The engineering of the prehistoric megalithic temples in Malta

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ABSTRACT: The prehistoric megalithic structures of Malta and Gozo date back to a civilization of 4500 to 5500 years ago. Although now in ruins, their longevity is remarkable, and must be due to the inherent durability of limestone, properly selected, as well as to the underlying engineering principles and construction. Prehistoric civilizations are often, erroneously, perceived as technologically primitive, however these prehistoric structures are technologically remarkable. This paper proposes engineering principles underlying its longevity. Hitherto, many of the features of the extant structure have been explained as having “decorative” functions. The author suggests that these features should be assessed in the light of the possible engineering and constructional processes adopted; this approach is based on the belief that, particularly for civilizations in which energy resources were stretched, it would not make “resource” sense, if these features were not there for a specific purpose – it would not be, using modern terminology, sustainable.

1. INTRODUCTION

The megalithic temples of Malta have been dated back to the 4th millenium BC. The oldest of the major temple sites, Ggantija in Gozo, has been dated, on the basis of recalibrated radiocarbon dating, to 3600 to 3000 BC, the “youngest”, Tarxien, to 3000 to 2500 BC. This is therefore looking a civilization that lasted at least 1000 years. It is still not clear where it came from and where it disappeared to, and why.

The temple sites understandably underwent a number of changes over the 3500 – 2500 BC millenium. The Lower Temple in Mnajdra, for example, belongs to the older Ggantija phase, whilst the Middle Temple belongs to the Tarxien phase. It is therefore not surprising to find a significant difference in the characteristics of the stonework, in the quality of the workmanship, and in the decorative details. On the contrary, it is indeed surprising to observe that the structural principles, on which the temples are based, apparently remain so consistent over this period. These principles also appear to be surprisingly sophisticated.

To our knowledge the Maltese prehistoric megalithic temples are the oldest expressions of free-standing stone architecture. This extraordinary statement is made even more amazing not only by the fact that more than thirty prehistoric sites have been uncovered in the barely 320 sq.km. that make up the Maltese Archipelago, but also that the structures with similar characteristics, found in other neighbouring Mediterranean countries, such as the Balearics, the Iberian Peninsula, or Sardegna, generally have a much younger pedigree, and, in any case, do not have the whole range of characteristics of the Maltese megalithic structures.
Malta’s prehistoric temples are a series of megalithic structures that were “discovered” in the 19th century, although some of the major sites were recorded by travellers at least as far back as the 17th century. The 19th century and early 20th century saw the first systematic archaeological campaigns to uncover more of these structures. The early campaigns were probably not as scientific as they should have been, and included some degree of reconstruction, and also the removal of some earth mounds that, in hind sight, might have been central to understanding the way these temples were built. In order to understand the structural behaviour, and especially the construction methods, adopted by the prehistoric builders, it is obviously necessary to, first of all, translate, in our minds, the extant ruins into hypothetical complete structures. It is also necessary to avoid being misled by what may have been mistaken reconstruction carried out since the 19th century, but also, perhaps, before this “modern” period of interest in the monuments.

In his letter of the 19th November 1840, J.G.Vance describes the excavations carried out, at Hagar Qim, at the request of the Governor General Sir Henry Bouverie, and records how “the remains of ancient architecture” were uncovered, and how “a number of well-proportioned blocks…, scattered in different directions….., some lying in heaps, others singly” were found at the site. Although these descriptions are quite detailed, it is not easy to relate the megaliths illustrated in this letter to the way the configuration of the massive stones in this temple complex would be read today.

In subsequent years, the scattered blocks were lifted back in place, or what was presumed to be their original place. A degree of reconstruction and re-interpretation, often without detailed records, took place in many of the important temple sites, and these may lead to mistaken hypotheses about the original structures. In Mnajdra, for example, it is known that the front section of the Middle Temple was extensively re-modelled in the 1930’s, as was the rear perimeter wall. Some photographs of the excavation, of both the Hagar Qim and Mnajdra sites, record that the land surrounding the temple structures was much higher than is now the case. The photographs also record the removal of an earth mound at the back of Mnajdra – how much of this mound was modern, and how much prehistoric is nowhere recorded.
2. SHAPE AND MODELS

