5.04 Roof Framing

a. eaves joist construction
b. the dragon beam
c. the bow and string beam
d. sarking
e. the sawtooth roof
f. barrups
g. the steel square

Roof framing in Australia is more diverse in origins, and more innovative in its development, than one might expect. But it is mysterious territory, for it is hard to find any writing which seriously treats any aspect of it, and what little there is tends to be misleading.

Morton Herman has claimed that in general colonial practice the roof was framed merely by resting the ends of the rafters on the walls with no horizontal tie, whilst the ceiling joists rested independently upon the same walls. The spreading tendency was resisted by making the walls thicker, except where 'pole-plate construction' was used to turn this outward thrust into a vertical component.[1] Herman does not cite a single example, nor explain what he means by this semi-miraculous pole-plate construction. Subsequent writers such as Freeland, who calls it an 'open-couple roof',[2] have repeated Herman's basic claim, again without citing any example. However there is not the slightest evidence for this, either in primitive structures like the shed at 'Hadley Park' of about 1806, or in public buildings like the Hyde Park Barracks.

Whilst it is impossible to prove the negative, the fact remains that countless colonial frames are known which do not exhibit these characteristics, and there was no reason why they should. The principle of tying rafters was well understood in Britain, right down to a vernacular level. The ease by which a ceiling joist could be connected to the rafters made this an even more likely solution. There was, however, an occasional practice in Britain of relying only upon a collar tie, with no full tie across the base, and it is likely enough that this occurred in Australia. The rationale was to give more head room in buildings where the walls were low, but it was a practice unsuited to larger spans. As John Wood expressed it

> Cottages should not be more than TWELVE feet wide in the clear being the greatest width that it would be prudent to venture the rafters of the roof with collar pieces only, without danger of spreading the walls; and by using collar pieces there can be fifteen inches in height of the roof thrown into the upper chambers, which will render dormer windows useless. The collar pieces will serve for ceiling joists; and the small portion of the roof, that is thrown into the

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1 Morton Herman, *The Early Australian Architects and Their Work* (Sydney 1954), p 121 & note 4, p 235.

2 J M Freeland, *Architecture in Australia - a History* (Melbourne 1968), pp 12, 319.

> room, will not create those inconveniencies that attend rooms, which are totally in the roof.[3]

At the Van Diemen's Land Company establishment, 'Highfield', in Tasmania, the supposed chapel of 1842, has closely spaced pairs of lightweight rafters, each with a collar tie half way up, whilst the stable of 1836-7 has a system which is similar but that it is built out to create a curve on the underside, to carry what must have been a very handsome boarded barrel vault ceiling.[4] This system is illustrated by Francis Price, in four versions,[5] and by Peter Nicholson, without comment.[6] However R G Hatfield, in *The American House-Carpenter*, condemns this form of roof, for 'the small height gained by the omission of the tie beam can never compensate for the powerful lateral strains exerted by the oblique position of the supports, tending to separate the walls.'[7]

It cannot be stated with certainty that these frames were prefabricated In England, but many of the building materials were brought out by the company, and this seems likely enough. In the case of 'Woodlands', Tullamarine, Victoria, there is no question because the house was manufactured by Peter Thompson of London in about 1841, and built on site in 1843. The roof trusses - or rather assemblages, for they are not triangulated - are close-set and extremely light. The spacing is 545 mm in the house, and 475 mm in the stables, and the members vary between about 60 x 30 and 80 x 25 mm.[8]

A former stable building at 'The Ridge', Rosedale, Victoria, has some mysterious and unexplained features in the roof structure, including small angle braces at two locations. The roof is hipped, and the end slope includes one rafter aligned with the ridge. Just below the meeting point, short braces angle across to the hip rafters. There are three purlins to the slope, and the first set of these, a quarter of the way up, also have small braces running across to the hip rafter. In addition there are strange chock-like objects straddling the hip rafters, one in the bottom panel of the slope and one in the third.[9]

a. eaves joist construction

The most mysterious local form of framing is what I shall here call 'eaves joist construction'. This seems more descriptive than the term 'minor joist construction'

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3 John Wood, *A Series of Plans for Cottages or Habitations of the Labourer* [London, 1806 [?1781]), p 6: see also Miscellaneous plate U.

4 Forward Consultants, *The Highfield Conservation Report* [mimeograph report [Hobart] 1983], pp 8, 27, 35, 88-9; Miles Lewis, *Highfield, Circular Head, Tasmania* [mimeograph report (Melbourne) 1986], passim; Miles Lewis, 'Highfield and the VDL Company', *This Australia*, V, 3 (winter 1986), pp 21-2.

5 Francis Price, *The British Carpenter, &c* (London 1733), pl K.

6 Peter Nicholson, *Nicholson's New Carpenter's Guide* (enlarged edition, London 1825), I, pl AA & p 97.

7 R G Hatfield, *The American House-Carpenter* (New York 1852 [1844]), p 163.

8 Peter Lovell, *Woodlands Homestead Complex* [mimeograph report, Melbourne 1981], pp 13, 112.

9 Inspected 2001.

which I once tentatively adopted,[10] or 'jack joist construction' as previously used by myself and others, which has the potential to be seriously misleading.[11] Nor do I adopt the term 'cantilevered roof truss', used by R L Katzenberg in the United States, for the distinctive feature is not the roof truss, which cantilevers to form an eave in various other forms of construction: it is the treatment of the intermediate rafters and joists.

This construction first appears locally in Francis Greenway's Hyde Park Barracks, Sydney, of 1817-19. The side eaves of the pitched roof are carried out on short joists which are not continuous across the roof span in the fashion of ties. The natural result of this would be that the outer ends would drop under the load of the rafters resting upon them, and the inner ends would therefore see-saw upwards. To counteract this, however, the inner ends are restrained by a horizontal member running at right angles, or parallel with the wall. In the Barracks this member runs above the ends of the joists in a rather ad hoc way, as if it were the result of an alteration, or at least a change of intention during construction. In other examples it is normally in the same plane, and the joists are mortised and tenoned into it. This member runs from one truss to the next, and as each truss has a continuous horizontal bottom chord, it can receive the upward force (and can, at least in theory, have its performance enhanced by it).

The barn at Throsby Park, Moss Vale, was built before 1828, and not only is it built on this same system, but it also has the remains of the same false pediment treatment at the end as does the Barracks. Rachel Roxburgh refuses to accept the main triangular assemblies as trusses, and she describes the roof construction as follows:[12]

> three large strutting beams span the building from side to side. The outer ends of the rafters are supported on a pole plate carried on cantilever jack joists, the other ends of which are tied down about 18 inches inside the walls by stringers spanning between the strutting beams. The whole structure is further strengthened by short struts between the strutting beams and the rafters.

The same roof construction appears later in the barn at Browley, a few kilometres away, built by John Waite, an associate of Charles Throsby.[13] The same system is

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10 Miles Lewis, 'Against the Grain', *Historic Environment*, VI, 2 & 3 (1988), pp 7-8.

11 'Jack joist' is the term used by Roxburgh, infra, but is misleading because these joists are not the equivalent of jack rafters. Jack rafters are those which are shorter than the standard roof rafter because they run up to a hip. Thus they very in length from almost nothing up to almost the standard rafter length. The form of joist that various analogously, and might therefore be called a 'jack joist', is found in a traditional English box frame with an upper level jettied or corbelled out on at least two adjoining faces. This is achieved by having a major joist on the diagonal extending out from the corner of the building - the horizontal equivalent of a hip rafter. The joists of varying length which run in from both sides of this would be the horizontal equivalent of jack rafters - hence jack joists.

12 Rachel Roxburgh & Douglass Baglin, *Colonial Farm Buildings of New South Wales* (Adelaide 1978), p 92. For the dating Roxburgh cites Colonial Secretary In-Letters re Land, Throsby, Archives Office of New South Wales. This pedimented building form seems to have been a standard type, and another example is the early flour mill at Mt Gilead, Campbelltown, New South Wales, though I know nothing of the nature of the roof construction. Illustration in the National Library, Canberra, reproduced in D I Stone & D S Garden, *Settlers and Squatters* (Sydney 1978), p 37.

