STRUCTURAL ASPECTS OF TRADITIONAL CRETAN MASONRY

Glowacki, Kevin Thomas[1]; Nichols, John Morgan[2]; Holland, Nancy Lee[3]

[1] PhD, Assistant Professor, Texas A&M University, Dept. of Architecture, kglowacki@tamu.edu

[2] PhD, Associate Professor, Texas A&M University, Dept. of Construction Science, jm-nichols@tamu.edu

[3] PhD, Associate Professor, Texas A&M University, Dept. of Construction Science, nholland@tamu.edu

The island of Crete has a long tradition of stone masonry construction, beginning over 8000 years before present. As noted by architectural historians, the vernacular architecture of modern (pre-World War II) villages on Crete has many close parallels with house remains uncovered in the archaeological record of the Minoan Bronze Age (ca. 3000-1050 BCE). Archaeologists have used modern ethnographic comparisons effectively to shed light upon issues ranging from the interpretation of ancient house plans to a better understanding of construction techniques, the use of local resources, and the effects of abandonment processes on the built environment. A full-scale replica of a typical Cretan house from the 12th-11th century BCE (Late Minoan IIIC period) is planned for construction in College Station. The first stage of the building will comprise a single room, ca. 6.20 m by 5.20 m, constructed of stacked limestone with minimal earth mortar, timber ceiling beams and laths, a layer of brush, and topped with a flat clay overlay. The purpose of this paper is to outline the design and structural analysis of the building, and to discuss issues related to construction processes, climate, and ventilation that may apply to both archaeological/historical and modern contexts. Modern interest in this traditional type of building technique stems from the use of limestone blocks in construction, and the potential it has to be a key element of the greening of building construction practices. This study forms one element of a major study of limestone and its uses.

Keywords: *Cretan masonry, limestone construction, Minoan culture, vernacular architecture*

INTRODUCTION

The use of stone, such as limestone, in construction dates from the earliest records of human history in many parts of the world (Wright 2005). It is only later that the use of kiln-fired bricks replaced stone. As a construction material, limestone has a number of advantages over more recent, man-made materials: while heavy and sometimes difficult to quarry and transport, it is reasonably easy to work, has excellent thermal and soundproofing properties, and is a cost-effective material (Baker 1914). Research undertaken by a group at Texas A&M University has focused on the use of limestone masonry in different historical contexts, ranging from simple vernacular architectural forms to monumental constructions requiring large investments of time, money, and specialized knowledge. Studies published to date include the architectural design, history and structural action of buildings such as the 13th-14th century A.D. Narbonne Cathedral in southern France (Paul 1991; Nichols 2010; Nichols, Paul, and Nichols 2010; Nichols, Paul, and Nichols 2011; Paul 1991) and the failure of its limestone blocks under shear loads (Holland, Paul, and Nichols 2010). Our analysis of the history of limestone building techniques also relates to more contemporary concerns. For example, limestone is a common building material in Texas, which has become a leader in the United States in the quarrying of limestone blocks. The increased use of limestone is due to the relative abundance of the material close to the major population centers, in part displacing fired bricks in some forms of construction, such as decorative storefronts. Moreover, the use of limestone in place of brick has the potential to be a key element of the greening of building construction practices. The present paper constitutes another element of a major study of limestone and its historical uses in the built environment, focusing on the design and structural analysis of "vernacular" limestone-built houses on Crete in the 12th and early 11th centuries B.C. Our purpose is to outline not only what can be inferred from the archaeological record about such buildings, but also to set out the planning for a modern recreation in College Station, Texas, in order to gain new insights into the construction process, climate, and ventilation issues that may apply to both archaeological/historical and modern contexts.

LIMESTONE MASONRY AND VERNACULAR CONSTRUCTION ON CRETE

Located ca. 95 km southeast of mainland Greece and ca. 295 km northeast of Libya, the island of Crete is situated in one of the most seismically active regions of Europe. As illustrated in Figure 1, Crete is the largest island in the "Hellenic Arc," a prominent tectonic feature created by the subduction of the Africa Plate beneath the Aegean Sea Plate in a curving line from the Ionian islands and the western Peloponnese through Crete and Rhodes to western Turkey (Higgins and Higgins 1996).

