Environmental response of mudbrick settlements: the case of Korestia villages in Western Macedonia

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Abstract. In Greece until the middle of the last century there were several buildings constructed from mudbricks. Nowadays, in a number of settlements there are mudbrick buildings, but the only organized residential complex with buildings built with mudbricks is situated in Korestia, in mount Vitsi, north of Kastoria region. This paper focuses on exploring the environmental response of these settlements, which combine a rich natural environment with a distinctive architectural physiognomy. By examining the urban planning, the morphological characteristics of the area and the relationship between the built and natural environment, it is possible to establish a framework of sustainable development that is environment-friendly. Sustainable management of the built environment of the Korestia implies a new dialectic between natural and man-made environment, with the aim of presenting proposals and multidisciplinary actions for the integrated development of the site. In essence, the remarkable housing stock is being studied and the heritage of the site (rich architectural and cultural heritage, natural parameters such as mountain, forest, river, etc.) is highlighted in order to transform itself into a force that prevents the population from leaving the area and at the same time creates conditions for re-housing and strengthens the tourism growth with low ecological footprint.

1. Introduction
Clay is one of the oldest materials intensely used by humans over the past creating interesting works. It is an abundant natural material with importance both in building and in art. This paper focuses on the exploration of the environmental response of the Korestia mudbrick settlements which are located in a rich natural environment. The main purpose of the current work is to highlight the environmental dimension of this residential complex in Korestia and to promote it in terms of sustainability.

This paper also examines the prevailing view about the unreliability of earthworks and draws conclusions about the revival and development of the area, the formation of its new identity with a view to preserving its traditional and historical physiognomy. By the implementation of mild and environmentally friendly interventions, the settlements can regain their role and enhance the quality of life in the wider area, as they really deserve.

2. Methodology
The methodology consists of site research, building footprints and interviews with local actors and residents, in order to understand the bioclimatic behaviour of settlements, which will help in drawing up design proposals for the existing residential stock.

3. Properties of clay and mudbrick structural elements
Clay as a raw material is found in large quantities in nature and is recyclable [1]. As a building material, it keeps the indoor air moisture constant, typically ranging from 50% to 55%, and, due to its moisture balancing capacity, it constitutes an ideal environment for wood, contributing to its durability and lengthening its lifetime. Clay has the ability to preserve the quantities of straw mixed in the mudbricks.
Concerning the environmental dimension of mudbricks and clay building blocks, it is further noted that these materials:

1. exhibit an extremely high thermal inertia. Mudbricks harness the local climate better than the other materials. They have high heat capacity per weight unit compared to traditional and modern structural materials, excellent thermal properties and good thermal conductivity. In winter season, they show reduced heat losses, in relation to stone and concrete and they take better advantage of the day's solar radiation by storing a large amount of heat, compared to other materials, to meet the building's heating needs throughout the 24-hour period and deliver it later, keeping indoor temperature fluctuations at very low levels. Overheating is delayed in summer, thus the rooms are kept cool for several hours of the day [2],

2. have high perspiration, a property that allows the moisture balance inside a building,

3. are recyclable and green building materials, related to the low percentage of the energy required for their production and their transport from the place of their origin to the place of construction,

4. are non-combustible,

5. contribute to the binding of chemical compounds and to the reduction of the level of radioactive emissions while at the same time they act as a high-frequency electromagnetic radiation barrier [3],

6. do not burden the environment both during the construction phase and during their disintegration [4]. The most serious disadvantage is the sensitivity to moisture.

4. Historical review of the use of clay

Archaeological data certify the existence of mudbrick structures about 10,000 years ago and their use concerns both remarkable monuments and humble constructions. The production of mudbricks in molds developed in the area of Mesopotamia 7,000 years ago [5]. In Neolithic and Mycenaean Greece structures with raw bricks [6] were found in several areas (the wall of Eleusis of the 5th century BC, Dispilio, in fortification works, Akrotiri Thira, neolithic settlements of Thessaly, etc). During the Byzantine period the use of the mudbricks becomes second priority, as opposed to the Islamic world (figure 1). In Europe, the building with earth materials was widespread until World War II. Later on, this way of construction gave its place to new industrial building materials.

