

Message of the President of ISCARSAH Stephen Kelley

Dear Friends and Colleagues,

Once again we held a successful meeting at the University of Minho in Guimarães, Portugal on 23 July thanks to the efforts of Paulo Lourenco. We had 14 participants, two of which were guests. In addition we met many of the international students who are enrolled in the Erasmus Mundus program that was established through the efforts of ISCARSAH Expert members Paulo Lourenco, Pere Roca, Claudio Modena, and Miloš Drdáký.

Some things that we can look forward to in the future are the establishment of an ISCARSAH Member expertise and experience database. In addition our aspiration is that the Newsletter will become a Scientific Journal. For those of you who are not able to meet us face-to-face at meetings, writing for the Newsletter is a good way to introduce you to the rest of the members. We are a group of esteemed experts but we are also a community!

We are looking for someone who will actively administer both our Facebook and LinkedIn pages. We are increasingly finding that these are effective tools to connect with like-minded experts worldwide. If you have an inclination for social media please contact me directly at skelley@wje.com

Through the efforts of Expert Members Tom Morrison and Lyne Fontaine there will be a one day ISCARSAH Seminar on October 29, 2103: *Overview of Basics and Advanced Areas of Conservation Engineering*. This seminar is being held in conjunction with the ICOMOS Canada National Workshop for Structural Engineers that will be hosted in Ottawa, Ontario, Canada. ISCARSAH members Donald Friedman, Peter Elliot, Will Teron, and Steve Kelley will also participate. Details of the seminar and workshop can be found on the ISCARSAH website. The concept of the seminar is to introduce ISCARSAH to the community of Heritage Conservation Engineers in Canada. This should serve as a model for many of you who might see a similar need in your region of the world. Look for a report on this activity in an upcoming Newsletter.

Though no definite dates have been set for the next meeting of ISCARSAH we are considering Korea (in conjunction with the International Conference on Conservation of Stone and Earthen Architectural Heritage in May 2014; New York, NY; Japan; and Chile. Of course we will meet at the ICOMOS General Assembly in Florence, Italy in the fall of 2014 as well.

I look forward to seeing many of you again at one of these venues and meeting some of you whom I have never met before.

Sincerely,

Stephen J. Kelley
President - ISCARSAH



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Stephen Kelley

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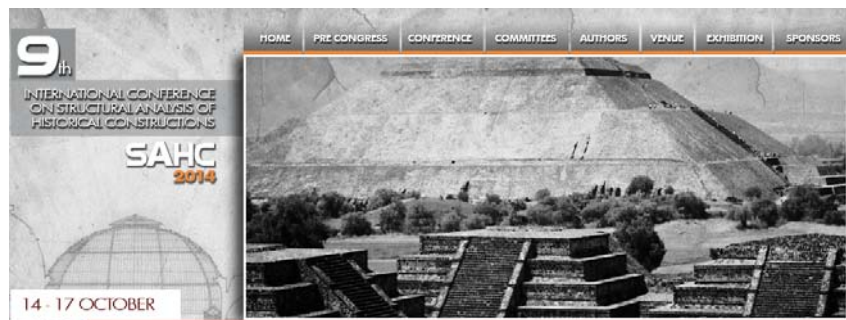
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2014 International Conference on Structural Analysis of Historical Constructions (SAHC2014) Mexico City, Mexico (15-17 october 2014)

The main topic of the conference is related to the concept of environment, which receives increasing attention, and is attractive to the governmental authorities and societies.

Innovative ideas are expected about the reuse of Historical Constructions, respecting their character of heritage and, at the same time, addressing current requirements for safety and comfort. Aspects considering the use of non-environmentally aggressive materials, life-cycle analysis and sustainability will be welcome.

The scientific program includes parallel sessions and poster session. Keynote lectures by leading experts and promising young researchers will be presented. One day pre-conference course will be offered.

The webpage, for abstract submission, is now available.

<http://www.sahc2014.mx>

Important Dates:

Abstract Submission: 15 November, 2013

Notification of provisional acceptance: 15 January, 2014

Manuscript submission for Review: 15 April, 2014

Notification of final acceptance: 30 May, 2014

Submission of final manuscript: 30 June, 2014

Conference General Contact:

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International Scientific Committee on the
Analysis and Restoration of Structures of
Architectural Heritage

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Culture, landscape and monuments in the city of Kyoto

The restoration of the Imperial Gateway at Nijo Castle (2012-2013)

Olimpia Niglio¹ - Noriko Inoue

¹Professor of Architectural Restoration - Kyoto University, Graduate School of Human and Environmental Studies

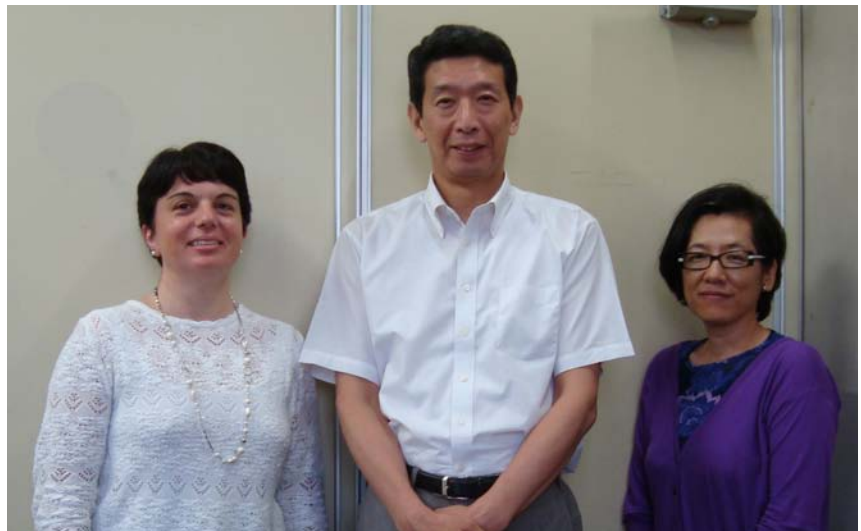
Since its establishment in 794, Kyoto, the ancient capital of Japan, has set the cultural tone for the nobility, the Imperial court and eventually the nation at large. The cradle of Japanese culture, Kyoto has a brilliant history of more than 1200 years beginning with the establishment of the Heian-kyo capital and is characterized by a perfect combination of culture, architecture, landscape and ancient traditions. The varied components that form the attractive landscape of Kyoto are the mountains, temples and shrines, gardens, residential areas and the configuration of the ancient city. In December 1994 several historical monuments of the city of Kyoto were included in the list of the UNESCO World Heritage Sites. In addition, Kyoto was recognized to be an outstanding example of traditional human settlement and land-use, represented by the culture and relationship with the environment. In addition as the centre of Japanese culture for more than 1000 years, Kyoto illustrates the development of Japanese wooden architecture from the Heian period (794-1185) to the Edo period (1603-1867) as seen in the religious architecture and the art of Japanese gardens, which has influenced landscape gardening all over the world.

How has the cultural program of Kyoto changed after being added to the list of World Heritage Sites? We had an interesting meeting (June 14, 2013) with Kozo Hiratake, General Director of the Culture of the Municipality of Kyoto regarding this issue. Director Hiratake explained that at the beginning the citizens did not understand the importance of its inclusion on the list and it was only later that they recognised the value of this

acknowledgment.

The results have been evident in the architectural restoration works as well as in the new constructions which have been built in relation with the heights of the ancient buildings following a public debate in the 1964's about the height of a

1. the height of buildings; 2. panoramic views; 3. subsidies for conservation of the urban landscape; 4. restoration of architecture; 5. restoration of urban skyline. Following these main points today the city of Kyoto is an interesting example of harmonious dialogue between an-



Municipality of Kyoto (June 14, 2013). From right Noriko Inoue (Otemon Gakuin University, Osaka), Kozo Hiratake General Director of the Culture of the Municipality of Kyoto), Olimpia Niglio (Kyoto University).

panoramic tower and in the 1980's about the volume of a large hotel in the city center. This experience has shown a strong interest of the citizens and they have also had a strong influence in the preservation of the ancient architecture and of the landscape. Meanwhile, important works of contemporary architecture have also been realized outside the old town centre, such as the new railway station which was designed by the Japanese architect Hiroshi Hara and opened in 1997. In particular after 2007 the new political of the landscape in the city of Kyoto has provided more controls about the following five points:

cient and contemporary culture. Director Hiratake then presented the cultural program of Kyoto, a city with a rich tangible and intangible heritage. This concept of intangible heritage was first introduced by the new national law of 1950. The city has important laws to protect this heritage but relies rather on concrete actions with the direct participation of citizens. The Municipality of Kyoto does not intend to force the projects with limitations but contrary it intends to promote an active and participatory conservation of the city. Whilst the city promotes the protection of heritage there are also many

local community initiative projects. The schools also play a very important role in the gathering and dissemination of knowledge and for the valorization of the cultural heritage with young students studying and visiting the city's monuments and museums as well as participating in cultural activities.

The ancient architecture, intangible heritage and nature comprise the cultural landscape of Kyoto. This city is surrounded by mountains and crossed by two major rivers: Kamo in the East and Katsura in the West. The citizens, whose lives are harmonically related to this landscape, know and appreciate this environment. This relationship is an ancient one which is part of the traditions that they have handed down for generations. The citizens have also utilized all major natural resources (in particular wood) from the mountains in the building and architectural restoration of temples, shrines, and houses.

Kyoto pays attention also to the protection of the Japanese National Heritage property. There are many examples of which the most important is the restoration of the Imperial Gateway of the Nijo Castle. The restoration began in February 2012 and was completed in July 2013. With the support of the General Director Kozo Hiratake, we were fortunate enough to visit the restoration site of the imperial gateway in Nijo Castle on June 25, 2013.

The restoration of Imperial Gateway (Kara-mon) at Nijo Castle

The World Heritage Site of Nijo Castle in Kyoto, an architectural treasure not only for Japan but the world as a whole, was built in 1603 by Tokugawa, the most notable member of the Tokugawa clan and founder of its shogunate. Built as Tokugawa's residential palace, the castle was completed in 1626 by the third Tokugawa shogun, Iemitsu, with the addition of struc-

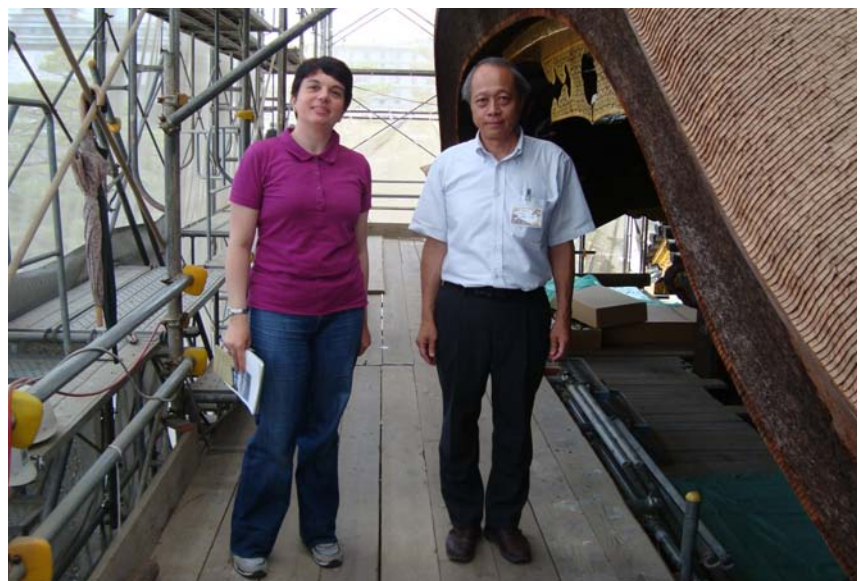
tures transferred from Fushimi Castle. Nijo Castle is one of the finest examples of architecture of the Azuchi-Momoyama Period (1573-1603) and Edo Period (1603-1867) in Japan, as it makes wonderful use of early Edo period building designs (shoin-zukuri architectural style), and lavish paintings and carvings that Iemitsu generously commissioned. In 1884 the Castle became the property of the Imperial family. It was donated to the City of Kyoto and renamed Nijo Castle in 1939. In 1994 the castle was designated as an UNESCO World Heritage

Site. The Honmaru Palace was destroyed in a large-scale fire in 1788. During the fire of 1788 the Imperial gateway to the palace, built in 1626 for an Imperial visit, and Ninomaru Palace were saved.

This gateway (Kara-mon) or Shiyaku-mon gate serves as the entrance to the Ninomaru Palace. The gateway and the Ninomaru Palace are authentic of the year 1626. With the collaboration of the Architect Tamaki Goto, Director of the architectural restoration of the gateway, we visited the site. This gateway has



Kyoto. The Imperial Gateway in Nijo Castle before the restoration (2008 © Olimpia Niglio).



Kyoto. The restoration site of the Imperial gateway in Nijo Castle. June 25, 2013. Architect Tamaki Goto (Municipality of Kyoto, Nijo Castle) with Olimpia Niglio (Kyoto University).

four important characteristics:

1. hiwadabuki, a roof covered with layers of Japanese cypress hinoki;
2. shikyaku-mon, structure composed of two large, main pillars, centered in line with the roof and of four pillars of support, two in the front and two in the rear;
3. zengonokikarahafutsuki, two main sides with similar formal characteristics;
4. kirzuma-tsukuri, construction with gable roof.

The Kara-mon is characterized by a particularly configured curve called kara-hafu that we find in many temples in Japan. The outer panels of the gate have carved cranes, butterflies and flowers, while the inner panels offer Chinese lions, tigers and a dragon. These panels are bas-reliefs in wood and they are painted with typical colors.

The natural properties of materials require a restoration every 30 years. This time cycle is strongly linked to the nature and to the transmission of ancient building traditions. This time



Kyoto. The restoration site of the Imperial gateway in Nijo Castle. June 25, 2013. Details of the bas-reliefs in wood and of the decorations with typical colors. (2013 © Olimpia Niglio).

cycle is a fundamental part of the culture of restoration in Japan and its cultural roots are very deep and not always easily explained. The restoration of the National Heritage property of Japan is done according to the transmission of ancient knowledge and the establishment of a harmonious dia-

logue between tangible and intangible heritage, a common characteristic of the Japanese culture of the restoration. The direct observation of the restoration work has made it possible to evaluate many cultural aspects that are the basis of the architectural conservation in Japan: in particular the ancient



Kyoto. The restoration site of the Imperial gateway in Nijo Castle. June 25, 2013. Detail of the kara-hafu. The dark area is not restored. (2013 © Olimpia Niglio).

techniques of execution and the carpentry of wood. With the last major restoration of Kara-mon in Nijo Castle carried out in 1975, the works planned between 2012 and 2013 have primarily concerned the restoration of the painted wooden parts, the copper decorations and the wooden sculptures in accordance to an ancient Japanese technique. After careful analysis of the state of conservation of the cypress bark roof, the works management has established a partial restoration of the roof.

The Scientific Committee, appointed by the Ministry of Culture, has also approved the partial restoration; which effectively restored only the most damaged areas leaving visible the parts of the roof that have been restored and those that have been conserved. This methodology of restoration was applied to the gateway only after assessing the conservation status of the materials. Only the degraded materials have been replaced. It is fundamental to note that the choice of the restoration method is evaluated on case-by-case.

The architect Goto explained the difficulties in finding the natural materials and the technique for extracting the bark from the cypress tree. Today in Japan there are only 10 companies working in the specific field of finding, removing and correctly working with the wood and bark of the cypress for the restoration of ancient architectures.

Subsequently we have analyzed the technical execution of the restoration and we have observed the excellent state of conservation of wooden structures that are original to the seventeenth century.

The decorative parts in copper and the wooden sculptures were disassembled and restored in the laboratory. On the restoration site it is possible to observe drawings showing the assembly stages of these works of art.

The restoration work will be inaugurated September 30, 2013.



Kyoto. The restoration site of the Imperial gateway in Nijo Castle. June 25, 2013. The Architect Goto describes the restoration of roof with bark of the cypress. (2013 © Olimpia Niglio).



