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# Earth and Straw Constructions in Crete

**Future potentials**

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# Preface/ Abstract

What are the prospects for the use of alternative building materials in Crete? The substitution of conventional materials like cement, firebricks etc. with earth and straw generally has been connected with less $CO_2$ emissions, better thermal performance and healthier indoor environment in buildings. However, at the moment there are restraints that need to be surpassed for their wider use. The hardest limitation is the skills gap and the public acceptance which can be both summarised as lack of awareness. There are some controversial issues like the construction costs and the locality of straw, too. However, the good qualities of earth and straw will eventually outweigh the difficulties for their dissemination in constructions.

# Acknowledgements

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My tutor, Louise Halestrap, was an important asset during this work, both personally and academically. I am deeply thankful to her.

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# Contents

# Abbreviations

LCA=Life Cycle Analysis

EF= Ecological Footprint

EE=Embodied Energy

RH=Relative Humidity

BREEAM= Building Research Establishment Environmental Assessment Methodology

LEED= Leadership in Energy and Environmental Design

EPBD= Energy Performance Building Directive

KENAK= Greek Regulation for the energy efficiency of buildings

EPC=Energy Performance Certificate

Common building materials=concrete, steel, aluminum, timber, stone

Alternative/ natural building materials= earth, straw

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# 1.Introduction

There is an urgency for humanity to lower $CO_2$ emissions considering the environmental concerns about climate change and the sustainability of our lifestyle practices (Randle D., 2008). Considering the energy expenditure and generated pollution generated during construction but also the operational phase of buildings, it must be a priority to consider other than conventional ways to build (Ding C., 2009). In Greece, the building sector is responsible for 40% of the total national energy consumption and this will continue to rise if there are no imminent changes in the construction industry (Daskalaki, 2011). Building green is the way for the future when we consider current ecological, legislative and cultural drivers and sooner or later there will be market advantage, too (Tucker S., 2010).

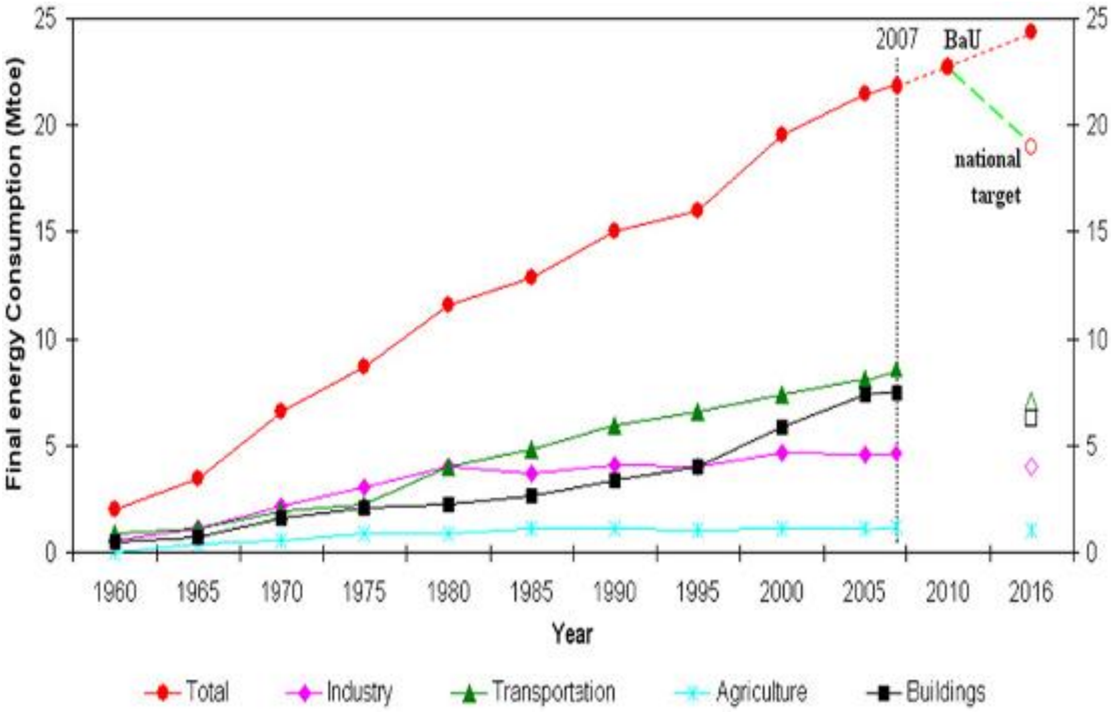



*Fig.1 Distribution of the total energy consumed in Greece (source:Dascalaki 2011)*

Parameters like bioclimatic design, water use, airtightness, environmental site provisions, eco-friendly materials are in the front line of eco-building. The choice of construction materials is only a part of a project, but they do have a large share on the environmental impact of building (Venkatarama, 2001). Alternative natural materials like straw, stone, wood and earth are principally characterized by low embodied energy: they are usually locally sourced, almost unprocessed and recyclable after the lifetime of the building. Therefore, natural buildings are a choice of environmentally conscious people.

One material which is experiencing popularity recently amongst self-builders and home owners around the world is straw. It has several remarkable advantages in terms of cost, abundance, and sustainability and it is a highly efficient thermal insulator (Brojan L., 2013). In the island of Crete, at the moment there is a small but growing minority who has chosen to build with strawbales or a clay-straw mix as an infill for the walls of their timber framed homes. On the other hand, earth is maybe the most common building material on earth (Minke, 2007) because it is cheap, abundant and it is a heavy mass material ideal for temperature fluctuations.

*Purpose of the thesis*

This research aims to investigate the construction of buildings from alternative natural materials (i.e. straw, earth) in terms of comfort, environment, feasibility and compatibility within the Cretan context. Do they have an advantage? Are they recommendable and safe? Is there a present and a future for natural buildings of earth and straw in Crete? What are the motivations, incentives, limitations and difficulties for alternative natural buildings in Crete?

The thesis will be useful for people:

- interested in building with earth and straw in Crete
- interested in the feasibility or the performance of such buildings
- interested in facts from existing case studies.

The motivation behind this work was the passion of the author for sustainability and the belief that people should find new solutions in this new technological era for humanity. Hopefully, more people will be ready to challenge the commonplace of construction in Crete in the long term without compromising comfort, and without high budget requirements.

