Masterclass: Corbelling III/Roofs

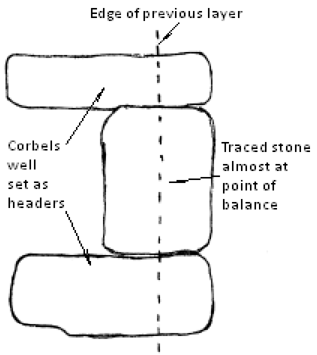
The last two instalments of *"Masterclass"* have examined the theory of corbelling and its effect on a couple of practical considerations. Hopefully I have established the following, in no particular order: tilting stones can be swings and roundabouts with regard to what can be gained by being able to extend a stone out further over the one below, but is important for weatherproofing; to remain stable under its own weight each subsequent layer can be poked out more than the last but for early courses the difference is miniscule, higher up you can project stones more, but this is only really for the last few courses; cantilevering enables stones to be projected more but the structure might be less stable as a result.

"Stonechat 16" (downloadable from https://www.box.net/shared/5b3or9xyv1) dealt with building geometrical shapes out of stone, various aspects of that article are referred to in this one, but only in passing. Readers should refer back to *"16"* for the basic principles and approaches.

There are several corollaries to the fact that stones on shallower parts of curves (ie lower in the structure) have less of an overhang. Perhaps most importantly they are by and large much less likely to be projected too far for their length, are thus less reliant on cantilevering. There are still various points to consider with stone use and placement. In practice individual stones are going to vary in both shape and size. This of course has implications on how they should be placed.

If you're forming a triangle (or coned roof) then the projections are going to be fairly uniform. They will vary slightly depending on the thickness of the stone, since thicker stone needs more projection to maintain any given angle. Hence the stones are not necessarily going to be projected the 'correct', theoretical optimum amount, for their length. In practice this means that shorter stones will rely on counterbalancing/cantilevering for stability, whilst longer stones will be more stable than essentially necessary. Problems are only likely to occur if you are projecting many shorter stones 'too' far.

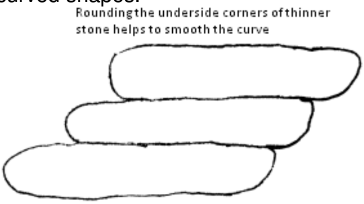
"Tracing" (placing stones with their long axis along the build line) is potentially far more unstable here than on a dry stone wall since the stone is poking out. It's all to do with centres of gravity, traced a stone's centre of gravity will be closer to the overhanging edge than if placed as a "header" (length in). At least on a dry wall the centre of gravity is 'battered in', once overhung, traced stones will be less able to accommodate movement whilst remaining stable (just as with a wall, but in a wall the same stone would have further to move before being unstable). This is particularly important when considering the possibility already mentioned, that 'you are projecting many shorter stones too far'. Problems are most likely to occur where you are tracing a stone to match the projection of adjacent headers (as shown left). As the headers will still be stable with a larger projection they are likely to be projecting by an amount that is too much for a matching traced stone to really support the next layer(s) – (a problem I encountered on the vase 'constructed' in *"Stonechat 16",* they appear stable until you place the next layer, which unless very long tips them).

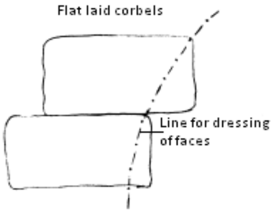


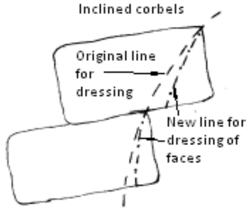
Structurally the stones should really only be placed as headers. Since corbelling is generally going to have some load bearing function over a void, the need to avoid tracing it is probably even more important than normal.