The temple structures have a number of consistent characteristics. The megalithic structures are assembled from large stone blocks, so-called megaliths, apparently without the use of any bedding mortar. The stability of these stone structures therefore depends on the structural form, as well as on the mutual interlocking of the rough surfaces of adjacent blocks. The constructional features include the use of (i) upright free-standing block assemblies, that form “trilithon” portals along the main axis of the temples, (ii) other upright blocks that are used to define the semi-circular apses, which are arranged sequentially along the axis, and (iii) horizontal megaliths, laid in “courses”, forming horizontal arches that corbel out, one course above the other, to form vault-, or dome-, like structures. These inner walls are surrounded by external walls with specific constructional features, such as the alternation of tangential and transverse orientation of the megaliths to form an interlocking outer ring. The space between the inner walls and the outer wall is, generally, filled in.

The basic typology for a temple unit consists of a longitudinal axis, normally also an axis of symmetry, terminating in an apse, and along which is a varying sequence of pairs of lateral apses, or lobes. The external shape of one temple unit is thus broadly ogival, merging into a concave façade. The temple complexes, particularly the four major ones, however, consist of more than one temple unit, and the basic configuration is modified as one temple unit follows another in time, and coalesces with the previous one to form one single complex.

The temple plan typologies range from the three lobes of Mgarr, or Mnajdra (Upper Temple), through the five lobes of Ggantija or Mnajdra (Lower and Middle Temple), to the seven lobes of Tarxien. The temples have obviously been modified over the centuries, sometimes extensively. The odd apse, in these configurations, is the one at the end of the axes of the temples – which is more or less developed depending on the site. It is reasonable to presume that the sequence of pairs of apses, along a linear axis, owes at least as much to constructional and structural requirements, as to the requirements of ritual.

One of the most fascinating aspects of the study of the prehistoric megalithic temples is that amongst the archaeological material excavated are found what must be considered as amongst the oldest architectural models, now preserved in the National Museum of Archaeology. The larger of these models refers to what appears to be a typical pair of apses, which pair forms the basic unit in the construction of the temples. It also illustrates what must have been the external appearance of the structures, and perhaps gives a hint of the original roofing system. In the Mnajdra Middle Temple, there is what must then be considered as one of the earliest architectural drawings, or more properly, engravings – the elevation of a typical temple, having similar characteristics as exhibited on the small models. It is likely that both the models and the wall engraving are post-construction representations of the temple structures, possibly with some votive meaning; however, it would be attractive, albeit implausible, to consider these as instructions to the prehistoric builders!
3. STRUCTURE

It is known that the structural stability, and, no less important, the constructional feasibility, of the stone roof of a single, circular, cell, such as the girna or the nuraghe, is based on the stability of the complete horizontal compression ring of stone. A simple description of the corbelled stone chamber could be a series of stone rings, one on top of the other, each ring having a diameter smaller than the previous one. Every complete ring is stable by virtue of its resistance to the compression, (that is, the reduction in the length of the circumference), which would be necessary for the ring to fall through a space that has a smaller diameter. The individual components of the incomplete ring, however, must either be independently stable, or else they have to be supported by some “falsework” until the ring is completed. The individual components of the ring could be independently stable, if, for example, each stone is corbelled off a lower stone, with the projecting part not being too large compared to the part resting on the stone.

Each complete ring of stone, resting on a previous, and larger, ring of stone is inherently stable, because in order for it to collapse under uniform loading, which can only happen by falling inwards, it requires a reduction of its circumference. In other words, if the individual components of the ring are in contact with each other, the stone ring will develop a horizontal compression force to resist such collapse. The stability of the ring therefore depends on the contact between the vertical faces of these “voussoirs”, and hence on the shaping of these voussoirs to a wedge shape, so as to achieve full contact. If such a contact were absent, the stability would then depend only on the individual stability of each corbel. A vertical slice through a corbelled structure would be stable only if the structure were closed at the top – that is, only if the slice formed a complete vertical arch.