Approaching key people for natural building in the island was the way forward and learn the difficulties, the fruitful efforts (or not) and the level of satisfaction they have. Under a qualitative research, with the help of interviews and questionnaires, architects and engineers share their views on natural buildings in Crete. Furthermore, two case studies are presented with details of construction, functionality, design and related implications. Furthermore, digital thermometers were placed both indoors and outdoors of the building site to measure temperatures and evaluate thermal comfort. The occupants/owners/self-builders answered a broad scale of questions with basic issues: Are the specific natural buildings easy and affordable to construct, enjoyable to live in and therefore recommendable?

The thesis begins with a review of the literature on what is an ecological building, the properties of natural building materials and continues with a look in the island and Cretan architecture elements. Then, the research findings are presented in Sections A and B. Section A contains the presentation and analysis of 11 unstructured interviews and three completed evaluation questionnaires. In section B, the presentation and analysis of two case studies take place accompanied with occupants' evaluative comments, temperature measurements and photographs. The conclusions from the findings close the study.

# 2.Ecological building

## 2.1. Significance of ecological building

*'What is the use of a house if you haven't got a tolerable planet to put it on?' (Thoreau, 1860)*

The Greek root of the word ecology is *oikos*, which means home. So *eco-home* is a circular definition. Sustainability is a perception of "home coming". The core idea of sustainability is that our actions and decisions today do not inhibit the opportunities of future generations on the planet (Bruntland, 1987). Consequently, sustainable design considers the long term effects on the users, the environment and the preservation of our natural resources.

"The broad aim of sustainable buildings is to improve the quality of our lives" says McMillan (1983). And there are three important issues to consider for approaching it: a) control the consumption of resources b) environmental loading (GHG emissions) c) Indoor environmental quality (Chwieduk, 2003). So, ecological or "green" building seeks to minimize the negative environmental impacts on the earth by ecologically sourced materials and moderation in their use, efficient energy use before, after and during construction and last but not least encouraging a healthy lifestyle for the inhabitants (Harris D.J., 1999).

Early in the design process, one could calculate the implications of building materials, orientation, glazing and other physical factors, so as to identify a sustainable approach for a building. Standards for sustainable homes have been formalized by rating systems like LEED and BREEAM. These are used for evaluating and categorizing buildings according to their "green" performance. The appraisal of buildings is done through benchmarks on broad areas like the use of materials, land, energy and water as well as the decrease of landfill waste and the profits for the community (McMillan, 1983).

A new challenge for architects and builders is the idea of designing buildings thinking ahead of their end, and this approach is called the "cradle-to-cradle". Buildings made from natural, organic materials like earth, straw, timber are completely assimilated in the surrounding environment after the end of use of the building since nature has been designing from cradle to cradle forever (Berger W., 2009).

Human well-being is all the more related to feeling connected with nature according to the science of Ecopsychology. The sustainable design movement has been crossing paths with biomimicry, which searches the way nature designs solutions and applies the methods in man-made design (Croome Cl., 2004). In architecture, a major step is embracing the beneficial effects of natural materials. Green buildings can be a way to bring about the reconnection between humanity and nature, probably a way to a healthier, happier, more sustainable life.

Apart from the above, natural building projects can be self-built with the help of volunteers who want to learn how to build through workshops on-site. This is a chance for people of all ages and regardless of gender, to come closer and be creative, to be engaged in outdoor activities improving their health and practical skills, to help each other and of course reduce costs of building construction. All in all, natural buildings are not only a reference to energy efficiency and eco-friendly materials, but they also embrace community development, social empowerment and ecological awareness (Jones B., 2009).

Connecting people, society and nature is a special feature of green buildings and a step towards social sustainability. To conclude with a quote by Pan Feng (2011): "Green building will take the interaction and the balance between human society and nature as the starting point of development, and define mankind themselves as a part of natural, to re-think and delimit man and manmade environment in the world position." (Pan Feng, 2011)

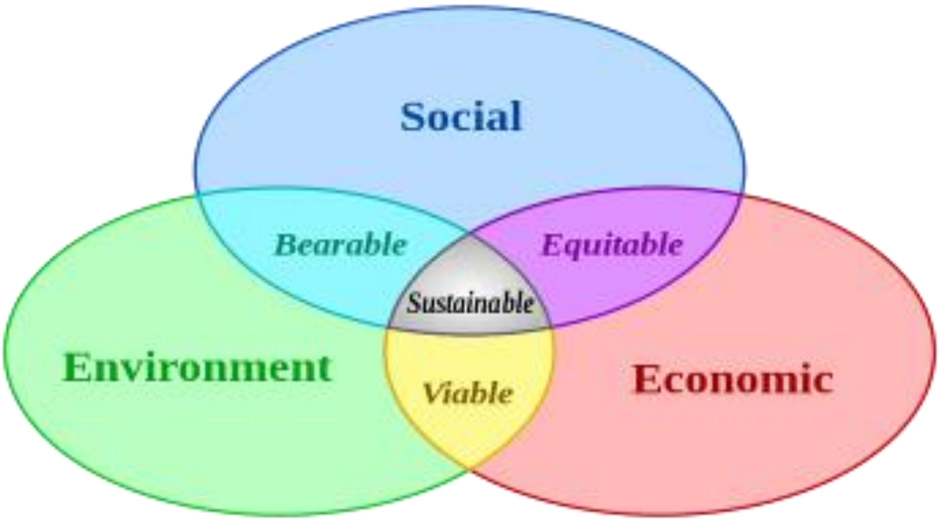



Fig.2 Sustainability has multiple relationships and interactions in all social, economic and environmental sectors (source: Atkison et al., 2009).

## 2.2.The sustainable site

Vegetation, solar orientation, wind direction, biodiversity, urban density characteristics, climate of the area, existing flora and fauna, surrounding buildings, water availability, access to the site and the locality of the materials are all characteristics related to the field location. The site analysis and landscape architecture are crucial points for adopting an environmental strategy within the plot of construction.

Bioclimatic design is essential for any building and it incorporates at least east-west axis building orientation with wide southern openings and solar shading. The sun's energy is used in favor of the residents for passive thermal comfort. Moreover, natural lighting, noise reduction and unobstructed ventilation are among the essential features of the architectural design. Renewable energy sources, green roofs, landscape views are also arranged through the design of the building site.