I suppose theoretically corbelling should be graded as a wall. Given that a thicker stone needs more of a projection to maintain an angle then for any given size then in a curving corbel it should be lower in the corbelling than a thinner one as it will not need projecting as far shape-wise. Stone thickness is of little relevance structurally. Technically as a corbel is projecting the end of the stone is more likely to crack given the weight above it than if battered in. Basically if one stone projects over the other the lower stone provides a potential cutting edge along which the upper stone may fracture. In practice this is only likely to be a problem with extremely thin stone. In terms of tipping the centre of gravity will be at the same point along its length for a given stone regardless of thickness. It just moves up as the stone thickens which affects how it will tip sideways rather than lengthways (i.e. relative to the overhang).

Stone thickness will, however, affect the smoothness of the shape of the inside of the ‘dome’ , relieving triangle, or whatever the corbelling is for. Thicker stones will require more shaping to even out the curve/angle. Inside ‘domes’ they are sometimes just rounded off rather than cut to an exact curve. With thicker stone there tends to be more shaping to create an angled face. If the stones are tilted then the amount of shaping required to match the curve accurately will be greater. Interestingly the slightly rounded stones will appear to give a smoother, less scalloped curve when tilted. Thinner stones - as with garden features (as detailed in *“Stonechat 16”*) – can be used to produce more even and more curved shapes.







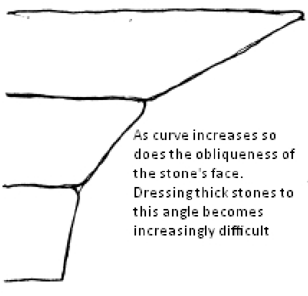
This shaping is however not all about aesthetics. Lassure points out it will also serve *“to reduce its overhang weight to the minimum”*[1]. Practically this might make little difference given amount chipped off relative to the overall volume of the stone, however every little helps and the stone will technically be more stable or potentially projected a little further.

Of course the stones do not have to be shaped at all, leaving the interior rustic as was the case with the Kielder Wave Chamber – see left (and

Kielder Wave Chamber interior © Chris Drury

Inside a trullo cone © Evan Oxland

Cabane Canadienne seen in “*Stonechat 22”*), or in the reconstructed pig sty at St Fagan,s shown later.



The thicker the stone the more awkward the cutting of the angle for stones towards the apex becomes (see diagram right). This is probably another reason while cones/ogives are more common. In some instances, as with many trulli (Stone huts/houses found in Apulia, Italy) you have to wonder how the faces keep to the angle of the curve without being tipped up at the tail. This is a conundrum which I have yet really to get to the bottom of, but it makes for an interesting (well I think so) diversion.

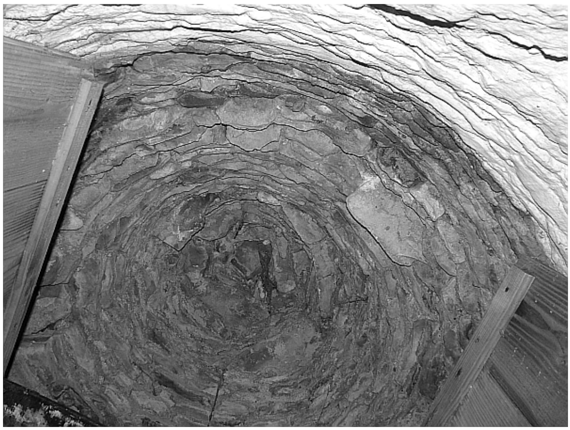
The trullo (singular - trulli is plural) shown below has fairly typical stone for these specific structures. This one is clearly conic, but some are far more domed, and whilst authors such as Edward Allen insist they were built without any formwork[2], it is often difficult to see how this was achieved in practice. Allen's book shows a collapsed trullo where much of the dome can be seen in cross section[3]. The top courses clearly tip into the void. It is unclear how domes/cones of this form were finished. Christian Lassure has suggested to me that these finely finished, more dome like structures, are primarily found in towns (such as Alborobello, a World Heritage site which contains over one and half thousand trulli), and that the one shown by Allen in particular 'cannot possibly have been erected without centring', and was probably 'built (for a price) by specialist stone masons and cutters'. Evan Oxland has visited the area and suggests this is typical of residential trulli, regardless of the location, having seen similar even in more rural areas. Rarely are they just shepherd's huts. He has suggested that in some instances it might have been possible that much of the dome is built corbelled, and then closed using some formwork. As Evan commented to me 'there has been so many periods of intervention and reinvention of the trulli that it's tricky to claim that one form/style is idiomatic - they're all so varied'.

