Elementary principles of carpentry ...

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Section III. Of the construction of floors.

SECTION III.

OF THE CONSTRUCTION OF FLOORS.

133.—The timbers which support the flooring boards and ceiling of a room are called, in carpentry, the *naked flooring*. There are different kinds of naked flooring, but they may be all comprised under the three following denominations; viz. single joisted floors, double floors, and framed floors.

First, Single joisted floors. A single joisted floor consists of only one series of joists. *Plate* IV. *fig*. 38, shews a section across the joists of a single joisted floor.

Sometimes every third or fourth joist is made deeper, and the ceiling joists fixed to the deep joists, and crossing them at right angles. This is an improvement in a situation where there is not space for a double floor. *Fig*. 39 shews a section of a floor of this kind. It increases the depth of the floor very little, and will not allow sounds to pass so freely as a single joisted floor, and the ceilings will stand better. The ceiling joists, *a*, *a*, are notched to the deep joists *b*, *b*, *b*, and nailed.

134.—Secondly, Double floors. A double floor consists of three tiers of joists; that is, binding joists, bridging joists, and ceiling joists: the binding joists are the chief support of the floor, and the bridging joists are notched upon the upper side of them: the ceiling joists are either notched to the under side, or framed between with chased mortises; the best method is to notch them. *Fig*. 40 shews a section of a double floor across the binding joists *b*, *b*, *b*. The bridging joists *d*, *d*, are notched over, and the ceiling joists *a*, *a*, are notched under the binding joists.

135.—Thirdly, Framed floors differ from double floors only in having the binding joists framed into large pieces of timber, called girders. *Fig*. 41 shews a section across the girders of a framed floor; where *b*, *b*, *b*, are the binding joists.

Single joisting makes a much stronger floor, with the same quantity of timber, than a double or framed floor, and may be constructed with equal ease to the same extent of bearing; but the ceilings are more subject to cracks and irregularities; consequently single joisted floors of long bearings can be used only in inferior buildings.

When it is desirable to have a perfect ceiling, a double floor is used; and when the bearing is long, a framed floor becomes the most convenient. The following experiment was made on the comparative strength of framed and single joisted floors by Professor Robison.

136.—Two models were made 18 inches square; one consisted of single joists, the other framed with girders, binding joists, bridging and ceiling joists; the single joists of the one contained the same quantity of timber with the girders alone of the other. They were placed in a wooden trunk 18 inches square within, with a strong projection on the inside for the floors to rest on; and small shot was gradually poured over.

The single joisted floor broke down with 487 pounds, the framed floor with 327 pounds.* The difference would not be quite so much on a large scale, because the girders would not be so much weakened by mortises. This is not the only case where apparent strength has turned out to be real weakness; and shews how necessary it is to distinguish those parts which really support a load from those which only appear to do so.

OF SINGLE JOISTED FLOORS.

137.—In order to make a strong floor with a small quantity of timber, the joists should be thin and deep; but a certain degree of thickness is necessary, for the purpose of nailing the boards, and two inches is perhaps quite as thin as the joists ought to be made; though sometimes they are made thinner.

To find the depth of a joist, the length of bearing and breadth being given, for a single joisted floor, when the distance apart from middle to middle is 12 inches.

Rule. Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 2·2 for fir, or 2·3 for oak, will give the depth in inches.†

Example. Required the proper depth for a fir joist, the bearing being 12 feet and the breadth 2 inches?

Here $\frac{12 \times 12}{2} = 72$, and the cube root of 72 is 4·16; therefore $4{\cdot}16 \times 2{\cdot}2 = 9{\cdot}152$ inches, the depth required; or $9\frac{1}{4}$ inches is near enough in practice.

On account of flues, fire-places, and other causes, it often happens that the joists cannot have a bearing on the wall. In such cases a piece of timber, called a *trimmer*, is framed between two of the nearest joists that have a bearing on the wall. Into this trimmer the ends of the joists to be supported are mortised. This operation is called *trimming*. The scantlings of trimmers may be found by the same rule as those for binding joists, Case 2, art. 150; the length of the joists framed into the trimmer being equivalent to the distance apart in binding joists..