Kyoto. The restoration site of the Imperial gateway in Nijo Castle. July 30, 2013. Detail of the kara-hafu after the restoration (2013 © Olimpia Niglio).



Kyoto. The restoration site of the Imperial gateway in Nijo Castle. July 30, 2013. The copper decorations and the wooden sculptures (three-dimensional) after the restoration (2013 © Olimpia Niglio).

La restauración de la Rocca Pia en Tívoli: de cárcel a Museo de la Ciudad

María Margarita Segarra Lagunes

Dipartimento di Architettura - Università degli Studi Roma Tre

Construida en la segunda mitad del siglo XV, como fortaleza papal en la ciudad de Tívoli, la Rocca Pia ha atravesado los siglos, adaptándose a nuevos usos y vigilando, desde el punto más alto del núcleo urbano, los fértiles valles a su alrededor.

Su edificación se inicia en 1461, con una torre circular de más de 36 metros de altura – la torre Mayor – a la cual sigue la torre Mediana, que se concluye ya al año siguiente. A la muerte del papa Pío II Piccolomini, la construcción se interrumpe hasta el pontificado de Sixto IV de la Rovere, quien prosigue la realización sin lograr terminarla. Es solamente hasta el papado de Alejandro VI Borgia, a finales del siglo XV, que, con la edificación de las dos torres en el lado norte, se completa el cuadrilátero fortificado. La solución adoptada corresponde a la planta tipo de las fortalezas militares de la época y tiene puntos en común con otros castillos realizados en el centro de Italia en esos años: el castillo Borgia de Nepi, el castillo de Julio II en Ostia, la fortaleza de Civitacastellana y la de Civitavecchia. Los gruesos muros de las torres y de los caminos de ronda aseguran una protección total del recinto defensivo.

Para facilitar el acopio de material y acelerar su construcción fue utilizada piedra recuperada del Anfiteatro romano de Bleso y de una construcción militar precedente, probablemente de la época de Federico II. Al centro del patio central fue colocada una gran cisterna para el almacenamiento de agua. Ya a mediados del siglo XVI, el castillo se engloba en el perímetro de murallas de la ciudad y se aportan mejoras al sistema de abastecimiento hídrico, con la realización del Acueducto Rivellese, que asegura la dotación de agua en su interior, aún en caso de asedio prolongado.

Durante los siglos XVI y XVII el edificio conserva la tipología y el uso original, albergando una guarnición militar al servicio del papa. Sin embargo, con la ocupación napoleónica, en los primeros años del siglo



Civitatib Tyburis delineatio, planta de Tívoli en el siglo XVII. En la parte superior, la Rocca Pia englobada en el circuito de murallas.

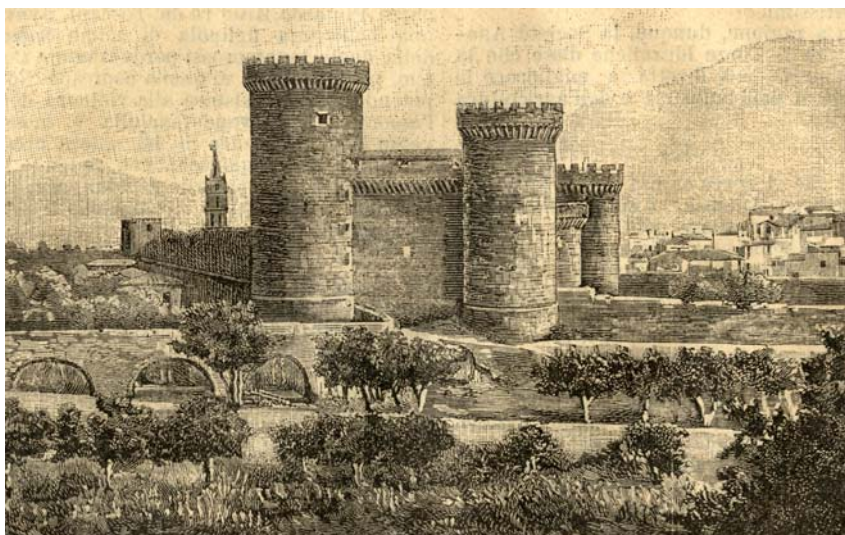


Nicolas-Didier Boguet, la Rocca Pia de Tívoli (en la segunda mitad del siglo XVIII). En primer término, la Torre Mayor; a la derecha, los arcos del Acueducto Rivellese, (Gabinetto Nazionale dei Disegni e delle Stampe, Roma).

XIX, su función se modifica para ser convertido en cárcel. Ello significa transformaciones arquitectónicas importantes, que conciernen sobre todo el interior del recinto: se construye un edificio adosado al muro norte, que alberga las celdas de los detenidos y una capilla, en la que puede decirse misa. Asimismo, las

torres Mayor y Mediana sufren transformaciones, con divisiones internas que permiten recabar ulteriores celdas.

Se modifica también el sistema original de acceso, anteriormente resuelto por medio de un baluarte de planta cuadrada y completamente exento, situado frente al in-



La Rocca Pia, en una xilografía de finales del siglo XIX.

greso principal del castillo, que alojaba en su interior una escalera de caracol, que conducía al nivel de la entrada. De ahí, por medio de un puente levadizo, era posible acceder a la puerta principal de la Rocca. Con las transformaciones aportadas para modernizar el edificio, el baluarte ya en parte en ruinas, se une al edificio, por medio de una escalera que lo abraza exteriormente y que, de manera mucho más cómoda, permite alcanzar el nivel de la entrada.

Durante todo el siglo XIX, la Rocca alterna el uso como cárcel y como cuartel, hasta la Unidad de Italia, en 1870, cuando finalmente se decide destinarla a cárcel civil, uso que mantiene hasta los años sesenta del siglo XX. Para ello, se llevan a cabo obras de reparación y

de adecuación al nuevo uso, restaurando sobre todo las cubiertas, las almenas de las torres y realizando caminos de ronda cubiertos en las terrazas de los cuatro lados de la fortaleza.

Con el desalojo de la cárcel, a partir de 1967, el edificio queda abandonado y sin propuestas para reconvertirlo a un uso útil para la comunidad. Después de poco más de cuatro décadas, gracias a un financiamiento conjunto del Ministerio de Bienes culturales y de la Provincia de Roma, se da inicio a una nueva etapa, consistente en las obras de restauración del edificio y su transformación en Museo de la Ciudad de Tívoli.

Si bien, por una parte, al inicio de esta nueva etapa el castillo se presentaba en un estado de completo

abandono, por la otra, no era difícil constatar su excelente técnica constructiva, que había resistido ataques y terremotos de casi cinco siglos. De menor calidad, al contrario, la adición decimonónica, que además había sido sometida a varias transformaciones funcionales, incluso con la demolición y reconstrucción de las bóvedas a alturas diferentes. En esta porción del edificio, en efecto, era posible comprobar el escaso encastrado de los muros transversales con la fachada neoclásica, lo que ponía en peligro de desprendimiento de ésta última, en caso de un terremoto significativo.

El proyecto de restauración¹

El proyecto de restauración parte del principio de conservación integral del edificio, con las huellas de las transformaciones y de los usos que tuvo a través de los siglos. De esta manera, las celdas de los detenidos, mantenidas casi completamente en su espacio interior, se convierten en salas del museo, en las que se narra la compleja e interesante historia de la ciudad: no debe olvidarse que, desde la época pre-romana, Tívoli fue esencial en el desarrollo de Roma, siendo el lugar que abastecía de piedra (travertino y toba) a la capital del imperio, primero, y del papado, después.

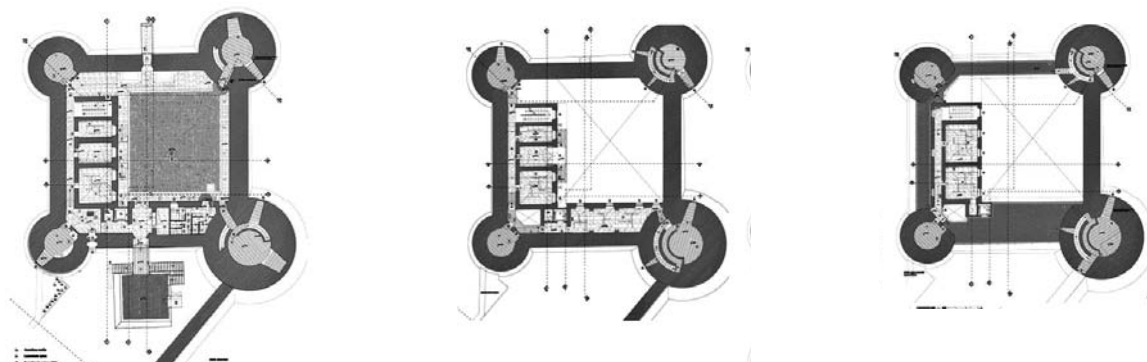
Desde el punto de vista estructural, no se consideró necesario efectuar intervenciones de consolidación o refuerzo de la mampostería *quattrocentesca*.

Solamente en el cuerpo napoleónico, en el que eran visibles los desprendimientos del muro de fachada, fueron insertados tirantes de acero, ahogados en el pavimento y fueron reforzados los encastrados de los muros con intervenciones de *cuciscuci*, reintegrando, con la misma mampostería de piedra y ladrillo, las partes faltantes. La inserción de un ascensor en un punto en el que permite el acceso a cualquier tipo de público, a todas las plantas del edificio e, incluso, al sistema de caminos de ronda de las terrazas, comportó algunas aperturas en la mampostería, que fueron compensadas con una estructura en acero,



La Rocca Pia, en una foto aérea anterior a la obra de restauración. Del lado izquierdo, el Anfiteatro romano de Bleso.

¹ El proyecto de restauración de la Rocca Pia es de María Margarita Segarra Lagunes (2004-2008), con Mario Manieri Elia y Giovanni Manieri Elia, Città Futura (instalaciones y estructuras).



Plantas principales de la Rocca Pia, en el proyecto de restauración.

anclada a la misma mampostería. La demolición de la escalera decimonónica, que soldaba la fachada principal de la Rocca al baluarte frente a ésta, permitió constatar que, a pesar de los años transcurridos, la piedra de la fachada se encontraba en excelentes condiciones. Se tomó la decisión de realizar una escalera contemporánea, en acero y madera, parcialmente escondida por el baluarte, que conduce a los visitantes siguiendo un recorrido parecido al antiguo: una vez alcanzada la cota de la entrada, desde la parte superior del baluarte, éstos se encaminan hacia la entrada de la Rocca a través de un puente (que evoca el puente levadizo original, desaparecido por lo menos desde hace ciento cincuenta años). En el interior del baluarte fue reallizada una excavación que permitió

recuperar los restos de la escalera de caracol mencionada por los documentos históricos y de la que se había perdido toda evidencia.

El pequeño edificio será destinado a punto informativo para los numerosos turistas que visitan la ciudad.

El patio central del castillo ha sido restaurado completamente, restituyendo los acabados superficiales en materiales tradicionales y con pintura de cal, adicionada con pigmentos naturales. Todos los elementos nuevos – escalera de acceso, revestimiento exterior del ascensor y puertas, de las que no se conservaba ninguna en buen estado – han sido realizados en acero cortén, de manera de denunciar con claridad toda nueva intervención.

El interior de las celdas, como se ha dicho, fue conservado casi sin mo-

dificaciones. La ventanería original, completamente desaparecida, fue sustituida con marcos tradicionales de madera; los pavimentos en ladrillo de las torres fueron conservados enteramente, reintegrando las piezas faltantes. Los pavimentos de las celdas del cuerpo napoleónico, no existentes desde hace varias décadas, fueron rea-lizados en losas de travertino, material local que se integra armónicamente con el resto del edificio.

Por el momento las obras de restauración se han concluido y se ha dado inicio al proyecto museográfico: las salas expondrán grabados y acuarelas de pintores de los siglos XVII, XVIII y XIX (Piranesi, Rossini, Giuntotardi, ecc.), así como fotografías de los siglos XIX y XX, que muestran lugares de la ciudad de Tívoli en diferentes



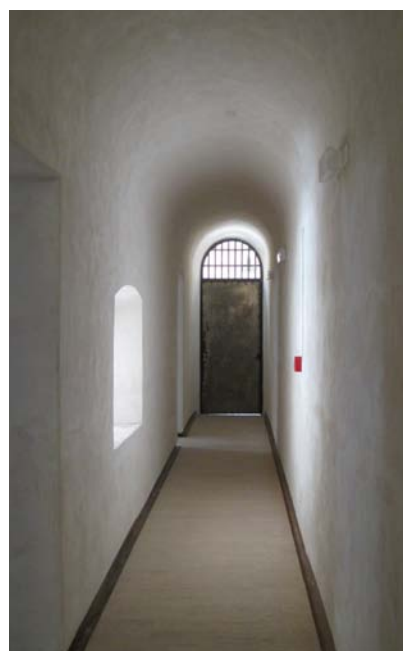
Fachadas del patio principal de la Rocca Pia, antes y después de la restauración de las superficies, con técnicas y materiales tradicionales. En la imagen de la derecha, al centro, se nota el nuevo volumen del ascensor, revestido con láminas de acero corten.



La nueva escalera de acceso a la Rocca y, a la derecha, el puente que comunica el baluarte con la entrada principal al conjunto.



La fachada restaurada de la Rocca Pia.



Uno de los pasillos de distribución de la antigua cárcel, hoy completamente renovado.

momentos históricos y sus principales monumentos, hoy inscritos en la lista del Patrimonio Mundial de la UNESCO: Villa Adriana, Villa Gregoriana, Villa d'Este. La intervención en la Rocca ha permitido también llamar la atención sobre la urgencia de intervenir en el adyacente Anfiteatro romano de Bleso, para el cual existe ya un anteproyecto que prevé que el edificio, con limitadas reintegraciones, pueda ser utilizado para llevar a cabo espectáculos, sobre todo en el periodo de verano, conformando con la Rocca Pia un excepcional polo cultural.

Seismic behaviour of traditional stone masonry minarets in Bosnia and Herzegovina

Report on the Case study

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Introduction

The Case study on traditional minarets is one of nineteen case studies performed within the work package nine of the international research project NIKER (2010-2012) concerned with various aspects of seismic behaviour, assessment and strengthening of elements, subassemblies and structures of historical buildings.

The common effort of the engineering firm Interprojekt from Mostar, University of Padova and Politecnico di Milano, comprising data collection, on-site investigation, numerical modelling and seismic analyses resulted with very interesting and useful conclusions and provided hints for future research.

Background

Traditional minarets in Bosnia and Herzegovina are dating from 15th to 19th century, the period of Ottoman ruling in the region. Three types may be noticed: (i) stone masonry minarets of predominantly polygonal shape, (ii) stone masonry minarets of squered shape and (iii) timber structured minarets. The study is concerned with the first type as presented in Figures 1-3.

These slender and tall masonry structures, typically attached to the mosque building at the base level, have demonstrated a very good structural behaviour exposed to hazardous seismic and wind actions over the period of several hundred years. However, collapse of the same type of minarets was noticed on the occasion of earthquakes in Turkey from 1999 and 2001.

Bosnia and Herzegovina is situated in the seismic active region of the Southeast Europe where in most cases PGA of 0,2 g and in some parts 0,3 to 0,35 g has to be considered.

The research is based on the post-war experience in assessment and reconstruction of stone masonry minarets and other buildings of cultural heritage.



Figure 1. Hadži-Alija mosque in Počitelj, Bosnia and Herzegovina.

Scope of the Study

Data collected for twenty polygonal minarets were considered in the numerical analysis for generalization of the results. The on-site investigation on two minarets performed within the case study, as well as the earlier referenced investigations, was used for calibration of the model. Besides the complex nonlinear analysis, a simplified calibrated linear elastic analysis was also performed in order to provide a suitable tool for preliminary assessment.

Contribution of the CFRP reinforcement at the inner side, as applied in one case, was considered in the nonlinear seismic analysis. Besides the standard seismic analysis, the influence of specific elements is carefully considered: the inner spiral staircase, the rigidity of the connection between the lower part (base) of the minaret and the adjacent mosque building, possible change in stiffness in time and influence of the reinforcement with carbon fibre strips (CFRP) applied at the inner side.