However, the dome has two mechanisms by which loads can be carried. The first mechanism is that of the horizontal ring, as discussed earlier, and the other mechanism is that of the vertical arch that exists in any vertical section through the dome. The two mechanisms co-exist, and the load is distributed between these two mechanisms in accordance with the relative stiffness of the two – and depending, obviously on the geometrical configuration of the dome. In the so-called “false” dome, the stone rings have horizontal interfaces, and therefore the frictional resistance, vital for vertical arching action, may be diminished (although it is not absent). In the “true” dome, with the voussoir joints cut normal to the curved surface, the vertical arching action may be more significant, although, in many structures this is also impaired by, say, uneven settlement under the dome perimeter. Arching action, in fact, also requires rigid abutments. Furthermore, when the dome has an occulus, that is, an opening at its crown, the vertical arch is incomplete, and therefore the important load-carrying mechanism is the horizontal, or circumferential, ring, at least in the regions around the occulus, whether the dome is termed “true” or “false”.

The structural mechanics of the single cell funerary chamber have been extensively studied. Cavanagh and Laxton have published an analysis of the Mycenean Tholos Tomb, which it must be remembered, is at least a thousand years younger than the Maltese prehistoric temples. Cavanagh and Laxton discuss what they identify as the three mechanisms that are available for the stability of the tholos tomb. In addition to the vertical arch action, and to the horizontal ring action, they propose that the system of corbelling is, by itself, also possible, provided the corbeling is taken high enough to bridge the span of the structure. This is only feasible in the context of an overburden that balances the over-turning moment that results as the corbelled wall goes higher and higher. Although, in their paper, Cavanagh and Laxton quote the observations of the original students of the tholos tombs, Cockerell and Donaldson, as saying that “in its horizontal position at least, the arch was clearly understood by the architect who designed these chambers”, they discount the importance of horizontal ring action in the Mycenean tholos tomb, primarily because of the major interruption represented by the entrance shaft that pierces the circular shape.
Although this approach ignores the mutual interaction of the different mechanisms, the interruption to the horizontal stone ring, presented by the “entrance shaft”, is a very relevant issue to the discussion of the structural system of the prehistoric temples in Malta. The basic structural unit seems to be that formed by a pair of apses. The horizontal circular compression ring is clearly interrupted by the temple axis, an axis that presumably was made necessary by ritual requirements of entry into the spaces created by the stone structures. The particular system of joining pairs of apses, adopted in the local megalithic structures, consists of the “trilithon” portals that not only mark the axis of the temples, but connect one half of a horizontal circular ring, in one apse, to the other half of the horizontal circular ring, in the opposite apse. In other words, the “trilithon” portals form the structural continuity necessary for a modified form of “dome action”, which includes both corbelling mechanisms, as well as horizontal compression actions. It is also very likely that any roof structure, now missing, would have contributed a further mechanism of load transfer through a modified vertical arch action.

Plate 3. Clockwise from top: (i) and (ii) Lower Temple Mnajdra, showing corbelling rings over apse; (iii) External Wall, Ggantija, showing alternating flat and tapered vertical megaliths; (iv) Split/truncated dome equilibrium, explaining structural need for strong portals along axis

The term “trilithon portal”, that is a portal formed by three megaliths, two uprights and one lintol, is probably also technically incorrect, for the portal is formed by four megaliths. The vertical sides of the portal are not only restrained at the top by the horizontal lintol, but are also embedded, at the bottom, in appropriate holes, or slots, dug into the solid stone thresholds, so as to form a box structure. The top restraint, formed by the lintol, is often not merely dependent on friction, as in a megalith simply laid on top of the uprights, but in many instances the lintols are notched so as to provide a lateral lock for the upper end of the uprights. This box receives the horizontal thrusts from the incomplete circular rings. If the semi-circular rings are wedged against solid abutments, each layer, although incomplete, is stable enough to carry more rings, until the space over the apses is closed by a sort of hemi-spherical dome, or until the reduced span could be covered by flat structural elements (made of stone or timber).

The success of the horizontal arching action depends on the proper contact between the vertical joints of the “corbelled” rings, and between the vertical joint formed with the portal structure itself. The recent reconstruction work on the Middle Temple at Mnajdra10, 11 has enabled us
to observe that the megaliths that form part of the horizontal “corbelled” rings are wedged-shaped, and are also tightened against each other by stones wedges inserted at the back of the joints, that is, at what would be the extrados joints. It is obvious that, in many other locations in the temples, this tightness of the horizontal stone rings has been lost. The stone lintols over the portals have, in many instances, been damaged, or have disappeared, so that the box portal no longer exists, and weathering mechanisms and anthropogenic actions have otherwise impaired the contact between the vertical sides of the stone rings. At this stage, therefore, the stability of the individual stone members of the ring would be simply that of corbelling over the lower members, and the stability of the whole would depend solely on the stability of this one mechanism.