* Enclyclopædia Britannica, art. Roof, sect. 47.

† The constant numbers in this, and in all the rules for flooring and roofing, are derived from the scantlings of timbers that were found to be sufficiently strong; this is considered to be the best method of obtaining those numbers, because it is difficult to calculate the weight that a floor has to support; yet it is easy to ascertain whether a floor be sufficiently stiff or not after it is executed. These comparisons have not been made from single observations, but from various ones on bearings of very different lengths. The constant numbers are taken higher for oak, because the oak is seldom straight grained, and very subject to warp.

The two joists which support the trimmer are called *trimming joists*, and they should be stronger than the common joists. In general it will be sufficient to add one-eighth of an inch to the thickness of a trimming joist for each joist supported by the trimmer. Thus, if the thickness of the common joists be 2 inches, and a trimmer supports 4 joists, then add four-eighths, or half an inch; that is, make the trimming joists each $2\frac{1}{2}$ inches in thickness.

When the bearing exceeds 8 feet, single joisting should be strutted between the joists to prevent them turning or twisting sideways, and also to stiffen the floor; when the bearing exceeds 12 feet, two rows of struts will be necessary; and so on, adding another row of struts for each increase of four feet in bearing. These struts should be in a continued line across the floor, and short ends of boards put in moderately tight, and nearly of the depth of the joists, are quite sufficient; indeed such pieces simply nailed are better than keys mortised into the joists, because they require less labour, and do not weaken the joists with mortises. The well fitting of the struts is an essential part in making a good ceiling.

For common purposes single joisting may be used to any extent that timber can be got deep enough for: but where it is desirable to have a perfect ceiling, the bearing should not exceed about 10 feet: on account of the partial strains produced by heavy furniture, such as bedsteads, and the like, of which the greater part may rest upon only two or three of the joists, and of course bend these below the rest so as to break the ceiling. Also, where it is desirable to prevent the passage of sound, a framed floor is necessary. The passage of sound may be reduced in a single joisted floor, by putting strips of list or thin slices of cork along the upper edges of the joists, to nail the boards down upon.

OF FRAMED FLOORS.

Framed floors consist of girders, binding joists, bridging joists, and ceiling joists.

Girders.

138.—The girders are the chief support of a framed floor: their depth is often limited by the size of the timber, but not always so, therefore the method of finding the scantling may be divided into two cases.

Case 1. To find the depth of a girder when the length of bearing and breadth of the girder are given.

RULE. Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 4·2 for fir, or by 4·34 for oak, will give the depth required in inches.

139.—*Case* 2. To find the breadth when the length of bearing and depth are given.

RULE. Divide the square of the length in feet, by the cube of the depth in inches; and the quotient multiplied by 74 for fir, or by 82 for oak, will give the breadth in inches.

Example to Case 2. Let the bearing be 20 feet, and the depth 13 inches; to find the breadth, so that the girder shall be sufficiently stiff.

The cube of the depth is 2197, and the square of the length is 400; therefore $\frac{400}{2197} \times 74 = 13{\cdot}47$ inches, the breadth required.

In these rules the girders are supposed to be 10 feet apart, and this distance should never be exceeded; but should the distance apart be less or more than 10 feet, the breadth of the girder should be made in proportion to the distance apart.

Girders for long bearings should always be made as deep as they can be got; an inch or two taken from the height of a room is of little consequence, compared with a ceiling disfigured with cracks, besides the inconvenience of not being able to move on the floor without shaking every thing in the room.

140.—When the breadth of a girder is considerable, it is often sawn down the middle and bolted together with the sawn sides outwards; the girders in the section, *fig.* 41, are supposed to be done in this manner. This is an excellent method, as it not only gives an opportunity of examining the centre of the tree, which in large trees is often in a state of decay, but also reduces the timber to a smaller scantling, by which means it dries sooner, and is less liable to rot. The slips put between the halves, or flitches, should be thick enough to allow the air to circulate freely between them. It is generally imagined that it strengthens a girder to cut it down, reverse it, and bolt it together again; it is in fact weakened by the operation, but the method is recommended here for the reasons above stated.