Results

The analysis of data collected for twenty minarets provided the following summary:

- Slenderness (total height divided by diameter of the shaft) ranges from 7 to 30;
- Total volume (of masonry) varies from 15 to 156 m³, and the unit volume per meter of height, from 0,86 to 3,58 m³/m;
- For the unit mass of 2 t/m³, total mass varies from 30 to 312 t, and for the unit mass of 3 t/m³, from 45 to 468 t;
- Compressive stress at the bottom, induced by the self weight varies from 0,22 to 0,34 N/mm², for unit mass of 2 t/m³, and from 0,32 to 0,51 N/mm², for unit mass of 3 t/m³.

The results of the testing and structural analysis indicated the following conclusions:

- The comparison of the results of dynamic testing performed in 2012 on two reconstructed (new) minarets with the results of dynamic testing performed before 1992 on four old minarets (with similar geometry and material characteristics), shows that the old minarets are significantly less stiff than the new ones, presumably due to the loss and decay of material (especially in joints) and also due to the less rigid connection to the mosque building. This fact leads to the recommendation that history of construction needs to be carefully explored in order to understand the assessment results correctly. Also, the loss of stiffness over a time needs to be considered;
- Nonlinear and simplified analyses show that, for the case of horizontal action, the most vulnerable part of the minaret is the area of the bottom part of the central shaft (the top of the transition from the base to the central shaft). This matches the real situation evidenced during the earthquakes in Turkey 1999 and 2002;
- The bottom area of the upper part of the shaft (just above the balcony level) needs to be carefully analysed as well. One should note that the opening for the exit to the balcony level is weakening the regular section;
- Nonlinear analysis indicates that carbon fibre (CFRP) strips improve the seismic behaviour by reducing the concentration of tensile stresses and redistributing it to a wider area. Using of CFRP strips or any other strengthening needs to be carefully assessed for each case separately. Bonding of CFRP strips to the parent material is of the paramount importance for the efficiency of the strengthening. Besides the structural assessment, all other aspects of pro-

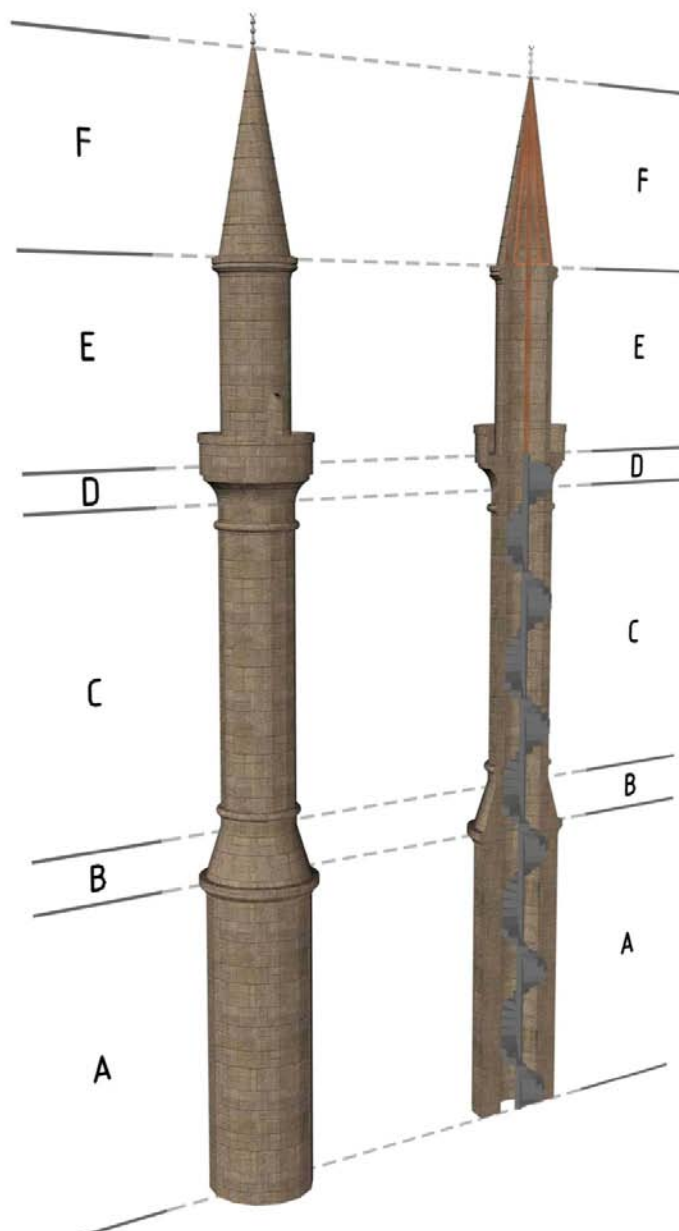


Figure 2. 3D view of the minaret with the vertical section and marking of characteristic parts in Mostar, Bosnia and Herzegovina.

tection of cultural heritage need to be considered;

- Simplified linear analysis may be used as a tool for preliminary assessment and evaluation of the need to perform a more complex analysis;
- The on-site testing performed in 2012, may serve as the basis, in technical and organizational sense, for future inspection and/or monitoring activities. Continuous dynamic and static monitoring would provide valuable information on the structural behaviour. In case of financial and organizational limitations, other reduced methods may be considered (e.g. punctual dynamic inspection combined with continuous static monitoring);

The conclusion on the bearing capacity of the minaret structure subjected to seismic or wind load and the decision on the need for intervention are based on the results of the following steps:

- Visual inspection and obtaining the information on construction history, geometry, materials, local seismic and wind action, soil condition and damages;
- The simplified analysis performed as the first analysis for each minaret, should provide a preliminary information on the danger of collapse;
- If overturning or exceeding compressive or shear strength are indicated as possible, a more complex numerical analysis should be performed in order to confirm whether strengthening is required or not. Within this step it is also necessary to decide whether the on-site inspection and/or monitoring is required or not;
- If inspection and/or monitoring is required then the calibration of the structural model and the final structural analysis should be performed, both for the unreinforced and the reinforced structure;
- If the intervention is required and consequently implemented, then monitoring and validating the intervention efficiency is advised.

Free downloads

Case study on Seismic behaviour of traditional stone masonry minarets in Bosnia and Herzegovina may be downloaded from <http://www.interprojekt.ba/niker-en>

All public documents resulting from NIKER project may be downloaded from <http://www.niker.eu/downloads/> NIKER Catalogue (web based tool that links earthquake induced failure mechanisms, construction typologies and materials, interventions and assessment techniques) may be accessed at www.niker.eu



Figure 3. Koski Mehmed-pasha mosque in Mostar, Bosnia and Herzegovina.

Acknowledgements

The research leading to this result has received funding from the European Union Seventh Framework Programme under grant agreement no.244123 and support funding from the Ministry of Civil Affairs of Bosnia and Herzegovina from the Grant "Programmes for the preparation of Projects and Potential Candidates for Fund Resources EU-FP7" for 2010. Contribution of colleagues and institutions in obtaining information on geometry and materials of traditional minarets is gratefully acknowledged.

The National Bank of Greece Administration Building and the Acharnian Gate of the Ancient Athens Circuit Wall

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1 Introduction

The majority of the major Greek cities have been built over the ancient ones, some of them over a series of old cities (modern over medieval, medieval over Byzantine, Byzantine over ancient, ancient over prehistoric, prehistoric over Neolithic etc.).

The existence of antiquities in the ground environment in urban areas makes it unfavourable for the developer, mainly for two reasons: Firstly because there is a demand that the archaeological resource, if significant, be preserved in situ and secondly because the need for construction of new buildings and other structures next to existing monuments and historic buildings pose, most of the times, significant construction difficulties. In both cases innovative engineering solutions are required to overcome these difficulties.

Athens, a large modern city with a history of more than 5,200 years (starting in prehistoric period, around 3200 BC) and one of the largest economical, political and cultural centres of antiquity, holds into its substratum an archaeological treasure. Fig. 1 shows the major archaeological sites in the centre of Athens and among them the walls of the city constructed in the 5th century B.C. by Themistocles. Experience has shown that practically there is no square metre within the walls where shallow excavations will not find ancient ruins.

Any excavation in the centre of Athens is supervised by the archaeological service and, depending on the significance of the ruins and the cost of the land expropriation (if they are found in a private property), decision is made whether they should remain in situ, either in the open air or in the basement / ground floor of the new building to be visited, or can be moved or can be

thoroughly backfilled and build on top of the fill without destroying them. Of course, there are many cases where the construction of the new building was completely cancelled because of the significance of the antiquities found.

It is obvious that in the case where the antiquities are kept visit able under the new buildings, the role of the geotechnical and structural engineers is very significant, since they have to design the foundations without destroying the antiquities and the immediate superstructure in a way that permits the nice display of the antiquities. Similarly, the construction of a new building next to a monument or a historic building requires elegant geotechnical design in order to avoid damaging the monument. Finally, the preservation, the restoration or the rehabilitation of an old structure poses many challenges to be solved by the geotechnical engineer.

The geotechnical interventions in the process of building in ancient cities



Fig. 1 Major archaeological sites in the centre of Athens (in brown colour).

range from simple measures as thorough backfilling the antiquities, to complex applications as micro piling and fore poling under the antiquities or ground movement control using integrated hydraulic jacks to push back retaining walls. In this paper the geot-

technical intervention required in order to retain the antiquities of the Acharnian Gate in the basement of the new administration building of the National Bank of Greece in the centre of Athens, having two underground parking levels under the antiquities, is presented.

2 The Acharnian Gate

The earliest known fortification of Athens dates back to the mature prehistoric times. This is the "Kyklopeon" (Cyclopean) and the "Pelargikon" wall, surrounding the rock of the Acropolis during the Mycenaean period (late 2nd millennium BC). The completion of the consolidation of the Athenian municipalities, as well as the Athenian predominance in the Greek politico-economic life by the beginning of the 6th century BC, led to a proliferation of its size and subsequently to extend its limits through the application of new housing projects firstly by Solon and subsequently by Peisistratus and his successors (Peisistratides). According to Thucydides testimony, the new larger city of Athens was surrounded by a wall. However, no trace of this archaic perimeter fortification is revealed today, since this wall was destroyed by the Persians.

After the battle of Plataea (479 BC) and the withdrawal of the Persian army from Greece, primary care of the Athenians was the fortification of their city. So, within just a year, Athens and the northern part of the Acropolis received new fortifications (Fig. 2), named after the archon of that time Themistocles. The perimeter wall had a total length of about 6,500 m, average height 8 m, thickness 3 m and had at least 13 gates, including the Dipylon (Double Gate) to Keramikos, the Iera Pyli (Holy Gate) on Iera Odos (Holy Road), which lead to Elefsina, the Piraeus Gate, the

Dimiai Gates on the Nymphs' hill and the Acharnian Gate on the road to Acharnes. Remains of Themistocles' fortifications are saved in many different parts of Athens.

At the north side of the perimeter wall, at the intersection of the current roads Aiolou and Sofokleous are the ruins of the Acharnian Gate, referred to in inscriptions as well as by Essychios. As its name shows, lead to the municipality of Acharnes and the Parnitha, ensuring communication with the entire basin to the North of the city of Athens. Outside the gate there was a cemetery across the road. The archaeological excavation prior to the construction of the new administration building of the National Bank of Greece (Karatzas Building) at the centre of modern Athens (see Fig. 2) brought to light important antiquities



Fig. 2 Topographical map of the Classical Athens and the Themistocles Wall. The blue circle points the Acharnian Gate.

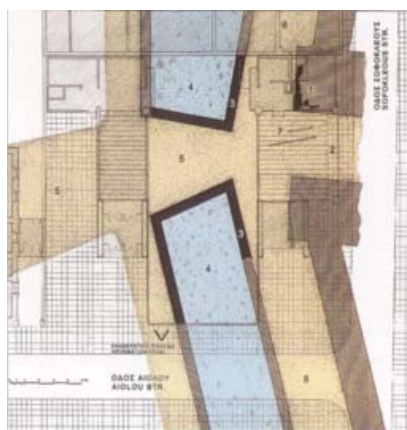


Fig. 3 Antiquities found at the site of the National Bank of Greece Administration Building. 2: Acharnian Gate of the ancient Athens circuit wall. 1: Scanty remains of the city wall (most likely foundations of a tower). 3: Extended parts of the front rampart (proteichisma). 4: Moat (tafros). 5: Ancient road preserving on its surface the grooves of cartwheels (location 7). 6: Peripheral road of the circuit wall.

concerning the approach to the most important Acharnian Gate of the ancient Athens circuit wall (Fig. 3) with scanty remains of the city wall (most likely foundations of a tower), as well as extended parts of the front rampart (proteichisma) and the moat (tafros). An ancient road was also found, preserving on its surface the grooves of cart-wheels. The road crosses the peripheral road of the circuit wall and intersects the front-rampart and the moat. It is identified with the ancient road from Athens to Acharnes. The archaeological excavation started in 1974, while the design of the building started in 1997.

3 The National Bank of Greece Administration Building

The preservation and the exhibition of the antiquities were prerequisites for constructing the building at this site. This, combined with the other operational prerequisite that the building should have underground floors, under the antiquities, formulated a serious geotechnical problem, requiring innovative solution to be overcome. The building was designed taking into account these requirements. Fig. 4 shows



Fig. 4 Drawing of the National Bank of Greece Administration Building with the antiquities preserved in the ground floor-basement and ground-basement plan.

a drawing of the building with the antiquities preserved in the ground floor – basement and Fig. 5 the cross section T1 with the antiquities preserved in the ground floor – basement.

According to the geotechnical investigations, the subsoil consists of a surface fill layer of about 2.50 m thickness, for which the geotechnical parameters are:

$\gamma = 19 \text{ kN/m}^3$, $\varphi = 38^\circ$, $c = 5 \text{ kPa}$, $E_s = 50 \text{ MPa}$,



Fig. 5 Cross section T1 of the National Bank of Greece Administration Building with the antiquities preserved in the ground floor-basement. The underground floors below the antiquities are also shown.

while the main geological formation of the site is bold schist with the following geotechnical parameters:

$\gamma = 21 \text{ kN/m}^3$, $\varphi = 25^\circ$, $c = 20 \div 80 \text{ kPa}$, $E_s = 60 \div 80 \text{ MPa}$

The construction of the building started with the construction of the temporary support of the excavation slopes and of the antiquities.

Assuming that the level in front of the new building on the Aiolou street was ± 0.00 , the final depth of the excavation was at -14.50 , with the top of the antiquities at -0.50 to -1.40 and the bottom at -2.60 , while the anticipated foundation level of the ancient city wall was at -6.00 .

In order to create a working platform for the construction of the temporary support, the whole site was filled with earth materials up to the level ± 0.00 . Before this, the antiquities were wrapped with wooden plaques (2.5 cm thick) and polythene sheets (Fig. 6) to avoid damages, while layers of geotextile were placed within the fill for more safety.

Fig. 7 shows the plan of the whole temporary support system, i.e. that for the excavation walls and that for the antiquities.



Fig. 6 Protection of the antiquities before earth filling.

The “Berlin” type wall was used for the temporary support of the vertical slopes of the excavation. This is a rather flexible support system consist-



Fig. 7 Plan of the temporary support system for the construction of the National Bank of Greece Administration Building.

ing of vertical steel beams (2 U 260) (sometimes of bored reinforced concrete piles), earth anchors and shotcrete (Fig. 8).

The method of the forepoles (horizontal micro piles) was used for the support of the antiquities. First, steel tube piles were placed round the antiquities. In the next stage the forepoles



Fig. 8 The “Berlin” type of wall used for the temporary support of the excavation slopes.

were constructed using Ø 250 mm rotary hammer drill and reinforcement consisting of two concentric steel tubes, the external having external diameter Ø 193.7 mm and thickness 7.1 mm and the internal having external diameter Ø 139.7 mm and thickness 7.1 mm. The micro piles were filled with

cement mortar with a 2:1 cement to water ratio. After the construction of the fore poles horizontal steel beams HEA 260 were welded to the steel piles under the fore poles, in order to act as their support after the excavation of the ground under the fore poles (Fig. 9). To ensure the good contact of the fore poles and the steel beams, shotcrete was applied. Finally, steel tube trusses Ø 508 mm / 8 mm thick were used for the lateral support of the system.

