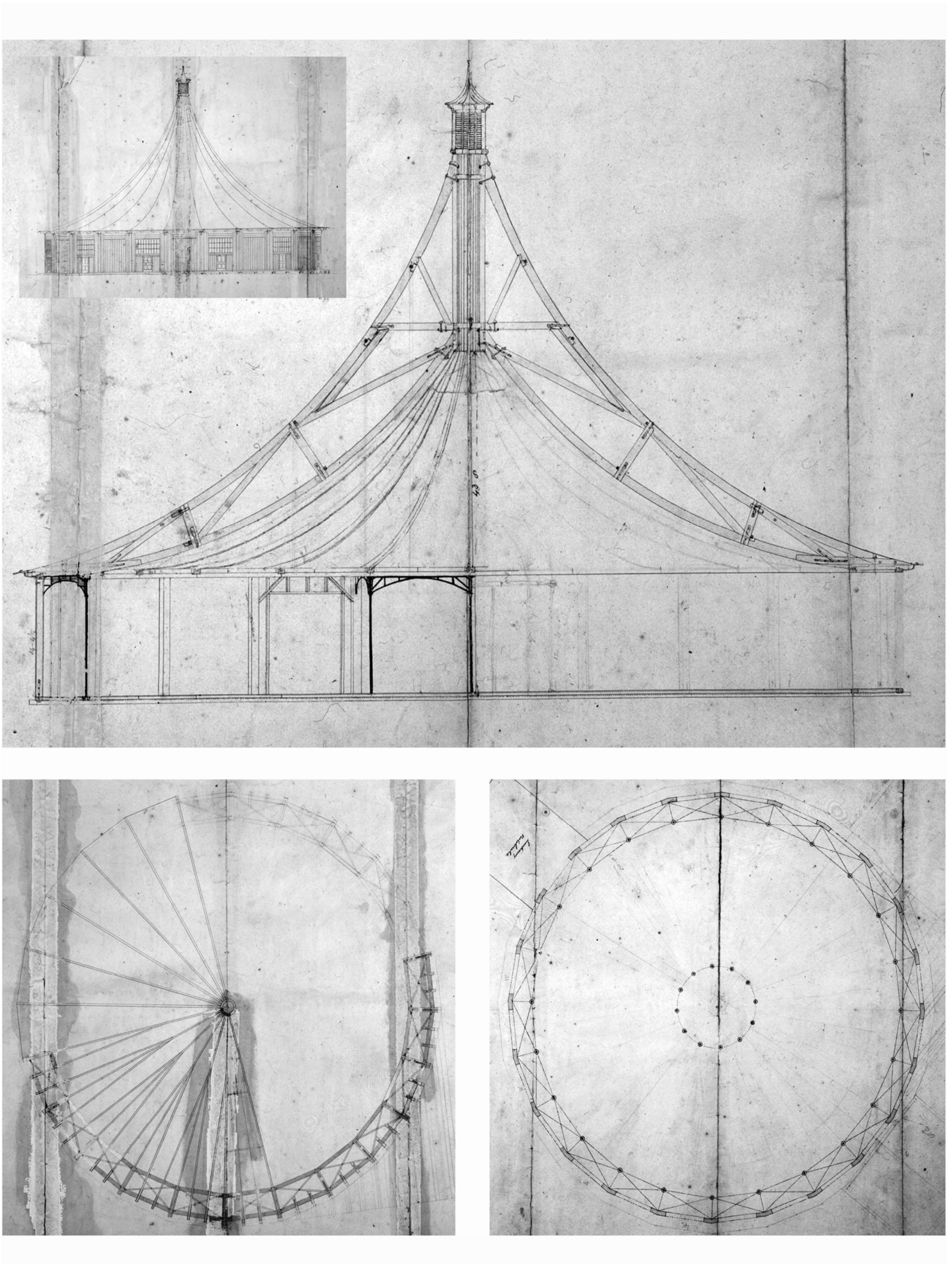


Figure 3. Drawings of the ‘Tent Room, Carlton House’: Section (top), elevation (inset), roof plan (left) and ground plan (right). All are unsigned, but dated May 1814. The National Archives (TNA): Public Record Office (PRO) WORK 43/575, 43/574, 43/573).

Dismantling the Polygon Room, 1818.

Despite being retained by the Prince Regent at Carlton House, where it saw occasional use as a ballroom during summer fêtes, it was clear by the summer of 1818 that the Polygon Room had outlived its original purpose. The celebrations marking Allied Victory were long over, Carlton House itself was in decline, and the expense of maintaining the remaining temporary buildings was a drain on the finances of the Office of Works. On 7 August 1818, the Surveyor-General, Colonel Benjamin Charles Stephenson was informed that it was “the Prince Regent’s Pleasure that the great circular Room in the Gardens of Carlton House should be removed from thence ... [and] transferred to Woolwich, there to be appropriated to the conservation of the trophies obtained in the last war, the artillery models, and other military curiosities usually preserved in the Repository of the Royal Artillery” (PRO WORK 1/9, p. 43). Nash, stationed in Brighton, clearly had other hopes for his building, for later that month he wrote to Stephenson, mentioning a “proposition I had to make related to the application of the building as a Church…when I come to town I will show you a design and calculation on that subject” (PRO WORK 19/11/5, f. 39). In fact, Nash considered the building “applicable to many purposes … indeed I think it would be a useful building in any of the dockyards and other government establishments” (PRO WORK 1/9, p. 61; WORK 19/11/5, f. 38). The Prince Regent’s wishes prevailed, almost certainly influenced by Sir William Congreve (1772-1828), Comptroller of the Royal Laboratory at Woolwich and inventor of the well-known Congreve rocket. Congreve was a longstanding acquaintance of the Prince, and needed more room to display the museum pieces that had arrived from Paris. Even so, his proposal was not approved without considerable wrangling, his application initially being turned down by the Treasury, which, fearful of the costs of dismantling, transporting and re-erecting the building, thought that it should be sold to a private builder.

It being such a large and intricate building, Stephenson wrote to Nash for advice as to how to dismantle the Polygon Room. Nash gave detailed instructions that reveal his constructional knowledge. Among other things, he proposed the erection of a giant central scaffold, from which vantage point “the hoops …which bind the upright timbers of the roof together and form the cylinder” could be removed, with blocks and pulleys employed to disengage and lower the ribs safely. Nash pointed out that the “building has been constructed so as to take to pieces and be refixed”, and it was therefore important that the ribs (which could be taken down whole), purlins, posts and plates should be numbered and drawn (PRO WORK 1/9, pp. 59-61).