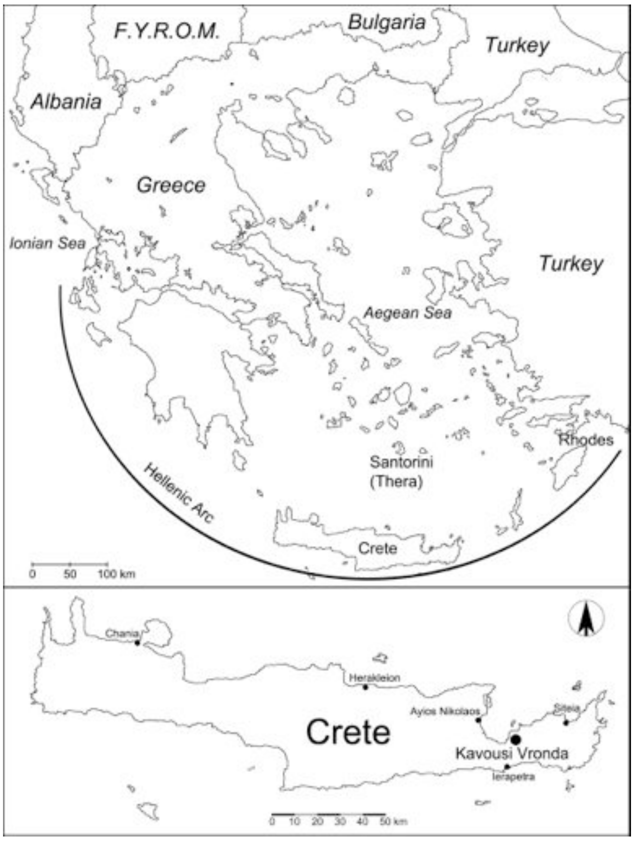

Figure 1: Crete as located relative to Greece and Turkey

One of the major rock types on Crete is limestone, a sedimentary material composed of calcium carbonate, silt, sand, clay, and remnant elements of earlier sea dwelling creatures.

Typically on Crete, limestones are of Permian-Triassic date and appear as hard, fine-grained, and often brecciated; many have undergone some diagenesis to become crystalline (Higgins and Higgins 1996; Rackham and Moody 1996; F. McCoy, pers. comm. 2010). In the field, these limestones may occur with vague joint sets that are approximately at right angles breaking in nearly cubic or rectangular blocks, and so through careful selection may be used in construction with little or no dressing or modification. As a basic building material, limestone was used on Crete both for entire walls, as illustrated in Figure 2, or, less frequently, as stone socles supporting sun-dried mudbrick superstructures (Shaw 2009; McEnroe 2010).

Figure 2: Façade of a traditional house (abandoned) in Kavousi, Crete

VERNACULAR CONSTRUCTION TECHNIQUES OF ANCIENT CRETE

The building to be constructed for our experiment is closely based upon the preserved remains of houses at the archaeological site of Kavousi Vronda (see Figure 1), a small rural hamlet of the Late Minoan IIIC period (ca. 1200-1110 B.C.) located in the northern foothills of the Thriphti Mountains in eastern Crete (Glowacki 2007; Day, Klein and Turner 2009; Day and Glowacki, forthcoming). While the preserved structures at this site generally lack architectural refinements (e.g., cut ashlar masonry, half-timbering, pier-and-door partitions, plastered walls, multiple stories, evidence for modular planning) found in "affluent" or "polite" architecture of the preceding "palatial" periods of Bronze Age Crete (Palyvou 2005; Shaw 2009; McEnroe 2010), these modest buildings represent the type of houses and vernacular architectural traditions that formed the major part of the built environment of ancient Crete in all time periods (McEnroe 1999; Soles 2003). Comparable elements of design and construction are still found in modern ethnographic parallels observed in traditional villages and isolated field-houses (Vasileiades 1983; Rackham and Moody 1996; Mook 2000; Glowacki and Dafedar 2010), attesting to both the conservative nature of vernacular building traditions and the success of such "simple" architectural forms in a seismically active region.

The builders of the Kavousi Vronda settlement utilized local fieldstones for the load-bearing walls (Klein and Glowacki, forthcoming). The bedrock of the archaeological site is a grayish, often heavily brecciated, dolomite (“dolomite limestone”); this forms the primary building material, in carefully selected but minimally worked cobbles and small boulders (> 0.25 m). Outcrops of the bedrock are frequently incorporated into the foundations. The lower levels of the walls can have some quite large boulders (>1.0 m), but smaller boulders and cobbles are used above. A harder, more crystalline limestone is found immediately to the south (in scree or talus deposits fallen from the mountain slope) and those blocks were also used, especially in the superstructure where straighter façades were desired.