In the next stage the ground under the fore poles was excavated (Fig. 10) and a layer of shotcrete, reinforced with steel wire mesh was applied. Temporary supports of steel frames were



Fig. 9 Construction of the fore poles under the antiquities.

used in some places.

Fig. 11 shows views of the excavation and the support of the antiquities. The final difficult step was the concreting of the roof slab of the 2nd base-



Fig. 10 Excavation under the antiquities. Temporary support with steel frames.

ment, just under the fore poles supporting the Acharnian Gate. Due to the presence of the members of the temporary support system (steel tubes and beams), the concreting of the slab was made in sections, providing special attachments for the continuity of the steel reinforcement bars.

It is worth to notice that, because of the significance of the antiquities, the support systems of the excavation slopes and of the antiquities, though temporary, have been designed to sustain seismic loads. On September 7, 1999, when the excavation had reached the level of -10.00, a shallow earthquake of magnitude M 5.9 occurred in the north-western suburbs of Athens, at a distance of about 18 km from the construction site. Accelerations as much as $a = 0.229 \text{ g}$ and $a = 0.511 \text{ g}$ (questioned) have been measured in the centre of Athens (at a distance of about 0.5 km from the site), however the support responded extremely well, without any failures and damages.



Fig. 11 Partial excavation and excavation to the final level.

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«Ighrem», «ksar» : Analyse morphologique et structurelle

Cas d'étude du ksar Ayt Yahya Ou'atman, Goulmima (Province Errachidia, Maroc)

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1. Introduction

Le ksar, établissement humain collectif, est un ensemble de bâtiments (maisons, mosquée) à terrasses, entouré de puissants remparts avec plusieurs portes. L'une des caractéristiques du ksar est son dispositif de défense, des tours avec une architecture de terre.

La structure morphologique du ksar Ayt Yahya Ou'atman affecte une forme coplanaire quadrilatère dont les deux diagonales lui confèrent le plan d'un losange. Dans son ensemble, elle est compacte, dense et limitée par un rempart continu renforcé par des tours de garde et percée par deux entrées bastionnées.

Le ksar Ayt Yahya Ou'atmane se caractérise par ses tours de guet à base carrée, appelée aguddim, qui avaient

pour objectif de surveiller les périmètres agricoles et les canaux d'eaux, comme le rapporte Ch. De Foucauld sur l'architecture ancienne de terre crue dans la vallée de Ghéris : « Ce sont des tours isolées de 10 à 12m de hauteur, en briques séchées au soleil, de forme carrée. Elle sont surtout nombreuses sur les lignes formant frontières entre les localités ; elles s'y dressent d'ordinaires par deux, se faisant face, une de chaque côté. Dès qu'éclate une guerre entre qsars, chaque parti emplit ses tours d'hommes armés avec mission de protéger cultures et canaux et de tirer sur tout individu du camp opposé qui passe à portée »¹.

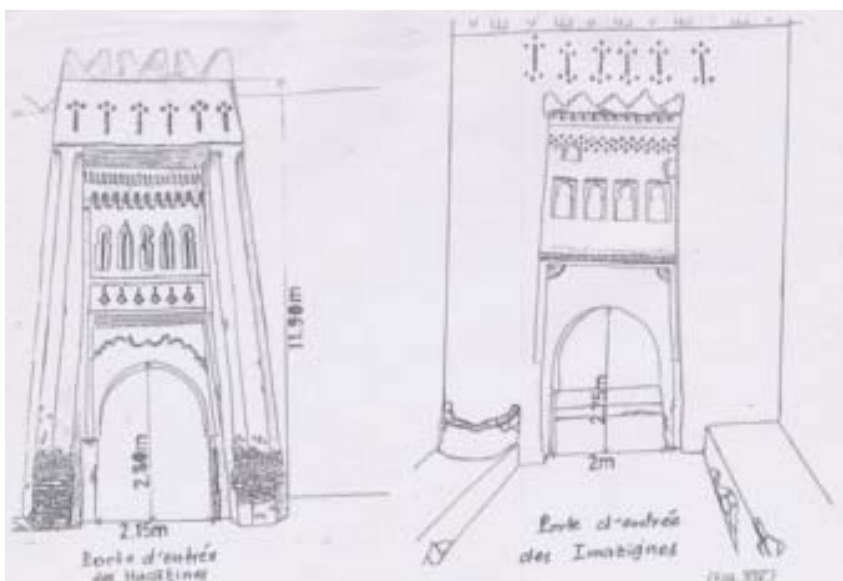
Les deux entrées du ksar Ayt Yahya Ou'atmane, entrée des Haratine et celle des imazighn, ont visiblement accaparé tout le soin du bâtisseur grâce à leur aspect architectural et ornemental. Elles ont été réalisées « Selon les règles d'un art militaire périmé et à la façon des portes monumentales des villes »². Leurs arcs d'entrée présentent une forme presque identique, mais leurs parties supérieures présentent des différences architectoniques très remarquables.

L'intérieur du ksar Ayt Yahya Ou'atmane est accessible à partir des deux portes par deux rues principales ramifiées en plusieurs impasses et des ruelles secondaires. Les deux rues axiales de 1.5 à 3.0m se rencontrent au niveau de la grande place de forme rectangulaire de 15 x 12m².

Ces rues de 1.5m à 3.0m de largeur sont couvertes par endroit par des planchers de maisons. Etant donné la hauteur importante de 4m, les planchers sont supportés par des piliers engagés de part et d'autre dans les murs délimitant le passage.



Plan du ksar Ayt Yahya Ou'atmane. 1. Grande place ; 2. Placette ; 3. Grande Mosquée ; 4. Quartier imazighn ; 5. Quartier Haratine. Source : Aba Sadki, « Une Cité Oasienne de Ghéris : ksar Ayt Yahya O'athmane : Etude Historique, Architecturale et Archéologique », Mémoire INSAP, 1995.



Les deux entrées du ksar Ayt Yahya Ou'atman. Source : Aba Sadki, « Une Cité Oasienne de Ghéris : ksar Ayt Yahya O'athmane : Etude Historique, Architecturale et Archéologique », Mémoire INSAP, 1995.



L'une des tours d'angle de forme carrée, ksar Ayt Yahya Ou'atman.



Porte d'entrée des imazighn, ksar Ayt Yahya Ou'atman.



Porte d'entrée des Haratine, ksar Ayt Yahya Ou'atman.

2. Les caractéristiques architecturales de l'habitat amazigh

L'unité du ksar, en plus de la mosquée, est la maison construite en terre crue qui se compose de deux à trois étages et d'une terrasse, desservis par un escalier étroit et sombre. Une façade de la maison peut donner sur la ruelle d'accès alors que les deux autres sont mitoyennes soit avec les remparts soit avec les maisons voisines.

2.1 La mosquée

Le ksar abrite à proximité de la grande place une mosquée qui se distingue par son minaret visible depuis la grande place et par son entrée qui donne sur l'une des allées axiales. Dans le cas du ksar Ayt Yahya Ou'atman, le minaret est une structure relativement élancée de forme pyramidale et de hauteur de 12m; il est construit uniquement en briques crues. L'intérieur de la mosquée est équipé d'un puits de profondeur de 34m et d'un foyer pour chauffer l'eau sous forme de fosse creusée au centre et au dessus de laquelle prend un chaudron accroché au plafond par une chaîne. L'espace d'ablution est de forme rectangulaire allongée de 15m sur une pente douce pour permettre l'évacuation des eaux vers une rigole souterraine. Quant à la salle de prière, elle est importante car elle occupe un espace rectangulaire d'environ 13.5 x 21.0m². « Cette grande salle abritait, jusqu'à 1981, une richesse ornementale importante. Durant cette année, elle a subi un remaniement dû aux pluies violentes



Motifs ornementaux (Porte d'entrée Haratine), ksar Ayt Yahya Ou'atman.



Entrée de la mosquée, ksar Ayt Yahya Ou'atman.



Minaret : Forme pyramidale relativement élancée.



Structure originale des contreforts dans l'espace des ablutions.

et aux inondations qui envahirent la plaine... Le résultat fut la destruction de quelques maisons et l'effondrement de la terrasse de l'oratoire³. Avant cette catastrophe, la toiture était supportée par une structure composée de 24 piliers de forme octogonale, coiffés de chapiteaux ornés, comme le confirme E. Laoust quand il évoque les mosquées de la région de Tafilalet et du Ziz « ... sont non seulement spacieuses et proprement entretenues, mais leurs salles, aux gros piliers octogonaux et aux chapiteaux ornés, présentent un intérêt archéologique, telles les mosquées du Gris ... »⁴.

Malheureusement, une grande partie de la structure originale a été remplacée par des poteaux en béton armé formant une trame de 4m x 2m



Minaret et terrasse de la grande mosquée, ksar Ayt Yahya Ou'atman.



Autre vue du minaret depuis une terrasse de maison, ksar Ayt Yahya Ou'atman.



A gauche, structure originale des contreforts dans l'espace des ablutions ; à droite, structure de piliers en béton armé, ksar Ayt Yahya Ou'atman.

et seulement quelques contreforts préservés et engagés dans le mur mitoyen entre l'espace des ablutions et la salle de prière.

2.2 La maison

Concernant l'habitat, l'unité courante dans le ksar est édifée sur 3 à 4 niveaux avec des murs porteurs construits en terre. Le rez-de-chaussée de la maison est destiné aux bêtes. La cuisine d'hiver et deux pièces (chambre



Maisons donnant sur la grande place, ksar Ayt Yahya Ou'atman ; rez-de-chaussée occupé par le bétail.

à coucher et réserves) occupent le premier étage alors que dans le deuxième et le troisième étage, les usages sont plus variés, notamment les pièces d'hôtes. Finalement la terrasse est un élément extrêmement important de la maison, puisque elle est utilisée pour dormir en été et pour sécher certains produits de la récolte.

2.3 Les matériaux et les techniques de construction des murs

Le mur de pisé (Leuh) est la technique fondamentale de construction. Les éléments de renfort et les linteaux uti-



Technique du pisé et du adobe : brique de terre crue. Source : Conservation manual for Earth Architecture in the pre-Saharan valleys of Morocco CERKAS / UNESCO World Heritage Centre / CRATerre-EAG, 2005. Murs en terre crue : pisé et brique de terre.



Eléments de renfort en bois de palmier ; bande de bois pour la stabilité des fissures.

Rue principale et structure des piliers engagés dans les murs, ksar Ayt Yahya Ou'atman.

A droite, soubassements en pierres hourdées, ksar Ayt Yahya Ou'atman.



lisés sont des bandes de bois de palmier. La brique de terre crue ou l'adobe (Toub) sert également à la construction de murs mitoyens et l'appareillage des décors de façades. Ainsi, l'épaisseur des murs en pisé au rez-de-chaussée est importante de 80cm à 1.0m pour des hauteurs de 4.0m ; elle passe à 60cm pour les banchées du premier étage pour atteindre 40cm au dernier étage avec banchées ou brique crue.

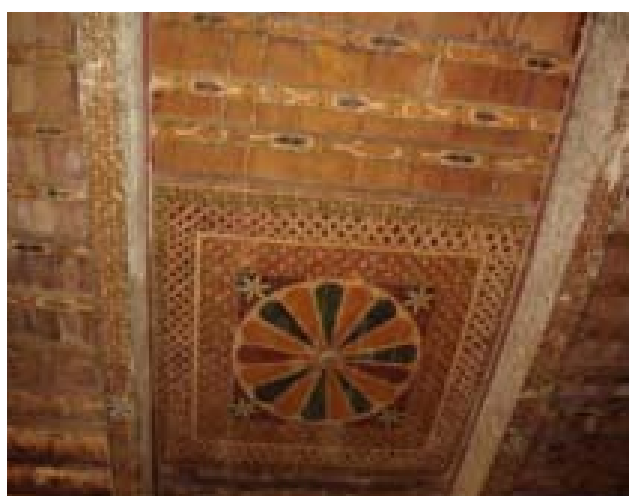
2.4 Les matériaux et les techniques de construction des planchers



Technique de construction de toiture. Source : Conservation manual for Earth Architecture in the pre-Saharan valleys of Morocco CERKAS / UNESCO World Heritage Centre / CRATerre-EAG, 2005.



Structure des murs et de plancher de maison en ruine, ksar Ayt Yahya Ou'atman ; matériaux de construction : pisé, briques de terre crue et bois ; planchers composés de poutres en bois et de roseaux tressés.



Plafonds en bois décoré : cas de deux maisons à ksar Ayt Yahya Ou'atman.

Le bois est l'élément principal dans tous les éléments de construction soumis à la flexion.

Les bois de palmier et d'eucalyptus sont le plus utilisés dans la construction des planchers qui sont composés de poutres espacées de 20 à 60 cm et recouvertes de plusieurs couches végétales (des feuilles de palmier, palmes, ou de roseaux tressés).

L'ensemble est couvert d'une couche de 15 à 20 cm de terre pilée. La portée des poutres en bois de palmier peut atteindre 2.5 m, portée qui conditionne les dimensions spatiales des pièces intérieures. Notons qu'il y a des planchers qui dépassent cette portée et des plafonds en bois décoré dans les pièces d'hôtes de quelques maisons.

2.5 Autres éléments architectoniques

Nous allons essayer de mettre en évidence d'autres éléments architectoniques, notamment les ouvertures, les ornements et les motifs décoratifs, qui caractérisent l'architecture en milieu amazigh.

Les fenêtres : On trouve actuellement des fenêtres de toutes sortes, mais on peut distinguer celles qui sont originaires du ksar par leurs formes rectangulaires ou carrées munies de grilles en ferronnerie dont les motifs restent sobres.

Les motifs, les décorations et les ornements : ces éléments affectent généralement les parties supérieures des grandes portes et les façades donnant sur des espaces découverts, notamment les places. En effet, les motifs architecturaux et les formes ornementales sont réalisés dans les murs en briques crues avec appareillage en plans verticaux et horizontaux, en s'inspirant d'autres arts décoratifs : tapisserie, tissage, tatouage...

3. Les mutations spatiales et les modifications de l'habitat

Les ksour en milieu amazigh, notamment les habitats traditionnels implantés dans l'espace provincial d'Errachidia, se sont parfaitement adaptés, le long des siècles, à la population, à ses besoins de défense et aux rigueurs du climat. Leur architecture et leurs modes d'établissement à Errachidia et à Goulmima en ont fait un patrimoine architectural de valeur. Cependant, de profondes mutations sociales, économiques et spatiales s'y sont produites ces dernières années avec de nouveaux besoins et de nouvelles exigences.

A titre d'exemple, l'eau et sa gestion sociale deviennent centrales et primordiales pour faire face aux besoins agricoles traditionnels de la population.

Une part de cette gestion s'est



Fenêtres simples munies de grilles en ferronnerie ; autre type de fenêtre en bois.



Exemples de décorations à ksar Ayt Yahya Ou'atman.



Espaces cultivés irrigués par les canaux, ksar Ayt Yahya Ou'atman.



Bornes fontaines et canal d'irrigation, ksar Ayt Yahya Ou'atman.



Eclatement extra-muros.



Nouveau lotissement visible à partir des terrasses du ksar.



Dégradation du plancher au niveau de l'entrée du ksar Ayt Yahya Ou'atman.



Une partie en ruine du ksar Ayt Yahya Ou'atman.

matérialisée par la réalisation de puits et de canaux d'irrigation pour les espaces cultivés (palmiers, fourrage, légumes ...) ainsi que des bornes fontaines pour l'alimentation en eau potable.

Un autre phénomène que connaissent les ksour, est l'éclatement extra-muros sous la forme d'un habitat dispersé et individuel ou carrément l'abandon du ksar pour aller s'installer dans les nouveaux lotissements qui étouffent la palmeraie, polluent l'eau et dégradent le paysage urbain.