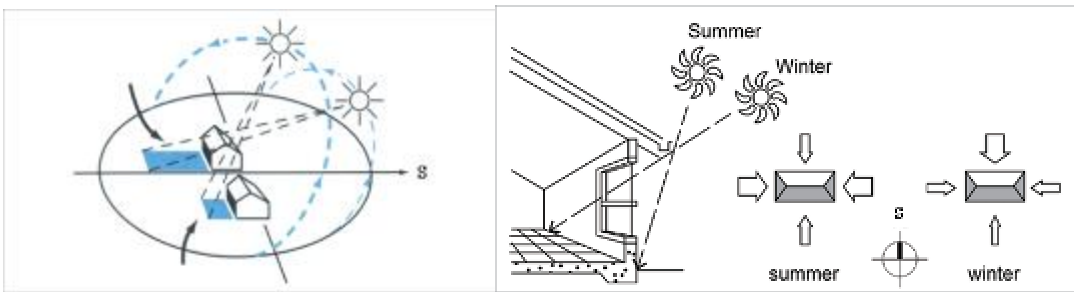



Fig. 3 Bioclimatic design considers the sun's angle during summer and winter
(source: www.yourhome.gov.au/passive-design/orientation)

According to ecopsychology, natural environment has a positive impact in the human psyche and the connection with it can signify a reason of healthy, balanced lifestyle (Frumkin H., 2001). If the home is designed to resemble a natural environment or even better it encourages a live interaction with nature, it encompasses harmonious living.

## 2.3. Energy

Worldwide, the energy demand of buildings is a significant percentage (40%) of the total energy consumed nowadays. Greece is not an exception and statistics show the number is expected to grow even more in the following years (Papathanasopoulou, 2010). Building green is to minimize the energy expenditure and replace electricity to renewable energy resources whenever possible ps. from the sun by photovoltaic panels, from the wind by windmills, by the earth heat in the form of hot water etc.

In addition, there are two phases of energy expenditure to consider when we talk about green buildings: embodied and operational energy. The energy spent in the process of construction is called embodied energy. The operational energy is the energy spent by the occupants when they live inside the building and includes heating, cooling, lighting and any use of electric appliances in general (Bribian, 2011).

### 2.3.1. Embodied energy

The embodied energy of a material is the energy that has been spent to manufacture and transport the product to the building site when it is ready for use (McMullan, 1983). It requires the assessment of raw-material production, manufacture, use and disposal including all intervening transportation steps necessary or caused by the product's existence. A building's embodied energy (MJ/kg) is the energy used for its complete materialization. The supplies (e.g. transport) of the workforce and the operational machinery are energy expenditures, too. It would be omission not to mention how to deal with the vast amount of rubbish generated and sent to the landfill (Harris Cindy, 2009)

Locally sourced materials have lower embodied energy because of the short distance of transportation and moreover the packaging is possibly minimal as they can be purchased in bulk. Natural materials like sand, clay, reeds, timber can be found locally and they have received minimal manufacturing. If the energy used is multiplied by the carbon intensity of the fuel used, we can refer to embodied carbon of a product. For example, the use of renewable energy reduces significantly the embodied carbon $CO_2$ but the embodied energy stays the same. Also, plant or tree based materials store carbon during their lifetime and they act as a carbon sink. Therefore, natural buildings can have significantly low embodied carbon since materials like wood or straw act as carbon sinks or lime plaster absorbs carbon during its lifetime.

As far as embodied energy, it incorporates a lot of energy from the extraction of raw materials, to manufacture them, package and deliver them to the site and use them (Bribian, 2010). Moreover, the excavations, the management of the waste to the landfill and the energy required by the workforce are all comprising the so called embodied energy. The choice of natural ecological materials assist in lower energy costs because of the minor processing and often their locality. For example, straw may have embodied energy 4 $kW/m^3$ and conventional bricks 1462 $Kw/m^3$ (Brojan, 2013)

### 2.3.2. Operational energy

Thermal comfort is the expression of satisfaction with the surrounding built environment which some characterize as our third skin. It is becoming all the more important for the well-being in modern societies and therefore cooling and heating up a place can be the major energy expenditure of a building. However, there are design solutions to avoid this. For example, passive solar implements a building's elements like thermal mass walls or southern glazing for collecting solar energy. Also, airtight openings and thermal insulation can save a lot of energy by minimizing temperature fluctuations. Indoor environment which is unsatisfactory can result in thermal stress which may even prove fatal: deaths caused by extreme heat or cold is not uncommon for sensitive groups of the population as we are moving towards higher temperatures because of the global climate change (Pelsmaker, 2012).

## 2.4. Environmental Assessment Methods

A brief description of three selected tools for environmental assessment which have been broadly used during the previous years

- Life cycle analysis
- Ecological footprint

### 2.4.1.Ecological footprint

A classic tool for the environmental evaluation is ecological footprint. It can be used for anything, like products or humans and people. But it has some drawbacks which make it barely possible to suit a building project. It tells us nothing on the precise location of the ecological resources we use and if we overuse it or not. It makes no distinction between ecological resources we use from distant or local land. Moreover it does not measure the intensity of exploitation of soils or biodiversity loss (Galli A., 2011). Limitations of E.F. stem from it accounting for goods in terms of embodied energy and not for other resource use and waste. Moreover, data is not typically available on a life-cycle basis.

Moffat et al note that the EF method assumes all energy and material requirements should be met from renewable resources and judge this ‘a major disadvantage’. It fails to fully describe the complexity of the relationships that a city establishes with its rural neighborhood. Hence it falls short of being a policy tool for sustainable management of our ecological resources. (Alapetite Julien, 2010). Despite this, EF has been an efficient communicating tool to raise awareness about environmental degradation caused by excessive consumption. But the results are barely suitable for construction planning and design, as information on real use of local materials land is lost in the process of calculation.

### 2.4.2.LCA

Life Cycle Analysis or cradle-to-grave analysis (McDonogh&Braungart, 2002) considers the full range of the environmental impacts of a product during its whole lifecycle: conceptual stage, design, construction, and lately even deconstruction (cradle-to-cradle analysis). An overall assessment with LCA measures raw-material production, manufacture, distribution, installation, use and waste disposal including all intervening transportation steps necessary or caused by the product (Mc Mullan R., 2007).

As far as the building sector is concerned, LCA can serve well the measurement of building materials or technologies (Chwieduk D., 2003). However, it is not a preferable tool at the moment for evaluating a whole construction because making an LCA analysis requires a large dataset handling. The calculation tool has to be adaptable to the different decisions taken throughout the life cycle of the building, which makes it even more complicated. Such tools have been developed in only a few countries (Life cycle assessment in buildings: The ENSLIC simplified method and guidelines, Tove Malmqvist).