13 Roxburgh & Baglin, *Colonial Farm Buildings*, p 107.

used, again with false pediments, a mill at Goulburn of 1836, later the Windy Willows Brewery, which some believe to have been designed by Greenway, for it is very much in his style. It is also used in outbuildings, possibly dating from the 1830s, at Old Wesleydale, Cholmondley, Tasmania. Here the freestanding buildings have hipped roofs, so the question of a pediment does not arise.

The house prefabricated in Sydney for the use of James Busby, first government resident in New Zealand, and today known as the Waitangi Treaty House, has been claimed to have similar eaves joist construction, but it is unclear to what extent the roof was rebuilt in 1936, so that one cannot rely upon it for detailed information, and it now has ashlar pieces (as defined below) transmitting load vertically from the rafters to the walls. It was designed by John Verge in 1831-2 and then modified by Ambrose Hallen, but whether the detailed roof construction was the responsibility of either architect or of a carpenter, is not apparent. Clive Lucas, who has made the claim, also asserts that eaves joist construction is a perfectly normal form in colonial architecture, but this has yet to be substantiated.[14] One later though undated example is a barn at 'The Mains' on the upper Murray, which has trenail joints, dragon beams at the corners, and true eaves joists, though with little or no eave overhang.

Traditional British roof trusses do include short horizontal members like joists running in from the eaves. However, the common form has the eave projecting hardly at all, and these members extending across the thick masonry of the wall. Far from being indirectly restrained at the inner end, in the manner described above, there is a short strut known as an 'ashlar piece' running vertically from this inner end up to the rafter or raking roof principal.[15] What is created is merely a small triangle resting on the wall member, and the base of this is better described as a bearing plate than a joist. The same basic system is found in Australia, probably far more commonly than eaves joist construction, and two examples are the barn at 'Caoura' near Marulan, New South Wales, probably built in about 1840,[16] and the stables at G H Cox's house 'Burrudulla' at Mudgee, of 1864. Both are 1½ storey structures, and the architect's drawings for the latter survive.[17] There is no tie across the base of the rafters, and there are short joists returning in from the eave, but they extend only as far as the inner face of the wall. At this line there are ashlar pieces which transmit the weight of the roof downwards, but there is none of the distinctive see-saw arrangement of the eaves joist form.

In Canada, and allegedly in Europe, this form of construction may be extended so that the horizontal member creates a distinct eaves overhang on the outside and also projects substantially inside,[18] but the vertical strut at the inner end nevertheless

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14 Personal discussion with Clive Lucas, 19 July 1990. Lucas has cited a number of other buildings as having the same construction, but upon further questioning they appear to be different in principle, mostly with short joists at the short end of the roof, at right angles to the main trusses or principals, which is a perfectly common and almost unavoidable detail in a hipped roof.

15 D T Yeomans, *The Trussed Roof* (Aldershot [Hampshire] 1992), pp 14-15. Yeomans illustrates two forms, one of them in connection with scissor trussing at Ely Cathedral.

16 Roxburgh & Baglin, *Colonial Farm Buildings*, pp 110-111.

17 Reproduced in Rachel Roxburgh, *Early Colonial Houses of New South Wales* (Sydney 1974), pp 313-5.

18 Eric Arthur & Dudley Witney, *The Barn* (New York 1988 [1972]), p 138.

eliminates the see-saw effect and renders it quite distinct from the Australian form. One intuitively feels that the latter must be of British origin, but consultation with a number of British colleagues[19] has produced no evidence of its use in Britain. It can however be shown that the system evolved in Maryland, USA, and in fact one step in the evolution can om;y be found in France. Whether the development in Maryland was really an autonomous process, and whether it had any direct effect in Australia, are unanswerable questions.

One can take as a starting point a building in Fowey, Cornwall, which is thought to be of the fourteenth century or earlier, and which shows the ongoing influence of cruck construction.[20] Related to this is a house in Maryland, 'Ocean Hall' of 1703, in which the exterior walls are of masonry, but the roof (and attic) is framed with a pair of cruck-like rafters which bend down and inward at the base. Because of this curvature, short horizontal members are required to frame a straight line of roof slope out from the rafters, though they do not project past the wall at all.[21] A clearely related roof form appears in France and is illustrated in Pierrre le Muet's *Maniere de Bien Bastir* of 1643. It has the same quasi-cruck principals as at Ocean Hall, their feet falling within the masonry walls. Above are rafters which likewise rise from straight above the outer wall face, but in this case the top of the wall corbels a little further out, allowing a small length of rafter at a shalloweer slope, and creating a slight bellcast at the base of the roof.[22]

The house 'Cedar Park', Maryland, dates from 1702, and though it is slightly earlier than Ocean Hall shows a further stage of development. There are no curved or cruck-like principals, but as in le Muet's roofs the rafters are straight and run directly down to the line of the wall, and subsidiary rafters are placed over them at the base to create a bellcast profile, so that the eave is built out beyond the wall line. The underside of the eave is formed by short joists somewhat reminiscent those at Ocean Hall, but now projecting past the wall.[23] There is some logic in the system, because the true joists run at right angles between the principal ties, and the short joists are a rational way of building out from the outermost of these to create the eave. The final development in Maryland is when the complete system, just as used in Australia, is found in a stable building dating from some time between 1755 and 1795 at Thomas Owings's property, 'The Meadow', Owings Mills.[24]

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19 Sir Bernard Fielden, conservation architect; Mr John Sanday; Mr Peter Smith, all at Lausanne, October 1990.

20 Eric Mercer, *English Vernacular Houses* (London 1975), pp 78, 84.

21 Transverse section taken from the Historic American Buildings Survey measured drawings of 1976 by Gary Carson and Chin Hoang for the St Mary's City Commission and the Maryland Historical Trust, reproduced in H J Heikkenen & M R Edwards, 'The Key-Year Dendrochronology Technique and its application in Dating Historic Structures in Maryland', *APT Bulletin*, XV, 3 (1983), p 18.

22 Pierre le Muet, *Maniere de Bien Bastir pour toutes sortes de Personnes*, (Paris 1647), pp 103, 105; a number of similar roofs appear in smaller scale sections elsewhere.

23 Drawing by Gary Carson and Chin Hoang, in Gary Carson et al, 'Impermanent Architecture in the Southern American Colonies', *Winterthur Portfolio*, XVI, 2-3 (Summer-Autumn 1981), p 145. Cedar Park is dated to 1699 in E B Wilson, *Maryland's Colonial Mansions and other Early Houses* (New York 1965), p 127.

24 My information is from Roger Lee Katzenberg of Kann & Associates Inc of Baltimore, who has kindly provided illustrations: letter of 15 December 1992.

None of this is to assert that the Australian system derives from that of Maryland, which seems relatively improbable. Both may have derived from some British or Franco-British tradition as yet unidentified, probably in some provincial location which has attracted little attention, but it is not likely that the evolution took place autonomously in Australia in the short time available. Given that its first known use here is by Francis Greenway, it seems probable that research in Bristol and the West Country will shed further light on the matter.

b. the dragon beam

The 'dragon beam' or 'dragon piece' refers to a traditional English roof carpentry detail which is also found in Australia, but to most people the term evokes something quite different.

The term 'dragon beam' was first used in the seventeenth century in Godfrey Richards's edition of Palladio of 1663, to which we will return, but it has had a series of different meanings. Those which applied in the seventeenth and eighteenth centuries are somewhat unclear. Robert Plot, apparently quoting Christopher Wren, refers to 'two *Dragon* (perhaps rather *Trigon*) *Beams* or *Braces* lying under the *Joists*' of Wren's Sheldonian Theatre, Oxford.[25] They are in fact two diagonal beams running horizontally under the ceiling joists to form a V in plan over the rectangular portion of the building. They are clearly too slender to carry any significant vertical load, and are not really beams. As braces to resist horizontal distortion in the building they might be of some effect, though it is difficult to see how that could really be required in a masonry building on this scale. The more interesting question is why they were termed 'Dragon', and the solution is assisted by the reference to 'Trigon'.