Cette mutation est liée en grande partie à la dégradation de l'habitat traditionnel du ksar et au manque de salubrité, d'hygiène et d'équipement. Quelques habitants, contrairement à d'autres pauvres ou ceux qui croient encore aux traditions, souhaitent prospérer et disposer d'un autre type de logement, moderne, mieux adapté et bien équipé.

L'habitat en milieu amazigh vit depuis plusieurs décennies une dégradation du cadre bâti et un dysfonctionnement de ses institutions socio-culturelles.

Il souffre actuellement d'une insalubrité, d'une fragmentation de l'unité domestique et d'une carence en infrastructures et en équipements. Cette dégradation n'est pas seulement physique, elle est aussi fonctionnelle et sociale dues au changement du mode de vie et des mentalités des usagers. La suroccupation des maisons du ksar autrefois occupées par de grandes parentèles, aujourd'hui par des familles sans liens de parentés, soulève non seulement des problèmes de confort moderne, mais également de cohabitation et d'intimité. Cette situation a contribué à accélérer la dégradation de ces espaces de valeur historique souvent remarquable. Ce processus s'est accéléré au cours des dernières années et quelques maisons sont inhabitées et tombent en ruine.

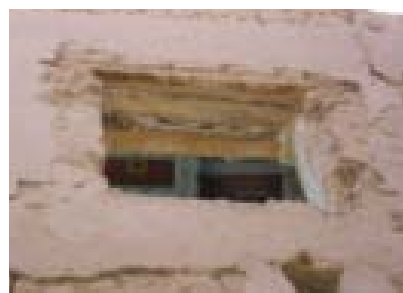
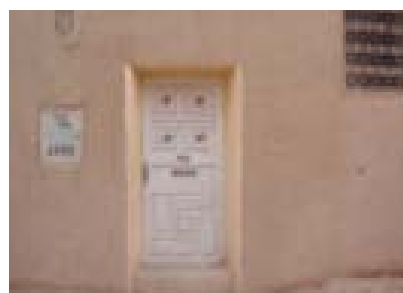




Effondrement de plancher sur ruelle, ksar Ayt Yahya Ou'atman.



Nouvelles portes dans les remparts.



Nouveaux matériaux remplaçant la terre.

Nouvelles portes dans les remparts.

Par ailleurs, dans les maisons habitées, souvent de nouvelles ouvertures, notamment les portes, sont réalisées dans les remparts.

Le phénomène de la rénovation et de l'amélioration du cadre bâti peut être tout aussi regrettable que la perte des formes et des détails physiques et architecturaux au profit de nouveaux matériaux et dispositifs incompatibles notamment le béton armé et l'aggloméré de béton.

¹ Laoust E., « L'habitat chez les transhumants du Maroc central (L'Igram), in. Hesp. Vol. XVIII, fasc ; 2, 1934 ; (La maison), Vol. XIV, fasc. 2, 1932 ; (La tente), Vol. XIV, fasc. 2, 1930.

² Terrasse H., Kasbas berbères de l'Atlas et des Oasis, Ed. Horizons de France, Paris, 1938.

³ Aba Sadki, « Une Cité Oasienne de Ghéris : Ksar Ayt Yahya O'athmane : Etude Historique, Architecturale et Archéologique », Mémoire INSAP, 1995.

⁴ Laoust E., « L'habitat chez les transhumants du Maroc central (L'Igram), in. Hesp. Vol. XVIII, fasc ; 2, 1934 ; (La maison), Vol. XIV, fasc. 2, 1932 ; (La tente), Vol. XIV, fasc. 2, 1930.



Nouvelles ouvertures dans les remparts.

The Prehistoric Architectural Model from Ta' Hagra, Malta

Analysis of Form, Mode of Construction, Structure

Gennaro Tampone

Summary

The models of existing or designed buildings, to be usually found in the development of the architecture, both as study means and as representation medium, are rather rare in pre- and proto-history. In any case they rarely are so defined to allow of a full deduction of the characteristics of the building they represent.

The model, found between 1923 and 1926 in the archaeological excavation of the prehistoric megalithic templar complex of Ta Hagra (IV m.) in the Malta Island, carved in Globigerina Limestone, now conserved in the Maltese Archaeological Museum, on the contrary allows, in spite of its very small dimensions (4,5 x 3,7 x 2,5 cm c.), of an accurate interpretation of its architectural characteristics, say material, formal, technical-constructive, structural.

Well-known and frequently mentioned, the find has never been the object of systematic studies. Examined the theses of other Scholars who cited it, the author proposes the results of his analysis made with the instruments of the history of architecture and structural engineering (Laser scanner 3D survey, FEM etc.).

It represents a building of elliptic shape of about 6,5 x 4,5 x 2,70 made with large stone blocks, thus a megalithic one, vertically placed, with alternation of orthostatic and diatonic elements, connected without mortar; it is covered by 5 adjacent "beams" (the most ancient ever represented), i.e. lithic elements rectangular in section, placed on edge, of the supposed length of 5 m c. (the longest one); the beam system is stabilized by a couple of slabs at each end of it, placed flat on the walls.

The model, that belongs autonomous architectural values with a few original and advanced solutions, is the confirmation of the building techniques of the coeval architecture of the prehistoric megalithic Maltese temples

mainly as regards, in the temples, the presence of a lithic covering that still is a matter of discussion in the academic setting.

It is probably the embodiment of the development of architectural intuition by a builder of megalithic architectures, made by his own hands.

Foreword

Models of existing or newly designed buildings, commonly found in architectural history, both as instruments of architectural research and as an interpretative medium, are quite rare in pre- and proto-history.

On the contrary, edifices of this period, generally hypogeal, excavated in the rock, in imitation of built structures, are frequently found in regions characterized geologically by the presence of unfissured formations of soft rock, especially biocalcarenes. Examples of these are the "domus de janas" of nuragic and pre-nuragic Sardinia (St Andrea Priu, Putifigari, for example) and the Etruscan tombs, mainly in the Cerveteri area, excavated in the so called periodo orientalizzante (VII c. B. C.) or of Volumni's Hypogeum (end of III c. B. C.) in Perugia. Referring to their spatial and formal features, their materials, and their load bearing structures, can be considered as models of dwellings, which were built of masonry and sometimes covered with a timber roof, generally with fine connotations.

The prehistoric Maltese context

In the Maltese prehistoric context the extremely complex Hypogeum of Hal Saflieni in Paola - that was excavated in three different levels, each level having a different extension and which was repeatedly enlarged over a long period of time (from the middle to the end of the III m.) - corresponds to the end of the temple period (spanning from the middle of the IV m to the middle of the III) belongs to the second cat-

egory of models. This hypogeum, that constitutes the place of the dead, consists of an articulated complex of chambers, wherein are reproduced the most significant formal and structural elements of the open air coeval megalithic temples, in particular the vaults - even if partial - which developed uninterruptedly over a millennium. These "underground dwellings" reproduce the form and condition of the place built for the divinities and confer on the dead a divine, or at least a supernatural stateliness.

It ought to be added that the Maltese prehistoric context during the period of the building of the megalithic Temples (IV - III m.) is a very fortunate exception, being characterised by an extraordinarily large number of singular architectural models of high quality that were produced contemporarily with the architecture.

These are stone and terracotta artefacts which generally reproduce buildings or parts of them, or allude to ground floor plans of buildings, mainly those of the temples. A few rare engravings on stone are also to be found, as for instance the well known carving on one of the internal megaliths of the Mnajdra Temple complex which is generally interpreted as the view of one of the sides of a templar building. At present there is no way of dating this and other engravings and therefore no scientific research can be started.

Considering the shape and small dimension of the so called "amulet" found at the Tarxien temple complex in Malta, as having possibly been conceived as an ornament, may be a decorative pendant, or a souvenir and not as an architectural model, although it could allude, through its shape, to a building similar to those built at that time.

Furthermore a few models of the ground floor plans of buildings are not to be overlooked, amongst which is the

plan that Ugolini (Ugolini, 1934, cit.) associated with a palace.

When excluding the cited Hal Saflieni Hypogeum, and restricting the field,

there are three finds that in the Maltese context can more appropriately be considered as architectural models: the large model of the façade of a temple



Fig. 1 - Models of the prehistoric megalithic architecture of the Maltese Archipelago. The model was found in three pieces at Tarxien (Tampone).



Fig. 2 - Models of the prehistoric megalithic architecture of the Maltese Archipelago. The model (a copy in the photo) was found at Hagiar Qim (Tampone).

building (Ceschi, 1939, cit.; Evans, 1959, 1982, p. 129, cit.), the very small model (object of the present paper) found during the excavations of the Ta' Hagarat temple complex in Malta directed by Th. Zammit¹ (in reality entrusted to volunteer helpers) (s. Evans, 1959, cit.; 1982, p. 129, cit.), and a mobile altar, an extraordinary piece of furniture, found in the excavation in the first apse of the larger temple of the main complex of Hagar Qim, Malta.

In the case of the first model, considering the dimensions, the perfect proportions of the constituent parts, the existence of all technical details and their extreme accuracy and precision, the Author puts forward the hypothesis that it is a "project", a project made in order to attain the patron's approval, which would then be handed over to the builders for construction. On the whole, this is a remarkable model that rightly inspired Ceschi and many others to restore the façade of the larger Temple in the Tarxien complex and, more in general, of several other buildings of the same period.

Regarding the third model, the present Author (Tampone, 1991, p. 259, cit.) has proposed: first, that it is an architectural model; and secondly, that it represents an aedicule made up of four columns supporting a horizontal slab on which a thick vessel is placed. The building overhangs a tree that, placed at its centre, is visible from all four sides in between the columns. As the tree is a theophany, the perceptible expression of the divine, and was considered as such shortly afterwards, such as in Minoan Crete, it is plausible to imagine that the architectural altar represents a building for accommodating and sheltering a divinity - in other words a temple.

The minuscule model found at Ta' Hagarat (Malta), one of the most archaic temple complexes of the Ggantija phase, justifies a special mention. This is not primarily for strict archaeological reasons, but particularly for the formal, constructive and structural information that it can provide, augmented by the propitious fact that the object is almost complete.



Fig. 3 - Models of the prehistoric megalithic architecture of the Maltese Archipelago. The model was found at Ta Hagra (photo D. Cilia).

Therefore the most appropriate methodology for investigating this model is through an architectural analysis, with advanced multi-disciplinary methodology for this kind of study, that could be extended to all the cited connotations.

Although very well known, repeatedly cited, emphatically exposed at the National Archaeological Museum of Valletta, Malta and reproduced in the majority of the publications on prehistoric Malta, the model has been the object of fleeting, short conjectures, including Ceschi's intuitions (see overleaf), and the sporadic attempts of reconstruction of its ground floor and structure, like that carried out by Ugolini (see overleaf). Despite the evident expressive qualities of the object, no systematic studies on the architectural characteristics of the model have ever been started.

The analysis carried out by the author on the building represented by the model and, in particular, on the covering system, had the primary goal of assessing its characteristics, mainly the aesthetic, constructional and structural ones, showing the original connotations. The secondary task was to try to give an answer to the several unsolved problems presented by the built architectures of the time, due to the fact that all of them arrived to us mutilated and deprived of covering.

The present essay shows the results of that analysis.

The find

The model was found during the excavation campaign carried out between

1923-1926 at the temple complex of Ta' Hagra. This object was classified (Zammit, 1929, cit.) as the model of a hut. L. M. Ugolini (Ugolini, 1934, cit.), who correctly assumed that this could provide direct information on the form of the contemporaneous temple buildings, produced a ground floor plan (Ugolini, 1934, p. 58, dis. p.167, "A. La Ferla dis."), restoring the missing part



Fig. 4 - Photo by D. Cilia of the Ta Hagra model (photo D. Cilia).

at the back and visualized the restoration of the inside. His assumption of the existence of an internal wall facing made of well cut vertical blocks, set in a regular arrangement - as in the middle and last phases of the Tarxien tem-

ples- seems to allude to a hypothesis that it belongs to a late developmental phase (see below).

Understanding that the model was fundamental to help interpret the construction and the structural characteristics of the contemporaneous Temples, C. Ceschi (1939, cit.) was the first to publish two photographs of it, putting them, significantly, in the introduction of his book (Ceschi, 1939, pp. 4-5).

Assuming that it represented a building with sacral functions and "model of a sanctuary", he called it monocellular (i.e. with only two side apses; the term "cella" (cell) is taken from Ugolini, cit.). He thought that it referred to a lost archaic type (of which no traces were ever found), from which, following a cells (apses) addition process, the known temples were derived².

J. D. Evans called it (Evans, 1971, pgs. 35, fig. 32, 11, 12, cit.) a model of a megalithic building, oval in plan, with an entrance defined by a trilithic frame, roofed with seven horizontal slabs and thus a "model of a sanctuary" (Evans, 1959 (1982, p. 22, fig. 77)).

G. Tampone (Tampone et al., 1987, p. 6, cit.) described the model as an oval find, recognising that it has similar fea-

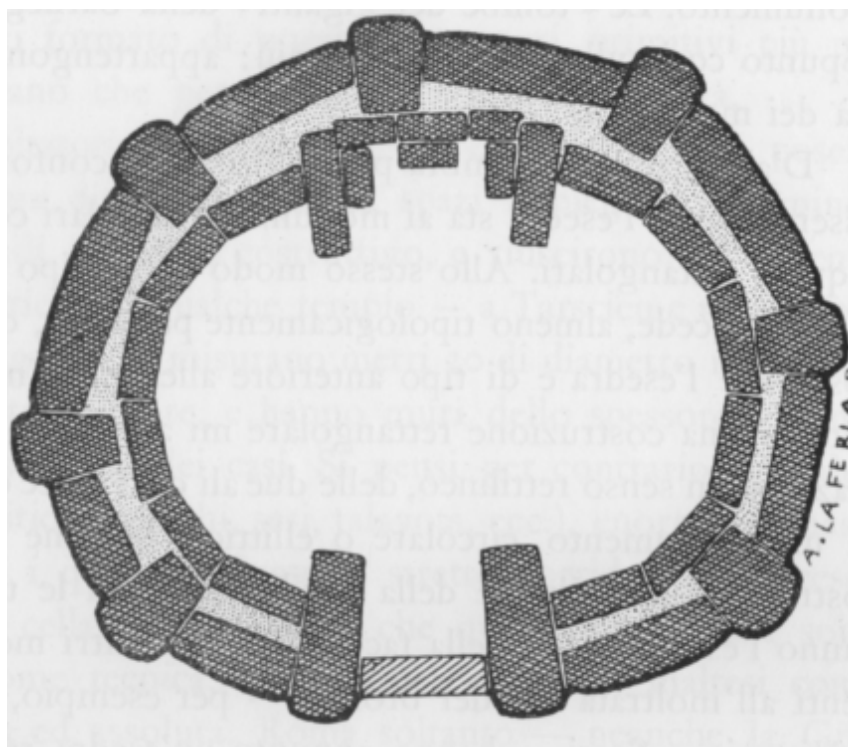


Fig. 5 - L. M. Ugolini, representation and interpretation of the small Ta Hagra model.

tures to the built architecture of the period. He observed that the roof is composed of five beams placed on their narrower end and by two pairs of side slabs placed flat on the walls. These side slabs seem to be needed in order to increase the height of two areas of the walls to attain that of the beams - those at the end - where the span is smallest. The Author has given here the elevations, a plan without the interior and a bird's eye view. Given the analogy with the small Mnajdra Temple, it is assumed to be archaic.

In a successive paper (Tampone, 2001, sez. I.a, p. 3, cit.) the Author, giving a bird's eye view with an hypothetic transversal section, interpreted it as a building covered by five stone beams placed on their narrower edge and by two couples, one at each end, of stone slabs laid horizontally one upon the other, meant to stabilize the cited beams and to radius the roof profile, forestalling the considerations exposed in the present contribution.

According to A. Pace, in a recent book edited by D. Cilia (Cilia, 2004, cit.) on Maltese pre-historic antiquities, which includes scientific contributions by the principal experts on the archaeology of the Maltese temple complexes, as well as protagonists of direct research and excavation on the Temples, the model, cited in the general part of the volume and in several chapters, forms part of an ample Maltese prehistoric architectural iconography. It also includes the engraving at Mnajdra, the so called "amulet" and the fragmentary model of Tarxien (see above).