Building Complex I-O-N serves as an example of vernacular architectural design and construction techniques (Figure 3). Located on the western slope of the site, the complex expanded in an agglutinative manner from an initial three-roomed house to a much larger multi-household complex (Glowacki 2004; 2007; Day and Glowacki, forthcoming). The primary load-bearing walls were founded directly on bedrock, following natural topographic contours. Walls were built using a “two-skin” construction method, with relatively large stones used for the inner and outer faces in more or less horizontal courses, while smaller stones and earth were used to fill the interstices. In order to prevent splaying and provide horizontal bonding, larger through-stones were also used at irregular intervals to span the entire width of the wall. Large boulders were frequently employed at the basal level of corners, and straight-edged stones were selected to form wall terminations marking doorways.

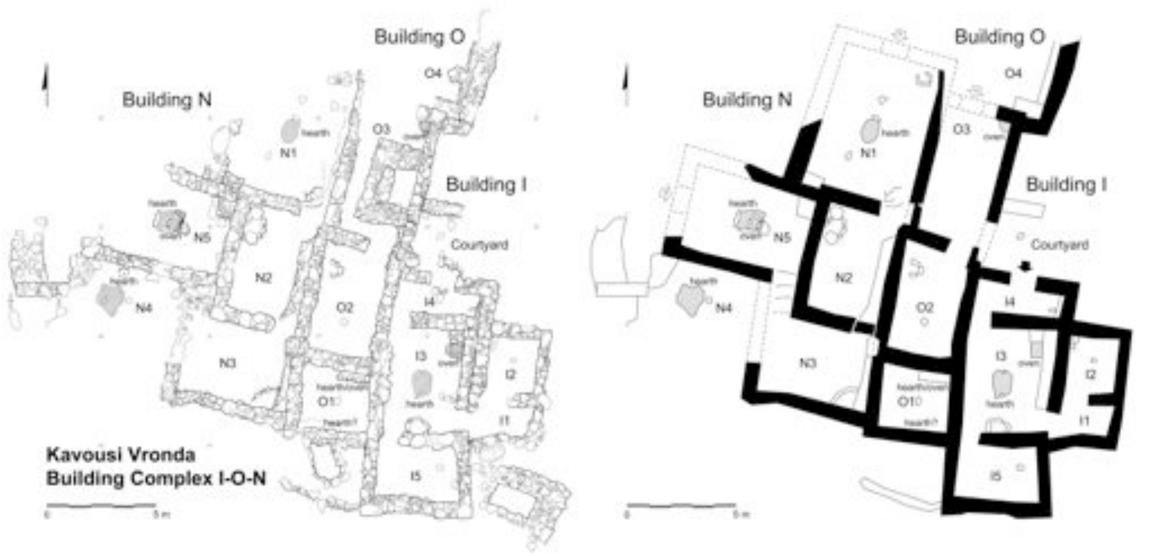

Figure 3: Building Complex I-O-N: State-plan (left) and restored schematic plan (right)

None of the walls at the archaeological site were preserved more than 1.0 m. in height. Reconstruction of the superstructure therefore depends upon close analysis of the excavated strata of material above the earthen floors of each room, which usually consisted of a thick, undulating layer of “clay” (argillaceous earth) covered by a layer of rubble wall collapse; rarely were organic materials preserved, but carbonized wood from at least one building at the site appears to represent the charred remains of a ceiling beam. Based on comparisons at other Minoan sites and with ethnographic parallels found in the vernacular building traditions of eastern Crete (Figure 4), the evidence suggests that the walls were built to their entire height in stone and included timber ceiling beams spanning the width of the room and set into recesses built into the wall (Figure 5); the beams were then topped with smaller branches set as a lath course, a layer of brush, and several layers of clay. Roofs were essentially flat, but probably included a slight slope for drainage. Rooms with hearths and/or ovens also included an opening in the ceiling to evacuate smoke, possibly through a chimney pot resting on the crossbeams above.