A diagonal was also known as a *diagon,* as defined by Blount in 1656,[26] and Shute's *Architecture* of 1563 somewhat similarly stated that 'A strike ouerthwaite the great square from corner to corner, that line is named the Diagonus'.[27] It seems clear that in describing the Sheldonian the term *dragon* should read *diagon,* and as Wren himself is making a somewhat pedantic distinction, the error is less likely to be his own than that of his printer, or, more probably still, that of his transcriber Robert Plot. It seems that Wren (if he was indeed Plot's source) has thought it necessary to distinguish two diagonals which form a V or triangle, from a simple diagonal. A trigon was a three sided figure, or triangle, and one of its more particular meanings was a triangular instrument used in surveying and dialling [the design and construction of sundials].[28]

At this point we are confronted by a red herring. Richard Neve's *City and Countrey Purchaser* of 1703 (the first English dictionary of architecture and building) says

[25] Robert Plot, *The Natural History of Oxford-Shire: being an essay towards the Natural History of England* (Oxford 1677), quoted in Christopher Wren, *Parentalia, or Memoirs of the Family of Wrens, &c* (London 1750), p 336.

[26] Thomas Blount, *Glossographia, or a Dictionary Interpreting such Hard Words ... as are Now Used* (1656), quoted in the *Oxford English Dictionary.*

[27] John Shute, *Architecture* (1567), Div. a, quoted in the *Oxford English Dictionary.*

[28] Thomas Fale, *Horologiographia; the Art of Dialling* (1593), quoted in the *Oxford English Dictionary.*

'Dragon-beams are 2 strong Braces or Struts, that stand under a Bressummer, meeting in an angle upon the shoulder of the King-piece.'[29] This makes very little sense, as a 'king piece' or king post is not used under a bressummer. Joseph Moxon's *Mechanick Exercises,* published in the same year, gives the same definition except that it is 'upon' rather than 'under' the bressumer, which does make sense.[30] It therefore seems likely that Moxon was if anything the originator and Neve the imperfect copyist. Moxon's illustration is incompletely labelled, but in the key to it the dragon beams seem to be equated to struts. As they are to rest upon the shoulders of the king piece, it is clear that they are the angled struts within the king post truss which depicted in Moxon's illustration. Given that these are diagonal members the term 'diagon' or 'dragon' is perfectly reasonable, but is supererogatory as there were and are other terms, such as 'struts', in more general use to describe these members. Wren referred to them as '*Braces* or *Puncheons*'.[31]

Peter Nicholson was the first to challenge Moxon's definition - or in fact Neve's version of it - saying:

> The writers of the present work have never heard the term applied to story-posts and bressummers, nor have they been able to learn any such application of it; the word *beam* is improper for any piece of timber, that stands slanting as a brace or strut.

He surmised that Neve, being a 'philomath' rather than an architect or tradesman, 'might have been misinformed by the workmen, among whom he made his enquiries'.[32] This, however, is not a sufficient explanation, for Neve and Moxon were published in the same year, and seem likely to have drawn upon a common source as yet unidentified.

Although Neve was clearly wrong in placing the dragon beams under the bressummer, his definiytion was followed by others. Moxon's definition is repeated almost verbatim in Chambers's *Cyclopedia* of 1788: 'two strong braces or struts which stand under a breast-summer, and meet in an angle on the shoulder of the king-piece'.[33] Chambers's definition was in turn followed literally by Rees and substantially by Crabb, Harris and Weale,[34] none of whom seems likely to have had any idea of what it actually meant.

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29 Neve, *Builder's Dictionary* (1703), quoted in p 304.

30 Joseph Moxon, *Mechanick Exercises* (New York 1970 [London 1703]), p 160.

31 Plot, *Natural History of Oxford-Shire,* quoted in Wren, *Parentalia,* p 336. However, this itself is an unusual usage. Neve (2nd edition) sv *Punchins* [*sic*], defines them as short pieces of timber carrying a considerable weight, and standing between the posts (also 'door-punchins' on either side of a door).

32 Peter Nicholson [ed Edward Lomax & Thomas Gunyon], *Encyclopedia of Architecture, being a new and improved edition of Nicholson's Dictionary, &c* (2 vols, London 1852), I, p 304.

33 E Chambers, *Cyclopædia* (3 vols, London 1788), I, sv Dragon-beams.

34 Abraham Rees, *The Cyclopædia or Universal Dictionary, &c* (39 + ?6 vols, London, 1819), XII, sv Dragon Beams; George Crabb, *Universal Technological Dictionary* (2 vols, London 1823), I, sv Dragon Beams; W Harris et al, *The Oxford Encyclopaedia, &c* (7 vols, Oxford 1828), II, p 862; John Weale, *Rudimentary Dictionary of Terms used in Architecture &c* (London 1860), p 160.

It is the term as used by practical carpenters, relating to an element supporting the hip rafter, which is under discussion here. In all intelligible eighteenth and nineteenth century references, it term refers to a sort of aborted tie beam for the hip of the roof. A short brace runs horizontally at 45º in plan between the top plates at the corner of the building; from the middle of this and at right angles (that is, under the line of the hip) there extends to the corner junction of the plates a short member, which is mortised at the outer or corner end to take the base of the hip rafter. It seems to have had two purposes. The first is simply to provide a proper base into which this rafter could be tenoned, rather than running it uncomfortably at 45º onto the corner junction of the top plates. The other is to provide the restraint from outward spreading which the hip rafter otherwise appeared to lack, because it was not tied horizontally at the base like the common rafters. As John Wood expressed it, 'The diagonal piece is the abutment to the hip rafter'[35] - though this makes no real structural sense.

The short diagonal beam to take the base of the hip rafter seems to be widespread in Europe,[36] and its first quasi-appearance in England precedes the name 'dragon beam'. A hint of it appears in the spire of the thirteenth century church of St Mary Magdelene and St Mary the Virgin, Wethersfield, Essex. There the angle beam alone is present, with no diagonal brace to support it, because the plates are set in from the edge of the eave, and the proto-dragon beam is able to run back to their point of intersection.[37] The earliest true dragon beam is in the roof of Inigo Jones's Banqueting House, suggesting that it might have derived from Italy, like other aspects of Jones's roof framing. This seems persuasive because in England the use of the hipped roof form was exceptional in more formal buildings before the Renaissance, whereas in Italian and subsequent Renaissance work it was the norm. In the Banqueting House, however, it is not unique to the corners of the roof. A similar form of bracing is used also to receive the ends of alternate jack rafters in the end slope, being those which do not fall over a ceiling beam. This is a detail which has not been reported in other buildings.[38]

Just as the detail first appears in one of the first Palladian inspired buildings in England, so does the term for it appear in an English edition of Palladio. Godfrey Richards gives 'Rules for framing roofs' at the end of his edition, identifying 'Dragon beams for the hip to stand on'.[39] However this does not mean that Richards has derived the detail from Palladio, for he had not translated from Palladio's Italian but from Le Muet's French edition, which diverged considerably. Moreover Richards himelf had replaced Le Muet's roof designs with others drawn by William Pope of London, so it is possible that Pope was drawing upon British sources. On balance, however, the fact that the term is rarely linked to the detail for some time after Richards, suggests that they do not share a substantial British history.

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35 Wood, *Plans for Cottages*, p 12.

36 It is illustrated in G P Schillinger, *Der Zimmer Bau-Kunst* (Nürnberg 1745-8)), reproduced in Hugh Pagan, *Architecture Catalogue 44* (London 2002), p 42.

37 Hewett, *English Historic Carpentry*, p 86.

38 John Webb's record drawing of the Banqueting house roof, reproduced in D T Yeomans, *The Trussed Roof; its History and Development* (Aldershot [Hampshire] 1992), p 41.