### 2.4.3. Building evaluation

There are tools which evaluate a building and issue certificates with grades assessing the green performance and the incorporated green feautures. The LEED of USA and BREEAM of UK are the oldest and currently most popular tools worldwide and they are considered benchmarks (Ref). LEED is mainly suitable for commercial construction. It would not be appropriate to apply LEED into a small project of a self-built earth home because the approach is very different (vernacular vs technological innovation). BREEAM is similar to LEED but there is a special part called “Code for sustainable Homes” (CSH) which deals only with domestic projects.

In Greece, there is KENAK regulation for energy efficiency which is compulsory for all new buildings. It was implemented in accordance to the European directive EPBD in 2010 with the aim was to reduce direct energy expenditure from heating, cooling, A/C, hot water, lighting etc (Dascalaki, 2011). The regulation requires certified building products with standard U-values in order to issue Energy Performance Certificates for the classification of new dwellings according to their efficiency (Dascalaki, 2011).Notably, KENAK is an assessment tool employed only for the energy efficiency of the building not a holistic scheme for the greenness of buildings in all aspects.

# 3.Natural Materials

## 3.1. Why Natural Materials

Construction industry produces almost 50 % of toxic and radioactive waste affecting soil, water and air (Delgado, 2011) and also, CO2 emissions are rising with most obvious consequence the climate change and endangered global health (Venkatarama, 2001). The impact of building materials takes place from extraction to manufacturing, transportation and finally installation at the building site (Bribian, 2011). The use of more ecological construction materials and techniques represent a major contribution to a more sustainable eco-efficient construction industry (Niroumand H. et al., 2013)

Since a building apart from the general impact on the environment, has also continuous interaction with the occupants, it can affect much more directly their health and well-being e.g. “sick building syndrome”. An *ecological material* has to incorporate at least the following two aspects according to Eliza Fanzoni (2011):

•Renewable and locally produced, relatively unprocessed, recycled and recyclable.

•Friendly for human health, i.e. free from volatile organic compounds, hazardous fibers dispersion, radon emission, biological pollutants proliferation and presence of damp in parts of the building or on surfaces).

Traditionally the choice of building materials has been a matter of cost, availability and suitability for the specific case but nowadays, there is one more necessary quality: to be environmentally friendly (Cindy Harris, 2009). The selection of locally available natural materials is one of the easiest ways to minimize embodied energy by saving the transportation requirements. Besides minimizing embodied energy, it is equally important to produce buildings with a high recycling potential in order to reduce the use of energy and resources (Cabeza L., 2013). The assessment to what degree a building material is sustainable can be generally evaluated by identifying the extent of reclamation and recyclability of the retired construction and the integration of recycled part in the new building material (Lee B., 2011) Moreover, natural materials can be very easily recycled or disposed in the environment without polluting and there is also the possibility to easily reuse straw and earth, possibly in another form or mix.

| Credit Description Points | | |
|---|---|---|
| 1 | Building Reuse | 4 |
| 2 | Construction Waste management | 2 |
| 3 | Materials reuse | 2 |
| 4 | Recycled Content | 2 |
| 5 | Regional Materials | 2 |
| 6 | Rapidly Renewable materials | 1 |
| 7 | Certified wood | |

Fig.4 Points under the materials & resources
Category of LEED (source: USGBC, 2009)

Portland cement is the most widely used manufactured construction material in the world although it is highly energy consuming and a major contributor of CO2 emissions. During its production it consumes plenty of natural raw materials, clays and solid fuels and produces a massive production of $CO_2$ emissions in atmosphere due to the extremely high developing temperatures (1500°C). (Giesekam, 2014). Also, fire clayed bricks require huge amounts of energy to be manufactured, even more than cement (Venkatarama, 2001). These facts do not include transportation energy expenses but we know that in Greece usually manufacturing of building materials like cement, bricks etc happens locally most of the times (Papamanolis, 2005)

However, there are natural alternative choices with minimum energy expenditure. The use of cereal straw for wall infill was a common reality in places with wide field crops and large availability of straw in New Zealand (Hall Min, 2009). Lime can substitute cement as a more ecological stabiliser mortar for the foundations as well as outside the house as a finish plaster (Pelsmakers S.). Sheep's wool can be a great substitute of conventional insulation materials (Giesekam, 2014). Mountainous rocky terrains like the Greek islands would take advantage of stone or granite for creating homes. Earth is a construction material which is used widely all over the world even now, as a prevalent solution especially for developing countries (Minke, 2000).

Many studies have been and are still being conducted to explore the environmental performance of conventional building materials and their alternatives (Brojan L., 2013). For example Brojan L. et al. (2013) compared a strawbale lime rendered wall and an insulated fired brick wall to find out that the first is a much more ecological option. Morel (2000) investigated case study buildings with local natural materials in France and the calculated embodied energy was at least 285% less than any similar conventional building. Alcorn at al. (2010) conducted life cycle analysis of different house types from completely conventional to best practice ecological solutions using natural materials such as straw and earth and found that they reduce CO2 emissions almost to zero. Giesekam (2014) suggests the following ways to reduce carbon emissions from the building constructions: use of natural materials, exchange of ingredients in the material manufacture process, improved design and fabrication, reuse and recycle components.

In the present research, we explore the potential of alternative natural materials like straw and clay for the building sector in Crete. In the following paragraphs there is a short description of these materials with data from the literature.

## 3.2.Straw

Straw, as a natural material with minimal manufacturing, is a chance to reduce annual emissions from construction and operation phase of a building and even achieve to be net absorber of CO2 in the lifetime of a building (Alcorn et al.). The most sustainable solution is achieved by using local strawbales, which save a lot of emissions, time and energy from transportation. They also create a healthy indoor environment, as it has been proved by a plethora of studies (Ashour T., 2010).

Strawbales have good insulation properties thanks to the air captured in between the fibers and due to the thickness of the wall, since normally bale width is at least 60 cm. Therefore, bale walls weatherproof the interior of a building, lowering energy bills for heating and cooling. Additionally, straw regulates the indoor humidity content especially combined with natural lime plaster which is breathable and allows drying which is important for straw durability (Marks L.R, 2005).

The origins of straw bale building method date from the $19^{th}$ century in the USA, Nebraska (Carfrae J., 2011). For more than a century, this type of construction has been quite uncommon on the border of mainstream techniques. Only in 1994 the first contemporary strawbale house was built in the UK and since then it is all the more gaining popularity (Carfrae J., 2011). There are two structural types for constructing with strawbales:

a) load bearing: the walls take the loads of the roof and the straw itself has compressive strength which is enforced by plastering

B) post and beam or timber framed construction: bales are used as in-fill blocks between or around structural frame.