A. Torpiano (Torpiano, in Cilia, 2004, pg. 348, fig.1, cit.) interprets the model as a building roofed with seven beams put side by side but certainly made of stone. R. England (England, in Cilia, 2004, note 13 and p. 415, cit.) sees in the model analogies with the Xemxija and Zebbug prehistoric tombs (Trump, 1973, cit., had already formulated this hypothesis especially in relation to Zebbug). However, he expresses the opinion that the material used for the temple coverings and for the roof of the found cannot be other than stone.

D. H. Trump, in the last edition of his well known archaeological guide of Malta (Trump, 2008, p. 192, cit.), describes it as a three-dimensional model, a single-celled structure, oval in plan, its curve convex façade completing the curve of the external walls. He maintains that it is not clear what kind of structure the roof of the model is meant to represent, and that it gives little help with the vexata quaestio of how the temples were roofed. He observes that "seven bars are shown" in the roof, but is not apparent whether they are slabs of stone or timber beams. In any case, he judges, following Evans' theory, the span excessive for stone slabs. On the basis of the width of the entrance thrilith he estimates the size of the represented building as 10m -13m long, about the size of the smallest, eastern, temple of Mnajdra.

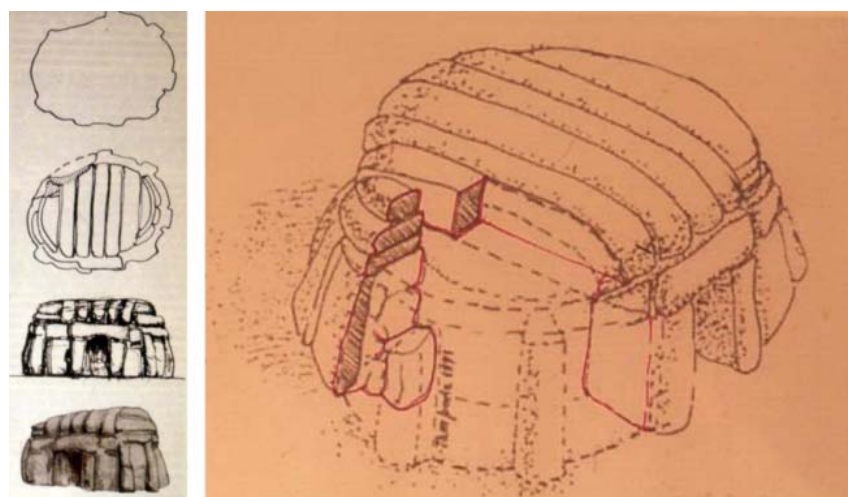


Fig. 6 - Views of the Ta Hagraat model (Tampone, 1987). Resolution and structural interpretation of the model (Tampone, 2001).

Description

The model is made of Globigerina Limestone, the same material used for the construction of the temples of Tarxien and Hagar Qim and others but not for that of Ta Hagraat (where it was found) and of Ggantija. The same limestone forms the inner walls of other temples such as Mnajdra. Ta' Hagraat and Ggantija, in fact, are both built for the most part of Coralline Limestone. From a petrographical point of view (Vannucci S., Cassar J., Tampone G., 1985, cit.) Globigerina Limestone is a

typical bioclastic limestone with micritic cement, showing a granulometry from fine to medium fine. It is a pure limestone (calcite > 92%), containing small amounts of quartz, feldspars, apatite, glauconite and clay minerals. The porosity of this material is high, usually in the range of 32% - 40% (Cassar and Vannucci, 1983; Vannucci et al, 1985), with a high percentage of the pores being micropores (< 4µm in diameter) (Vannucci et al, 1994).

No analyses are currently available to help assign the material of the model to one of the three members (Lower, Middle, Upper with an interval of two banks of phosphatic nodules) which make up the Globigerina Limestone Formation of the Maltese Islands. It is generally assumed, however, that the most commonly used material for building purposes is the Lower Glo-

bigerina Limestone, which has always proved to be the most durable of the three members. This can be described as a typical "soft limestone", being very easy to carve and shape; it thus forms part of the large family of the Oligo-Miocene "soft limestones" which are widely diffused in the Mediterranean basin, including Turkey, Israel, Tunisia, Spain and Italy (Cassar and Vannucci 2001).

The stone used here is very hard and homogeneous and compares with the average type of Lower Globigerina

Limestone. The find is sufficiently well preserved, although there is a missing area at the rear on the right. However, the shape of the missing part can be inferred, by symmetry, from the left part which is complete.

The actual object has a few sub-horizontal cracks that are incomplete, dividing it

assumed that one of the main reasons for its being made was to show, as in the large model from Tarxien, the formal organization of the exterior and the constructive-structural system.

Formal and lay-out characteristics

With respect to the general formal

an approximate elliptical shape.

The external shape of the facade is unusual, as it is convex, unlike all the other Maltese megalithic architectures which have a concave facade. The absence of this formal characteristic makes this model absolutely original and, perhaps, can be thought to have a function which is neither cultural or religious (see below).

Renouncing to designing the facade in a concave shape with the consequent formal emphasis of the front and to the improvement of the same stability, a different concept of stability is adopted in respect to that of the temples, opting for a bi-axial symmetry, similar to that around a central vertical axe. Another fundamental difference from the built temples is that their perimeter is made up of convex curves corresponding to the chambers, alternating with junction curves, concave lines or straight segments.

Regarding, the internal arrangement, the building represented is apparently made up of a single room, or maybe two side chambers (v. Ugolini, Ceschi, cit.). It cannot be discerned from the exterior whether there are any internal partitions or mouldings on the walls. The model therefore is quite similar to the archaic temple of Mnajdra, which is, today, rather damaged and altered during some past "restoration" works.

The temple however can be seen to have a concave facade, possess apses, and is thus conceived according to a quite different formal concept.

The entrance to the building is on one of the two long curved sides of the model. This consists of a trilithic portal, emphasized by the projection outwards of the constituent blocks, thus being constructed in a manner similar to the

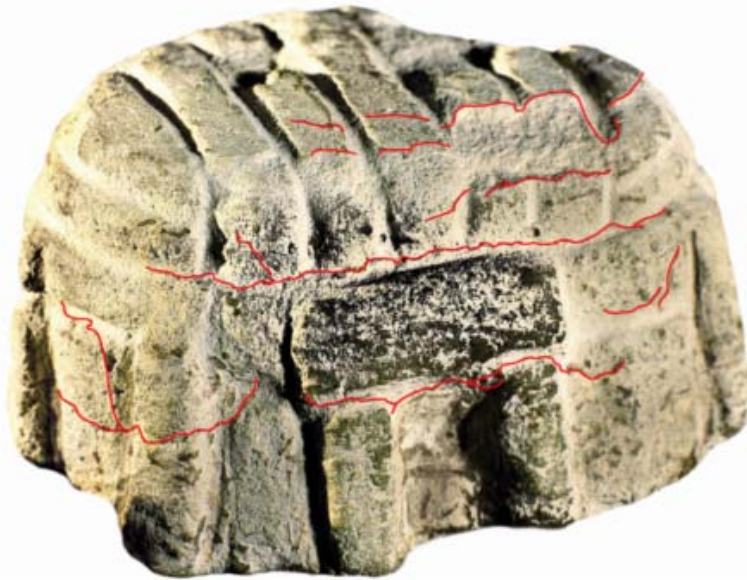


Fig. 7 - Cracks detected on the small Ta Hagrat model (Tampone, 2010) (photo D.Cilia).

into sub-horizontal curved surfaces, with a few ramifications, located in the upper part at three different levels.

These cracks are probably due to a local lack of homogeneity also associated with a lack of calcitic cement, that has led to a reduction in cohesion between the already formed strata and those still being formed, leading to breaks, brought about by variations in the thermo-hygrometric regime. The possible impacts during the carving of the object could also be partially responsible for these cracks.

Although of modest dimensions (4,5 x 3,7 x 2,5 cm circa), the model is finely carved, possibly with the use of flint tools or, more probably, of obsidian, that was imported to Malta from Lipari and Pantelleria and could be shaped into sharper blades. The model is well proportioned in its various parts and is practically free from imperfections (those present are partially due to defects in the stone). Because each feature is clearly represented, it can be

characteristics, the model represents a megalithic building whose exterior walls are definitely slanting towards the interior, from bottom to top (a feature mainly appreciable in the diatonic blocks). It is in the shape of half a walnut - one of the most stable forms known - similar to that of a clod of earth whose inclination is determined by the angle of internal friction. Thus, the building is extremely steady.

Even though the object now appears to have an oval base, it must be understood that this is due to the fact that it is now lacunose. Adding the missing part, it can be seen that the base had

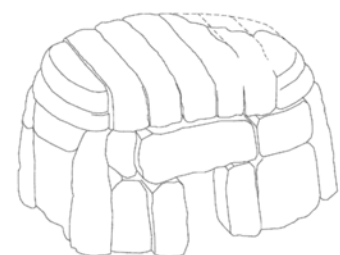
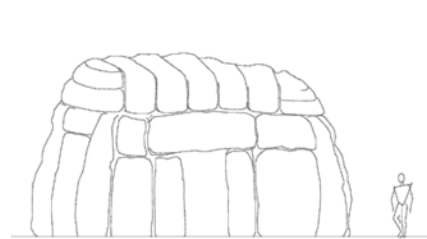


Fig. 8 - Representation of the small Ta Hagrat model (Tampone, 2009, con Derinaldis).

doorways of the built temples. The entrance connotation of the portal is also accentuated by having a very large monumental lintel, comparable to that which is to be found in the main building of the Ta' Hagrat complex (and that was reinstated by C. Zammit). (Here the two surviving temples, built of Coralline Limestone, as already mentioned, are not however single chambered and therefore have a perimeter which is basically shaped like an ogive and a concave facade).

The roof, in transverse section, is curved, sloping on both sides. The beams represented here are slightly different in height, and the left side of the roof is, for the most part, higher than the right side.

The building which the model represents lacks any other opening apart from the entrance.

Tectonic and structural characteristics

Various elements are all perfectly identifiable in the model, with few exceptions, and are all destined, in different ways, to fulfil load bearing and closing roles.

The model is characterised by the use, probably without the addition of mortar, of megaliths that show clearly to be organized on the continuous wall in an architectural order. This consists of a rigorous sequence of orthostatic elements (tangential to the perimeter) and diatonic ones (perpendicular) bulging slightly outwards. It is confirmed in the latter element the entasis and tapering of the shape which has already been observed for the analogous elements of the temples of Ggantija and Hagar Qim (Tampone, 1993, cit.). It is difficult to understand however the arrangement of the diatonic and orthostatic elements in the panels lateral to the entrance due to the wear of the object.

There are two vertical blocks placed immediately to the right of the entrance, a characteristic which is unseen in other positions, where the blocks are overlaid by slabs placed flat, making up the architrave. These lintel blocks can be clearly distinguished from each other, are well aligned and run all

around the building just like the tambour of a dome. In areas away from the entrance, however, the architrave is carried, necessarily but imperfectly, only on the lateral orthostats (in the model the subvertical face of the megalith on the right recedes).

This, therefore, is a representation of a building whose walls are built in a similar manner to the external wall of Ggantija, which has for the most part been authenticated and is quite well conserved, or even similar to the temples of Mnajdra. By comparison with contemporaneous buildings, one can suppose, as did Ugolini, that the walls are made up of two leaves that enclose an infill of stones. What is, however, purely a deduction as it is not based on any objective observation whatsoever, is the belief of that Author (implicit in the reproduction of La Ferla's drawing) that the internal walls are actually made up of refined slabs.

The structural features are those of greatest interest, especially due to the

pecially in the weaker sections (the convex); this also included utilising sensible measures such as leaning together two blocks on their edges or even creating vertical indentations between blocks (detected by the Author at Hagar Qim in the main building and in the anterior temple; Tampone, 1993, 2001, cit.). Other measures included utilising the weight of the diatonic elements, whose external surface is inclined towards the interior of the building, allowing this weight to act on the other blocks, too. It seems that the external face of the tangential blocks is vertical.

The diatonic uprights were originally nine in number, thus confirming Ugolini's interpretation (in fact some are missing in the model because of the gap which is present). The odd number is due to the fact that, corresponding to the two uprights which make up the trilithic entrance, there is only one element at the back. In the contemporary buildings the concave facades do not



Fig. 9 - Side elevation of the main (North) Temple of Ggantija (Tampone, 1983).

fact that even today many scholars - apparently without valid reasons - still doubt that the temples were roofed over and that the roof was in fact made of stone.

The alternation of blocks on end and on edge was meant, as in the built temples (v. Tampone, *The Structural System ...*, 2001, sez. I.a, p. 2, cit.), for stability, es-

pecially in the weaker sections (the convex); this also included utilising sensible measures such as leaning together two blocks on their edges or even creating vertical indentations between blocks (detected by the Author at Hagar Qim in the main building and in the anterior temple; Tampone, 1993, 2001, cit.). Other measures included utilising the weight of the diatonic elements, whose external surface is inclined towards the interior of the building, allowing this weight to act on the other blocks, too. It seems that the external face of the tangential blocks is vertical.

seen, for example, in the main temple of Ggantija, where one of the orthostats at the back has started to rotate towards the exterior, and, in 1936, was propped up with iron profiles).

The model under study is completely roofed over; the roof consists of rectangular beams which are obviously made of stone and are placed, in a most logical manner, with the short side of the section on the walls, hence knife-edged. These rest directly on the walls without the insertion of other stone elements: an exceptional example of constructional synthesis.

The beams, that are perfectly identified in the model by the carving, are five in number. They are placed, as Ceschi had observed, perpendicularly (in reality with slight imprecision) to the main axis of the building and are laid side by side. These act in lieu of a single stone slab – in technical language, a plate – which however would have had to be far too large. These have, on the whole, comparable strength of a hypothetical plate, but are less stable due to the fact that they are separate elements (with danger of rotation on their supports and, less probably, lateral instability). It must not be forgotten that using a single slab, which was probably practically impossible to quarry, transport and lift into place, would also have meant that this fragile element would have had to be precisely fitted all along its perimeter, in order to provide uniformity of pressure and to avoid cracking. This, however, would not have safeguarded the building from the possible effects, on the hypothetical slab, of eventual uneven settlements on top of the walls. In the Maltese temples this is, in fact, one of the main causes of the collapse of the roofs and the successive fall of the entire building (Tampone, 2001, cit.). The use of beams, each of which can comply localised subsidence of the walls without compromising the integrity and the functioning of the other beams and slide in the vertical plane in respect to the two adjacent ones, is a technical and practical construction measure which would help resolve the problems cited above. We



Fig. 10 - Restoration of an interior of the prehistoric megalithic Temple of Mnajdra, the vault of which is completed with lithic slabs (C. Ceschi, 1939).

can reasonably assume that the valuable ideal reconstructions – internal perspectives – drawn up by Carlo Ceschi and relating to architectonic spaces and, in particular, the roofing, for Ggantija and Tarxien, which made use of stone slabs laid side by side (see overleaf), are only inspired by the same model under study.

In order to avert the danger of instability of the beams, consisting in the possibility of buckling of each element around the axis passing through the supports, the stability, in the model, is assured by the presence of two slabs at each extremity laid flat on the upper part of the wall; these guarantee the connection of the lower part of the building with the roof, i.e. with the set of beams (Tampone, 2001). This is, on the whole, an ingenious device, that is common in Maltese prehistoric megalithic architecture, and is used to stabilise the vertical blocks both along the perimeter as well as at the external and internal doorways, but unknown elsewhere, aiming to avoid the overturning and the disruption of the

beams. An important example of this device includes the presence of very thick slabs that make up the flooring of a few of the chambers in the central temple of Tarxien, and which are aimed at stabilising the diatonic uprights in the external parts of the wall.

The total number of members on the roofing is nine i.e. five beams and two couples of stabilizing slabs, as the uprights already mentioned.

The beams are arch-shaped on the extrados and are also rounded towards each upper extremity. The central ones are shaped at the lower front end to allow for the previously mentioned architrave at the entrance to be arch-shaped. In the model one cannot obviously find any clue that could help deduce the profile of the intrados.