Detailed though the written instructions were, Stephenson foresaw the need for on-site assistance. He was concerned most about “the great size and weight of the Ribs, the height of the cupola, and the very nice mechanical construction of the whole Building [which] will require more than ordinary care and abilities, to remove … with safety” (PRO WORK 1/9, pp. 61-2). Nash wrote back to Stephenson on 30 August, explaining the more troubling aspects of the disassembly, including the tricky part of disconnecting the ribs, each of which has been calculated to weigh about 1.75 tons. Nash reassured Stephenson that he had “consulted Nixon who built it under my directions and he is of the same opinion with me that with the centre scaffold I proposed and the jacks triangles and blocks, the ribs may be taken down with great ease – and that the scaffold being erected and a competent number of men they may be taken down in a week" (PRO WORK 19/11/5, f. 39). In a further letter, dated 4 September, Nash offered further reassurance, saying that he would make Nixon available on-site so that the carpenter could "explain the construction of the building and advise on the taking of it down" (PRO WORK 19/11/5, f. 41).

The Rotunda was duly dismantled in the autumn of 1818. Only five men were employed to do this, and just two, a carpenter named Jeffry Wyatt (who had been entrusted with its original erection), and a labourer called Francis Swinney, did the hard toil. William Wyatt, Labourer in Trust at Carlton House, superintended the work, and also sorted and numbered the materials; William Nixon was on hand for the first two days in an advisory capacity (PRO WORK 4/23, f. 269 and f. 307; WORK 1/9, p. 111; WO 44/642, f. 356).

Re-erection at Woolwich, 1819-20

The re-erection of the Rotunda was long drawn-out. When it reached Woolwich is not clear, but it was in early December that Congreve requested that orders be given to the Commanding Engineer at Woolwich "to make the necessary arrangements for its erection on the brow of the Hill at the Eastern boundary of the Repository Grounds, that spot being the most convenient as well as the most picturesque situation for it" (WO 44/642, f. 358). Bureaucracy delayed progress for a further six months, and it was not until 14 June 1819 that Congreve could order "that the erection of the Rotunda be proceeded upon" (WO 44/642, f. 368). During this period it was decided to substitute brick walls for the original timber enclosure, owing to the "exposed situation" of the new site. The Board of Ordnance had nearly 1 million bricks in storage, and it made sense to use some of these (WO 44/642, f. 362). During this period – or perhaps a little later – the decision was taken to introduce the central column that survives. In any case, on 21 October Lt-Colonel John J. Jones, the Commanding Engineer in charge of the re-erection, informed Congreve that "The Building is now in such an advanced state, that besides the interior furnishing, little remains to be executed, but painting and nailing on about one third of the canvas covering to the weather boarding of the roof, raising about half of the masonry column to support the dome, and repairing the fixing in the window and door frames" (WO 44/642, f. 382-3). However, a particularly severe winter seems to have stymied completion, and it was not until May 1820 that Jones able to declare the building as "being in a state to be occupied" (fig. 4).

In overall form and structural behaviour the re-erected building that stands at Woolwich is much the same as the building erected in Carlton House Gardens. Some of the original materials were found to have had decayed beyond re-use during the course of rebuilding, but they were replaced by duplicate items. These included a large number of joists, rafters, floor and roof boards, as well as spikes, nails, bolts, etc. and a new inner and outer canvas lining for the roof, replacing that which had been supplied initially by James Baber's Patent Floor Cloth Manufactory. Besides the addition of brick walls, which assisted the wall posts in supporting the wall plates, the principal modification was the introduction of a giant stone Doric column (fig. 5). It has long been presumed that its purpose was to help bear the additional weight of the lead roofing, thought to have been added in *c*.1819 when the Rotunda was rebuilt. However, the lead covering was not added until the mid nineteenth century, probably in *c*.1861, when General Lefroy undertook a major refurbishment of the museum (PRO WORK 43/577; Bartelot 1978, pp. 108-9). Until then, the roof covering comprised solely of half-inch deal boarding under canvas sheeting. So why was the column introduced? The reason doubtless stems from the fact that the structure's status was now permanent. It may have been intended as a failsafe, in the event that the iron hoops binding the ribs together broke, or to ensure that a particularly strong wind-generated deflection of the timbers did not end catastrophically. Then again, its imposition may have been as much symbolic as structural, dignifying the museum interior with a feature associated with permanence and authority. Certainly there is a commemorative aspect to it, for the names of former artillery officers adorn the shaft, although at what point the painting of these began is unknown. But we can assume that its structural role became all the more crucial from *c*.1861, because the weight of the new lead roof would have imposed considerable loads on the timber roof structure otherwise, causing it to spread outwards and thrust excessively against the enclosing walls.

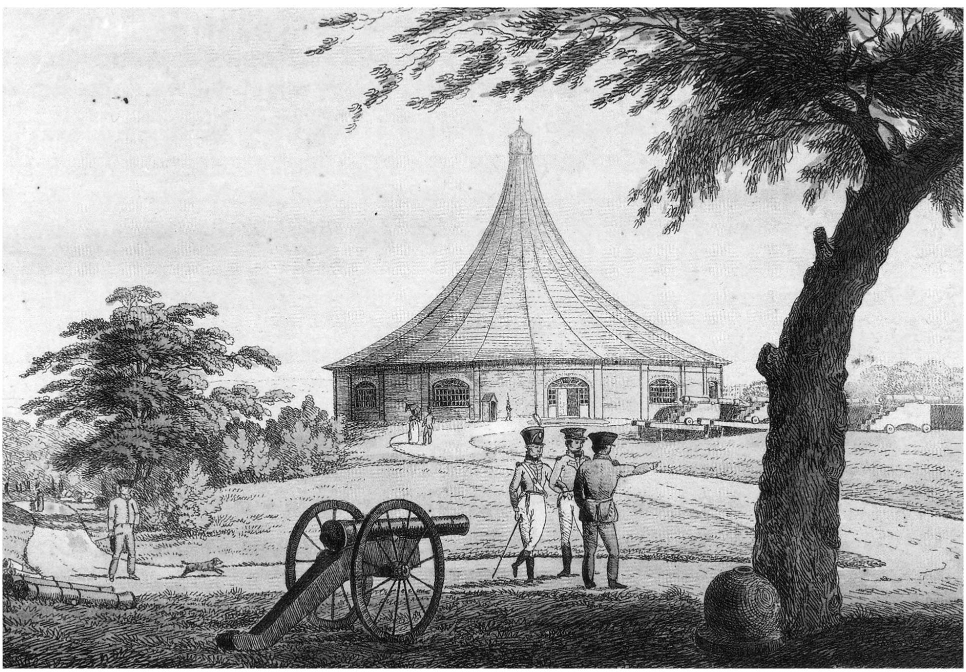


Figure 4. A view of the Woolwich Rotunda published by R.W. Lucas in June 1820, just weeks after its completion