39 Nicholson, *Encyclopedia of Architecture*, I, p 304 (see also p 82), cites the second or third edition of Godfrey Richards [ed], *Translation of the First Book of Andrew Palladio* (1676), p 230, which refers to figure or plate C.

Francis Price's *British Carpenter*, of 1733, does not refer to dragon beams or pieces, but simply to 'pieces upon which [the] hips are to stand'.[40] William Pain in 1763[41] and Abraham Swan in 1768[42] illustrate them but make no reference to them in their texts. John Wood in 1781 uses no special term, referring simply to a 'diagonal piece'.[43] However Batty Langley refers to 'dragon-pieces to receive the feet of the hip-rafters',[44] and the terms 'dragon beam' or 'dragon piece' were applied by Peter Nicholson and most of his successors.[45] In his *Encyclopedia*, however, Nicholson at one point gives separate definitions for the dragon piece, which is the piece for the foot of the rafter, and for the dragon beam. In attempting to explain the dragon beam he quotes Moxon, Neve and Richards, but unhappily concludes 'a proper explanation of the word ... has not been given.'[46] Elsewhere in the same work dragon beam is synonymous with dragon piece.[47]

Richards presents a rather strange diagram in which hips, common rafters and wall plates are all projected into one plane, and it shows no angle braces: instead his dragon beams appear to continue in at 45º and meet each other on the axis of the building.[48] They are thus full length diagonal beams, and might in principle have given rise to the misunderstanding that the diagonal of a jettied upper floor should be termed a dragon beam. The difficulty with that hypothesis is that two centuries elapses before that misunderstanding manifests itself, for after Richards all authorities concur on the short dragon beam and the angle piece. Price shows the standard

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40 Francis Price, *The British Carpenter, &c* (London 1733), p 12.

41 William Pain, *The Builder's Pocket-Treasure; or Palladio Delineated and Explained, &c* (London 1763), pl xxxvi & p 57.

42 Abraham Swan, *The Carpenters Complete Instructor, in Several Hundred Designs* (London 1768), plate showing ceiling plan.

43 Wood, *Plans for Cottages,* p 12.

44 Nicholson, *Encyclopedia of Architecture,* I, p 304, citing plate 2 of the Addenda of an unspecified Langley book, probably either *The Builder's Complete Assistant* of 1738, or *The Builder's and Workman's Treasury,* of 1741.

45 Peter Nicholson, *Nicholson's New Carpenter's Guide* [enlarged edition] (London 1825), pl xxxvi; [Peter Nicholson], *Practical Carpentry, Joinery and Cabinet-Making* (London 1839 [1826]), p 136; Robert Stuart, *A Dictionary of Architecture* (3 vols, London, no date [1832]), II, sv Dragon-Piece; J C Loudon, *An Encyclopædia of Cottage, Farm, and Villa Architecture, &c* (3rd ed, London 1846), p 1299 (referring only to 'dragon ties' or angle braces, which are metal straps, and not to dragon beams); Joseph Gwilt, *An Encyclopædia of Architecture* (London 1888 [1842]), p 616, §2009; S C Brees, *The Illustrated Glossary of Practical Architecture and Civil Engineering, &c* (London 1853), p 148; S H Brooks, *Rudimentary Treatise on the Erection of Dwelling-Houses* (5th ed, London 1882), pl XX (showing both elements but naming only the angle brace); James Newlands, *The Carpenter and Joiner's Assistant* (Glasgow 1861), p 260; E L Tarbuck, *The Encyclopædia of Practical Carpentry and Joinery, &c* (Leipzig, no date [?c 1860]), p 168; E S Eyland, Francis Lightbody, & R S Burn, *Working Drawings & Designs Architecture and Building* (Edinburgh, no date [c 1863]), p; John Ogilvie, *Imperial Dictionary, English, Technological and Scientific* (2 vols, London 1867), I, p 606; R S Burn, *Building Construction* (Glasgow 1877), pp 117-8; G L Sutcliffe [ed], *The Modern Carpenter Joiner and Cabinet-Maker* (8 vols, London 1903), VIII, p 418; George Collings, *Roof Carpentry* (London 1893), p 127; A C Passmore, *Handbook of Technical Terms Used in Architecture and Building, &c* (London 1904), p 120; Henry Adams, *Cassell's Building Construction* (London, no date []), pp 276-7; R V Boughton, *The New Carpenter and Joiner* (3 vols, London, no date [?c 1940]), II, p 32; W R Jaggard & F E Drury, *Architectural Building Construction* (4th ed, 3 vols, Cambridge 1945, 1946, 1947), III, p 241.

46 Nicholson, *Encyclopedia of Architecture,* I, p 304.

47 Nicholson, *Encyclopedia of Architecture,* I, p 499 & pl IV facing.

48 Nicholson, *Encyclopedia of Architecture,* I, pl 1 facing p 83.

pattern (at the corners of the building only)[49] and James Smith's *Carpenter's Companion* apparently does the same. However Smith reportedly shows all these pieces let into each other in the same plane, a horrendous proposition where the three of them meet at the corner, and one which was later regarded by Peter Nicholson as 'much inferior to the present practice, where both the angle-tie and the dragon-piece are fixed above the plates'.[50] The detail was standard in Britain throughout the nineteenth and up to the mid-twentieth century. R S Burn explains that the angle brace or 'angle tie' is used even in small buildings, whilst the dragon beam or 'dragon tie' is added in larger roofs, and is connected to the brace with a tusk tenon joint.[51] The detail continues to appear in twentieth century texts such as W B McKay's *Building Construction,* which, interestingly, illustrates an example in which the detail has a real function. The roof has a bellcast profile at the base, which has necessitated moving the bottom ends of the faters in from the edge, and without a dragon beam there would have been no proper fixing for the base of the hip rafters.[52]

Percy Thomas is exceptional in that he gives both meanings: the roof dragon beam and the diagonal cantilevered dragon beam.[53] Another exception is G L Sutcliffe, who presents a clearly erroneous diagram with no dragon beam, but an angle brace into which an apparently vertical hip rafter is mortised.[54] The *Shorter Oxford Dictionary* follows Nicholson, and Scott's *Dictionary of Building* gives a similar definition,[55] and the term 'dragging piece' appears as late as the 1950s in the fourth edition of Stubbs's *Building Encyclopedia,*[56] while elsewhere in the same work it appears simply as 'dragon'. The usage 'dragging' suggests an alternative derivation of the term as meaning a piece in tension, or a tie. But this has so far been found only in much later texts, and must be assumed to be a spurious back-formation.

In the United States the detail is hardly ever shown in texts,[57] but it occurs in 1820 in the drawings of the Sumter Courthouse, North Carolina, by the English-born architect William Jay,[58] and the term itself appears in Sturgis's dictionary.[59] The detail seems to be regarded as exotic in New Zealand, and Martin Hill, who has found it there, surmises that it was intended to strengthen the building against earthquake, notwithstanding the fact that he himself reproduces an illustration from an (unspecified) English text of 1780 which shows virtually the same detail.[60]

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49 Price, *The British Carpenter,* plates F & FG.

50 Nicholson, *Encyclopedia of Architecture,* I, p 89. In the somewhat obscure copy of the Smith illustration available to me: James Smith, *The Carpenter's Companion: being an Accurate and Compleat Treatise of Carpenter's Works, &c* (London 1733), pl 1.

51 Burn, *Building Construction,* p 118.

52 W B McKay, *Building Construction* (3 vols, London 1945 [1938], 1944, 194), I, p 75.

53 Percy Thomas, *Modern Building Practice* (4 vols, London, no date [c 1935]), II, p 448; III, p 374.

54 G L Sutcliffe [ed], *Modern House Construction* (6 vols, London 1909), I, p 152

55 John Scott, *A Dictionary of Building* (Harmondsworth [Middlesex] 1964), p 104.

56 S G B Stubbs [ed], *The Building Encyclopedia* (4 vols, London, no date [c 1955]), I, p 45, p 104.

57 The exception is a book which is clearly of English origin, though published in Philadelphia: P N Hasluck, *Cassell's Carpentry and Joinery* (Philadelphia 1912), pp 123, 125, 128.