There is no doubt that the maker of the model imagined these elements to have been prepared with a precise stereotomy, possibly employing schemes such as “anathyrosis” (already observed within the Maltese temples by Ceschi, 1939, cit.; and in more detail by Tampone, 2005, cit.) so

as to allow for the perfect fitting of the nine elements. This too can be observed in the construction of the multiple external or passageway portals of the contemporary temples, whose up-rights are made of sub-vertical slabs which fit perfectly even though their faces are not flat.

It is possible that the beams could have had an underlying indentation at the two extremities to permit the effective positioning and linking to the underlying walls.

Dimensions, calculated verification and dimensioning

This applied research was carried out by means of observations on the original model, which is housed at the National Museum of Archaeology in Valletta, and on the macrophotographs taken by D. Cilia (Cilia, 2004, cit.). A survey was also carried out on a plaster mould of the same.

The mould, which bears some imperfections due to the cast, was laser scanned by a team working with Arch.

D. Blersch in the laboratory of the Centre Diaprem of the University of Ferrara. The scans were later restituted resulting in a virtual model and a large scale solid model.

In this way it has been easier to observe, and also possible to draw sections, construct views from various directions, carry out measurements and establish proportional relationships, by taking the height of the entrance portal as a baseline.

Furthermore, in order to substantiate the hypotheses made, calculations were made using the Finite Element Analysis (FEM) model which utilises the elements beam, plate and brick; in this case a model was constructed which was made up of brick elements.

Calculations were based on the height of the entrance and the length of the longest roofing beam within the model, which was assumed to be 5m long, thus working out the other dimensions (Tampone et al., 1987, cit.) from the proportional relationships thus established.

The principal model thus made was

based on a hypothesis wherein a beam (the central one) is resting on two supports, where the extent and the distribution of the tensions generated were studied. Deformations and displacements were also studied. One model is based on a beam with an external (extrados) profile which is straight, while another assumes a curved profile, thus taking into account the real shape of the stone model find (see fig. 13, 14).

It was, therefore, assumed that the building represented by the model could have been 8,47m long (8,50) and 6,57m (6,60) wide externally, with a height of 4,73m (4,70), dissenting from Trump's statement, which assumes the value of circa 10m for the major length; the internal dimensions on the ground would be 6,5 x 4,5 x 2,70 m.

Inversely, a length of 5m, on the basis of theoretical and practical considerations, was assumed to be the greatest length possible to manufacture, transport, raise and put in place a resistant beam which would not crack. This is the longest beam of the model, made out of Globigerina Limestone, the softest of the Maltese limestones. Several varieties of the same lytotype exist, which are much more compact and homogeneous, such as that of the very large megalith which is to be found on the right hand side of the main temple of Hagar Qim.

The established length of 5m also derives from the knowledge of blocks which are to be found, in nature or in situ, resting on their ends, and also from experimental tests (Torpiano, 2002, from Xuereb Dissertation, 1999, Malta University). In fact is not quite exact, and is not based on any objective datum, the Evans' affirmation (Evans, 1959, cit.), followed by Trump's statements, that the roofing resistant lithic elements could only have a maximum length of 2,5m. Torpiano (in Cilia, 2004, cit., p. 336) also agrees with the possibility of using elements of up to five or six m.

Measurements of the virtual model, verified by the dimensional analysis of the photographs by Cilia, have determined the average approximate dimensions of the central beam, whose central section can be said to be 0,75m



Fig. 11 - Interpretation of the constructive and structural characteristics of the Ta Hagraat small model (Tampone, 2009, with Derinaldis).

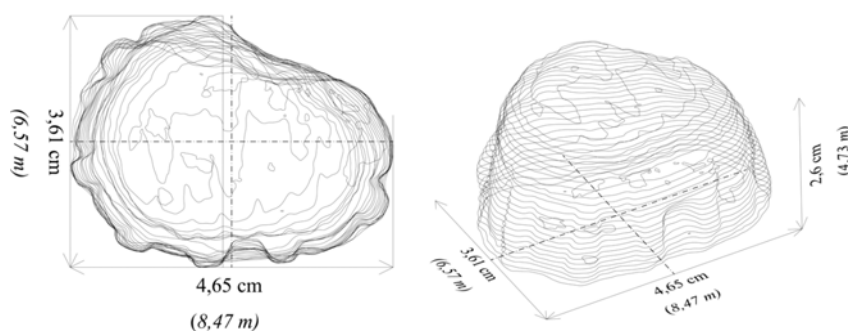


Fig. 12 - Restitution of the 3D laser scanner survey of the Ta Hagraat small model (D. Blersch, 2008).

wide and 1,00m high. These calculated dimensions absolutely exclude the possibility that the beams, which are squared, could be made of wood, a material which has been suggested as an alternative to stone by several authors (Evans, Trump, ..), unless one were to suggest a composite beam, which is improbable, and of which there is absolutely no trace in the model.

The beam has been assumed to be resting on two continuous supports, if one considers the wall to be ca.1m thick. The data and technical characteristics of Globigerina Limestone which form the basis for these calculations were inferred from the direct testing of samples carried out in 1997 in the Laboratory of the Faculty of Engineering of Florence and subsequently published (Tampone, Pieri Nerli et al., 1999, cit.).

These verification calculations were obtained for a beam of Globigerina Limestone of dimensions 0,75 x 1,00 x 5,00 m, whose characteristics were an apparent own weight of 1,700 kg/m³, E (Young's modulus) 112,800 kg/cm². The results are given below (v. Tampone, Pieri Nerli et al., 1996). The calculations also include the additional weight of 100 kg/m³ which was added to account for the weight of the tegument for a total estimated weight of 1,800 kg/m³. The internal tensions vary within the following ranges:

It can be deduced that the maximum principal tensions, obviously in the

centre line of the beam, due to both traction and compression, are always less than 2 kg/cm², a value which is certainly very far from that which can cause the rupture of the limestone under study. The shear tensions are negligible.

The compression tension on the wall is extremely low, less than the unity; it is less than 1,5 at the base of the wall. One should have a clear understanding, even if the matter goes beyond the intention of this essay, that at a certain moment soon after construction, the beams, due to unavoidable discontinuities of the contact surfaces, rested only on smaller areas of the walls therefore the pressure was actually concentrated and not negligible; this situation could have caused failures and in general the crack of the walls, as the real architectures show. In a following phase, although the beams are made of stone, they undergo deformation, though very limited, concentrating the load of each end on the edge of the wall (see model). In some cases, also due to this process, the solicitations can reach significant values that can cause crashing ruptures of the edges of the wall or, because of shear tension, on the beam. Up to a certain extent, these problematic can be taken into control by means of an accurate and correct placement of the elements during the construction, of protection with a tegument

(concretion or other) and with constant maintenance.

Conclusions

The model does not represent a generic functional building, but one endowed with its own clear, formal, distributive, constructive and structural characteristics. In other words, a fine expression of architecture. The object, in its astonishing respect of proportions, despite the extremely small size, has a high aesthetic value, which is certainly intentional, besides being also a means of communication.

This model confirms, above all, the lack of openings, apart from the entrance, for the contemporaneous buildings, which had previously been assumed (Ceschi, cit.; Tampone, 1995, cit.) but which could not be confirmed due to the incompleteness of the surviving ruins or to the transformation made to the originals.

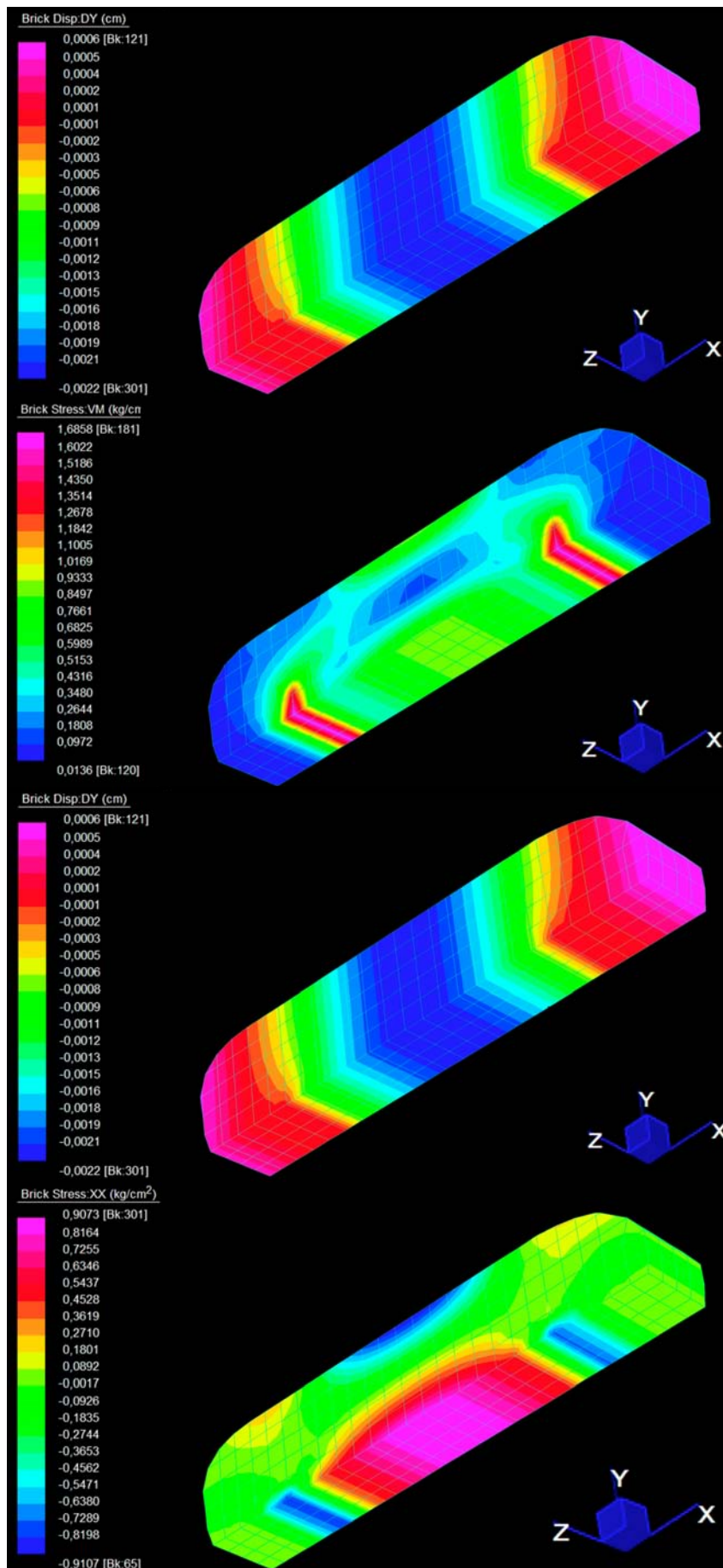
The great precision, accuracy and detail of the model, both as regards construction and structural aspects, are exceptional. The model provides us with an extremely clear and mature representation of a complex structural system. It is precisely that structural system which, with small variations, was employed throughout the Maltese archipelago for the construction of numerous buildings over a period exceeding a millennium. This system had, at the time of the making of the model, already gone beyond the phase of constructing simple buildings on the basis of the trilithic system, and had developed into a superior, in particular spatial, well defined concept based on - as this Author has already mentioned in many papers (amongst these the most extensive is Tampone, 2001, cit.) - the sophisticated manipulation of gravity, i.e. utilizing the weight of the elements as a useful resource to reach or to improve the stability of the buildings.

The great consistency, exhibited by the model in all aspects, with the structural system of the real architecture bestows on it a position of reliable whiteness and of total compliance with the built examples. This must, therefore, necessar-

Tensions according to the principal directions of load inside the beam in Globigerina Limestone

	Beam with extrados profile straight		Beam with extrados profile curve		
σ_{11}	0,9074	0,00	0,8506	0,00	kg/cm ²
σ_{22}	0,0587	-0,684	0,06	-0,627	kg/cm ²
σ_{33}	0,00	-1,8961	0,00	-1,8017	kg/cm ²
σ_{max} (criterium Von Mises)	1,6858	0,0136	1,6962	0,0144	kg/cm ²
σ_{max}	1,8961	0,0156	1,8917	0,0164	kg/cm ²
Maximum displacement along y direction	0,0022		0,0020		cm

	Beam with extrados profile straight		Beam with extrados profile curve		
σ_{xx}	0,9073	-0,9107	0,8506	-0,7986	kg/cm ²
σ_{yy}	0,1441	-1,7482	0,1398	-1,7586	kg/cm ²
σ_{zz}	0,00	0,00	0,00	0,00	kg/cm ²



ily hold also for those architectural elements which have not survived, such as the roofing, and in particular the system of the horizontal main elements (beams) and the auxiliary ones (stabilizing slabs).

In general terms, therefore, extrapolating from the Maltese prehistoric context, the model bears, in an extremely conscious and mature manner, the oldest known model representing, according to the Author, basic beams, i.e. of elements designed to cover the free span, having one prevailing dimension (the length), a rectangular section, placed so that the shorter sides of such sections are laid horizontally and are resting on two supports, loaded by forces acting in the vertical plane. In addition, these elements are of complex shape (see below) and are placed, even at this stage, in a totally correct and rational manner, that is with the base narrower than the height, and with a dimensional ratio (0,75 base x 1 height) which is most efficient. It is also extraordinary to notice that, all together, they constitute a system provided not only with strength but also with stability and equilibrium, that are the three conditions necessary to realize an efficacious and durable load bearing structure.

It is also extraordinary that, as already pointed out by the Author (1987, cit.; 2001, cit.), the beams are arch shaped at the extrados. It must be acknowledged that this characteristic would, of course, give the roof the right shape to throw off any rainwater. One must here, however, not claim the additional fact that these would also be endowed with the property of "uniform resistance" – this is, in fact, a modern mathematical abstraction, also noticed by G. Galilei, although applied to a real situation. However, it is to be noticed that the members thus described, as also pointed out for the architrave, are higher in the central section, which is, in fact, the area which is more stressed as the flexural moment is greater here. In order to hypothesize the profile of the intrados of the beams and of the entire roof, which was imagined to be

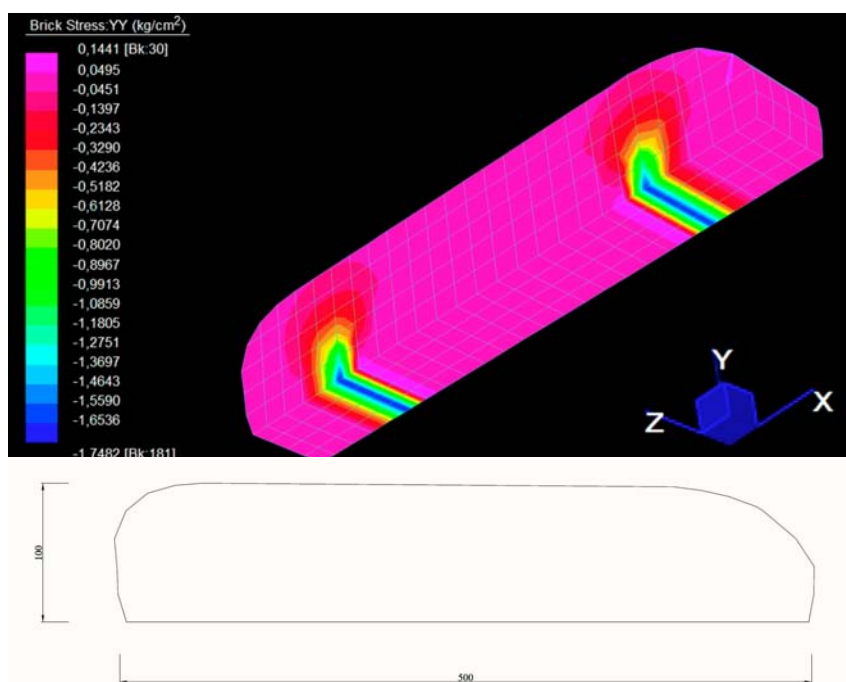


Fig. 13 - Straight extrados profile beam. 1. Displacements in the y direction, 2. σ_{max} (criterion Von Mises), 3. σ_{max} (criterion Tresca), 4. σ_{XX} , 5. σ_{YY} , A. Scheme. (Derinaldis, Tampone 2009).

flat by Ceschi, as can be deduced by his graphic reconstructions, we must bear in mind that in the Maltese buildings of the period there are no straight lines, neither in the elements which make up the building nor in its specific and general features. This leads one to hypothesize that the roof could have been shaped with a slight concavity, a form which could have been brought about by successive refinement after construction, also to ensure continuity with the topmost lines of the walls that were certainly inclined inwards according to the form common to all the prehistoric architecture of the European continent.