Others suppose that girders are cut down merely for the purpose of equalizing their stiffness; but admitting a girder to be bent considerably, the difference between the deflexions at any two points equally distant from the middle would not be sensible in girders of the usual form. The person who first practised the method of cutting girders down the middle undoubtedly did it with a view of preserving and not of stiffening them. We find that Vitruvius,* the oldest author on architecture whose works are extant, directs a space of two fingers' breadth to be left between the beams for forming the architrave over columns, in order that the air may circulate between and prevent decay.† Every one must have observed that decay begins in the first place at the joints,

* Vitruvius, lib. iv. cap. 7.

† The timber can only be weakened to the amount of the wood lost by the passage of the saw; and its strength is rendered more uniform by inverting the ends of the two pieces. It rarely happens that the butt and top of a timber have equal strengths. It is therefore reasonable to conclude that the girder is practically strengthened by the process recommended.—ED.

and other parts where the pieces are neither perfectly close nor yet sufficiently open to allow any dampness to evaporate.

141.—When the bearing exceeds about 22 feet it is very difficult to obtain timber large enough for girders; and it is usual, in such cases, to truss them. The methods in general adopted for that purpose have the appearance of much ingenuity; but, in reality, they are of very little use. If a girder be trussed with oak, all the strength that can possibly be gained by such a truss consists merely in the difference between the compressibility of oak and fir, which is very small indeed; and unless the truss be extremely well fitted at the abutments, it would be much stronger without trussing. All the apparent stiffness obtained by trussing a beam is procured by forcing the abutments, or, in other words, by cambering the beam. This forcing cripples and injures the natural elasticity of the timber; and the continual spring, from the motion of the floor, upon parts already crippled, it may easily be conceived, will soon so far destroy them as to render the truss a useless burden upon the beam. This is a fact that has been long known to many of our best carpenters, and which has caused them to seek for a remedy in iron trusses; but this method is quite as bad as the former, unless there be an iron tie as an abutment to the truss; for the failure of a truss is occasioned by the enormous compression applied upon a small surface of timber at the abutments. The defects of ordinary trussed girders are very apparent in old ones, as it is not simply strength that is required, but the power of resisting the unceasing concussions of a straining force, capable of producing a permanent derangement in a small surface at every impression.

142.—The above remarks are further confirmed by some experiments made by Mr. Barlow, of the Royal Military Academy, at Woolwich, the results of which are shown in the following table.

Description.	Length of bearing.	Weight.	Deflexion produced by the weight.
	ft. in.	pounds.	
Two truss pieces meeting against a king bolt in the centre, with plate bolts at the abutments..........	4 , 2	600	0·87
Piece of the same size, without a truss	4 , 2	600	1·00
Three truss pieces, with two queen bolts, with plate bolts at the abutments	5 , 8	500	2·25
Piece of the same size, without a truss	5 , 8	500	1·55

The pieces were trussed in the manner described by Mr. Nicholson, in his Carpenter's

Guide, Plate XXXIX.; the depth of the pieces 2 inches, and the breadth $1\frac{7}{8}$ inches. In the experiment with the girder having a king bolt and two truss pieces, there appears to be a slight advantage in trussing; but in the one in three lengths, trussing appears to have had no effect, it being much weaker than the untrussed piece.*

The methods of trussing proposed by Smith,† Price,‡ Pain, and Langley,§ are still worse; some in principle, others in the materials. The attempt to make a solid beam stronger in the same bulk, without using a stronger material than the beam itself is made of, is ridiculous; yet such has been the aim of most of these writers.

Though the usual mode of trussing girders cannot be relied upon, nor indeed any other timber truss that is made within the depth of the beam; yet, by adding to the depth, there are several methods that may be applied with success in extending the bearing of timber girders. But where the depth is limited, and the bearing considerable, iron must be employed, and the best mode of doing this is to make the girders of cast iron, each in one piece, if the bearing should not be too long for a casting, and in two pieces if it should be too long. These cast iron girders are simple, and cheaper than any kind of iron framing of the same strength; that is, when they are properly contrived, so as to make the most of the material.||

But it often happens that large founderies are not near, and consequently iron girders would be very expensive; we ought not therefore to omit showing how they may be dispensed with, where there is the means of increasing the depth of the floor, and this may generally be done without inconvenience.