58 H H Lerski, *William Jay* (Lanham [Maryland] 1983), p 178.

59 Russell Sturgis, *A Dictionary of Architecture and Building* (3 vols, New York 1901), I, p 823/4.

60 Martin Hill, *Restoring with Style* (Wellington 1985), pp 19, 21.

Both elements were used in a framed structure prepared in London for Collins's Australian expedition of 1803, and referred to as 'Dragging Tie Beams and Braces'.[61] An Australian specification of 1854 calls for 'diagonal and dragon pieces' to be four inches by three [100 x 75 mm].[62] A barn at 'The Mains', Upper Murray (probably soon after the mid-nineteenth century) has dragon beams but no angle braces. Because the roof is of eaves joist construction (as discussed below), it is possible to take these diagonal members in to meet at an angle with the longitudinal members running parallel with the walls. A grandstand at Kilmore, Victoria, has dragon beams and angle braces, both of which are pieces on the edge, rather than on the flat, with the brace partly let into the beam. Unfortunately it we cannot be certain whether the detail dates from the construction of the stand in 1873 or from its removal and re-erection at the present site in 1947. The Roman Catholic church at Morpeth, New South Wales, designed by J W Pender in 1877, had angle braces at the corners of the tower roof, which were probably associated with dragon beams, but this cannot be confirmed because the only drawing of the roof structure is from above, so that the dragon beams, if any, are concealed by the rafters.[63] A specification of 1878 for a bank in South Australia calls for 'Angle ties and Dragon pieces of 4" x 3" framed together, halved, and nailed to plates and hip pieces.[64] A store built in the 1880s at 'The Yanko', New South Wales, has an odd detail involving an angle brace and a dragon beam, plus a vertical strut rising from their junction to the hip rafter[65] - somewhat reminiscent of the medieval 'ashlar piece' in Britain.

The angle brace and the dragon beam, again appear in Nangle's *Australian Building Practice* from 1900 onwards,[66] and the most surprising survival of the form is in Norman Wallis's *Australian Timber Handbook,* published by the Timber Development Association in 1956.[67] The diagrams of house construction have angle braces too small to be of much use as braces, and not connected to the hip rafter by a dragon beam or any other means. This form of brace is a truly vestigial trace of earlier building practice. Elsewhere such angle bracing, in realistic sizes, had been very common, especially in buildings designed to be moved about. In Queensland, where it was still referred to as a 'dragon tie', it was used at both ceiling and floor level as an anti-cyclone measure.[68]

However most later twentieth century writers have appropriated the term 'dragon beam' (but not 'dragon piece') to apply to a diagonal corner beam used to carry a jettied floor out from two adjacent faces of a building. This usage can be traced to W

61 Robert Irving, 'The First Australian Architecture' (MArch, University of New South Wales, 1975), p 465, ref the account of the manufacturer John Cocksedge, Colonial Office 201/27, pp 111-112.

62 Russell, Watts & Pritchard, 'Specification for ... Dwelling houses ... at Elwood ... for Joseph Docker', 13 December 1854, Manuscripts Collection, SLV, p 8.

63 J W Pender, 'New Roman Catholic Church Morpeth', plan marked 'A', contract of 14 April 1897, in the Pender Collection of architectural drawings, Maitland, NSW [at Maitland when inspected in 1999, but due for removal to Newcastle University]

64 Reed & Barnes, 'Specification of Work to be done and Materials to be used in the Erection of Banking Premises at "Kooringa S.A." for the Bank of Australasia' (Melbourne 1878), p 17.

65 Inspected 1998.

66 James Nangle, *Australian Building Practice* (Sydney 1900), p 122; (4th ed, Sydney 1944), p 198.

67 N K Wallis, *Australian Timber Handbook* (Sydney 1956), p 292.

68 C J Virgo, *Australasian Building Knowledge*, vol II (Brisbane 1955), pp 72-3.

C Green in 1908,[69] but it probably became influential because it was taken up by C F Innocent. in 1916. Innocent writes as if as if the meaning were well established: 'The beam is called a dragon beam, and it has been assumed that this is an ignorant corruption of diagonal beam: more probably it is the beam upon which the joists seem to drag.'[70] Etymologically he is incorrect, and there seems to be no historical foundation for Innocent's definition of the beam. It probably arises from a misunderstanding of the nineteenth century meaning by Green or even earlier writers, which was taken up by Innocent, then by Batsford & Fry in 1934,[71] but which became general only in the 1960s.[72] The most authoritative recent work, J S Curl's *Dictionary of Architecture,* draws an elegant but factitious distinction, between a dragon beam, a dragon piece, and a dragon tie. The dragon beam is the diagonal of the jettied upper floor. The dragon piece is the short diagonal piece at the foot of the hip rafter. The dragon brace is an angled piece between a the beam and a wall plate, or between two wall plates, where it commonly carried the end of the of the dragon piece.[73] Unfortunately no such distinction is made in the historical sources themselves.

c. the bow and string beam

A somewhat distinctive innovation is found at Rottnest Island, Western Australia. In government buildings from the 1840s onwards a quasi-roof truss was created by cutting a beam half way through at the centre, making a smaller cut a little way in from either end, then splitting the beam horizontally from the central cut out to the end ones, swinging up the nearly-detached top pieces, and inserting a wedge between their ends so as to stabilise the shape as a flat triangle. This ingenious form required no nails or fixings, except possibly at the apex. The idea was taken up by R R Jewell, Clerk of Public Works in Perth, in his design for the governor’s house on Rottnest, in 1858.[74]

This was not the invention of the semi-literate Henry Vincent, Superintendent of the Native Establishment from 1839. It was a 'bow and string beam', which had been published in Britain in the *Transactions* of the Royal Society of Arts in 1820.[75] Somewhat similarly, in 1840, the *Civil Engineer and Architect’s Journal* reported a paper read to the Royal Institute of British Architects: one Laves took a forty foot

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69 W C Green, *Old Cottages & Farm-Houses in Surrey* (London 1908), pp 29-30, 33.

70 C F Innocent, *The Development of English Building Construction* (Cambridge 1916), p 165.

71 Henry Batsford & Charles Fry, *The English Cottage* (London 1938) p 28.

72 F W B Charles, *Medieval Cruck-Building and its Derivatives* (London 1967), p 12; R T Mason, *Framed Buildings of the Weald* (2nd ed, Horsham [Surrey] 1969 [1964]), p 106; John Fleming, Hugh Honour & Nikolaus Pevsner, *The Penguin Dictionary of Architecture* (Harmondsworth [Middlesex] 1966), pp 70, 161-2; J S Curl, *English Architecture: an Illustrated Glossary* (Newton Abbot [Devonshire] 1977), p 67; C A Hewett, *English Historic Carpentry* (London 1980), p ix (giving it as both a floor and a roof member); R J Brown, *Timber-Framed Buildings of England* (London 1981), pp 60, 61; Trudy West, *The Timber-Frame House in England* (Newton Abbot [Devonshire] no date), pp 41, 67, 90, 129.

73 J S Curl, *A Dictionary of Architecture* (Oxford 1999), p 212.

74 R J Fergusson, *Rottnest Island: History and Architecture* (Nedlands [Western Australia] 1986), pp 21-2, 26, 28, 37.

75 Wyatt Papworth [ed], *The Dictionary of Architecture* (London, published in parts, 1853-1892), sv Bow and String Beam.

[12 m] beam of fir and split it horizontally, except for the last metre at either end. He forced the split open with wedges, then inserted struts to keep the top and bottom apart in a lenticular profile. This clearly differentiated the tension and compression elements and considerably improved its performance.[76] Laves was the architect to the King of Hanover, and it was partly because his system was patented on the Continent that it was not taken up in Britain.[77]

d. sarking

The use of a boarded lining or sarking over the roof frame before the application of the roof cladding itself is standard European practice, whereas in Australia battens are the norm. The European practice has obvious advantages in terns of heat insulation, the physical support of some types of flexible roof cladding, and the ease of being able to fix this at any point rather than at the predetermined location of the battens. The countervailing factor is the extravagant consumption of timber involved.