However, if one were to judge the structural system of the temples simply on what survives, one would be ignoring the greater engineering sophistication that the two-apse unit seems to indicate. And ignoring this would then lead to the question of why would the prehistoric builders go to so much length to form wedged shaped stones, to notch lintols into the portal uprights, to wedge the rings from behind, and to make the other constructional features described above, if they did not have in mind to actuate this mechanism.

Underneath the horizontal corbelled stone rings, the lower part of the inner walls is composed of upright stone panels, of a different geometry to that of the stone corbels. These stone panels, also arranged in a semi-circle, and also locked against the portals, seem to have a slight inclination inwards, and are then locked into place, as a closed semi-circle, by the weight of the surrounding fill. It was originally thought that this fill consists of a mixture of soil and smaller stones. The recent work on the Middle Temple at Mnajdra\textsuperscript{10, 11} has shown that, at least for this period of temple construction, the fill consists of carefully inserted slivers of smaller stones, packed tightly against each other.

This infill is then, in turn, contained by the massive external masonry ring, that would, originally, have formed the outer layer of each temple complex. This is the outer appearance that would correspond to the stone models and stone engraving referred to before. The construction of this external skin is also fairly complex. Tampone\textsuperscript{7} has shown that, in general, the external skin consists of a sequence of radial and tangential megaliths, leaning against, and locked over, the infill. Tampone has led a study of the temple complexes of Hagar Qim and Ggantija, and, on the evidence collected, has identified an “entasis” in the main uprights, such that the tangential blocks wedge tightly into the external ring by virtue of their own weight. This wedging probably occurs in a vertical as well as in a horizontal plane.

The external appearance of a temple complex has been modified over the millennia since they were built, first of all as a result of the coalescing of adjacent temple complexes built at different periods, and, secondly, because of the loss of stones from these external skins, either through weathering or through human intervention. In Mnajdra, for example, segments of the original external wall of the Lower, older, temple, are now part of an internal wall which marks the boundary between the Lower and Middle temple. The back elevation consists of a rubble wall construction, of recent origin, probably erected to replace missing megaliths – or, perhaps, the missing megaliths were never there? In fact, the same “containing” action on the inner parts of the structure could be achieved by a large external earth mound. In many other prehistoric megalithic tomb structures in Europe, (say Brittany, or the British Isles), the external appearance is, in fact, that of an earth mound enclosing an inner stone structure. It is therefore not unreasonable to hypothesise that the earth mound excavated at the beginning of the century, from the rear of the Mnajdra complex, was meant to be the external containment structure, replaced, in other locations, by the external megalithic ring. Alternatively, it could also be suggested that the external ring was actually the first constructional intervention, intended to stabilize an excavation into an existing soil slope, in order to create the space for the construction of the temple. The
removal of all earth mounds around the temple sites makes it difficult to draw any conclusions in this regard.

Plate 4: Clockwise from top. (i) Typical portal structure, Mnajdra, with “trilithon” portal, adjacent transverse upright, and low cubic blocks; (ii) Ruins of portal structures, with triple uprights, Ggantija; (iii) Triple verticals along main axis, now displacing slowly, because of missing lintols, Mnajdra; (iv) Axial sequence of apses with strong portal structures, at Tarxien, and (v) at Mnajdra.

4. ROOFING SYSTEMS

One of the more commonly asked questions about the temples is whether the temples were ever completely roofed over, and if so, with which material. Ashby1 and others, excavating Hagar Qim at the beginning of the 20th century, opined that the structures were originally certainly roofed over. The small stone models referred to earlier, and the stone engraving at Mnajdra, also suggest that the pair of apses was roofed over, at some level, by horizontal structural elements.