THE STRUCTURAL DESIGN OF THE WOOLWICH ROTUNDA

There are three inter-related aspects to the structural design of the Rotunda that because of their special interest, deserve comment: the unusual geometry of the structure, the form and behaviour of the trussed ribs, and the use of laminated timber and specialised iron fasteners or connectors (fig. 5). Taking the first of these, Nash was faced with the difficulties associated with the peculiar tented form he wanted to achieve. Framing a three-dimensional hemispherical structure over a circular space was complicated enough in itself, especially if the span was large, since it brought with it the problems of intersecting structural members, of providing the basic frame for the outer dome shape using straight timbers, and, where an inner dome that rose above the wall plate was required, finding ways around the use of simple tie beams to counteract outward spread of the ribs. Framing a three-dimensional timber structure that looked convincingly like a tent both inside and outside, with a concave rather than convex curve, and which could not therefore rely on the mechanics of arch action, was perhaps more problematic. The fact that the structure ought not to exert any significant outward pressure on the (original) timber enclosing walls compounded the complexity of Nash's mission. In essence, Nash was tasked with creating a rigid catenoidal enclosure, one that covered an unobstructed area of some 10,600 sq ft, and whose 116 foot-span actually exceeded the clear diameters of many of what were then the world's largest domes, including St Sophia, Istanbul (115 ft) and St Paul's Cathedral, London (112 ft).

The Rotunda's elegant curvature, both inside and out, was based on the catenary, the curve formed by a chain or rope of uniform density hanging freely from two fixed points not in the same vertical line. Tent profiles were archetypal examples of catenaries, as were the hanging chains or ropes of suspension bridges. But although the catenary curve had been observed for centuries, its correct mathematical equation was not finally deduced until the early 1690s, appreciation of its inherent structural and geometrical advantages following. In1697 the Scottish mathematician David Gregory published his theoretical determinations on the subject. These showed that if the catenary curve was the most efficient profile for transmitting tensile forces, then it followed that the inverted catenary curve was the most efficient profile for the arch and the dome, acting in compression (Encyclopædia Britannica 2005). Wren and Hooke used this logic of converting pure geometry into mechanics in their final design for a self-supporting inverted-catenary inner-brick dome at St. Paul's Cathedral. Later, in 1744, Euler showed that the catenoid, or shape formed by the revolution of a catenary about its axis, had the minimum surface area for a given bounding circle (e.g., Weisstein 2005). In architectural terms this might have translated into the eighteenth-century realisation that, for a given circumference and height, catenoids required less cladding than hemispherical domes. Whether Nash was aware of these developments, and whether he thought to exploit them in the Rotunda seems doubtful. Nash was not mathematically minded, but he did possess an intuitive and discerning 'feel' for structure. At the very least, Nash was concerned with arriving at the correct catenary curve, as a light pencil sketch on the 1814 section shows (fig. 6). Taking a second aspect of the structural design, the form and behaviour of the trussed ribs, it is evident that the overall structure was conceived as a three-dimensional divided tie-beam truss, with the upright timbers of each opposing pair of half ribs forming the king post, the upper chords acting as the principal rafters, and the lower chords functioning as the tie beam (fig. 7).

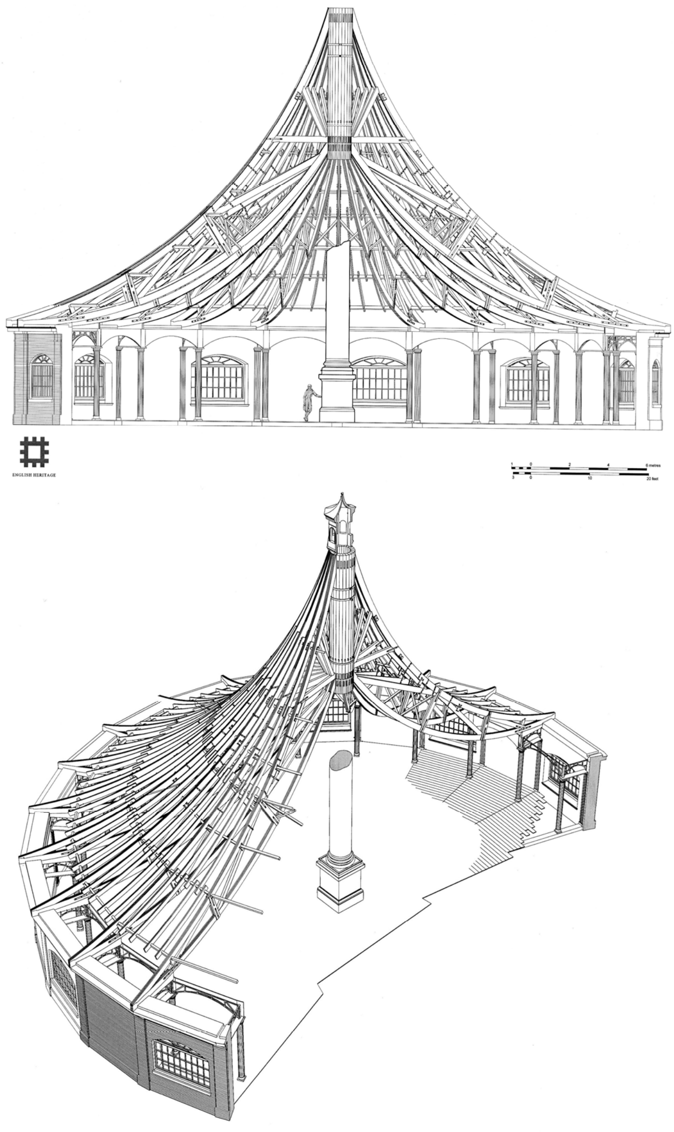


Figure 5. Section and Perspective views of the Woolwich Rotunda as it survives today. The central stone column was one of the last components to be added when re-erected in 1819-20, after the roof structure. Drawings by Andy Donald. [NB UNFINISHED DRAWING; COMPLRTED VERSION FEB 2006]

