A hypothesis on a building technique to determine the shape of the Nuragic tholoi

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The countryside and culture of Sardinia are characterised by the presence of Nuraghi, an architectural expression of the Nuragic Civilisation (2000–500 B.C.).

The expression «Nuraghe» is used for two different architectural types, corridor nuraghi and tholos nuraghi.

The first type has a flat ceiling corridor which runs through the whole structure, and slopes towards the top thanks to overhanging blocks. The planimetry is irregular, subquadrangular or elliptical and is only rarely circular.

Whereas a tholos nuraghe has one or more circular based chambers, one above the other. Their form is that of a tholos or falsacupola. This has been defined as a «classic nuraghe», both because of its numerous presence in the island and because of its «elementary» building technique i.e. a truncated conical tower, with successive additions of walls and angular towers producing the so-called Complex Nuraghi with labyrinthine planimetry e.g Su Nuraxi di Barumini, S. Antine di Torralba and the five-tower Nuraghe Arrubiu di Orroli.

Nuragic builders designed and built, apart from the nuraghi other architectural structures, of a sacred character such as fountains and holy wells and «Giants’Tombs» (collective graves), all with their own uses, but all with a single building technique i.e. an overhanging wall construction (evolution of the trilithic system).

The notable architectural development was made possible by the nature of Sardinian surface rocks, such as basalt, trachite and granite, with good building potential.

The single tower tholos nuraghe, the subject of my study, is from the outside a circular based tower with a truncated conical profile, built in the drystone method, i.e. without any form of cement, and with a complex arrangement of internal spaces.

The inclination of the external walls is produced by the position of the stone blocks which are sited one above the other is a horizontal order. Two different stone dressings can be easily distinguished in the external walls. The lower levels were made of cyclopic stone, with the blocks of polygonal stone roughly cut, laid in horizontal circles and infilled with smaller stones to level the next layer. The higher layers are of smaller size and have a wedge or quoin shape which allow an increased regularity of the horizontal layers. These higher levels are therefore more regular and more easily distinguished. The section of the construction is hollow-wall, that is, made of two walls between which there is a space which has been filled with rubble of different sizes. The two walls are joined by stone slabs positioned transversely and sunk into them to function as reinforcement.

Single tower nuraghi had originally at least two chambers, one above the other, the entrance to which was from the stair which, according to the slope,
could reach the floor above with a half or full turn, always clockwise, until it reached the summit of the tower where originally there was a terrace.3

The interwall staircase is an ever present element within the nuraghi, and two building techniques can be found in the thousands of towers «scala di camera» and «scala d’andito».

The first type begins from the main chamber and at a certain height from the ground (for example at Nuraghe Is Paras-Islì it begins at a height of 5.50 metres) and passing between the walls reaches the next floor. In most of these types of nuraghi, the base chamber is centrally placed in relation to the external diameter of the building and the thickness of the walls is insufficient to support the beginning of the staircase at this height. In fact the incline of the chamber wall determines, at a certain height from the ground, the height sufficient for the passage of the staircase.

The «scala d’andito» is, on the other hand, technically more advanced and probably more recent, because its construction presupposed a greater design ability compared to the previous one due to control of the whole eliptical development of the interwall staircase and the subsequent positioning of the upper chambers. The staircase has, in fact, a route from ground level to the top of the tower with spaces only for the entrance to the upper chambers. The circumference of the ground floor chamber is not concentric to the external circumference of the tower which means in section, the eccentricity of the chambers with regard to a vertical axis sited at the centre of the external circumference.

BUILDING TECHNIQUE

At the beginning of the construction of a complex and articulated building such as a nuraghe there is a plan, a theoretical and methodological formulation, which permits control of its completion. Building is not based on improvisation or spontaneous invention, but must be the result of the fusion of construction and project. It would be wrong, in fact, to consider the act of building and planning as casual. Planning and construction run side by side and are the result of the consolidation of acquired experience and building practice. A nuraghe was a construction in which structure and functionality were integrated, and there are no superfluous or secondary elements, every single element takes part in the stability of the whole. Studies so far undertaken into the building techniques of the nuraghi have been interested in the methods of transport and positioning of the enormous blocks of stone needed for their construction.