It is not surprising that sarking is occasionally found in Australia, especially in earlier examples and in some roofs designed for rigorous climatic conditions. One example is the Hyde Park Barracks in Sydney, where the original cladding was shingles. A Singapore house of the 1850s displays a mixture of flush and lapped boards, some of which seem to have been intended originally as cladding. Lapped boarding is normally used in a roof only where it is to be the exposed surface, but it may also occur where the boards are especially variable in breadth or thickness and would not produce a reasonably homogeneous surface. This is common in the inner roofs of double-roofed cool stores, as discussed below.

The material which specifically called for sarking were canvas or oilcloth (as at 'Woodlands', Tullamarine, Victoria), sheet metals such as copper and zinc, and in theory the galvanized iron tiles of Morewood & Rogers, though in practice sarking was soon dispensed with under these.

e. the sawtooth roof

The sawtooth roof, though used only for large industrial buildings, has a sufficiently interesting history to be worth considering here. The English mill or factory of the late eighteenth century was typically a three, four or five storey building, built to this height so as to best exploit a single source of power such as a water wheel or steam engine. The walls were of masonry but the interior framing was at first of timber. From the late eighteenth century the continual threat of fire stimulated changes in design whereby the timber columns were replaced with cast iron; the floors were carried on shallow brick vaults, or later were of sheet iron with concrete on top; the and timber beams were first encased in non-combustible material, then replaced with cast iron, and finally replaced with wrought iron. The majority of early warehouses, mills and factories in Australia, however, were of the old-fashioned timber-framed

[76] *Civil Engineer and Architect's Journal*, May 1843, p 160.
[77] Tarbuck, *Practical Carpentry and Joinery*, pl 27 & p 157.

type, with square columns chamfered at the corners, and short cross-heads between the top of the column and the beam, to spread the load. In some more advanced cases the columns were replaced with cast iron, or the timber cross-head gave way to a sort of cast iron sling within which the beam rested, and which in turn transferred load to the column.[78]

In the mid-nineteenth century an experiment was made in Britain with single storey design at Marshall's Flax Mill, Holbeck, near Leeds,[79] a model factory which almost certainly provided the inspiration for that in Disraeli's *Sybil*.[80] The innovative features of the building included a flat roof covered with soil and planted with grass upon which sheep grazed, conical glazed skylights, hollow columns to remove rainwater, sub-floor heating reticulated in pipes, and Egyptian styling of the office facade. Spreading single storey factories were now promoted by the engineer William Fairbairn, not with the heavy vaulting of Marshall's mill but with lightweight sawtooth roofing designed to face north and to admit floods of indirect daylighting into the work space. Fairbairn calls this 'the shed principle', mainly because it is lightweight and single-storeyed, and the invention of the sawtooth roof seems to be to him a matter of relatively slight import.

Fairbairn seems at one point to imply that he had used sawtooth roofing as early as 1827,[81] but his first documented example is the Weaving Shed (and perhaps also the Combing Shed) of Titus Salt's Saltaire Mills near Bradford. This establishment became well-known, not least because of its publication by Fairbairn himself in his *Treatise on the Application of Cast and Wrought Iron to Building Purposes*, of 1854.[82] At Saltaire Fairbairn's sawtooths had the principal rafters of timber, but the ties, and a single strut, were of iron. It was unlike Fairbairn to use timber at all in so significant a position, but when the sawtooth reached the Australian colonies in about 1865 it was translated entirely into timber.

The first Australian example seems to have been the mill of the Victorian Woollen and Cloth Manufacturing Company on the Barwon River, Geelong, built in three stages from 1865 to 1867, to the designs successively of Jacob Pitman and John Young.[83] It is also claimed that there was sawtooth roof on the Yarraville Woollen mills, Melbourne, of 1866 onwards.[84] The adoption of the shed or sawtooth form for a woollen mill was probably the natural thing when it had become so widely accepted for spinning and weaving mills in Britain, but its use in the wool store was a novelty. The reason for the innovation was that the top floor of a wool store was the place for

78 The former Cleve Brothers building at 573-7 Lonsdale Street, Melbourne, designed by Leonard Terry in 1858, has timber columns carrying cast iron heads of the sort described, at basement level, and cast iron columns at the ground floor.

79 C F Tomlinson [ed], *Cyclopedia of Useful Arts & Manufactures* (originally published in parts, later 2 vols, London n d [c 1852]), I, pp 630-1, 634, s v Factory; p 685, sv Flax; K J Bonser, 'Marshall's Mill, Holbeck, Leeds', *Architectural Review*, CXXVIII, 758 (April 1960), pp 280-282.

80 Benjamin Disraeli, *Sybil or the Two Nations* (London 1927 [1845]), pp 211-212.

81 William Fairbairn, *Treatise on Mills and Millwork* (4th ed, London 1878), pp 396-7.

82 William Fairbairn, *Treatise on the Application of Cast and Wrought Iron to Building Purposes* (London 1854), pp 159 ff, especially fig 59, p 162.

83 A S Y Loh, 'The First Woollen Mill in Victoria' (BArch, University of Melbourne, 1968), pp 3-6.

84 Information from David Moloney, Melbourne, 1992, based upon research by Gary Vines.

buyers to inspect the merchandise, and needed good and uniform light. The first New Siouth Wales example may have been the Mort & Co wool store in Alfred Street, Sydney. The design was by Edmund Blacket, but it is thought that the innovation is mainly attributable to his employee J H Hunt, who had seen the Saltaire Mill. Although there has been some doubt about the date[85] it certainly dates from 1867, for the drawing is dated 11 December 1866,[86] and Hunt's claim that it was the first sawtooth in Australia[87] is incorrect.

The oldest surviving sawtooth roof in Australia seems to be that of the wool store built by C J Dennys at Geelong in 1872, now, appropriately, a part of the National Wool Museum. It was used for a show floor, as at Mort's in Sydney, but so far as the evidence goes it may just as well have been evolved independently, inspired by the Victorian Woollen Mill in the same town. It was reported locally to be 'lighted like the woollen factories, by southern lights of ribbed glass in the roof, and ventilated by windows on every side'. The drawings, which survive, clearly show the fully evolved sawtooth system, as well as the timber framing with crossheads which can still be seen today (though the ribbed glass has gone). The sawtooth was taken up in other wool stores at Geelong, including those built by Strachan, some time before 1891,[88] demolished in recent years.

In the meantime the sawtooth system had been taken up in woollen mills elsewhere, including the Ballarat Woollen and Worsted Mill at the corner of Humffray and Hill Streets, Ballarat. The first stage, designed by the local architect Henry Caselli, was built in 1872-3 and extended in 1874, and both early portions have timber sawtooth roofs. Another example was E & W A Gaunt's Alfred Mills in Osborne Street, Williamstown, Victoria, established in about 1880, and it is interesting in that the site was orientated at about 45º to the compass, and the sawtooth lights were directed in part to the south-east, and in part at right angles to the south-west.[89] In Sydney the T S Mort store was followed by J Vicars & Co's tweed factory in Sussex Street, not later than 1876, where there were twenty-five sawtooths with raking faces.[90] The further spread of this system to factories generally cannot be precisely documented here, but a prominent example in Sydney was the National Art Gallery of New South Wales in 1885.[91] Examples in the Melbourne region include buildings at the Newport Railway Workshops from 1898 onwards, and extensions to the Sunshine Harvester Works at Sunshine, built for H V McKay in about 1906.[92]

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85 According to Emery Balint, *Record of Commercial Buildings Constructed in the Victorian Era in N.S.W.* (3rd ed, Sydney 1987), p 80, it was built in two stages, of 1864 and 1867. Balint had previously dated the building to 1866-9: Emery Balint, Trevor Howells & Victoria Smyth, *Warehouses and Wool Stores of Victorian Sydney* (Melbourne 1982), pp 23-4.