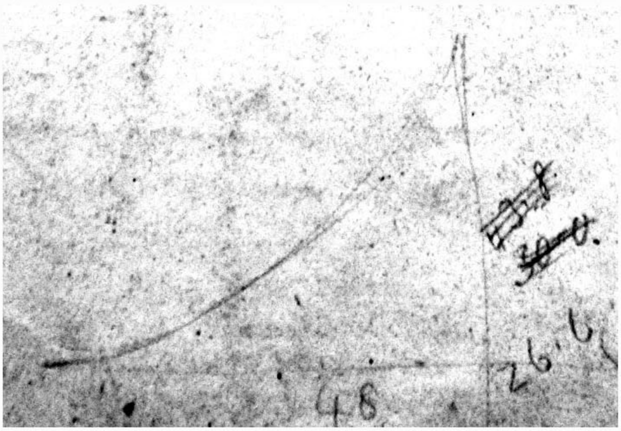


Figure 6. Sketch for a catenary curve on 1814 drawing (copyright National Archives)

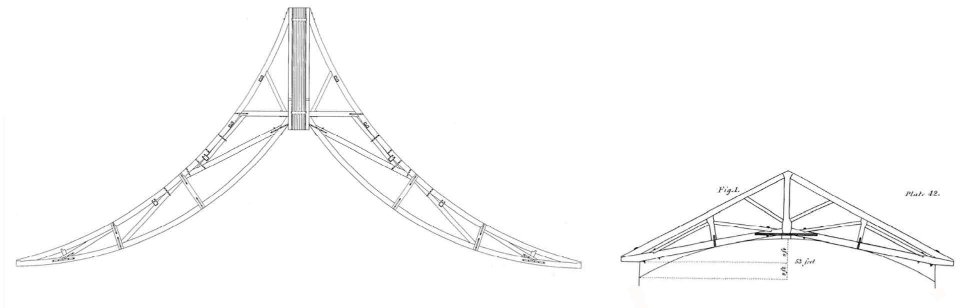


Figure 7 Divided tie beam truss arrangements in the Polygon Room (1814) and as illustrated in Asher Benjamin's *American Builder's Companion* (1811).

As Dr David Yeomans has shown, early nineteenth-century American carpenters seemingly devised and refined an ingenious trussed arrangement to accommodate raised ceilings, one that differed markedly from the usual British solution of raising the tie beam above the wall plate. The American architect Asher Benjamin, for example, illustrated a divided tie beam arrangement in the second edition of his *American Builder's Companion*, published in 1811 (fig. 7). By dividing the tie beam into two lengths and slanting each half upward to the king post, a higher ceiling could be accommodated without the problems associated with the raised tie-beam arrangement, the most acute of which was ensuring sufficiently strong connections to transmit the substantial tensile force between the tie and the principal rafters. But the major reason why Nash used the divided tie-beam truss for his Polygon roof was because, made up of two identical halves with a shared kingpost, it lent itself to a radial arrangement that eliminated the problem of intersecting tie beams. To have radially united 12 trusses of raised tie-beam configuration would have been almost impossible, and would not anyway have provided the requisite interior volume or curvilinear geometry.

Viewed in this light, the roof structure of the Rotunda is made up of 24 radial trussed half-ribs, bound together by their upright ends which form a giant shared king post. Notwithstanding the steeply concave upper and lower chords, the arrangement of each truss bears a noticeable similarity to that shown by Asher, which itself is loosely based around the king-post theme, with pairs of secondary posts and struts used to give support to the tie and strengthen the principals against bending. In both cases, the lower chord or tie beam provides restraint against the outward thrust of the principals, which in the case of the Rotunda is quite excessive, since, rather than being straight or curving inwards, it curves outwards. The weight of the seasoned timber roof structure alone, without canvas or boarded roof covering, is calculated to be in excess of 56 tons, and the outward thrust would have naturally tended to straighten out the ties. Thus the strength of the joints between the tie beams and the upright timbers forming the cylindrical king post, and the hoops binding these together, was absolutely critical to the success of the structure. Total reliance was placed on the ability of wrought iron to transmit and resist tensile forces at these points. Because of the inaccessibility of this part of the roof structure, it is unclear exactly how the tie beams are connected to the uprights, but a detail of Nash's original drawing suggests that heavy bridle straps and long coach bolts were essential (fig. 8). With the half-ribs given stiffness in their own plane by circumferential purlins and diagonal braces, and restrained from spreading outwards by the divided tie beam, the weight of the roof was transferred vertically onto the double ring of wall plates, with, ostensibly, little need for these to contain thrust. Again, these, like much of the roof structure, are inaccessible to inspection, and it is possible that the individual plates forming them are strapped end-to-end, producing two continuous polygonal 'tension rings' that may resist any remaining outward thrust. However, the original drawings do not indicate any ironwork connecting the plates (fig. 9).

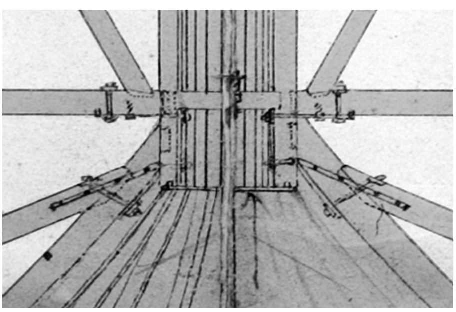


Figure 8. Detail of 1814 sectional drawing, showing ironwork used to connect the tie beams to the upright timbers forming the cylindrical kingpost

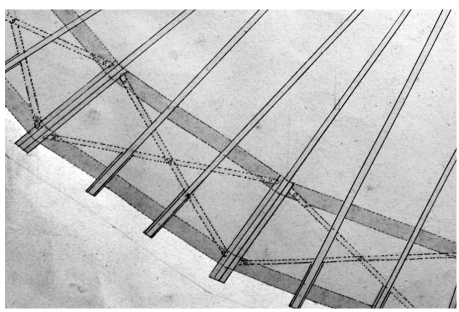


Figure 9. Detail of 1814 roof plan, showing triangularly braced double wall plate.

Figure 10. Forged-iron fishplate, used here to splice the laminated timber upper chord (Jonathan Clarke).

Figure 11. Inverted u-shaped iron stirrup, here fastening the laminated upper chord to two struts (Pat Payne, AA048109).