Barbara Jones (2009) in her book “Building with strawbales” claims that it is preferable to use load bearing method because it is easier for unskilled self-builders and cost effective (less timber is used). Experiments illustrate how the strength of fibers and the thickness of the plaster as well as the bale positioning itself can impact the structural strength of the plastered bale e.g. the strawbales plastered flat were 36% stronger than those plastered on edge (Vardy S., C.Dougall, 2006). But, the post and beam method is an old technique which relies on the established timber skeleton for structural support which doesn't incorporate any stress for clients and engineers (Jones B., 2009). A flaw is that it is usually challenging to fit in the bales and it also requires carpentry skills and more timber. In Greece, there is no possibility to get planning permission without a structural skeleton to support the loads due to the national anti- earthquake building regulations.

There are at least two ways for the use of straw to infill walls:

a) Straw bales are laid up and tied as bricks. Plasters are applied directly to the bales, or on to wire netting attached to the bales. When using the whole strawbales, because of the thickness and the material properties the achieved improvement of the thermal resistance can be even higher than traditional industrial insulations on brick wall (Alcorn et al, 2010).

b) Light-clay walls of the houses can be manufactured manually by soaking well long straw stems within a solution of clay and water. Clay contributes in the thermal mass storage which offers inertia for the fluctuations of day and night temperature differences.

The use of straw as a building material has some downsides, too. A problem is that straw needs meticulous storage and use because it is very sensitive to humidity and if the dampness exceeds 25% of the dry bale weight, there is likely to rot and to be damaged (Jones, 2011). However, this problem can be surpassed with appropriate storage and by keeping the bales higher from the ground and well covered by a roof (an old English proverb says "a pair of boots and a good hat"). Another stated problem is the mice and vermins that tend to create holes in the walls and try to create living conditions in them. Therefore the walls should be sealed tightly with plaster as soon as possible. All in all, for strawbales to succeed as a building material it is vital to apply a good natural plaster that will be maintained in good condition to protect the material from any dampness or life.

Fig.5 Load bearing strawbale building (source: www.solarhaven.org)

Fig.7 Timber-framed strawbale building (source: www.naturalbuilding.com)

Strawbales are highly insulative but they have no thermal storage capacity. So they cannot be used alone for passive solar design, but in combination with a thick indoor plaster or thermal mass interior walls. Moreover, if the house is overheated during the summer by solar irradiation or open doors/windows, it will be hard to lower the temperature because of the high insulation. Therefore it is essential to combine strawbales with large overhangs that protect from the rain and the sun irradiation but also with airtight openings and high quality glazing

Another issue under discussion, is the local situation of agricultural land. Due to land restrictions of a mountainous island like Crete the wide farming of cereals is not easy to realize. The plots are small because they were divided among many different owners that inherit them from their family. Also the use of machines in agriculture made the traditional ways of production less profitable and cereals are not grown anymore. The southern Mediterranean is affected by climate change turning into a semi-arid region which will not provide the necessary abundancy of water for cereals (www.climateadaptation.eu/). So there are serious considerations to whether there will ever be enough local straw in Crete to build houses from it widely. Yields of wheat and barley were minimized in the rest of Greece, too, probably rising the price of imported strawbales even more.

Considering the timber which is required for the load bearing constructions, it would be interesting to mention that wood is a very sustainable building material in comparison to bricks, aluminum, steel or concrete due to its much lighter processing. It has been associated with reduced carbon emissions and even negative carbon coefficients i.e. they store more carbon than emit during its life cycle (Cabeza L., 2013).

## 3.3. Earth

Earth or *dirt* or *loam* is a vernacular material that has been used for thousands of years traditionally in many different countries around the globe (Niroumand H., 2013). "Earth houses" are actually made by a mixture of clay, sand and sometimes gravel or even fibrous plant material (Minke, 2000). In different ratios, we can obtain a variety of mixtures that can be used with different techniques: rammed earth, cob, adobe, light clay, compressed earth blocks etc.

As most vernacular materials, it is a material simple to work with, which is an advantage for non-skilled self-builders (Bokalders V., 2010). It is easily accessible since it can be found everywhere in huge abundance with only the energy expenditure of excavation and transportation (Bokalders V., 2010). Therefore, earth building have a clear advantage as far as low cost and fuel consumption is concerned. For a more scientific argument, Fay et al. (1999) uses a hybrid EE analysis method only to find out that the use of earth as a construction material signifies major savings in EE comparing to conventional construction materials.

The perceived health benefits are both physical and mental. Earth walls are exceptional in absorbing excess humidity from indoor environment and even pollutants that may exist in moistened air (Fig.3, Bokalders V., 2010 and Minke 2000). Moreover, clay was found to considerably decrease aldehyde concentrations (Darling et al., 2011). Last but not least, earth is a material that inspires calmness, harmony, and it has unique charm which is a characteristic of all hand crafted creations.

Earth walls have high solar storage capacity due to the heavy mass. During the day, south walls absorb solar radiation keeping the interior cool. During the night the outside temperatures fall but the heat is released gradually indoors maintaining comfortable temperatures for the residents (Fig.7, Minke, 2000). According to an experimental research, a cob wall of 50 cm has almost the same thermal behavior as that of a concrete wall with 7-9 cm synthetic insulation (Brojani, 2013) but with significantly less carbon emissions.

Another way to consider earth for the building construction is the plastering. Clay plaster is regarded as the best material for moisture absorption and buffering therefore it is often used with the purpose of improving the interior climate. It is a porous material with humidity balancing effect as it absorbs moisture when there is excess humidity and releases moisture when the atmosphere is dry (Harris C., Borer, 1998).