An intense debate has raged since Ceschi⁴, in 1939, argued forcibly in favour of a roofing system based on a corbelled structure up to a certain height, and then roofed over by stone slabs, used to create a flat roof over the reduced span over each apse (or pair of apses). Other authors, notably Evans⁵, 1959, Tampone⁷,⁸,⁹, Bonanno², 1988, and Piovanelli⁶ in 1988, have contributed to this debate. A detailed engineering approach to the problem was undertaken by Xuereb¹⁴, in 1999, as part of his undergraduate research work.

In general, the solutions for roofing systems can be characterized by the following. It is possible that the corbelled stone structures continued upwards, as in the Mycenean tholos, until the upper oculus was very small, and was then either easily roofed over by small stone slabs, or left open. The main argument against this solution is the complete absence of any evidence that the external form of the temples could have been so high as would be required by this structure – as well as by the absence of the volume of stone material that one would have expected to find at the sites of the ruined structures.

It could also be that the apses were left completely open. This could make sense from the functional point of view – given Malta’s mild climate; however, this would leave unanswered
one very important question. Why would the prehistoric builders make such an effort to erect corbelled stone apses, if not to reduce the span across the apses? And why would this be necessary, if there were not the intention to exploit this reduction in span?

For the supporters of the thesis that the temple structures did have some sort of flat roof, the primary evidence for this consists of the afore-mentioned models and stone engraving, but also the Tarxien Hypogeum, which appears to replicate some of the architectural features of the temple structures above ground. Amongst those who support this proposal, the debate has also been on whether the flat roofing consisted of timber, or whether it consisted of stone slabs, as proposed by Ceschi.

The main arguments against stone roofing structures include the absence of sufficient remains of what would have been the stones for the roofs, but especially the perception that the locally-available limestone was not strong enough to span the approximately 5m void that would result from a corbelling system, taken up to no higher than 6m above the ground.

Although, the author does not believe that it is yet possible to present conclusive evidence in favour of one material or of another, it is possible to make the following observations. It is not true that globigerina limestone, which is the weaker of the limestones available locally, is not strong enough to span over 5m. The strength of a stone beam depends on its tensile strength, but also on its depth. The issue, therefore, is not whether the material is strong enough, but whether it would be possible to produce, and to handle, stone beams, of reasonably-practical sizes, to span over the 5 or 6m necessary. Laboratory studies by Xuereb\textsuperscript{14}, using stone beams 5.0m long, 0.5m deep and 0.35m wide, have shown that such a stone beam could successfully satisfy this function. The weight of this single stone beam is not trivial, but it is very comparable to the weights of the megaliths, which can still be observed at the temple sites, and which therefore could demonstrably be handled by the prehistoric builders. It is, of course, necessary to show how such a weight would not only be lifted in place, from the ground, but how it would be lifted up 6m in the air and positioned where necessary. This is a topic that will be discussed in the next section. However, in engineering terms, it could be stated that limestone, obtained in sizes which are feasible, both from the point of view of the quarry extraction operations, and also from the logistical handling and lifting operations, could fulfill the roofing function assumed in this hypothesis.

As to the other main objection, that there is no material evidence of the remnants of such roofing elements, it could easily be argued that the temple sites, once ruined and abandoned, would, very likely, be a source of stone material for other construction activities elsewhere. The use of stone or marble ruins as a “quarry” is a phenomenon that is common throughout many civilizations, and many geographical locations. Indeed, the more difficult question to answer would be why would the prehistoric builders, after so much engineering effort to erect the lower part of the temple structures in stone – presumably considered as a material with great durability when compared to other, easier to handle, building materials such as timber – then opt to erect the more critical roof structures in wood, or other, less durable materials. It is not impossible that they did roof the temple structures in less durable materials, but it would demonstrate a lack of consistency in the architectural concept of the monument, as a structure to last thousands of years. And, frankly, there is no evidence of inconsistency in their architectural or engineering thinking – quite the opposite.

5. CONSTRUCTION PROCESS

The architecture and engineering of the temple structures owes a lot to the raw material that is available on the island. The temple structures are built of globigerina or coralline limestone blocks, of sizes that can vary from half a tonne to over 2 tonnes, and, exceptionally, much more.
Local limestone affords reasonably good mechanical properties, and, particularly for the globigerina limestone, a reasonable degree of workability. This is, especially in the light of the limited tools available at that time, a very important consideration. The stone blocks could be extracted relatively easily from shallow open quarries, very often in close proximity to the site of the temple structures themselves. The relative compactness of the limestone, particularly globigerina limestone, the absence of marked bedding planes, and the limited amount of fissuring, would have assisted the extraction of large flat blocks of sufficient thickness.