143.—The principle of constructing girders of any depth is the same as that of building beams, and when properly conducted is as strong as any truss can be made of the same depth.

The most simple method consists in bolting two pieces together, with keys between, to prevent the parts sliding upon each other; the upper one of hard compact wood, the lower of tough straight grained. The joints should be at or near the middle of the depth. *Fig.* 42, *Plate* IV. shows a beam put together in this manner. The thickness of all the keys added together should be somewhat greater than one-third more than the whole depth of the girder; and, if they be made of hard wood, the breadth should be about twice the thickness.

144.—*Fig.* 43 is another girder of the same construction, excepting that it is held together by hoops instead of bolts. The girder being cut so as to be smaller towards the ends, would admit of these hoops being driven on till they would be perfectly tight, and would make a very firm and simple connection.

* See Barlow's Essay on the Strength and Stress of Timber.
† Smith's Carpenter's Companion.
‡ British Carpenter, Plate B.
§ Langley's Builder's Complete Assistant, Plate lii. 4th edit.
|| See Practical Essay on the Strength of Iron, Sect. II. for the principles of forming these girders.

145.—In *fig.* 44 the parts are tabled or indented together instead of being keyed, and a king-bolt is added to tighten the joints; the upper part of the girder being in two pieces. The depth of all the indents added together should not be less than two-thirds of the whole depth of the girder.*

146.—Another method of constructing a girder consists in bending a piece into a curve, and securing it from springing back by bolts or straps. A girder constructed in this manner is shown by *fig.* 45. Mr. Smeaton has adopted a similar method of strengthening the beam of a steam engine,† and the additional stiffness gained by bending beams in this manner is very considerable. The pieces should be well bolted, or strapped, and keys or tables inserted to prevent any sliding of the parts. In this manner a beam might be built of any depth that is necessary in the erection of buildings, and by breaking the joints of any length that is likely to be needed in the construction of floors.

The following rule may be used for finding the proper scantling or dimensions of these girders, viz.

Multiply 1½ times the area of floor the girder supports in feet, by the length of bearing in feet; divide this product by the square of the depth in inches, and the quotient will be the breadth of the girder in inches.

The thickness of the bent pieces may be about one-fiftieth part of the bearing, and as many of them should be added as will increase the depth to that proposed, unless the whole depth of the curved pieces exceeds half the depth of the girder; and in that case straight pieces should be added to the under side, so as to make the whole depth of the straight parts exceed the depth of the curved parts. When pieces cannot be got sufficiently long for the girder, care should be taken to have no joints near the middle of the length in the lower half of the girder.

Fig. 45 shows a girder for a 40-feet bearing, with the lower half scarfed at *a*, with a plain butting joint in the curved part at *b*.

147.—In the construction of floors it would be a great advantage to make each girder only half the breadth given by the rule, and to place them only 5 feet apart; to bridge the upper or floor joists over the girders, and notch the ceiling joists to the under side of them; and to omit the binding joists. There would be a great increase of strength and stiffness by adopting this method; and in point of economy, it is decidedly preferable; but it requires of course a greater depth of flooring.

148.—As the strain is always greatest at the middle of the length of a girder, it would be well to avoid making mortises there, if possible, either for binding joists or for any other purpose; and the most straight-grained part of the beam should be put to the under side.

* A girder similar to this is described by Mathurin Jousse, in his Art de la Charpenterie.

† Rees's Cyclopædia, art. Steam Engine, plate i. Girders constructed in this manner have also been proposed by Rondelet, L'Art de Bâtir, Tome IV. p. 145.

Also, timber girders should not be built into the wall, but an open space should be left round their ends, either by laying a flat stone over them, or by turning an arch to carry the wall above.

Girders should be laid from 9 to 12 inches into the wall, according to the bearing.

BINDING JOISTS.

149.—The depth of a binding joist is generally determined by the depth of the floor; but this is not always the case; therefore the rules must be given for two cases.

Case 1. To find the depth of a binding joist, the length and breadth being given.

RULE. Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 3·42 for fir, or by 3·53 for oak, will give the depth in inches.