![Figure 1. Yakhchalt in the Yazd city of Iran](image1)

![Figure 2. 1/3 of the world population resides in mudbrick buildings](image2)

Existing mudbrick structures (figure 2) clearly demonstrate that they are not worthless, but that they have shown excellent durability over the years and under various kinds of effects, such as earthquakes. In recent years, various architects around the world tend to showcase clay as a material of particular aesthetic value (figure 3).
The urban and architectural character of Korestia villages was shaped by various factors. These are the socio-economic and cultural composition of the local community, the natural wooded environment, the relief of the land, the dense hydrographic network, the Livadopotamos river and the long history of today's mountainous agricultural area. Most villages belong to the unplanned rural settlements type of the mountainous area and the manmade environment characterized by the creative morphological conjugation of folk and neoclassical architectural elements. The strong relationship between the natural and built environment, the low building density, the intense presence of the natural environment and the generalized use of mudbricks constitutes the identity and special character of this historic settlement complex. The settlements, which are designed on human scale, are designated by free placement, lack of dense and cohesive layout as well as flexibility in composition. The building system is discontinuous and public spaces were not designed, but they emerged organically. Major problems are the abandonment of the area, the low population stock and the lack of productive population. The majority of the buildings have two levels, there are some three-storey (figure 4) and quite a few one-storey used as warehouses.

Many of the buildings have a broad façade and are orthogonal, including rooms for living and auxiliary ground spaces. There is a variety of floor plans and some of them have T or Γ shape plans. In some settlements and mainly in Gavros, Antartiko and Ano Kranionas, there are “sahnisi” (protrusion)
(figure 5) and in others, such as Chalara and Mavrokampos, there are “twin-houses” which intend to accommodate the families of two brothers (figure 6).

Figure 6. The G. Stamkos’ “twin-house” which intends to accommodate the families of two brothers in Chalara (Source: Author’s archive).

Figure 7. Recessed balcony in a house in Mavrokampos (Source: Author’s archive).

The wooden balcony on the first floor appears often (figure 7), enriching the morphology of the built environment. Many churches are built mainly in post-Byzantine period (figure 8) and are constructed in the type of stone-built three-aisled wooden roof basilica with interesting wood-carved temples and bishop’s thrones, pulpits and paintings.

Figure 8. The eastern side of the Agia Paraskevi church in Ano Kranionas (1863) (Source: Author’s archive).

6. Environmental response of the Korestia settlements
A prerequisite for the revitalization of the area is its functional activation and its integration into contemporary economic structures, through an urban planning directly linked to the protection of the built and natural environment.

6.1. Residential scale response
Environmental factors as well as natural elements have determined the setting up of the settlements. Generally, the winters are cold and the summer season is cool. The spatial organization of the settlements was also influenced by the natural environment (forest area) and their social infrastructure (agricultural and livestock occupations), which are the two main morphogenetic elements of the built area. The villages’ location has allowed the penetration of farming and reduced the distances to the adjacent farmland that surrounds most settlements. The spatial form is directly influenced by the microtopography of the ground and by the strong natural axes of the immediate geographical area (e.g. Lapototamos, mountainous borders, forest, etc.). The water element provides a sufficient quantity of drinking water, for the irrigation of the cultivated areas and for the construction of the buildings (water, stones, etc.). There is a collaborative relationship between the inhabitants and the environment, while there was no exploitation of the local natural resources.

The construction of the buildings on the sunward side and at the foot of the mountain (exploitation of mountain and valley benefits) and the river route passing through each settlement are characteristic of the environmental response of the settlements. The sloping arrangement of some settlements, such as Ano Kranionas, ensures seamless ventilation, insolation and visual comfort. Annual sunshine charts show the relation between structured and unstructured space with the insolation of the area (diagrams 1, 2). The main orientation of the majority of the buildings is southern, which is beneficial in the cold period, with exceptions related to the land morphology and the view. The height/width ratios of several roads is generally small, which, in combination with the free building system, allows the visibility of the sky dome and hence the insolation and ventilation of the settlements. Finally, the area has an increased percentage of vegetation cover (phenomenon of non-deforestation of tree clusters around churches, monasteries, country churches, etc.).