Zammit has written about the tools that would have been available to the prehistoric builders. They would have used hand-axes of flint and quartzite, (obtained from volcanic islands in the vicinity), knives and scrapers of obsidian, wedges of wood or stone, pickaxes made of branched horns of antlers or of flint, stone hammers, wooden rammers, wooden levers, and wooden or stone rollers. The evidence for these tools is found in the archaeological objects uncovered during the various excavations of these prehistoric sites. The discovery of large stone balls, for example, examined in the light of the details in the lower surfaces of some of the enormous stones used for the external wall of Hagar Qim, say, could very easily explain how these balls could have been a feature of the process of lifting upright the enormous megaliths, obviously transported flat. The cart-ruts have also been interpreted as stone “rails” prepared to guide sledges loaded with stone from the quarries to the building sites, although this interpretation is not really satisfactory.

In the structural system explained before, the primary elements in the construction process would be the portal structures. These are the elements that give stability to the apses – the apses would not be stable without these portal structures. It is reasonable to presume, therefore, that the construction of the structure would commence by the construction of these portal structures. The first decision to be taken by the prehistoric builders would thus be the orientation of the axis along which the portal structures would be erected. It would be unreasonable to presume that the choice of orientation axis of a structure, that would be erected with so much effort and skill, and that was intended to last for generations, would be taken lightly. This would confirm the proposals made by other authors that the temples are deliberately oriented either to the stars, or to other stellar bodies such as the moon and the sun.

The first steps would thus be those of preparing the ground, - this would depend on whether the selected site were flat and level, (in which case it would be normal to expect the structures to be founded on an outcrop of rock), or sloping, (in which case, as in the example of the Middle Temple at Mnajdra, the ground would be leveled by careful packing of smaller stones). Once the axis of the temple was selected, the threshold stones, suitably worked and notched as discussed previously, would be put in place, and the uprights on either side of the portal structure dragged to the site and erected in place.

At this stage, before the operations of erecting the portal lintols were embarked upon, it would be reasonable to ensure that the uprights were rigidly held in place. Whichever technique was used to lift the portal lintels, to the not insignificant height of the top of the portal uprights - whether this were an earth ramp from the ground to the level required, or a see-saw level technique described by Zammit - it would always be necessary, at the final stage, to drag the lintol megalith over the top of the upright stones, and this would only work if the uprights were very rigidly held in space.

It is therefore possible to interpret the various features of the portal architecture as a means of providing lateral stability to the whole portal structure. These features include low stone cubes, placed at the foot of the uprights, other uprights oriented at right angles to the main uprights, presumably so as to provide lateral restraint in an orthogonal direction, as well as the system of
doubling or tripling the main uprights, in a concentric fashion, along the direction of the axis of symmetry.

Plate 5: Experiments with model blocks to show possible construction sequence. Clockwise from top:
(i) Setting out of axis, preparing strong thresholds, then uprights held in place by low blocks, then lintols pulled over, also, tripling of vertical blocks to consolidate portal; (ii) Semi-circular inner wall of apses erected, consolidated with rubble packing, held by outer wall structure erected over low peripheral plinth;
(iii) Concave façade, and erection of flat courses, and beginning of corbelling over apses; (iv) Internal view of corbelling closing gap until flat stones (or timber?) can be laid across void.

Once the portal structure were complete, it would then be possible for the prehistoric builders to define the internal spaces by erecting the first rings of other uprights, of much smaller scale, that form the base of the apses. These uprights would be stabilized by virtue of their slight inclination inwards, but mainly by abutting against the portal structure. The process would then continue by the erection of the horizontal courses of stone, the corbelled layers, by lifting suitably-shaped “vousoir” stones – again either by means of earth mounds, or by see-saw or other lever techniques. Once again, the stability of each corbelled semi-circular ring would be ensured by the abutment, and the wedging, against the portal structure. The corbelled structure would in this way rise up to the height of the portal structure.