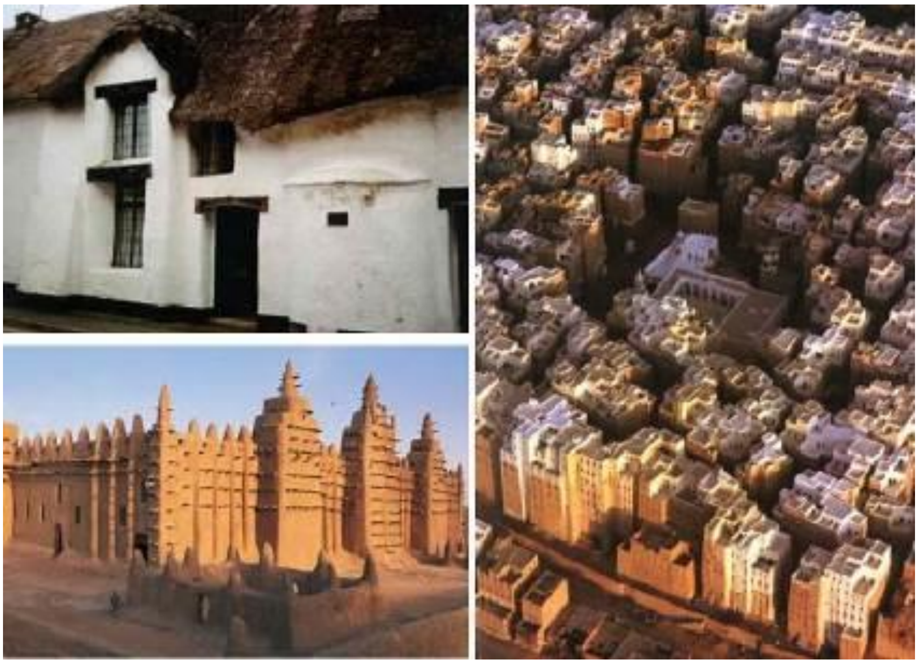


Fig.7 From top left: cob house in Devon, Yemen, Shibam temple (source: G.Minke)

On the other hand, earthen walls have high thermal conductivity, which indicates fast heat transfer (heat loss). But despite this, they are still great climate moderators partly because of their water content from continuous wetting and drying that stabilizes the perceived thermal comfort by the occupants (Parra et al.). Also, waterproofing is essential for the longevity of the structure, usually lime plaster is the outer skin of the building is a protection that allows breathing. A roof with wide overhangs is essential and the foundations made of stone are raised from the ground.

Earth walls have low resistance to compression and therefore require a structural skeleton to take the loads. This means the necessity of a wood skeleton and also architects and engineers have to be implemented for the design. It is a material that requires physical strength because it is labor intensive and it requires patience for self-builders (or paying builders for long hours of work) as it can be time consuming to see the walls rising. Moreover, it has low acceptability amongst most social groups because of the poorly maintained and badly designed earthen homes of the past and its modest vernacular origins. Another drawback is the restriction for the height of the building, since earth cannot be used safely for high rise buildings.

Jackson and Tenorio (2001) suggest that the attractiveness or desirability of a material is severely affected by marketing promotion. In western societies, products are often evaluated according to their price and the materials that are cheap are depreciated as low-quality. They note that in New Zealand the main difficulty to spread natural building was the perception of the public that earth buildings are for the poor and those with “hippie lifestyle”(Tenorio and Jackson, 2001). Moreover, Niroumand H. (2013), after conducting an international research for earth architecture, claims that the lack of education and the lack of awareness were the primary constraints for earth buildings to be widely spread in 6 different countries.

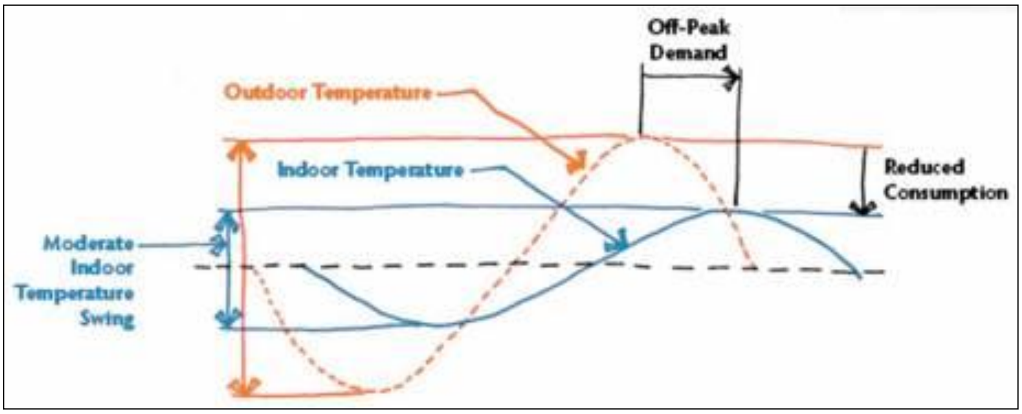



Fig.8 Earthen thermal mass moderates the indoor temperature swings (Minke).

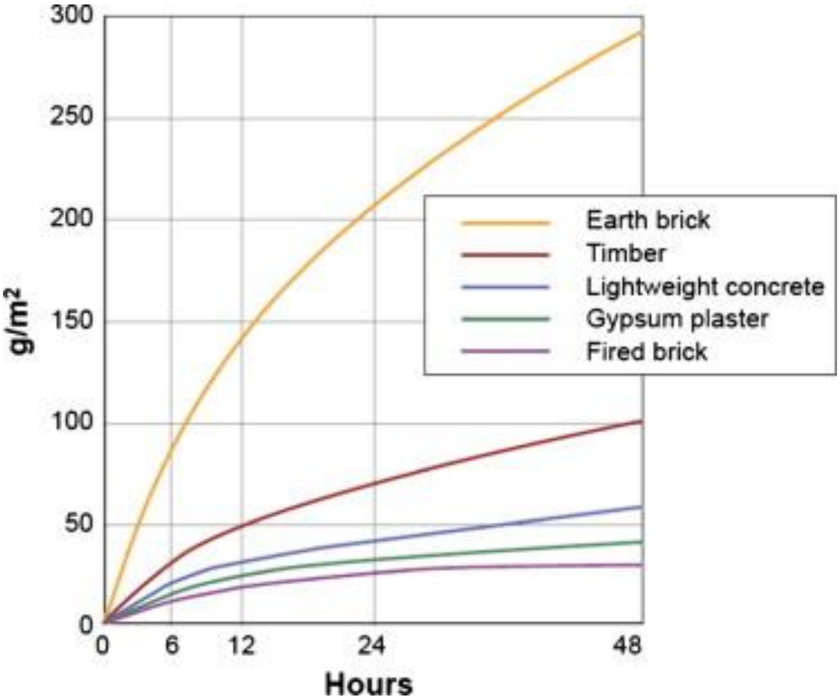



Fig.9 Weight of moisture absorbed by different materials when relative humidity increases from 50% to 80% (Bokalders V., 2010)