Figure 4: Partially collapsed (modern) field houses near Kavousi, Ierapetra, Crete

Figure 5: Interior of a restored, traditional-style house in Monastiraki, Ierapetra, Crete

One can see similarities with this type limestone wall construction in many locations around the world, with variations adapted to regional conditions and available materials. Lizzi demonstrated one technique for the strengthening of these types of structures after WW II (Lizzi 1981; Nichols, 1990; Nichols 1999). The construction techniques shown in Figures 2 and 4 are also consistent with the methods used in England to repair the stone walls within the Lake District National Park. One way to understand the construction techniques and the likely performance of the buildings is to construct and monitor one of these types of buildings in a controlled environment. This construction is proposed at TAMU.

BUILDING DESIGN AND DEVELOPMENT

The building to be constructed for the first stage of our project is based on one room (I3) of the Building I-O-N complex at Kavousi Vronda. This room was selected because it represents an important type of architectural unit that helps to define houses and households in the settlement. While the original plan of Building I formed a three-roomed structure (rooms I4, I3 and I5; see Figure 1), houses of one or two rooms are also attested at the site. Room I3 is the largest room in the house (ca. 4.6-4.9 m N—S x 3.8-4.0 m E—W; interior roofed area ca. 18.53 m^2) and contains a central hearth for heating and lighting, as well as a small oven and other features to indicate that it was the main activity area of the house (Figure 6) (Glowacki 2004; Glowacki and Dafedar 2010; Day and Glowacki, forthcoming).

Figure 6: Actual state (top) and 3ds Max visualization of Room I3, from the west

The proposed design for the model building is shown in Figures 7 and 8, and the principal dimensions are summarized in Table 1. Walls will be constructed of limestone blocks from sources in Texas; as far as possible we will use roughly dressed blocks to approximate the irregularly shaped fieldstones of the building in Crete. The random coursed walls will rise to a total height of 2.60 m, with a door opening of 1.70 m -- small by modern American standards but consistent with archaeological and ethnographic parallels. Timber (pine) will be used for ceiling beams that span the width of the room, set into beam sockets built into the wall. Above the level of the primary timbers, the wall thickness will be reduced by approximately half its width, forming a shelf to receive smaller branches and a layer of brush (sticks and leaves) to fill the gaps between the timbers; finally several layers of beaten/stamped earth and clay will complete the roof. In the center of the roof we will use a large terracotta jar (modified with an appropriate number of ventilation holes) to create a chimney. Since the chimney will be supported by the smaller crossbeams below, the construction will not require additional structural columns or posts.