One must therefore acknowledge in the model the presence of a structural roofing system, that is articulated and sophisticated also for that which concerns the ingenious stabilizing mechanism already described (the repeated pair of lateral slabs) and the curve of the extrados. This system, as of yet undocumented for any other preceding, coeval or later example, insofar as known to the Author, is hypothesized, also following other research directions, for the Maltese buildings of the time. This is testament to the advanced structural

concepts the Maltese temple builders had developed, apparently without external influence, as appears to be the case in this stage of our research.

The introduction of this system of beams in place of a single hypothetical slab, has reference not only to stability, but also to the process of construction (assembly and modularity criteria).

Full confirmation is then to be acknowledged to C. Ceschi's graphic restorations of the Mnajdra, Tarscien, Gigantjia Temples (Ceschi, 1939, cit.), that had been scornfully defined fanciful reconstructions by J. Evans (Evans, 1959, cit.). The roof adjacent slabs proposed in those drawings have to be considered beams, which the model demonstrates were known at the time. The interpretational drawings are entirely valid as far as one can hypothesize, for each element, slab or beam, the depth is sufficient to reach the necessary strength in relation to the span. In the same Temples, in fact, several examples have survived that prove the use of slabs solicited by bending, as is the case of those placed to form the external or internal trilithic portals.

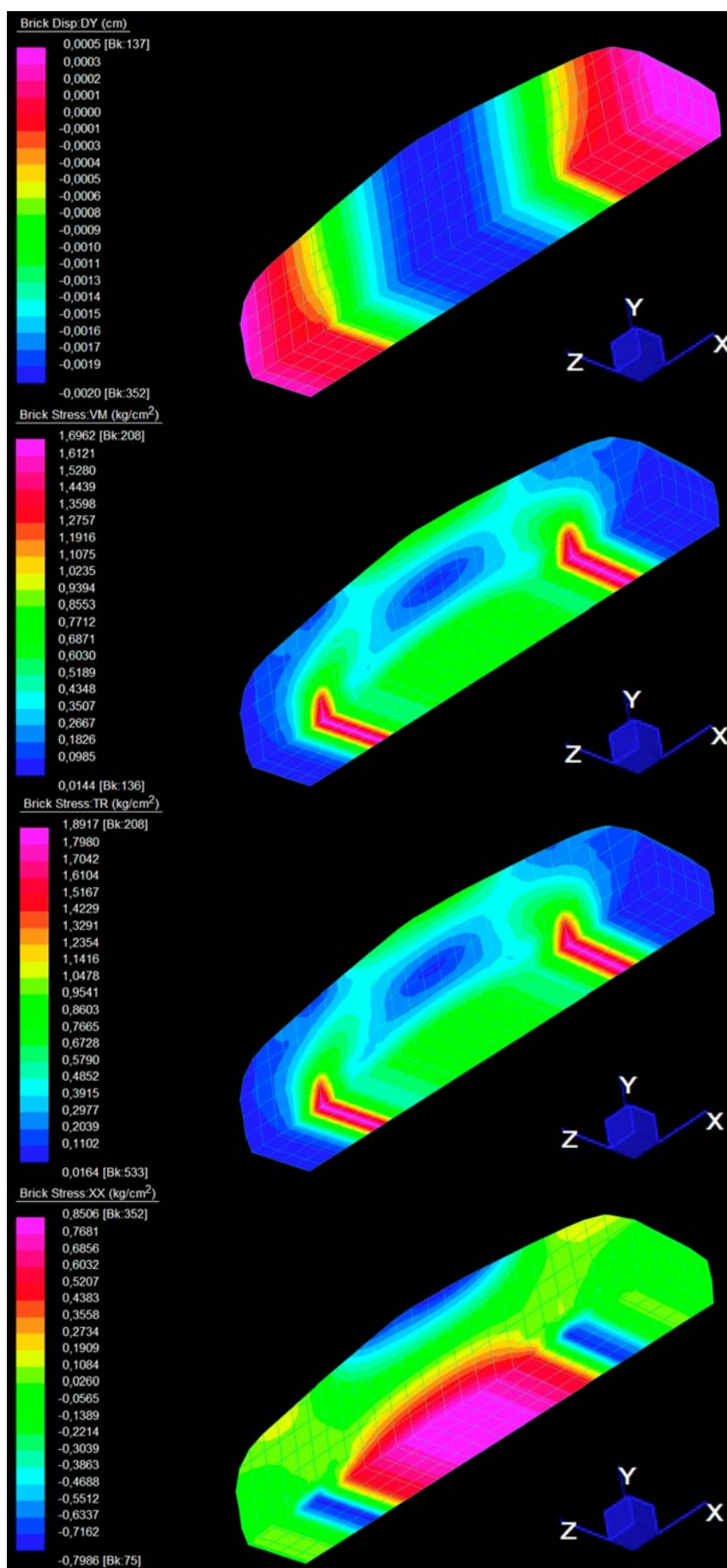
The exposed matters concerning the

shape, the lay out, the constructional characteristics and the structural system, on the whole, confer on the model an absolute originality. Therefore it is not possible to attribute it specifically to any of the phases of the known Maltese expressions of the period.

This shows a formal diversity with respect to the built examples, which show concave facades (this is a formal space element that is of extreme importance for liturgical purposes and, at the same time, for structural reasons - in practice the introduction of a horizontal arch (Tampone, 1991, p. 129; 1994, p.129, 133; 2001, p.4, cit.; and more recently also Torpiano, 2004, cit.) in order to absorb the forces generated by the whole building, with form and function that are similar to modern dams). The buildings also exhibit lateral wings, and an external perimeter of variable curvature but are discontinuous in its external profile, which apply also to the last phases if one considers the older Tarxien temples. The equilibrium and the general stability of the building represented by the model are obtained by means of a different arrangement, i.e. by means of symmetry between two axes perpendicular to each other. In this respect this is radically innovative.

The mathematical verification that was carried out and is presented above, demonstrates that the building could have been built without faults and its stability was amply assured when using the given dimensions and mode of assembly. What is more Prehistoric Man in Malta was certainly capable of raising and placing blocks of these dimensions and weight; here Torpiano is also in agreement (Torpiano, in Cilia, cit.).

Given that, as is well known, none of the Maltese prehistoric temples have roof that has survived, even though parts of them have been identified, and thus interpreted, within the complexes of Hagar Qim and Mnajdra, the model being studied here is the only direct, contemporaneous testimony of one type of roofing that was used (regarding the general theme of roofing see, among others, Tampone, 1991, p. 60,



cit.; 2001, I.a, p.4, cit.). This is, in the Author's opinion, another reason for its great importance.

There is also no evidence whatsoever of the existence of a building with these characteristics in the Maltese context or elsewhere.

It is inevitable that some critical questions should be asked, questions which however cannot be completely answered.

When was the model made? Who made it? Why was it made? What was the use of the building thus represented?

As regards the first question, keeping in mind the obvious impossibility of knowing the lay out and the arrangement of the internal walls of the building represented, a fact which places insurmountable limits on the powers of deduction, the answer can only be given in general terms if one considers the objective data: that it is contemporaneous with, or posterior to, one of the phases of construction and occupation of Ta' Hagra, to be identified with the so called (by the homonymous complex; 3600 – 300 circa) Gigantija phase and the following or partially overlaid Saflieni phase (3300 – 3000 circa), therefore before the final Tarxien phases (Pace in Cilia, p.149), fact that reduces the period to circa half a millennium.

Regarding the second question, one can only say that the unknown artisan knew the construction and structural techniques used in the temple buildings extremely well, to the extent that he was able to propose valid alternatives, and had doubtlessly a natural predisposition for miniaturisation. In addition, the precise position of each element and correct stereometry show that the craftsman had excellent manual skills.

However, he was not an artist but a highly skilled technician, perhaps even a creator of megalithic architecture. When also considering the excellence and the absolute coherence between form and function in the resulting model, one cannot assume that the model was made by an artisan under the direction of the creator; this was one and the same person.

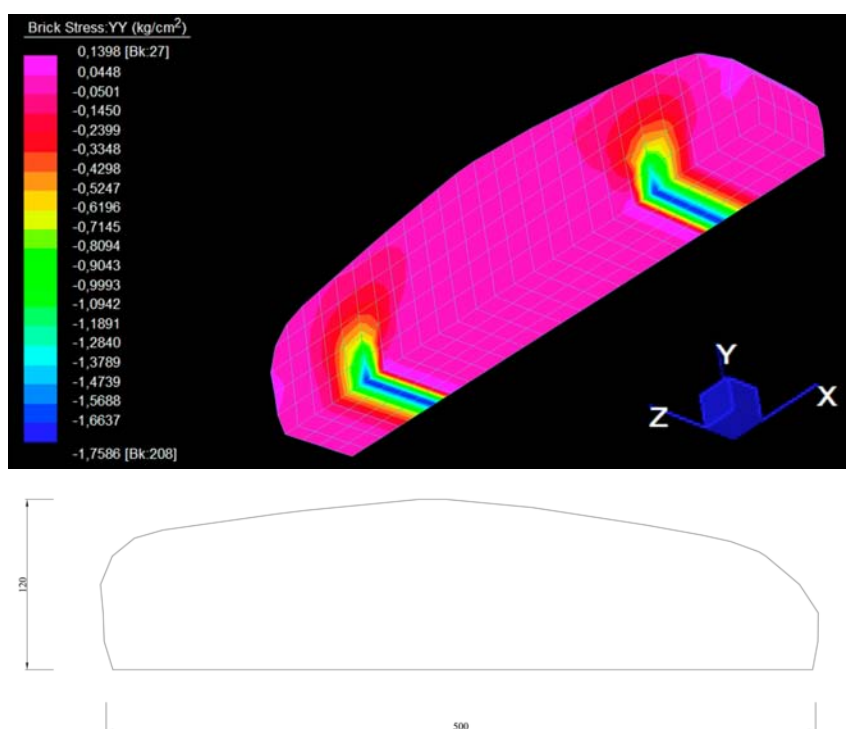


Fig. 14 - Curve extrados profile beam. A. Scheme. 1. Displacements in the y direction, 2. $\sigma_{\max}$ (criterion Von Mises), 3. $\sigma_{\max}$ (criterion Tresca), 4. σ_{XX} , 5. σ_{YY} . (Derinaldis, Tampone 2009).

The third question is certainly difficult to answer. The object is too small, and hence its details too difficult to perceive, to have been a “project” to be given to workers for the construction of a building. It was also too precise and technically elaborate to have been only a souvenir of an existing building or an ex voto or other object of devotion. One can only advance the fascinating hypothesis that, in the Stone Age, the minute model was meant to fulfill the function that would be, much later, ful-

filled by designs and models in an architect's atelier i.e. the embodiment of the development of architectural intuition, definite with the most minute technical detail, which was possibly also independent of the presence of a patron.

In order to address the fourth question, one must inevitably consider the absence of two elements in the model, both of which are specific to sacral functions, that is, the concavity of the facade and the vault, even if it is only

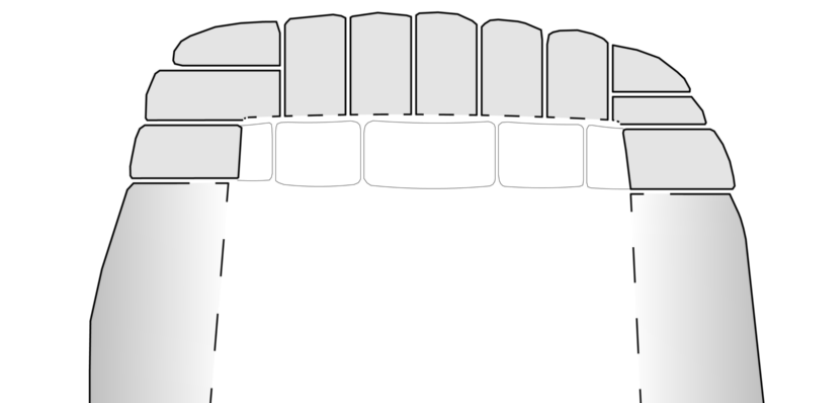


Fig. 15 - Hypothesis of structural section of the model (Tampone, with Derinaldis, 2009).

partial. Perhaps the find does not really represent a temple, as many authors have hastily sustained. Instead, keeping in mind the mirror image created by the two axes of symmetry and the external aspect of a building which can geometrically be defined a crystal, it can be surmised that this is a building with a social function, for example to accommodate the civil or religious representatives of a community (see Evans, concerning a “sanctuary”).

Architectural models found in Malta are in general consistent amongst themselves and also with all the architectural expressions found in Malta itself and in Gozo. This confirms the validity of each one of them, especially the one under discussion, together with the architectural remains, to act as a means of deduction of the prehistoric architectural concept of the Maltese Islands and the sophisticated technology elaborated to build with megaliths.

The Author expresses his gratitude, for the encouragement and the indications received, to the late Professor Antonino Di Vita, Archaeologist, Academician of the Accademia dei Lincei, who had expressed a very favorable opinion on the essay, and to Professor Giovanni Colonna, Archaeologist, Academician of the Lincei, who had manifested his appreciation for the essay.

He wishes to sincerely thank Architect Daniel Blersch, who brought together a team of Technicians at Diaprem (Centro Dipartimentale per lo Sviluppo di Procedure Automatiche Integrate per il Restauro Monumentale) of the Università di Ferrara to undertake the scans of the plaster model using a Leica laser scanner, and for the subsequent elaboration of data. These allowed for the establishment of relative dimensions of the model by Architect Pierpaolo Derinaldis, who carried out, on the basis of various hypotheses elaborated by the Author, and subsequent discussions, the calculations and the deter-

mination of tensions, as well as their distribution in the longest beam. Thanks are also due to Mr. Daniel Cilia, Maltese photographer and scholar on Maltese prehistoric architecture, who made available the extraordinary photographs shown in this paper and on which were fully verified the formal and volumetric characteristics of the model. Special thanks are expressed to Professor JoAnn Cassar of the University of Malta for the discussion on the topics related to the matter and the help in the translation of the text. Italy-Malta bilateral Research: C.N.R. D 1790051, with contributions of the Italian Consiglio Nazionale delle Ricerche and the Maltese Museums Dept. Researchers: G. Tampone (Scientific Director), S. Vannucci, J. Cassar, W. Ferri, G. Alessandrini, P. Pieri Nerli, I. Zetti et al.

Notes

¹ Themistocles Zammit, a Maltese doctor, Professor and Rector of the University of Malta, archaeologist. Excavated Tarxien and Ta' Hagrat, worked at Hal Saflieni).

² The passage in which the model is mentioned is unclear; the Author states that "it appears to have been modified (?) by means of a series of slabs placed vertically following an elliptical plan, alternating with other vertical blocks, placed in this case on the edge; the roof is composed of large slabs side by side situated on a plane perpendicular to the main axis of the temple." Maybe the term "modified" should be replaced with the word "constructed".

³ "... A comparison between the tombs at Xemxija and Zebbug and the small primitive temple plan of Ta' Hagrat reveals distinct common features and it is not difficult to assume the underground tomb as the ancestor of the temple (13 photo of the model that appears in other sections of the book).

⁴ The construction of an elliptical shape could have been known in prehistory from the characteristic that the sum of the distances of each point of the curve from two foci is constant; this could have allowed the design and easy manufacture of an elliptical curve by means of fixing two sticks at the foci and tracing on the ground with a stick tied to the end of a cord).

⁵ Called "esedra" by Ugolini, cit., and subsequently also by Ceschi, cit.

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