On a similar theme, if you look at the Gallarus Oratory shown below, the topmost stones seem to defy gravity. I found the following account interesting. The first documented description of the Oratory says… *"Some think that an heap of earth was first raised, in the form of the inside of the cell, and that they built over it and wedged in the keystone at the top … lastly, smoothed the walls on the inside with chisels … The stone is a brown free-stone, brought from the cliffs of the sea shore, which cuts readily, and is very durable."*[4] I suppose if the stone is easily workable then the shaping of thicker stones to have very oblique faces does become possible so the former (or major earthworks, an interesting idea, perhaps born more from a lack of understanding of dry stone work than anything else) would probably be unnecessary. The idea that the face was chiselled after construction is interesting as this was a method employed by the Egyptians, and much later the Incas.

Beehive of fahan Group, Dingle Peninsula © Sean Adcock

Whilst the principles above, deal with corbelling in general there are other aspects which relate to the formation of a roof.

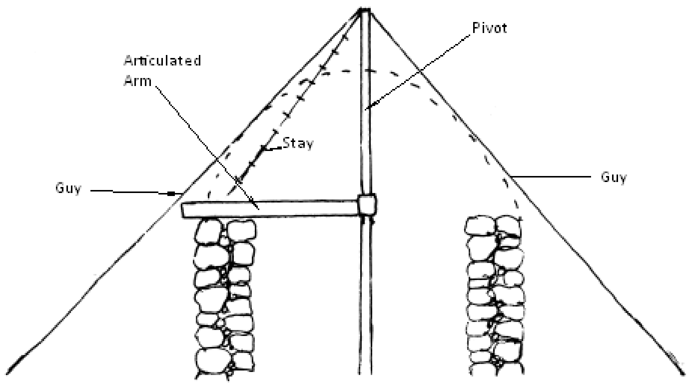
It has also been noted (part 1) that what are often intended to be domes end up more pointed. From what I have seen of pictures of stone huts many, perhaps even most are deliberately more pointed than domed. Essentially they are either conical – with evenly sloping sides; or ogival – a gradual, then increasing slope, forming a shape which in cross section resembles a Norman rather than Roman arch. As with the Clochans of Eire they often resemble skeps (old beehives).



Very pointed cone Welsh national History Museum St Fagan's, Cardiff © Sean Adcock

I suspect that this is because that without resorting to computers and mathematics maintaining fairly consistent small steps is easy. Understanding when and by how much to start 'exaggerating' the steps is problematic, and even as suggested in installment #1 counter-intuitive. Hence building by 'eye' is more likely to produce a cone than a hemisphere.

Not building by eye is of course an option, a number of methods (mostly variations on a theme, literally, revolving round a central pin) are outlined in *"Stonechat 16"*. The only method outlined (briefly) in Christian Lassure's *"Building a Dry Stone Hut"* - the only real practical written reference to dry stone corbelling I have come across - is to have a central bar, which he refers to as a pivot.[5] As described in "*16"* you can then either use strings (one with two marks or two separate – for inner and outer radii), or a rod attached to the pivot. A photographic record of a project is shown by Lassure in an 'insert' (appendix) with what is referred to as an *"articulated horizontal arm"*.[6] This is a more engineered version of the bar and rod method outlined in *"16"*, and interpreted in the diagram below. Guy ropes can be added to the pivot to hold it secure, it is however not clear how guys and stay rope interact at the top of the pivot.