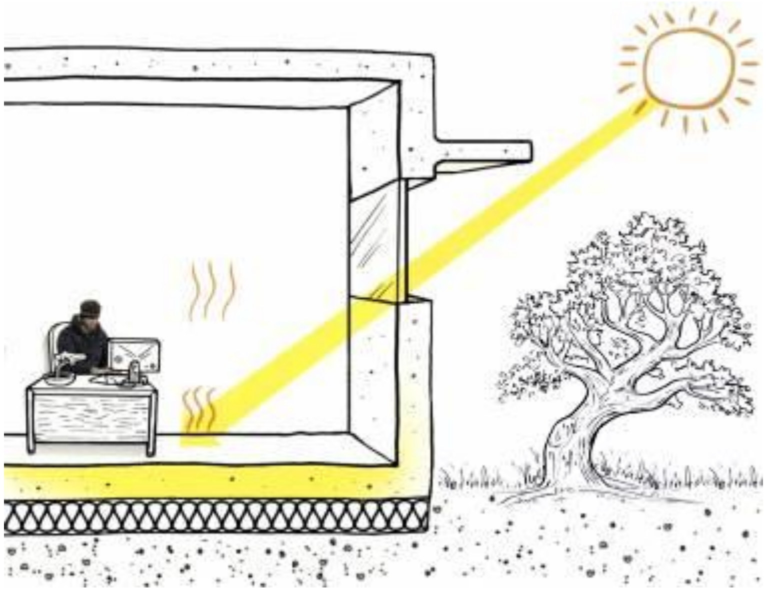


Fig.10 Earthen floor and walls store solar energy and release it gradually
(source: sustainabilityworkshop.autodesk.com)

## 3.4. Summary

Earth and straw can contribute to reducing pollution by saving energy during extraction, transport and manufacturing. Moreover, they are recyclable or reusable or can be completely assimilated with the earth once the building has reached the end of its use. Their efficient use offers thermal comfort with stable temperatures without necessarily the need of mechanical support systems. Also, they absorb pollutants and excessive humidity from the atmosphere offering a healthy environment for the occupants. They are simple to use and accessible, they can address to self-builders.

Among their drawbacks is the risk of rot or deterioration that is prominent without proper maintenance or protection from humidity. In Greece, the lack of experienced workers and lack of institutional accreditation or certifications providing the necessary information results in limited social acceptability and broad use of these materials. They should be used to take maximum advantage of their properties: earth's heavy thermal mass and straw's insulation properties. Natural materials can behave good or bad according to the existing conditions. However, there are some restrictions on the height and size of the building, there is not the possibility to rise up to two floors maximum for example.

All in all, natural building materials have many advantages but they have restrictions, too. So, they should be handled with care and attention and only to address specific needs and then they are reliable to last and offer good quality living.

# 4.The island of Crete

Intro

Crete is the fourth largest island in the Mediterranean area with 8,335 km2 and 623,666 permanent inhabitants (Mourelatos A., 1998). The different cultures occupying the island all through its history, since the Minoan times to Saracen, Arabs and Byzantine and more recently from Venetians the 13$^{th}$ century to Ottoman occupation from 16$^{th}$ to 19$^{th}$ century gave to the island the distinctive character it has today. Nowadays, the largest city and capital of Crete is Heraklion while there are some more urban centers: Chania, Rethymno, Ag.Nikolaos and Sitia. Tourism and agriculture are the pillars of the local economy.

## 4.1. Climate and agriculture

The island of Crete which is considered a semi-arid region today, enjoys Mediterranean climate with mainly two periods: a cold rainy semester (October-March) and a warm dry one (April-September). It receives a great level of sunshine all year round (Chartzoulakis K.S., 2001). Because of its long and mountainous terrain, there are a lot climatological variances, for example with yearly rainfall to range from 300mm (east) to 1000mm (west) and even up to 2000mm in the mountains. Although the precipitation is high, most of it is lost due to evapotranspiration or it runs off to the sea. Also, the rainfall is mainly happening during winter while the extended summers can be completely dry (Chartzoulakis K.S., 2001).

The area used for agriculture reaches 39% of the island while the majority of the crops are fruit trees. Climate change will be turning Crete in a semi-arid place and crops like cereals will be less and less appropriate for the land. Already now, row crops like cereals only share 15% of the cultivated land (Koundouri, 2006).This is mainly because of the mountainous landscape and the continuous division of the tillage due to family inheritances which results in small plots inappropriate for cereals. Cereal cultivation needs widespread fields in order to be profitable for the farmers. At the moment, it is not possible to be based in the current production of straw for a wide building construction. To what extent farmers could turn to cereal yields for producing strawbales for building is an issue under discussion. At the moment, the author assumes that the price of a stawbale in Crete ranges from 5 to 8 euros.

## 4.2. Vernacular architecture

Architecture in pre-historic Crete achieved a remarkable level by the 6$^{th}$ to the 1$^{st}$ century BC and during over 500 years it was flourishing under the Minoan civilization (Mc Enroe John, 2010). The local traditional architecture of a place is mainly influenced by the climate, culture, local natural resources (Papamanolis,2005). Mudbricks appear to have been one of the most common building materials used in domestic architecture in Bronze Age Crete and most probably there was even a set recipe (Nodarou, 2008) Things changed later, when the constant invasions and occupations of the island did not permit evolution and improvement for Cretan vernacular dwellings. In fact, everywhere the war living conditions turns people to take care of their primal needs. On the other hand, massive and impressive public construction works by the occupants, Venetians and Turks, are found everywhere in the island.

Fig.11 Cretan architecture in Bronze Age. (Source: www.destinationcrete.gr)

Even recently, building with natural materials used to be a commonplace in Crete among the residents of a village. People would use straw, clay, soil from the surroundings and organize themselves into groups for building their own dwellings. According to oral descriptions, the whole family and friends would collect soil, stones and bamboo sticks to construct their own houses and there was always help exchange between them. Since 2008, there is an organization based in Crete that is called PILIKO (Greek: Pilos=loam and ikos=home) and which was formed by architects and engineers that appreciate the value of earth buildings. They often run seminars and workshops for natural buildings with international professionals e.g. Minke G. and Jones Barbara in 2011. Their contribution is important in promoting familiarity and encouraging the use of natural materials. The following images are taken by their archive and show typical examples of natural architecture on the island and some of them in central Greece (photo archive link: www.piliko.gr).