The realisation of a work such as a nuraghe was a rather complex operation, requiring a notable use of resources and human energy as well as a functional organisation of the building site. Given the number of towers built it is reasonable to think that the building technique was the patrimony of the Sardinian people. They probably had on hand a clear building project, knew, possibly empirically, the characteristics of their materials, and above all knew exactly, given their experience, which were the critical points of the structure. In fact we find throughout the territory the same structural scheme, at least in its essentials.

We can imagine the coordinated work of a number of teams who undertook the choice, cutting and laying of the blocks. Machinery was used for raising the blocks. In fact a deliberately carved stone was found near Nuraghe S. Cristina di Paullatino, which was probably used as a counterweight on the building site.4

The first phase of the construction was establishing the building plan and therefore the organisation of the internal space of the tower and architectural choices such as the type of staircase, which as we have seen, determines and defines the details of the upper floors. As the construction rose, level by level,5 spaces were defined, full and open, which defined the final structure. The critical points were the open spaces such as openings, niches and especially the route of the intermural staircases. In the upper levels the external walls reduce in thickness (from medium at the base of 4 metres to a medium of 1.5 metres in the upper layers). This was due to both to the more regularly cut stones used at this level to the more regular levels of the layers, and to the inclination of the external wall.

The tholos, the system of covering the nuragic chamber, is created in dry stone concentric rings laid on above the other horizontalt. Every successive ring is positioned inward with respect to the lower one in order to produce a vertical section with a curved profile. As the building rises the blocks are smaller and the roof ends with the smallest blocks which are them selves closed with a cap stone. The resultant self supporting structure is capable of remaining standing.
during construction without the help of any system of centring.

The tholos is a revolving structure which has in fact both horizontal circular section and vertical symetrical section in relation to an axis which coincides with the perpendicular at ground level which pass through the apex. The volume determined by this structure is obtained by the rotation around the axis of the profile of the intrados. A structure geometrically defined in this way cannot be realised without the help of a building method capable of controlling its horizontal development, vertically and radially.

The aspect of the building technique on which this study concentrates is the discovery of a method, simple and efficient, for the determination and control in the building stage, of the archway soffit (intrados) of the tholos.

A building method to create an overhanging roof with the form of a nuragic roof has been proposed by two English scholars W. G. Cavanagh and R. R. Laxton who believe, after having studied 15 nuragic tholoi, that simple instruments such as treetrunks, sticks and ropes would suffice to check the curvature of the chamber as construction goes ahead. The method (Fig. 1) which they propose consists of siting a trunk of height equal to H units (one unit equals half of the layer height) at the centre of the chamber in a vertical position, place a wooden beam perpendicular to the trunk on the last layer built, tie a rope to the top of the trunk and move it as far as the upper edge inside the last complete layer.

Then one runs horizontally on the wooden beam a stick of two units of height, marked at the middle, until the rope passes this point, the next level must be positioned until it touches the stick. The same manoeuvre is repeated until the roof is closed.

This hypothesis, though based on the use of simple tools, is from the constructional point of view complicated and restrictive. In fact the method as proposed is applicable only to the tholoi which have a constant height of layers. Also, if the technique were used to construct a nuragic tholos with layers of a decreasing height from below to above, it would be necessary to have a different stick for each height of layer, making the method even more complex.

The present work, as an alternative to that of Cavanagh and Laxton for the control of the curvature of the tholos is based on a building technique which uses simple tools such as trunks, ropes and a plumbline.

The first construction phase of a nuraghe consists of establishing in plan the internal spatial organisation of the first level. Thus the external dimension of the tower, and the position of the chamber and its diameter are established. Having completed the first layer of stones (Fig. 2) a trunk of height H slightly inferior to the real height of the roof is sited in the centre of the chamber in a vertical position.

At the top of the pole is fixed a rope of a length equal to the distance from the point at the top of the pole to the upper internal edge of the first layer, plus the height of the layer itself.

At the bottom end of the rope a weight is attached producing a plumbline.

The overhang of the levels is determined thus: the rope is stretched from the top of the pole as far as the upper internal edge of the stone already laid, then the stone is moved until the weight at the end of the rope touches the ground. The same operation can be undertaken radially as many times as is necessary to position the various stones of the same layer. The process then continues layer by layer (Fig. 3).
To better understand the characteristics of the construction and the hypothesis proposed it is better to observe the geometric properties of this conic.