Unlike garden features having templates set, from which to measure the profile is not really practical. There is no explanation of how to measure from the pivot in *"Building a Dry Stone Hut"*. It seems likely that you mix eye and measure, by setting your first stone and then measuring from that setting all stones on that layer to the same offset from the pivot. Alternatively a scaled drawing allowing offsets to be calculated for any given height would give a measured approach facilitating replication of a defined profile/cross-section. *"16"* notes the problem that can occur if the line/bar is not horizontal. Given that a hut is going to be larger than a garden feature any error will be magnified, keeping strings level is likely to be very problematic. This is unlikely to be a problem with the 'articulated arm' as the stay rope from the top of the pivot to the arm should of course keep it horizontal.

Trulli roofs tend to be built using a slightly different approach. The dome is generally built as a single skin – no cantilevering here – with a tufa finial added to the very top. This is roughly shaped (tufa is very soft, the finial is later refined, plastered and painted). A wheel is pinned to the top and a string from this rotated around the cone as the roof is tiled. This is used to measure the distance of the course form the apex, ensuring that the tiling does not corkscrew. Traditionally the tiling/packing is done by eye with the end result almost but not quite perfect, bells or slightly bulging cones, generally symmetrical but not perfectly so. Often modern renovations are built far more accurately producing a clinical, somehow harsher finish to the cone.

This rustic approach seems to be the traditional approach for trulli, where the idea of anything to formalise or set out a shape seems to have been eschewed.

Another consideration is using the shape of a stone to its best effect. Not all corbelled roofs are circular, (famously the Gallarus oratory, which is oblong and resembles an up-turned ship's hull, interior shown below left), however where they are the shortest edge should as far as is practically possible be used as the face. This means

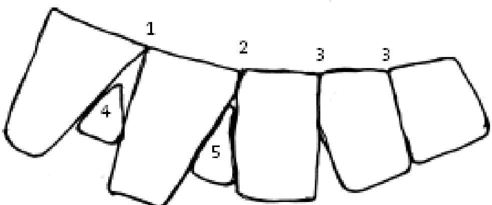
there is more weight towards the back, with the centre of gravity further from the outside edge, effectively making the stone more stable for any given overhang. Of course unless stones are ideal wedge shapes fitting the shortest face at the front isn't always going to be possible. Just remember that the more pointed the tail of

Finished trulli cone/dome awaiting tiling
© Evan Oxland

a building stone the nearer the face its centre of gravity will fall compared to another stone of the same relative dimensions, but squarer tail.

Image reproduced from http://www.flickr.com/photos/davers/135851096/ by kind permission © David Decharte

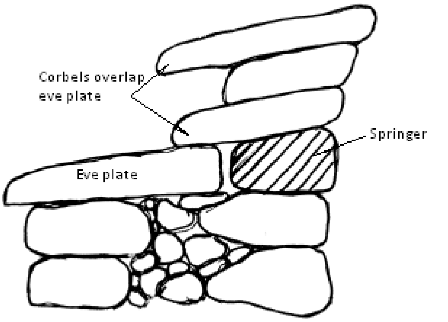
Trullo with slightly lopsided bell shaped cone © Evan Oxland



Maintaining a curve tends to lead to gaps between the adjacent edges of the building stones. Placing point to point contact is a bad idea with corbelling. As with a wall, stones placed thus are relatively easily displaced - all other things being equal. So as the stones are now overhung it is even more serious mistake. Care need to be taken to ensure better fits along the inside edges. Placing the stones with their shortest edge as the face will also help facilitate this, the 'wedge' shape being much harder to displace. Where the stones are pointed at least square off the ends of the points so there is some good contact within the structure. However you will almost inevitably end up with wedge shaped gaps, and you will need to carefully wedge the Vs with suitably shaped and sized stone. One of the neatest explanations of the need for this wedging is provided by Christian Lassure: *"The course is then self-binding and forms a coherent whole that will keep its shape."*[7]