150.—*Case* 2. To find the breadth, when the depth and length are given.

RULE. Divide the square of the length in feet, by the cube of the depth in inches; and multiply the quotient by 40 for fir, or by 44 for oak, which will give the breadth in inches.

These rules suppose the distance apart to be 6 feet; if the distance apart be greater or less than 6 feet, the breadth given by the rule must be increased or diminished in proportion. The breadth of the binding joists next the wall may be two-thirds of the breadth of the others; but in general they are made the same breadth, or such as are defective are selected for that purpose.

151.—The binding joists may be from 4 to 6 feet apart, but should not exceed 6 feet; and about 6 inches bearing on the wall is sufficient.

The manner of framing binding joists into girders is shown by *fig.* 46; and in fitting them great care should be taken that both the bearing parts, *a* and *b*, should fit to the corresponding parts of the mortice. This is the most important part of fitting in a binding joist, yet is often the least attended to. The tenon should be about one-sixth of the depth, and at one-third of the depth from the lower side.

152.—Binding joists that have only to carry a ceiling may have their scantlings found by the same rule as for ceiling joists (see art. 154); except that the quotient must be multiplied by 1·2 instead of 0·64 for fir, and by 1·25 instead of 0·67 for oak joists.

BRIDGING JOISTS.

153.—The rule for bridging the joists is the same as that for single joisting (see art. 137). They seldom need be more than two inches in thickness, except for ground floors, where they are laid upon sleepers; in which case, the depth may be found to a breadth of two inches, and an inch may be added to the breadth, on account of the situation; as when proper care is not taken to drain and ventilate the under side of a ground floor, the joists are subject to very rapid decay. It is a good practice to strew smiths' ashes, or even common ashes, under such floors, to prevent the growth of fungi. The ashes and scoriæ from a foundery, or any ashes that contain much iron, are the best. Mr. Batson found this an effectual remedy for the dry rot. He filled a space below the floor of two feet in depth, with anchor-smiths' ashes, and also charred the sleepers.* (See Sect. X. art. 342.)

CEILING JOISTS.

154.—Ceiling joists require to be no thicker than is necessary to nail the laths to; two inches is quite sufficient for that purpose.

To find the depth of a ceiling joist, when the length of bearing and breadth are given.

Rule. Divide the length in feet by the cube root of the breadth in inches; and multiply the quotient by 0·64 for fir, or by 0·67 for oak, which will give the depth in inches required.

Example. Let the bearing be 6 feet, and the breadth 2 inches; to find the depth of a ceiling joist of fir.

The cube root of two is nearly 1·26; and the length 6 feet, divided by this number; that is, $\frac{6}{1 \cdot 26} = 4 \cdot 76$; which being multiplied by the decimal 0·64, gives three inches, the depth required.

155.—If two inches be fixed upon for the breadth, the rule for ceiling joists of fir becomes very easy; for then half the length in feet is the depth in inches: that is, if the length of bearing be 10 feet, the depth of the joist should be 5 inches. The distance apart in the clear is generally from 10 to 12 inches, according to the length of the laths.

It is better to notch ceiling joists to the under side of the binding joists, and nail them, than to mortise and chase them in; because it requires less labour; does not weaken the binding joists, and the ceiling stands better. Oak is not so good a material for ceiling joists as fir, because it is more subject to warp; particularly if it be not well seasoned.

GENERAL REMARKS RESPECTING FLOORS.

156.—Girders should never be laid over openings, such as doors or windows, if it be possible to avoid it; and when it is absolutely necessary to lay them so, the wall-plates, or

* Transactions of the Society of Arts, Vol. XII. p. 265.

templets, must be made strong, and long enough to throw the weight upon the piers. It is, however, a bad practice to lay girders obliquely across the rooms; it is much better to put a strong piece as a wall-plate.

In the bearings of floors the caution of Vitruvius must be attended to; that is, when the ends of the joists are supported by external walls of considerable height, the middle part of the joist should never rest upon a partition wall that does not go higher than the floor;* for the unequal settlement of the walls will cause the floor to be unlevel, and most likely fracture the cornices.