The third noteworthy aspect of the structural design is the use of laminated timber and specialised iron fasteners or connectors. The upper and lower chords are made up from four layers of vertically laminated planks, strapped together so that the inner two break joint with the outer ones. The posts and rafters are also made from laminated timber, although in just three and two thicknesses respectively. Curiously, the 1814 drawings make no indication of laminated timber, although we must presume it was original to the design since there is no indication in the accounts of the re-erection that the ribs were modified or replaced. The 1814 roof plan also shows a different arrangement of rafters, and it would seem that there must have been a slight modification to the design after May 1814 when the plans were drawn, due perhaps to the practical advice of one of the carpenters involved at Carlton House, if not Nixon possibly John William Hiort (1772-1861), who Nash employed as Clerk of Works and Measurer (PRO WORK 6/27, f. 239). The use of laminated timber was a logical choice for the upper and lower chords as it gave them the necessary polygonal curvature without compromising structural continuity. Forces were transmitted from one plank to the other by a combination of direct timber-to-timber frictional bearing and the bearing on the coach bolts that passed through the connecting straps. Some of these connectors seem to have been specially designed for the purpose, including forged shaped fishplates (fig. 10), and Y-shaped two-way straps, used to connect the lowest brace with the foot of the lower chord (figs. 3, 5 & 7). For the most part however the planks were simply clamped and bolted together at the points where the posts and struts are joined to the chords, with the more usual bolted iron stirrups passing over the heads and feet of the posts, and over the back of the upper chord around the struts (fig. 11). Although the structural necessity of passing the straps over the back of the upper chord is questionable, it made sense practically, since the flat base of the inverted stirrup ensured vertical alignment of the roughly-hewn planks, creating a flush surface for the boarded casing. Passing the u-shaped pieces of iron over the foot of the posts was however structurally imperative, since they slung up the lower chords. Here, the use of laminated timber came into its own, for the outer pair of planks forming the posts were lapped over the innermost plank of the lower chord and the feet of the struts, enabling forces to be transmitted by both bolts and direct timber to timber bearing. Somewhat inelegant of appearance, it nonetheless avoided complex carpentry joints, and was therefore ideally suited to use in structures intended to be demountable, and where construction was in any case designedly hidden from view. A similar jointing technique with doubled posts of this type was used by William Wilkins in the roof over the hall at Downing College, Cambridge, erected some time between 1807 and 20. (Yeomans 1992, p. 171).

STRUCTURAL INFLUENCES AND RESPONSIBILITY

Illustrated forerunners

There is no known direct precedent for the Polygon Room at Carlton House. It was a highly innovative structure, a classic example of structural form following architectural appearance. That it took its catenoidal shape from military and festive tents there can be little doubt, as this was a form frequently on display in late Georgian Britain (**Fig 12**). But appearance was one thing, actually framing a large conical enclosure was another. Besides apprenticeship, the chief medium for the transmission and diffusion of structural carpentry techniques in the eighteenth and early nineteenth centuries were illustrated carpenter's manuals. As Yeomans has shown, besides providing instruction in the framing of roofs and floors, manuals of this period also dealt with elementary geometry and how it could be applied to the practical problems of setting out work (Yeomans, 1986). Francis Price, in the second edition of his *British Carpenter, or A Treatise on Carpentry*, published in 1735, illustrated a number of 'curvilineal Roofs of great Extent'. One of these, which he thought would suit as a round temple, gave a sweeping tent-like exterior, although the raised tie beam framing arrangement only allowed for a hemispherical interior (fig. 13). It is difficult to see how this trussed structure might have been realised three dimensionally given the problem of intersecting timbers, besides, it did not really resolve the problem of outward thrust, which Price thought was 'the chief difficulty to struggle with'. His solution was to reinforce the circular plate or curb by bolting a polygrammatic arrangement of timbers to it in the horizontal plane, an inelegant countermeasure that would have diminished the openness and circularity of the interior. A similar design appeared later in the century, within the 1769 edition of William Pain's *The Builder's Companion and Workman's Director* (Fig. 14). Pain was perhaps the most prolific British author of carpentry manuals in the late eighteenth century, and one of the hallmarks of his work was clarity of constructional detailing. Like Price's design, on which it was certainly based, this was essentially a raised tie-beam truss, embellished with additional principals, both curved and straight. But this design came closer to producing a conical interior that more closely mirrored the exterior, and it showed the widespread use of iron strapping rather than the pegged joints and bolted connections of Price's drawing.

It was, however, the thinking of the period's most accomplished British carpenter that most directly informed the structural design of the Polygon Room. Peter Nicholson (1765-1844), the prodigious and influential carpenter-mathematician, produced a design that seems, with the benefit of hindsight, to have broken new ground. First illustrated in his *Carpenter's & Joiner's Assistant* of 1797, his design for a "circular building" simultaneously solved the problems of outward thrust, intersecting members and of preserving interior volume and shape (fig. 15). What he proposed was a radial array of half trusses, their tie beams connected to the foot of a central shared king post via a multi-armed iron strap. In this case eight tie beams could be united, but, as he put it, the iron strap could consist of 'as many branches as there are tie-beams to be united'. With the strap firmly bolted to the king post, and with the tie beams firmly bolted to the strap, the whole structure would, according to Nicholson, be 'render[ed] … secure and permanent'. It was an adroit divided tie-beam arrangement that, thanks to the iron strap, connected the two halves of each opposing tie as well as the ties to the king post. However, it did not explain how the principals were united around the head of the king post, and it can only be presumed that a similar iron connector was to be employed there also. For stability it also required that the lowest struts were extended below the tie beams to brace against the polygonal walls, circumscribing the open space below the wall plate. Nevertheless, the innovative design continued to be published in subsequent editions of the *Carpenters & Joiner's Assistant* (Nicholson 1804, 1810, 1815, 1826a) and in other works by Nicholson (1826b), as well as being appropriated by others as late as 1843 (e.g. *Penny Cyclopaedia*, 1843, p. 147). The designers of the Polygon Room would thus have had ample opportunity to see Nicholson's design before May 1814, when the unsigned drawings of the Polygon Room were produced.