If the corbelling is to be sloped a springer (as with the springers which start off an arch, converting from flat to slope) course, usually constructed out of slightly wedge shaped stones will be required (see diagram below left). In the last edition the construction of the 'Cabane Candienne' showed a springer course built out of slightly sloped labs. These doubled as an 'eve plate' that is a stone which projects slightly beyond the wall immediately under the roof, so water drips off the roof away from the wall

Crossing joints assumes increased importance in a roof, not only in terms of structure, but for water proofing too. Careful 'tiling' of the outside should prevent most water penetration but any that does work into the structure percolates down and out. Crossing of joints on the internal skin (and sloping) prevents water penetrating into the actual room, however it will percolate down through the hearting/gap between tiles and corbel. To ensure this doesn't get into the walls an eve plate can be installed around springer level. (see left). Rather than rely on luck to ensure water doesn't penetrate the wall (and you don't have suitably enormous eve plates, you could try ensure that most of the stones in the two/three courses above springer are long enough that at any given point the eve plate is effectively overlapped.



Eve plates on Cabane built at 4th Canadian Rocktoberfest run by DSWAC
©John Shaw-Rimmington

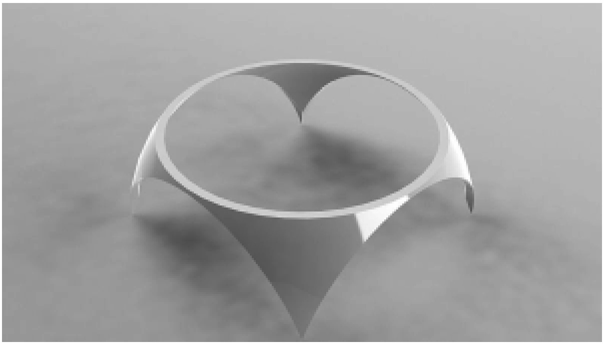
'Squinch' Blaen y Nant pens, Nant Ffrancon
© Sean Adcock

Not all buildings with coned roofs are rounded. As with Chris Drury's Cloud Chamber elsewhere in this issue some round roofs are fitted onto square buildings, which is where squinches come in. Having admitted at the outset that I knew very little, if anything, about corbelling, this series of articles has been something of a journey for me. At last we've reached a point where I do know what I'm talking about. I've been building "squinches" in the corners of sheep pens for as long as I can remember; I've even appeared on a DVD with one. Sheep particularly like using the corners of pens in their bids for freedom, squinches help overhang the coping making their escape attempts more difficult, only until now I had no idea these 'corner stones' had a name.

The Oxford English dictionary defines a squinch as as a *"straight or arched support constructed across the interior angle of a square tower to carry a superstructure"*[8] This superstructure is usually a dome. Apparently it was developed primarily during the 5th century as part of Byzantine architecture and was developed into the pendentive, essentially a triangular section of a sphere.