157.—Wall-plates and templets should be made stronger as the span becomes longer; the following proportions may serve for general purposes:

	inches.		inches.
For a 20-feet bearing, wall-plates	4½	by	3
30	6	by	4
40	7½	by	5

158.—Floors should always be kept about three-fourths of an inch higher in the middle than at the sides of a room when first framed; and also the ceiling joists should be fixed about three-fourths of an inch in 20 feet higher in the middle than at the sides of the room; as all floors, however well constructed, will settle in some degree.

In laying the flooring, the boards should always be made to rise a little under the doorways, in order that the doors may shut close without dragging; and at the same time it assists in making them clear the carpet.

The following remarks, from Evelyn's Silva, are also worthy of notice: "To prevent all possible accidents, when you lay floors, let the joints be shot, fitted, and tacked down only the first year, nailing them for good and all the next; and by this means they will lie staunch, close, and without shrinking in the least, as if they were all of one piece; and upon this occasion I am to add an observation that may prove of no small use to builders, that if one take up deal boards that may have lain in the floor an hundred years, and shoot them again, they will certainly shrink (toties quoties) without the former method."†

FLOORS CONSTRUCTED WITH SHORT TIMBERS.

159.—There are many curious methods of constructing floors with short timbers, which cannot be passed over without notice, and yet are scarcely worthy of it; because they are seldom applied, as long timber is always to be had. To those, however, who are

* Vitruvius, lib. vii. cap. 1.

† Evelyn's Silva, Dr. Hunter's edit. Vol. II. p. 217.

more inclined to pursue curious than useful information, the following notices respecting such floors may be acceptable.

Let ABCD, *fig.* 47, *Plate* IV., represent the plan of a room, and let four joists be mortised and tenoned together at *a*, *b*, *c*, and *d*, in the form shown in the figure; then it is evident that these joists will mutually support one another: each joist being supported at one end by the wall, and at the other by the middle of the next joist. This is one of the most simple forms, and will sufficiently explain the principle of constructing a floor of shorter timbers than will reach across the room.

The same thing may be done by mortising and tenoning the joists together in the form represented in *fig.* 48; and various other forms will readily suggest themselves, the manner being once understood.

A design for this kind of floor was given by Serlio;* and the celebrated mathematician Dr. Wallis has entered very fully into the investigation of the strength and disposition of these floors, in the first volume of his mathematical works. The researches of Dr. Wallis have been reprinted in Nicholson's Architectural Dictionary, art. Naked Flooring. The Dutch manner of framing these floors is given in Krafft's Recueil de Charpente, Part ii.; and several forms are exhibited in Rondelet's L'Art de Bâtir, tome IV. p. 149, &c.

160.—Perhaps the most singular floor that ever was constructed on a large scale is one that was executed in Amsterdam, for a room 60 feet square, which has no joists whatever. There are very strong wall-plates on each side of the room, firmly secured with iron straps at the angles, and rebated to receive the flooring. The flooring consists of three thicknesses of 1½ inch boards. The first thickness is laid diagonally across the opening, the ends resting in the rebates of the wall-plates; and rising about 2½ inches higher in the middle than at the sides of the room. The second thickness of boards is laid diagonally, but the direction is the reverse of the first thickness; and the two thicknesses are well nailed together. The boards of the third thickness are laid parallel to one of the sides of the room, and form the upper side of the floor, being also well nailed to the boards below. All the boards are grooved and tongued together, and form a solid floor 4½ inches in thickness.‡ This example shews how much may be accomplished by a well-disposed bond, and firm connexion of parts. This floor partakes of the nature of a thin plate supported all round the edges; the strengths of plates supported in this manner are directly as the squares of their thicknesses, and they are equally strong to support a weight in the middle, whatever the extent of bearing may be: but when the load is uniformly distributed, the strength is inversely as the area of the space it covers.‡

* Tutte L'Opera d'Architettura di Serlio da Scamozzi Vineg. 1600, lib. i.

† Rondelet's L'Art de Bâtir, Tome IV. p. 154.

‡ Emerson's Mechanics, 4to., sect. viii. prop. 73, cor. 5; or Marriotte's Hydrostatics, p. 248.