86 Peter Reynolds & Joy Hughes, 'The Blacket Years: Works 1863-1869', in Peter Reynolds, Lesley Muir & Joy Hughes [eds], *John Horbury Hunt: Radical Architect 1838-1904* (no place [Sydney] 2002), pp 44-5.

87 *Daily Telegraph*, 21 June & 21 Julyt 1887, quoted in Reynolds & Hughes, 'The Blacket Years', p 45.

88 Miles Lewis, 'Bay City Plaza, Geelong: Buildings of Conservation Significance' (mimeograph report, 1984), p 20.

89 Alexander Sutherland [ed], *Victoria and its Metropolis* (2 vols, Melbourne 1888), II, pp 602-3.

90 *Illustrated Sydney News*, XIII, 6 (27 May 1876), p 4.

91 Peter Reynolds & Joy Hughes, 'Private Practice', in Reynolds, Muir & Hughes, *John Horbury Hunt*, p 98.

92 Miles Lewis, *The Sunshine Harvester Works* (mimeograph report, Melbourne 1987).

f. barrups

One of the most interesting features of the later sawtooth roofs is the use of trussing rods to brace up timber framing members. The trussing of beams was a well-established practice in Britain from the eighteenth to the early twentieth century,[93] but it seems that the specific form known as the barrup may have been invented by the engineer Robert Mallet.

Francis Price's *British Carpenter,* of 1733, described various means of trussing 'girders' or large beams, to be used where they spanned more than twenty-four feet [7.2 m]. The beam would consist of two pieces of timber placed parallel. In the inner faces, where they met, would be rebated grooves to admit - half into each side - two raking pieces of oak, sloping up from near the bottom at the outer ends to near the top at the centre, where they met against a small vertical piece like a king post. With these three pieces set in place the two beams were bolted together to operate as one. The principle is in some ways reminiscent of the bow and string beam. Thus an apparently homogenous beam would contain hidden within it something like a concealed king post truss which lacked a bottom chord (for the surrounding timber performed that function). Price also illustrated an inverted version, with the pieces sloping down to the centre, but as this assumed them to be in tension rather than in compression it was unlikely to be so effective in practice.[94] James Smith's *The Carpenter's Companion* is exactly contemporary, and it also illustrates a range of trussed beams.[95] Two buildings in Philadelphia have trussed beams apparently derived from Smith's illustrations,[96] as does Oakley's *Complete Builder* of 1766.[97]

The Apothecaries Hall, Dublin, of about 1791, contained a trussed beam of Price's first type. A large beam of red pine was split in half in the vertical plane along its length, and two pieces of oak, sloping upward to met an iron key block at the centre, were let into the inner beam faces. This beam was reported by Mallet, after he was brought in to repair the collapsed structure in the 1830s. The new beam which he designed was, fittingly, almost the reverse of the old one, and was of Price's second type, but with iron members to replace the oak. It was built up of four pieces of timber, and either end was fitted into a cast iron shoe. From the top corner of each shoe a rod ran down on a slope, and was fixed to a small plate fixed under the beam at mid-span.[98] Thus Mallet had created a beam trussed up with tension members on either side, as opposed to a beam trussed up with compression members at mid-

93 See for example, Joseph Gwilt [ed Wyatt Papworth], *An Encyclopædia of Architecture* (London 1899 [1842])], sec 2021b, p 619; James Newlands, *The Carpenter and Joiner's Assistant* (Glasgow 1865), pl XL & p 149; R S Burn, *The New Guide to Carpentry, General Framing, and Joinery* (Glasgow, nd, c 1870), pp 343-4; and F W Macey, *Specifications in Detail* (3rd ed, London 1922), p 176.

94 Price, *British Carpenter,* p 6 & pl B.

95 Smith, *The Carpenter's Companion,* pls 4 & 5.

96 Smith, *The Carpenter's Companion,* pls 4 & 5.

97 Edward Oakley, *Every Man a Compleat Builder: or Easy Rules and Proportions for Drawing and Working the Several Parts of Architecture* (London 1766), p 39.

98 Robert Mallet, 'On the Means Adopted for Securing ... Apothecaries Hall, Dublin ...', *Architectural Magazine,* II (1835), pp 165-177.

thickness. The bracing was not fully concealed, as in Price's illustration, for the iron plate at the centre was below the beam. It required only that this be projected down even further, on an iron rod or dropper, to create a true barrup, and who first took this step we do not know.

During the 1830s and 1840s barrups were quite extensively used in Britain even for iron beams, one example being a riding house roof, also by Robert Mallet, before 1833. Mallet described this roof, in which the rafters were each braced, and then additional rod passed below them in a way which is immaterial for present purposes. Mallet did not write of it as if the rafter brace or barrup was itself a new invention;

> each is trussed by a round wrought iron rod ... cottered into each end, and passed under the projection, or bracket ... Thus each principal rafter becomes trussed[99]

Another example was the No 6 Boathouse at the Naval Dockyard, Portsmouth, of 1845.[100] A prominent use of the barrup to strengthen timber spans was Paxton's Crystal Palace of 1850-1, where the rafter/gutter sections were so braced:[101] Yet another was the Railway Workshops at Worcester, dating before 1865, where trussed purlins spanned 4.5 m between the principal trusses. Here each purlin was double, consisting of a pair of 230 a 75 mm flitches connected with bolts and spacers. The trussing bar was connected to special castings at each end, and ran through a cast iron dropper at the centre.[102] A variation was to use two droppers rather than one (like an inverted queen post rather than a king post truss). Eyland and Burn illustrate trussed beams in which there are bolts and droppers passing through the full depth of the beam and continuing downwards to receive the tension rod, and Burn calls these 'king bolt' and 'queen bolt trusses' according to whether there are one or two of them.[103]

At the Sunshine Harvester works outside Melbourne two droppers were used, while another variation was to use two parallel bracing rods, as at the Dalgety Wool Store, Gheringap Street, Geelong, of 1901,[104] and at the West Melbourne Gasworks.[105] After the 1890s the replacement of timber members with steel became more common, but the process was slow and was never universal. Crossheads tended to disappear entirely, because timber construction continued only in lighter weight work where shear was not an issue, but for long spans and heavy loads the trussed beam was still

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99 J C Loudon, *An Encyclopaedia of Cottage, Farm and Villa Architecture* (London 1846 [1833]), § 1939, p 967.

100 R J M Sutherland, 'Pioneer British Constructions in Structural Iron and Concrete: 1770-1855', in C E Peterson [ed], *Building Early America* (Radnor [Pennsylvania] 1976), pp 106, 108.

101 *Civil Engineer and Architect's Journal,* 1850, illustration reproduced in G F Chadwick, *The Works of Sir Joseph Paxton* (London 1961), p 91. Paxton's patent for his roofing system, including the cambering of the gutter, was no 13,186, of 22 July 1850, enrolled 22 January 1851: ibid, p 103.

102 Newlands, *Carpenter and Joiner's Assistant*, p 138 & pl XXII.

103 E S Eyland, Francis Lightbody & R S Burn, *Working Drawings & Designs Architecture and Building* (Edinburgh, no date [c 1863]), 'On the Principles involved in the Construction of Timber and Iron Framing', p 9; R S Burn, *The New Guide to Carpentry, General Framing and Joinery* (Glasgow, no date [c 1870]), p 13 & pl 2 figs 6 & 7. See also P N Hasluck [ed], *Cassell's Carpentry and Joinery* (Philadelphia 1912), pp 80-81

104 Alexander Selenitsch, 'Geelong Wool Stores' (B Arch, University of Melbourne 1972), pl 40.

105 Andrew Ward, 'Massey Ferguson Site', in Massey-Ferguson Site Study: Stage 1: Draft Report (Cultural Significance)' (anonymous mimeograph report 1985), p 85.

in frequent use at least as late as the 1960s.[106] The term 'barrup' for such bracing - derived from 'brace all rafters and purlins' - remains familiar to older practitioners.