The parabola is the geometric locus of the points on the plane equidistant from a fixed point called the Focus and from a straight line called the Directrix. It is also possible to define the parabola as a Limit Ellipse, and therefore as the geometric locus of the points on the plane for which the sum of the distances from two fixed points called Focus which is constant and belongs to the axis of symmetry and of which one to infinity. (Fig. 4)

To verify whether the curve obtained by sectioning the nuraghi tholos vertically through its axis is a parabola, the data obtained by Cavanagh and Laxton on a sample of pseudovolti were used.

Among the data published the following sections of nuragic tholoi were chosen, Is Paras-Isili, Palmavera-Alghero, S. Sabina-Silanus, the first and second chambers of S. Antine-Torrata and Oroli-Silanus. For each tholos the two scholars provide the coordinates of the points found during the measurement, referring to a Cartesian system beginning at the top of the tholos.

Having considered the generic function of the parabola \( y = -ax^2 \) (the negative sign indicates the concavity of the curve downwards) and notes \( x, y \) coordinates of the points in the tholos, the coefficient to determine the function of every single section remains unknown.

Assigning to \( x \) and respectively the values of the radius (regarding the axis of the tholos) and of the depth (regarding the apex) of a point chosen, based on the most probable parabolic alignment of the points, the coefficient of the parabola can be found.

For a generic point \( P \) we therefore have \( x_p, y_p \) and from the equation \( y_p = -ax_p^2 \) we obtain the coefficient \( a = \frac{y_p}{x_p^2} \).

At this point it is possible to obtain the function of the parabola with the data of Cavanagh and Laxton. Such comparisons (Figs. 6, 7, 8, 9, 10, 11, 12) and in particular the one relative to the figures of Nuraghe S. Sabina-Silanus would confirm the validity of my hypothesis.\(^8\)

The tholos is therefore a structure with a geometry which is also a building rule. In order to relate the equation of the parabola \( y = -ax^2 \) to the building method proposed it is necessari
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Definided as B and C, respectively the lowest and highest of the curve, we assume $x_B$ and $x_C$ as radii of the tholos with respect to B and C. Given the implicit equation of the parabola $y = -ax^2$ and the Cartesian coordinates of points B and C, it is necessary to find the value of the coefficient $a$ to determine the equation of the parabola which passes through the points of most probable alignment.

The equation for the required parabola has a coefficient negative and does not show the constant so the conic has a vertex at its origin and concavity towards the ground.

\[ y_B - y_C = a(x_B^2) \]

and that

\[ y_B - y_C = h, \]

la [1] becomes:

\[ h = a(-x_B^2 + x_C^2) \]

Once the coefficient of the parabola has been found, the hypothetical height of the tholos can be found by inserting the values of $a$ and $r$, radius of the base of the tholos, into the generic function of the parabola.

Theoretically this method is valid for the tholos which are no longer complete, which preserve a residual height of at least 3 metres and a notable beginning to the curve. The precision of the result obtained is linked to the regularity of the section and the reliability of the survey.

The hypothesis of the building method so far formulated helps us to understand the building technique and the geometry of nuragic tholoi, and therefore allow us to describe their spatial configuration and structure.

This is the starting point towards the definition of a geometric model before a structural analysis of the tholoi, a subject at the moment under study.

The necessity to investigate and understand the dynamic of the whole construction is dictated by the conviction that in order to preserve the historical testimony an adequate technical-structural knowledge is necessary.

At the moment the nuraghi (but this applies also to other nuragic construction such as a sacred Wells and Giants’ tombs) are in a very poor state, caused by the passage of time and because of attempts at consolidation of an irreversible nature used until now. Unfortunately the use of modern materials such as cement, metal bars and resins introduced via perforation cause permanent damage to the monument.