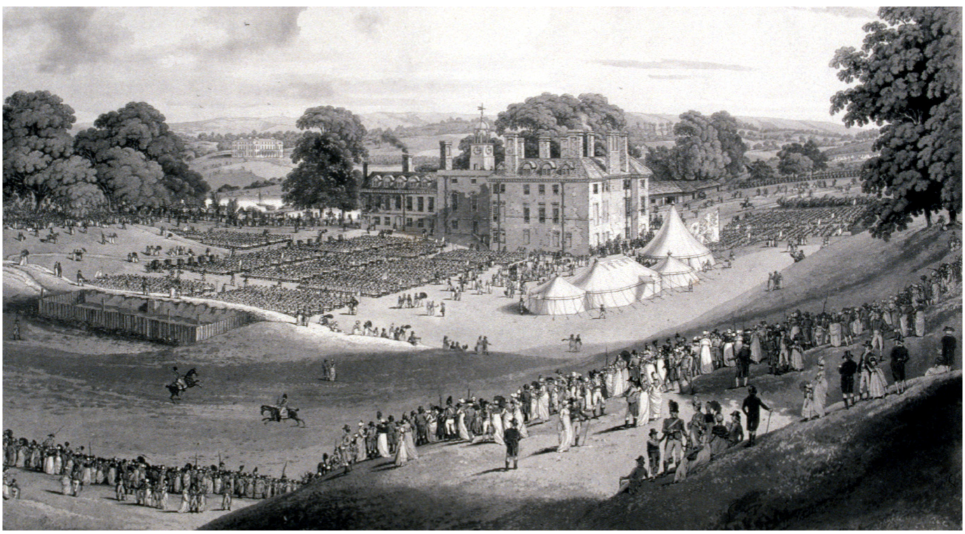
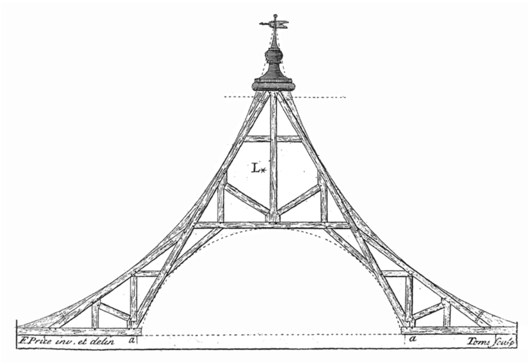
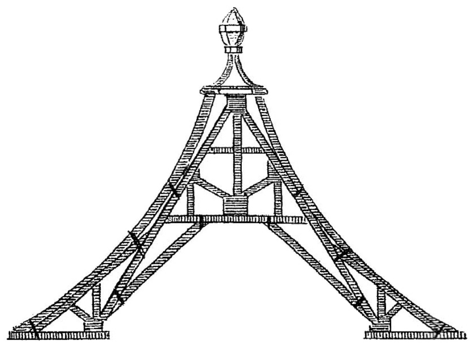


Figure 12. Marquees, including a giant bell tent, erected for an event for the Kentish military volunteers held at Mote Park in 1800, in the presence of the Royal Family. Engraving by Alexander W. Medium; © British Library, Maps K. Top. 17. 48.





Figures 13 and 14: designs for framing circular temples, that on the left illustrated in Francis Price's *British Carpenter* (1735); that on the right in William Pain's *The Builder's Companion and Workman's Director* (1769). Both are elaborations of the raised tie beam truss.

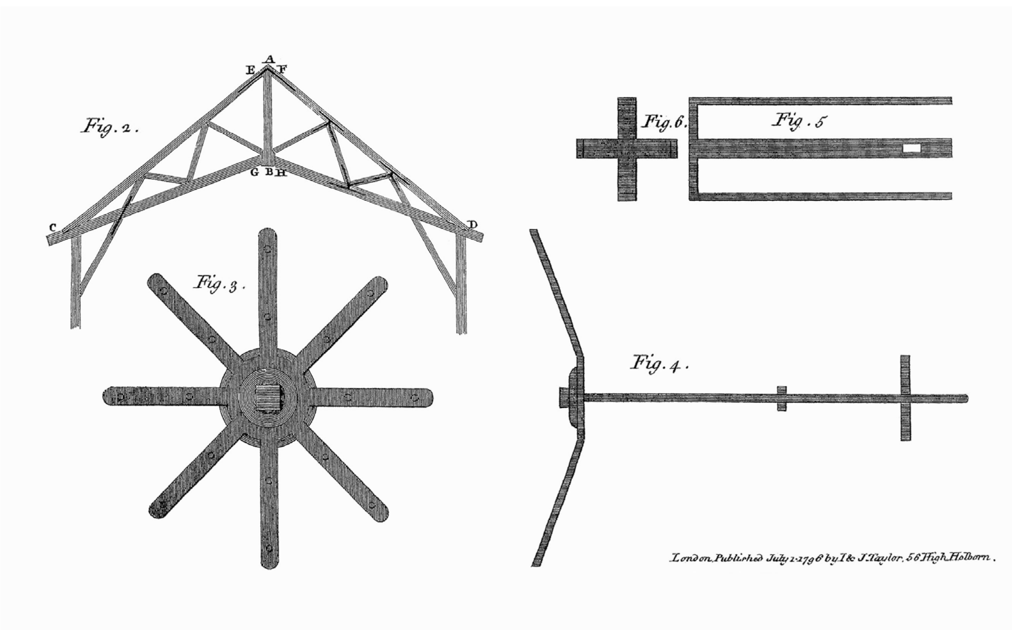


Figure 15. Peter Nicholson's design for framing a circular building. As well as being the first recorded example of a divided-tie beam truss, it incorporated an ingenious iron device for uniting the 8 tie beams with the king post. *Carpenters & Joiner's Assistant* (1797), plate 77.

Who designed the roof: Nash or Nixon?

Responsibility for the structural design of the Polygon Room is unclear. This is partly because the distinction between architect and carpenter was still blurred in the early nineteenth century, and partly because Nash was consistently at the forefront of architectural technology. He started out as a carpenter-architect, designing for example a new double roof for St Peter's Church, Carmarthen, in 1785 (with a young architect called Samuel S. Saxon), and by the beginning of the nineteenth century when he had reached gentleman-architect status, he was well practised in both structural carpentry and iron construction (Summerson 1980, p. 10). Nash was experienced in timber-dome construction, giving, for instance, Caledon House, County Tyrone, two domed extensions *c*.1812. When one of these domes began 'swagging', he gave explicit remedial instructions to the owner, demonstrating both his appreciation of timber shrinkage and the value of iron straps:

> the construction by which the dome is supported is capable of sustaining treble the weight... I am of opinion it will be found that the timbers have shrunk which all timbers will do - & that screwing them up into their place again will bring the whole right again - it is also possible that the carpenter who fixed the framing may have neglected to wedge it up tight or may have omitted the Iron straps. ...'
>
> (Nash 1815).