A local variation on the idea was patented in 1862 by Thomas Hale, together with his substitute for herringbone strutting which is discussed below. Hale claimed to be able to reduce the number of columns required, which may have had some validity in the case of a new structure. In existing buildings he could to some extent rescue beams which were deflecting excessively. In essence he sandwiched the old beam between parallel pieces of timber - 'checks' - each of which had let into its side a flat wrought iron tie in the form of a concave arc, with the ends threaded so that nuts could be used to adjust the tension.[107] A related concept was a purlin designed as a simple sandwich of a wrought iron plate bbetweeen two planks of timber, as specified in 1879: 'two 12" x 3" Wrot-deal flitches with 11" x 1/4" Wrot iron plate between - including screw bolts +c.'[108] In the United Stated the barrup was extended to all-iron construction when the engineer Benjamin Sevarson reiforced a shallow segmental cast iron girder with a pair of wrought iron rods along the bottom flange. The first known examples date from 1854-5,[109] and by 1865 a similar girder appeared in the catalogue of Daniel Badger's ironworks in New York, but there are no known examples in Australia.

g. the steel square

The steel square roofing method is in Australia very much associated with the name of the carpentry instructor and writer Alex Smith. However the method was far from being Smith's invention, or even an Australian one. One of the first to discuss it as a distinct topic was the prolific American architectural and building writer, Fred T Hodgson. By his own account he wrote his first essay on the steel square in 1868,[110] published some short papers on 'The Use of the Carpenter's Steel Square' in a trade journal in 1872, and then in 1875 published a further series in the *American Builder*. This resulted, he later claimed, in correspondence not only from the United States and Canada, but from Australia and New Zealand, urging him to publish the material in the form of a book.[111] In 1880 he published a small book on the subject, probably under the title *The Steel Square and its Uses*,[112] and in 1903 he followed this with his

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106 R G Pearson, N H Kloot & J D Boyd, *Timber Engineering Design Handbook* (Melbourne 1962 [1958]), pp 69, 171, 229.

107 Thomas Hale, Victorian patent no 560, 24 July 1862. For the test conducted by A K Smith see *Argus*, 13 September 1862, p 5.

108 G R Johnson, 'Bill of Quantities Metropolitan Meat Market, Bank, Hotel, and Two Shops, &c' (Melbourne 1879)., p 9.

109 S E Wermiel, 'An Unusual Application of Wire Cables from the 1850s: Benjamin Severson's Wire-tied Iron Girders', *Construction History*, XVII (2001), pp 44-5.

110 F T Hodgson, *A B C of the Steel Square and its Uses* (Chicago 1908), p 1.

111 F T Hodgson, *The Carpenter's Steel Square and its Application to Everyday Use* (4th ed, New York 1906 [1880]), p 1.

112 In F T Hodgson, *A Practical Treatise on the Steel Square and its Uses* (revised ed, 2 vols, Chicago 1917 [1903] & 1913 [1903]), I, pp 3-4, he refers to such a book but does not name it. However, in the *A B C of the Steel Square*, title page, he is described as the author of *The Steel Square and its Uses*

much more substantial *Practical Treatise on the Steel Square.*[113] This was revised at least until 1917, by which time Hodgson was freely acknowledging the works of others in the United States, Canada and Britain, and even, remarkably enough, 'Mr Joseph Wilcox of Sidney [*sic*], Australia, to whom I tender special thanks.'[114] In 1908 Hodgson produced a small handbook, *A B C of the Steel Square and its Uses,*[115] which was condensed from his other works.

In 1909 W A Radford, Hodgson's main rival as a publisher of building texts in the United States, devoted a substantial section of his book *Framing* to the use of the steel square in setting out the roof structure,[116] and in 1925 there appeared an anonymous work on a scale comparable to Hodgson's, *The Steel Square and its Uses.*[117] It is unclear whether this is another of Hodgson's or a rival, but the latter seems probable, given that it is totally anonymous, makes no reference to Hodgson or his works, and was not produced by Hodgson's regular publisher, Drake. As early as 1908 Hodgson had been complaining of the competing publications which were essentially derived from his work.[118] Subsequently, in Britain, Harold Ryder, 'an expert on the Steel Square', expounded its use for various purposes including roof work, in Boughton's *New Carpenter and Joiner.*[119] David Grant's booklet on the steel square appeared in 1936 and was republished at least until 1957.[120]

In Australia Alex Smith published an article on 'The Steel Square in Australian Roofing' in the *Australian Home Beautiful* in 1930,[121] followed by a book of the same title in 1932,[122] and another edition, called *Steel Square Roofing* in 1947.[123] The steel square was also discussed in general works on carpentry by Smith and others. It was also prominent in the excellent official manual *Carpentry and Joinery* prepared in 1945 for the Commonwealth Reconstruction Training Scheme, and subsequently reprinted by the Department of Labour and National Service.[124] After the war T C Bloomfield's *The Australian Carpenter and Joiner* devoted two extensive chapters to the topic.[125] Smith suggested that the best way to master the steel square was construct a small model of a roof, using disproportionately thick members to show the angles of the cuts, and illustrated one of these.[126] A model of just this sort has been found in the roof of house in Kew, Melbourne.

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113 Hodgson, *Practical Treatise on the Steel Square,* I, pp 3-4.

114 Hodgson, *Practical Treatise on the Steel Square,* II, p 5.

115 F T Hodgson, *A B C of the Steel Square and its Uses* (Chicago 1908).

116 W A Radford, *Framing* (Chicago 1909), pp 91-122.

117 *The Steel Square and its Uses* (2 parts in 1, Chicago 1925).

118 Hodgson, *A B C of the Steel Square,* p 1.

119 Harold Ryder, 'The Steel Square', chapter 13 of R V Boughton [principal author], *The New Carpenter and Joiner* (3 vols, London, no date [?c 1935-40]), I, pp 206-261.

120 David Grant, *The Steel Square: its Use and Mechanism* (London 1957 [1936]).

121 Alex Smith, 'The Steel Square in Australian Roofing. Part I', *Australian Home Beautiful*, VIII, 7 (1 July 1930), pp 44-6.

122 Alex Smith, *'The Steel Square in Australian Roofing* (Melbourne 1948 [1932]).

123 Alex Smith, *Steel Square Roofing* (Melbourne 1948 [1932]).

124 *Carpentry and Joinery* (Melbourne 1945), pp 136-140: 'Steel Square Method of Setting out Gable Roof'.

125 F C Bloomfield, *The Australian Carpenter and Joiner* (3 vols, Melbourne, no date [?c1950]), II pp 566-618.

126 Smith, 'The Steel Square in Australian Roofing', pp 44-6.

Another local publication was A W Hancock's *Apex Rafter Table*, 'an easy and accurate way of securing the lengths and cuts of Rafters, Hips, and Purlins, set out in such a way as to be accessible at all times.' When it was published in Melbourne in 1936 it included two testimonials from builders who had used it for eighteen months, though it is unclear whether this implies an earlier edition of the booklet or some form of private or semi-private circulation. One of the builders, G S Deans, said 'I consider it an improvement on the steel square, and ... have made a study of the square and have used it for the last 15 years.' The publication consisted of a few pages of explanatory notes and hints, and then a series of twenty-three tables arranged by increasing roof pitch, from 1 in 12 [4^o] to 12 in 12 [45^o], each giving rafter sizes for roofs of the slope in question, and from two to forty feet [0.6 - 12.0 m].[127]

> Coarse, cheap hessian with a strong fibre is better than finer cloth, as it gives a better key to the size. The hessian should be strongly sewn in broadsides, the size of each wall and ceiling, without puckering the edges, and fixed to the plates, joists and studs with stout clouts. The ceilings should be taped.

127 A W Hancock, *The Apex Rafter Table* (Melbourne 1936), passim.