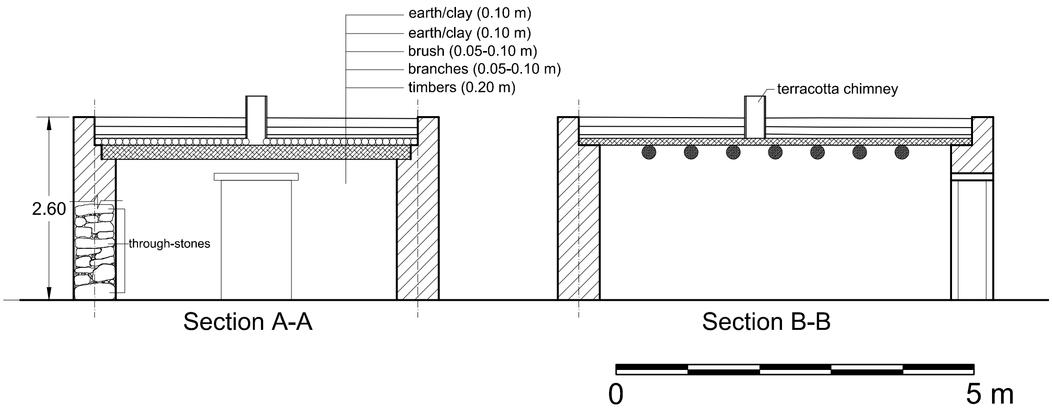

Figure 7: Cross sections of the model house

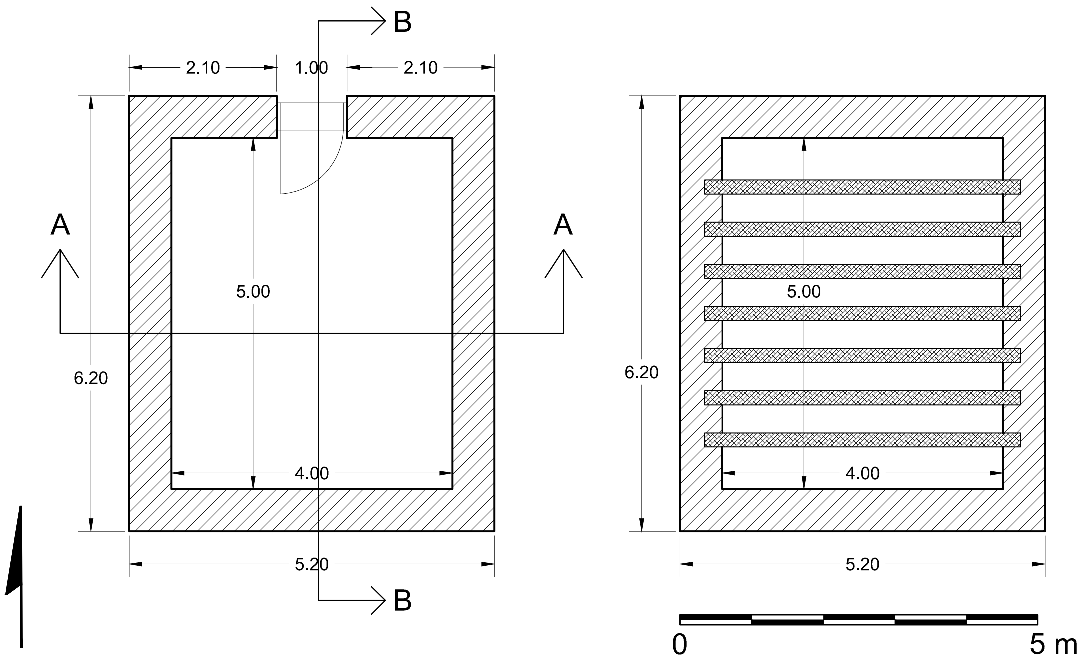

Figure 8: Plan showing walls and door (left) and setting of ceiling beams (right)

Alternative plans are also being considered at this stage of design.

Table 1: Dimensions of proposed limestone building

External dimensions	6.20 x 5.20 m
Internal dimensions	5.00 x 4.00 m
Width of walls	0.60 m
Height of walls	2.60 m
Height of door opening	1.70 m
Diameter of ceiling beams	0.20 m
Diameter of branches (laths)	0.05-0.10 m
Layer of dry brush	0.05-0.10 m
First layer of earth/clay	0.10 m
Second layer of earth/clay	0.10 m

CONCLUSIONS

Vernacular architecture reflects a variety of environmental and cultural issues that may apply to both archaeological/historical and modern contexts (Oliver 2003; May 2010). The forms and techniques of vernacular architecture are related to, among other things, the materials available locally, the geography and topography of the building site, the natural environment and climate, along with the size and function(s) of the building to be constructed. Analysis of historic buildings, and the recreation of buildings constructed in vernacular techniques and styles, can offer insights into a variety of research questions concerning the built environment, such as the amount of material and energy used in construction (Abrams and Bolland 1999), the relationship of architectural form to environmental conditions and the heating, lighting and ventilation of interior spaces (Geva 1995; Moody 2009), and seismic performance (Driessen 1987). For example, while masonry buildings are generally vulnerable to earthquakes, the analysis of stone construction types used for millennia in seismically active regions such as Crete has the potential to yield valuable information about some underlying causes of failure and collapse, as well as solutions adopted to improve seismic resistance. Our proposed limestone building will also explore the thermal characteristics of such constructions, as well as modifications that have been – or could be – made to reflect the changing environment. Limestone also has a number of advantages in terms of construction when compared to the manufactured concrete that has in part largely displaced its use in modern times. Lessons from the past may allow us to see more clearly how limestone masonry may be a key element in the greening of building construction practices in the future.

Construction of this type of building by architecture and construction science students brings into sharp focus the interdisciplinary work of construction, as these students will be working from rough plans and from materials of varying size shape and texture. This exercise is considered to be a valuable lesson in understanding the basic elements of masonry construction in pre- or non-industrialized cultures and how the study of traditional architecture can have an impact on developing a greener world. The results of the work will be presented at a future masonry conference.

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