Near the end of his career Nash maintained that "No founder ever furnished me with a design for any casting I ever used". Summerson thought that "Nash was the last English architect to consider himself not only an architect but an engineer" (Summerson 1991, p. 15).

Nash's proficiency in structural design is only half the story, for T. F. Hunt wrote in 1830 that the roof of the Rotunda "was designed or invented by, and executed under the direction of, the late William Nixon, a modest and retiring man, of rare worth and talent" (Hunt 1830, p. 97). Unfortunately, Hunt is not entirely reliable, and may have conflated the London carpenter William Nixon (d.1826) with a Carlisle-based builder and surveyor of the same name, who died in 1824. A later edition of the book, published in 1836, says that he came from Carlisle and designed the county gaol there, shortly before his death; there is no evidence that Nixon the carpenter worked in the north. In fact very little is known of Nash's William Nixon at all. Trade directories show that two carpenters, William Nixon and William Nixon Jnr. (presumably father and son) were working from Cockfosters, Enfield Chase, in 1808 (Holden 1808). By 1811 James Wyatt, Surveyor General, had made Nixon a superintendent of works at Carlton House. It was there that Nixon came into Nash's orbit, and into the employ of the Office of Works, through which he was clerk of works at Brighton and general superintendent at Buckingham Palace. In his will of 1826, written from St James's Palace, he bequeathed his architectural books to his two sons, William and Charles Nixon (PCC PROB 11/1725). He had clearly developed an excellent working relationship with Nash, one of his executors, over the last fifteen years of his life. Nash paid tribute to Nixon for his work at Brighton in a letter of *c*.1821, declaring him 'the most diligent attentive and the most honest

Clerk of the Works that I have ever met with' (Summerson 1980, p. 106). His son, William Nixon Jnr. (d.1848), who eventually headed the Office of Works at Edinburgh, enjoyed an even closer working relationship with Nash, and was probably employed as Nash's agent and clerk of works on the Isle of Wight. (Pinhorn 2000, pp. 122-3; Crook & Port 1973, p. 707).

Figure 16. The Woolwich Rotunda's 24 individual bevelled king posts, strapped together with hinged iron hoops, and fortified against timber shrinkage by wedges and packing pieces. Barrel making might have inspired this arrangement. (Jonathan Clarke).

The structural design of the Polygon Room must have been intensely collaborative at all stages. As we have seen, in 1818 Nash stated that Nixon built the Rotunda 'under my directions' (PRO WORK 19/11/5, f. 39. This leaves scope for Nixon to have resolved detailed aspects of the structural carpentry, such as the ingenious method of connecting 24 half trusses using beveled kingposts, hoops and wedges (fig. 16). This practical modification of Nicholson's contrivance was probably derived from experience or knowledge of coopering or timber winding-drum manufacture. Nixon probably had more need, and more opportunity, to keep himself abreast of developments in structural carpentry. He was no doubt familiar with Nicholson's work if not the man (Treve Rosoman 2004 and pers comm.). Nixon may even have introduced the idea of divided tie-beam trusses, as the only practical means of structuring the interior catenoidal form that Nash wanted. It should, finally, be remembered that on top of other commitments Nash had to design 15-20 temporary buildings in less than three months. He cannot have devoted much time to any.

CONES AT BRIGHTON

In 1815, the year after the Carlton House fête, Nash began remodeling the Brighton Pavilion for the Prince Regent. His preliminary design for the east front was a somewhat uninspired affair, with a large onion dome in the centre, flanked by smaller, squatter domes either side. The design that was erected in 1817-20 is the celebrated medley of domes, cones and minarets that survives today, with two sweeping concave tent-roofs balancing the central convex dome. Nash stated that he had placed both designs before the Prince Regent in 1815, and that the Prince chose the conical version, even though it was more expensive. Some historians, however, maintain that the final solution was only arrived at during the course of building work in 1817 (e.g. Jackson-Stops 1991, p. 28) Whatever the truth of the matter, the tented roofs over the music and banqueting rooms were direct progeny of the Polygon Room, smaller, but in some ways more refined. Brighton's the two soaring conical timber frameworks span 40ft between wall plates, each being made up of 20 radial laminated timber half-ribs strapped together by their upright inner parts (fig 17). For these lower, flatter ceilings it was possible to tie the lower chords with collars, accomplished by an 20-armed bolted-timber armature that avoided problems of intersection. The feet of the ribs are seated on cast-iron brackets, which project from a timber wall plate that in places is strengthened by iron beams, and which is variously carried on timber squinches, flitched beams and brick walls. This complex 'flying wall plate' construction seems to have been designed to counteract, or safeguard against, the spreading of the timbers. But the most surprising difference between these structures and their prototype is the absence of members connecting the lower and upper chords. Each half-rib has just two posts, the upper, which is accessible to view, being of doubled form, like in the rotunda, with timber bridging pieces between (fig. 18). This paucity of web members is possible because the laminated upper and lower chords were considerably stronger, made up for the most part of five thicknesses of closely fitting planks. Only in the higher part of the upper chords did they reduce in thickness to three planks. Consequently, the laminated chords are better equipped to resist bending, with less need of support along their length. Unlike in the Rotunda, the planks were cut to the required curve, and, it is worth noting, the overall quality of carpentry is greatly superior.