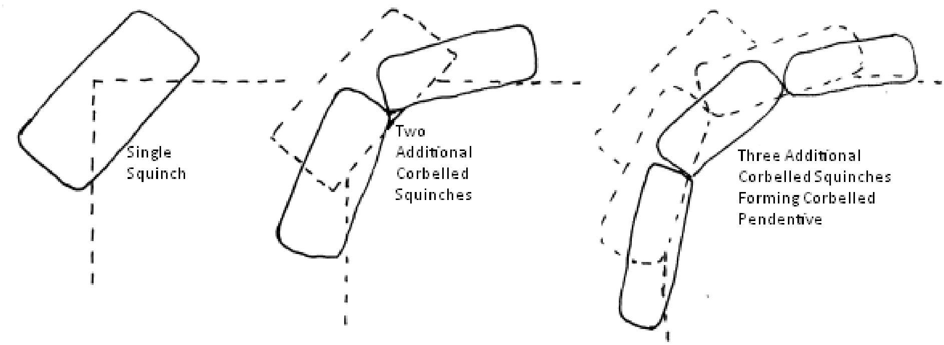
A series of corbelled squinches will in effect form a pendentive (below). As these `corbels` (supported as they are at either end they bridge rather than corbel) are cutting a corner and projecting more than corbelled stones they do not want to be too thin. In practice the ends do not need to lap very far onto the wall, although the less they lap the greater the risk of collapse if there is any movement. The deeper the lintel used then the less the problem as the back corner will sit well into the wall. The biggest problem is likely to be butting the stones, point contact will mean there is less stone on the ones below, and some dressing of the edges is advisable. Similarly it would be best to avoid tracing a whole series of squinches on top of each other. If you are building a corbelled pendentive traced squinches should be liberally interspersed with headers.

In many after the initial squinch just by corbelling corners a little more than edges the round shape is sort of tapered into rather than through forming a pendentive. You can just about see this in the photo below where the square corner becomes increasingly rounded as the cone progresses.



Pendentive reproduced freely from http://en.wikipedia.org/wiki/File:Pendentives.jpg

Finally a few random thoughts, the first quite literally. All of the examples seen here use regular stone. There is no reason why random corbelling would not work to form a dome, but it would be very complicated and far more likely to go wrong. As a roof is



somewhat structural and collapse doesn't bare thinking about, stick to regular stone!

When corbelling a roof you are literally working in ever decreasing circles, and as gap closes you will have to build from top…make sure you get the first bit right!

Corbelling doesn't just have to be about openings or roofs. Most readers will be familiar with the 'wailing wall' of Gorseddau Quarry, Cwm Ystraddlyn (there is a brief mention of this wall in the Branch news section). The wall shown below left was built in the mid nineteenth century apparently to prevent slate from the adjacent waste heap spilling onto the tramway which ran at the wall's base. It is almost exactly 4m high with the top overhanging the base by around 1.5m. Whilst there has been quite a lot of working of the stone considerable use is made of the natural slope of many stone's faces, placing them upside down compared to a battered wall. This is a method also employed on some walls on the Gower Peninsula. The top course or two in effect corbel out, the coping then has inverted faces, the top of the wall then effectively lightly overhangs the base increasing sheep-proofing.

Inside corner of trullo, square at base, rounded in roof. Note also flattened arch!
© Evan Oxland

Finally you have hopefully noticed that with rounded roofs you are building curves, the radius of each getting smaller, and the curve thus tighter as you progress. This of course has implications with stone setting and shaping (the more regular blocks of trulli are better suited for these curves than longer faced slabs for example). Essentially you are just applying the principles for building a curve, which I'm not going to deal with here. That's another story for another day.

Above Cwm Ystraddlyn; right Gower.
Both © Sean Adcock

BIBLIOGRAPHY AND REFERENCES

[1] Lassure. C. *Building a drystone hut: an instruction manual.* 2nd edition. Études et recherché d'architecture vernaculaire no.29. CERAV, Paris 2009. p.11
[2] Allen.E. *Stone Shelters*. Massachusetts Institute of Technology, 1969
[3] See Allen.E. 1969. p 86
[4] C. Smith, *Antient and Present State of the Countyof Kerry* (Dublin, 1756), p. 191.
in Peter Harbison, "How old IS Gallarus Oratory? A reappraisal of its Role in Early Irish Architecture" in *Medieval Archaeology*, Vol. XIV, 1970, pp. 34-59
[5] Lassure 2009. (p.12).
[6] Lassure 2009. (Inserts pp. XVII-XVIII).
[7] Lassure 2009 (p.20).
[8] Shorter Oxford English Dictionary. OUP 1993

Thanks to everyone especially Evan for photos/help

Sean Adcock