The structure would still be liable to distress, for example by displacement of one of the lower apse uprights outwards. The longer-term structural integrity was thus achieved by packing around the periphery of the stone structure already erected, using small angular shaped stones, then enclosing this packing with a low ring of rectangular blocks which would form the plinth, and the means of righting the massive megaliths that form the external walls. The use of stone balls as bearings during this operation, or as locks to hold the base of the megaliths in place has already been referred to.

The sequence of alternate radial and transverse blocks forming the external walls has also already been referred to. The system presumes that the transverse blocks, invariably the largest to be used, would be erected first, in a nearly vertical position, but resting lightly inwards, against the stone infill surrounding the inner walls. The radial blocks, more longitudinal in shape, and worked to form a wedged shaped section, horizontally as well as vertically, would then be lifted in place in order to lock the external wall together.
It is not clear at what stage the concave façade would be erected. It could be that the façade is a merely architectural device, but this is, frankly, not likely. The concave plan shape is very likely related to the need to absorb horizontal forces at the façade, by a horizontal arching action into the ground. If this were the case, the façade would need to be in place as part of the process of erecting the external wall, if not before this phase.

At this stage, it is likely that an earth mound would have reached the top level of the construction to allow the transport of stone blocks to the upper levels of the temple. The same earth mound would probably exist before the erection of the external wall of the temple. It would therefore need to be removed, during the late stages of the operations, and its retaining function replaced by a continuation of the system used for the external wall. Unless it were vital for the monument to read as a free-standing structure, another hypothesis, however, could be that the earth mound, particularly if located at the back, was retained. The earth mound would also be the means by which any roofing structure, including stone beams, could be dragged up, and put in place. The lateral stability of the walls of the temple structure would be vital for this process.

Over the years during which the temples were in use, the compactness of the structural system would have enabled them to resist earth tremors, unless of gigantic intensity. The shapes described above are in fact amongst the most stable in the case of earth tremors. The temples would, however, be subject to many interventions by subsequent generations of users, including, as mentioned before, the construction of adjacent temples, and the coalescing of different constructional features.

Plate 6: From left (i) 6.5T megalith, Hagar Qim, with concave recesses for horizontal transport over stone balls? (ii) Concave recesses at base of uprights, Hagar Qim, for pivoting of blocks over plinth, or locking in place? (iii) Lateral support structures for making alterations?

It is also possible to trace direct engineering interventions, such as the excavation of the stone infill between inner and external walls, in order to create additional chambers. A case in point exists in the Lower Temple at Mnajdra, to the right of the main entrance. This is the area that was affected by a collapse in 1994. The collapse involved the failure of a curious table-like structure, that provided lateral support to an enormous megalith, located between the Lower and Middle temple, but which clearly belonged to the originally external wall of the Lower Temple. The megalith in question was in fact inclined inwards, compacting what would have been an infill of stones locked against the inner chamber walls. When the need arose to create an additional chamber – (perhaps, because of the ritual need for an oracle chamber?) – it would have been necessary to excavate the stone infill, from the top. It is clear that the prehistoric builders were aware of the pressures induced inwards by the megalith in question, because, it is also clear that, as the excavation proceeded downwards, stone “props”, in the form of large flat stone slabs, are inserted into the void, locking against the two stone sides, before the excavation proceeded downwards. Additional vertical props were inserted as the excavation proceeded, in order to make sure that these horizontal props did not fall down. This process was repeated at least twice, in this location, before the whole chamber was excavated. The large vertical column, lo-
cated immediately to the left of the doorway carved in the apse uprights in order to give access to this new chamber, can also be interpreted as a form of “pile”, inserted into the ground as the excavation proceeded, in order to ensure the stability of the internal wall construction, which, incidentally, contains the highest corbelling system still in existence.

It is possible to identify other locations where stone elements were inserted, from the top, as would be expected once the area were infilled, in order to prop the sides of the chambers during excavation of the spaces between inner and outer walls. These operations were cleverly done, although it is likely that they tended to weaken the overall structure. Nonetheless, they survive, as do a number of other features. This is quite remarkable for 4500 to 5500 year-old structures, and very hard to beat with today’s engineering!

REFERENCES

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