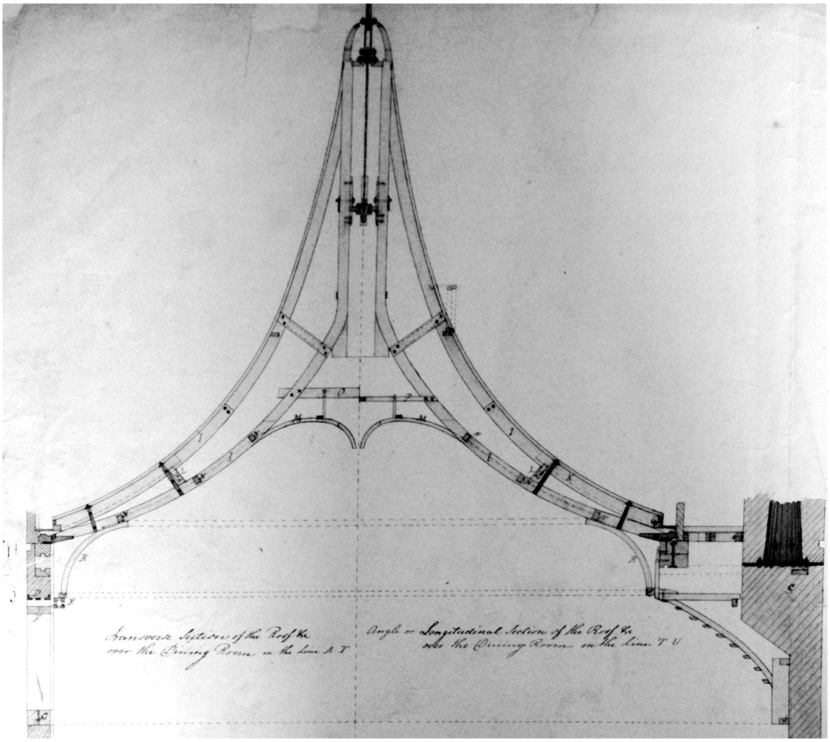


Figure 17. Section through Banqueting Room roof, Brighton Pavilion, drawn up William Nixon, 1827. (By courtesy of the Royal Pavilion, Brighton).

Figure 18. Upwards view towards the apex of the laminated-timber roof over the Music Room, Brighton Pavilion. The inclined members are the array of upper struts, joining the upper and lower chords (Derek Kendall).

Perhaps Nash placed greater reliance on the inherent strength of laminated timber chords, rather than trussing, because he had seen William Porden's remarkable Brighton stable block (fig. 19). Erected in 1803-8, this 80ft-diameter dome was framed using twenty-four vertically laminated timber ribs each measuring just 12 inches by 9 inches at the bottom, diminishing to 9 inches square at the top. Porden, a pupil of James Wyatt and a friend of Nash, had based his design on the celebrated dome of the *Halle au Blé* (Corn-market), in Paris (Brayley 1838, p. 16). That structure, erected in 1782-3 by master cabinet-maker A. J. Roubo to designs by J. G. Legrand and J. Molinos, was itself the first major exemplar of the technique in over two centuries, reviving and improving methods pioneered by Philibert de L'Orme (*c*.1510-70) (Wiebenson 1973). The acclaimed French dome even inspired Thomas Jefferson to give his home, Monticello, a laminated timber dome in *c*.1800, thereby introducing the technique to America. (Beiswanger 2005). Nash himself never got to see the *Halle au Blé* during his only recorded visit to Paris in 1814, as it had already burned down. He did, however, see and admire its replacement, a virtual facsimile in cast iron, and it is tempting to think this might have inspired the elaborate iron structure framing the Pavilion's centerpiece, the great dome over the Saloon. Curiously the drawings for this, like so many of the others held at Brighton, are not signed by Nash, but carry the words 'Drawn by William Nixon, 1827' in the corner. Could this be Nixon junior, putting the record straight?

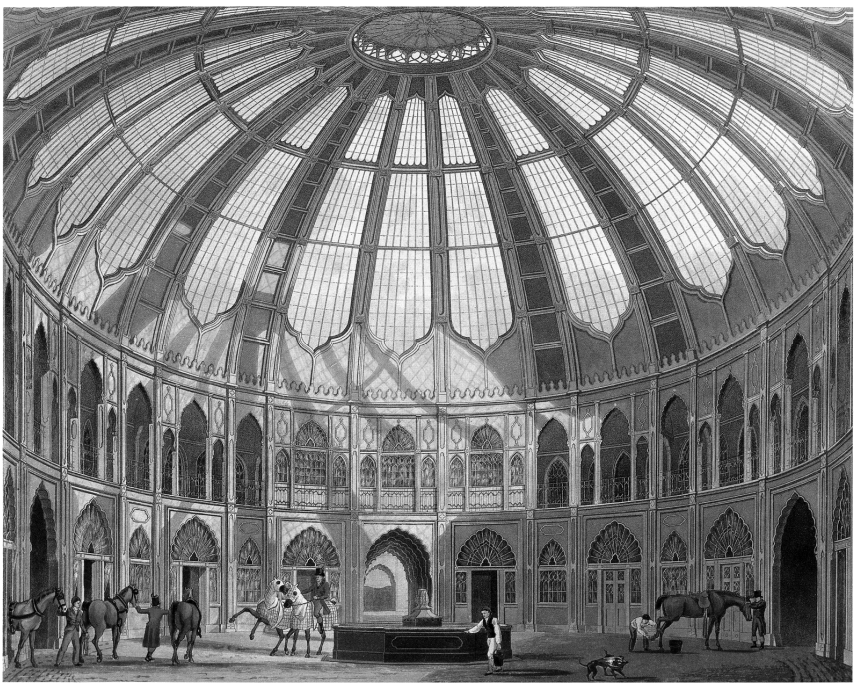


Figure 19. View inside the central Rotunda, part of William Porden's Riding School and Stables, Brighton Pavilion, erected in 1803-8. This dome was probably the first large-scale use of laminated timber in Britain (Brayley. E.W., *Illustrations of Her Majesty's Palace at Brighton, London*, 1838).

CONCLUSION: REGENCY STRUCTURAL INNOVATION

The early nineteenth century was a highly experimental period in the history of building technology, not just in terms of iron construction, which was taking bold strides, but also in timber engineering. The Woolwich Rotunda, or Polygon Room, embodies a number of progressive strands in late Georgian structural carpentry. Techniques of timber lamination, of specialised trussing, and of three-dimensional framing were all harnessed to create a new type of roof structure, the freestanding catenoidal enclosure. To this end, Nash and Nixon seem to have drawn on the somewhat abstract example devised by Nicholson, but in taking its guiding principles into the real world, they contrived their own technique of binding the whole structure. The similarity in the trussing arrangement of their half ribs to that depicted by Benjamin Asher in 1811 is palpable. But independent invention spurred by similar circumstances is more likely than any westerly transatlantic transmission of ideas. According to Yeomans, New England carpenters adopted the divided tie-beam truss largely because their churches and meetinghouses were timber walled, and hence unable to withstand the outward thrust of low-pitch roofs. Similar conditions prevailed briefly in the grounds of Carlton House, where a suite of semi-permanent panel-walled structures was erected, one of which still survives - though more by accident rather than design.

ACKNOWLEDGEMENTS

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