Diagram 1. Chalara. Annual sunshine chart (Source: Author’s archive).

Diagram 2. Melas. Annual sunshine chart (Source: Author’s archive).

6.2. *Bioclimatic response on building scale*

The domination of the mudbrick is an indication of confidence in the bioclimatic properties of this material. During the construction and transportation phase of the materials, energy was not wasted, given the short distance between the area of raw materials supply and the place of buildings. The majority of buildings exploit the solar gains due to their orientation and the high heat capacity of the building materials whose thickness range between 50 and 60cm. These materials contribute to the time lag (thermal delay due to the thermal mass) in the interior of the houses. The southern orientation of
the courtyard ensures sufficient insolation and protection from cold north winds, especially in winter. The dark soil materials around the buildings contribute to the formation of a zone which is characterized by a high radiation temperature that offers thermal comfort during the cold season. The elongated broad façade structures, their south orientation and the minimization of the openings on the north side of the buildings contribute to the reduction of thermal losses, while the number of openings offers visual comfort.

Elements that further improve the climatic conditions are the hagiati (covered balcony open or closed with glass located on the front of the house), the “sahnisı” (protrusion) and the balconies. The hagiati, at houses with south orientation, allows sunlight penetration which maximizes solar gains in winter. During the spring season the inhabitants painted the exterior walls of their homes in light colors resulting in increased reflectivity.

The mudmortar in the tiled roof contributes to thermal insulation and minimizes the possibility of wind inflow, reducing thermal losses. A similar advantage is offered by the reed layer, under the roof, a natural material with very good heat-insulating properties. Skylights on the roof enhance vertical ventilation during the summer period, creating a pleasant indoor climate. Stone fences function as windbreaks in winter, protecting against strong winds, while in summer they shade parts of the courtyard.

7. Proposals for the revitalization of the settlements through an environmental view
Mild interventions, that will improve the bioclimatic character of settlements and buildings, are:

- Upgrading of the residential environment (the settlements should be targeted for conservation and institutional proposals for the use of mudbricks, regulations, circulatory settings with pedestrian and cyclist priority should be made) (plans 1, 2).

Plans 1, 2. Intervention plan in Ano Kranionas (plan and section).

Plans 3, 4. Cobblestone new building of the interdisciplinary center for the study of clay and mudbricks (plan and section).
• Reorganization of the primary sector (e.g. new organic crops), tourism (eco-museum) and foundation of interdisciplinary center for the study of clay and mudbricks (plans 3, 4).
• Use of isolated gain system (the sun collector is not in contact with the heated space (plans 5, 6) and does not affect the appearance of the building shell).
• Restoration of the buildings (plans 5, 6) and limited construction of new ones with bioclimatic criteria (plan 7). Moisture protection of mudbricks is achieved by applying an external coating and modern waterproofing materials.

**Plan 5.** Reuse of an existing house in Ano Kranionas.

**Plan 6.** Reuse of an existing three-storey house as a guesthouse using a remote solar gain system.

**Plan 7.** Plan of the laboratory building.

• Emphasis on the environmental image of the area (reuse of building materials, double glass panes in wooden frames, bioclimatic planting with regard to the orientation of the openings, use of photovoltaic devices and solar panels, etc.).

**8. Conclusions**
The Korestia settlements is an example of incorporating the principles of bioclimatic architecture and sustainability within the framework of all the traditional settlements of Greece, highlighting the
multiple positive contribution of a natural material such as mudbrick umbrella. The use of local materials and the integration in the local environment and climate are factors that contribute to the particular architectural identity of the place. The mudbrick, as the predominant structural material of the region, can become reliable, under conditions (such as, drafting and applying modern regulations regarding to the construction of clay, adding natural fibers and powders to improve clay features, etc.), with good bioclimatic behavior. The reassessment of this natural material, with environmental criteria and the preservation of the landscape scale, without the construction of many new buildings, contribute to the upgrading of the residential area. The settlements develop a symbiotic relationship with the natural environment and, without disturbing their architectural value, by implementing mild interventions to minimize their energy consumption, they can become sustainable, as a focal point for tourism and cultural activities.

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