The work so far undertaken has not been done to resolve forever the problems inherent in the construction technique originally used, but should be seen as a first step towards an understanding of the structure, in order to make interventions possible which are less destructive which will allow a better preservation of these witnesses of our past.
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Figure 6
Curvature of the tholos in the Nuraghe Is Paras-Isili

Figure 7
Curvature of the tholos in the Nuraghe Palmavera-Alghero

Figure 8
Curvature of the tholos in the Nuraghe S. Sabina-Silanus

Figure 9
Curvature of the tholos in the first chamber of the Nuraghe S. Antine-Terralba
Figure 10
Curvature of the tholos in the second chamber of the Nuraghe S. Antine-Torralba

Figure 11
Curvature of the tholos in the first chamber of the Nuraghe Orolio-Silanus

Figure 12
Curvature of the tholos in the second chamber of the Nuraghe Orolio-Silanus

NOTES

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1. The expression «Nuraghe» comes from the word «nurra» which in the Sardinian dialect means «heap» or «cavità» and so a hollow construction. Nuraghi are mentioned in classical literature by the Greeks as dedali and tholos and by the Romans as castra (castles) and spelonche.

2. If, in fact, we observe the geolithological map of Sardinia compared to the density of nuraghi it is evident that, in the flat lands and alluvial plain these architectural outcrops become rarer until they disappear all together. The explanation can be found in the fact that building became more difficult in those areas in which the most suitable lithoid material was not immediately available on the surface.

3. Originally a nuraghe had an over hanging parapet built
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into its highest level, resting on alternative corbels and stone blocks and forming an integral part of the underlying wall. The discovery in the piles of stone caused by collapse, found at the base of several towers cut in corbel shape, and the finding of models of nuraghi showing this type of roof would confirm this type of overhang used to sustain an open terrace.

4. The use of wood, not only in the building stage but also within the finished nuraghi, has been found in some nuraghi in the form of internal-wall holes for the positioning of wooden roof-beams. Nuraghe Oes-Giave, a nuraghe with two external towers with a «scala d’adito» i this respect is of particular interest. Its interior is an open cylinder, originally covered by a single tholos. This environment was probably divided vertically by wooden garrets, resting on continuous horizontal stone ledges, one for each floor, joined by an interwall staircase of an ellipsoidal shape. This is a very refined solution of spacial use because the chambers preserve more or less the same size and do not diminish in diameter with height. Energy is also saved by avoiding the construction of a tholos for every chamber.

5. The Nuraghe Ruggiu-Chiaramanonti (Fig.), a single tower with tholos and «scala d’adito» in height interior at level of the passage entrance, stone slabs between the outer walls of the tower and the inner walls of the tholos, sunk, therefore, into the two parameters of the nuraghe. This particular feature, which can be found also in other cases, bears witness to the fact that the realisation of the tholos and the external walls of the tower took place at the same time and on horizontal planes, thus utilizing as a building base those layers already constructed.


7. The building method adopted for 15 nuragic tholoi is described as follow in their publication: «Our analysis is based on carefully measured sections of the domes. A rapid method on surveying was devised using lasers. In the final season this involved mounting a self levelling rotating laser at the centre of the vault, so that a diametric vertical section could be defined. A theodolite (a Kern DKM2), with a laser eyepiece mounted, was set up as far from the section as space would allow. The precise location of the theodolite in relation to the given section was calculated. The two laser spots were then aimed to coincide at a series of points round the sections as defined by the rotating laser. The position of each point could be calculated from the vertical and horizontal readings on the theodolite and the known perpendicular distance of the theodolite from the line of the section. This method is sensitive to knowing the precise location of the theodolite, but our measurement were found to be accurate to ± 1%». W. G. Cavanagh and R. R. Laxton «An investigation into the construction of Sardinian Nuraghi», 1987.

8. The discrepancy found in the alignment between the curve determined according to my hypothesis and the points discovered by Cavanagh and Laxton, are due to the summary working of the visible faces of the stone blocks, as the profile of the intrados is not regular. Not only, but the survey undertaken by measuring the rays at a constant but too short distance do not take into consideration the horizontal flights of the layers produces the error.

9. The principle on which the construction of nuragic tholoi is based, as we have seen, is the progressive overhanging of the stone blocks. The same criteria can be found in the other types of architectural construction built by the Nuragic people, in the hypogeic tholoi of the holywells, in the system of closure of the corridors of the bastion in Complex nuraghi, as also in the single corrido of the Giants’ Tomb. It is also possible the hypothesis in these last two cases the use of the method used for the tholos, with the difference that, in the case of the corridors, there is a translation of the parabola along a horizontal axis and not radially as happens in the tholoi. This subject is at the moment being studied.

REFERENCE LIST


costruzioni nuragiche, Collana di Architettura, Milano, Franco Angeli.