Fig.12 Piliko team for natural buildings in Crete. Adobe construction, 2011(source:Piliko)

Fig.13 Piliko team for natural buildings in Crete. Making earth bricks, 2012(source:Piliko)

Fig.14 Piliko Workshop with Gernot Minke in Anydri village, Chania 2010 (source:Piliko)


Fig.15 & Fig.16 Traditional adobe houses in Crete, Greece. (source: Piliko)

Fig.17 Traditional adobe house out of use in Crete, Greece. (source: Piliko team)

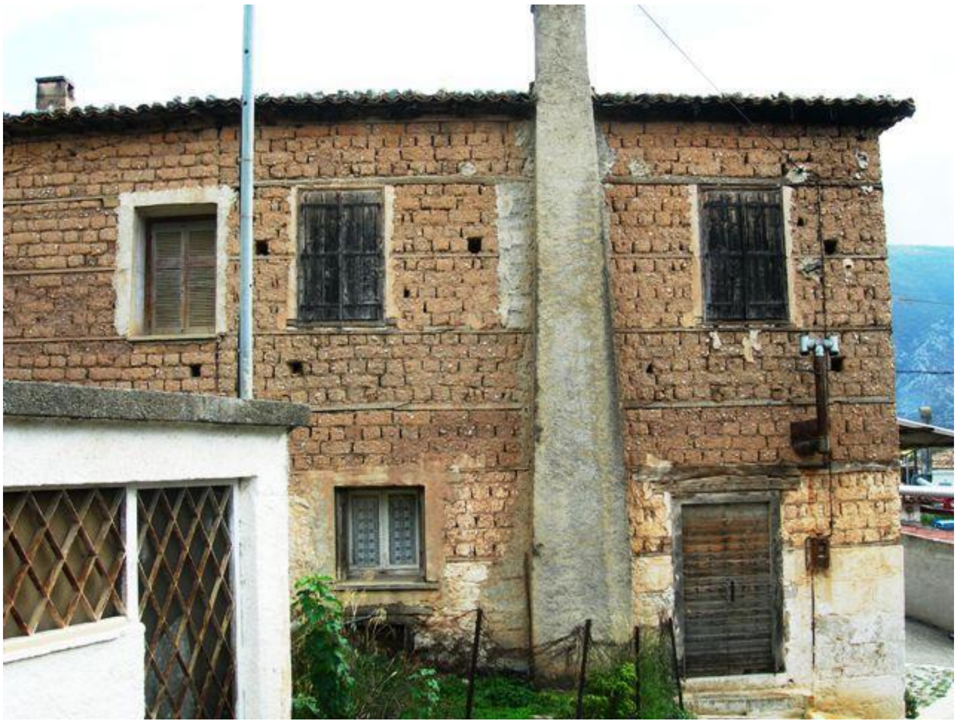


Fig.18 Traditional adobe house out of use in Greece. (source: Piliko team)

## 4.3. Contemporary Natural Buildings in Crete

After several decades of concrete and steel domination in Europe, alternative ecological methods of construction like earth and straw are regaining the interest (Giesekam, 2014). The author is assuming that there is the revival of natural buildings since 5-7 years in Crete. It is coinciding with the time of a severe economic crisis for Greece (Hatzis, 2015). According to author's estimation, approximately 2 strawbales, 3 light clays and 2-3 adobe were built and already occupied recently (Piliko team, www.piliko.com). There are pictures of contemporary buildings from natural materials in Crete in the following page. Apparently, the number is small yet but the information about natural building possibilities is spreading along the island.

There is a curiosity and interest about the conditions of living in such buildings because it is not so common in Greece. However, people started learning about this possibility through TV, newspapers and the social media have a large share to this. There are popular social media groups ("facebook") that inform people about practical, technical, legislative peculiarities and organize social event around natural building ("Natural building in Crete", "Natural building in Greece", "pilikoteam").

Lately, the building department gave a new incentive to build with natural materials. The thickness of walls made with natural materials like straw, earth, stone etc do not count in the total surface accredited for the planning permission according to the new building code for Greece, chapter 11. This offers an advantage to the owners both economically as well as in terms of more building space allowance. However, the Greek regulation for energy, KENAK, can be a complication since there is no certification for this material. The quality may vary significantly depending on the producer, crop, land etc. If one decides to use it as a building material, then it is compulsory to certify the material through laboratory testing.

Fig.19 A Private cob dwelling in south Crete, Anydri, 2006 (www.piliko.gr)

Fig.20 European sustainability Academy, a strawbale building in Chania, Crete (Piliko team)

## 4.4. Tectonic Plates Movement

The region of Crete lies in the zone with the highest seismic activity in Europe (Makropoulos, 1984) and one of the highest in the world, which is reflected in the construction of the buildings (Papamanolis, 2005). Greek engineers prioritize strong structural stability following the anti-earthquake guidelines of “EN Eurocodes” which are common rules for buildings and other civil works in all European countries. Eurocode 8 addresses to seismic design regulations and Eurocode 6 deals exclusively with load-bearing structures.

Earthquakes generate internal forces within buildings that may cause various level of damaging. These forces are called “Inertial Forces” and they are directly proportional to the mass (weight) of the exposed building. The greater the mass, the greater are the generated inertial forces. Subsequently, a lightweight construction like strawbale or light clay have an advantage in seismic design comparing to conventional concrete and steel construction (www.wbdg.org).

Load bearing buildings from earth or straw have never been designed and constructed legally under regulations in Greece (anelixis, www.anelixis.org). However, the strength of vernacular earthen constructions through time testifies the adoption of practices by workers that follow the rules of experience:

1 diaphragmatic function
2 tiers
3 protection of openings with wooden elements
4. growing mass distribution from the upper to the lower floor
5. limited height of earthen construction (ground floor and first floor).

Nowadays, the engineers in Greece have to use the Eurocode 6, which does not allow the transfer of loads on elements of raw earth or strawbales. Alternatively, one can use these materials as infill of a structural skeleton calculated according to regulations of Eurocode 8. The skeleton will support the loads of roof, floors, wind, snow, people and earthquakes. For strawbales and earth structures timber skeleton is commonly used as a natural organic material (anelixis, www.anelixis.org).

# 5. Methodology

## 5.1. Research Methods

The potential of natural building materials in Crete was investigated with qualitative research according to Alan Bryman's “Social research methods” (2001). The steps of qualitative research by Bryman are:

1. Making general research questions and direct observations
2. Selecting site and subject
3. Collection of data by interviewing, analyzing texts and discourse dialogues
4. Interpretation  of the field notes
5. Conclusions

The author followed the above guidelines of the path mentioned above by:

1. Focusing in literature about natural buildings nowadays
2. Identifying the past and present situation in the specific context (Crete)
3. Key people present their perspectives
4. Completion of evaluative questionnaires
5. Coding the results and interpreting the data
6. Visiting case studies and conduct qualitative unstructured interviews (conversations) with the occupants/ builders
7. Meausing data on site
8. Interpretation and analysis of findings
9. Conclusions

*Grounded Theory*

The key findings of interviews and questionnaires were approached with Grounded Theory. Grounded Theory is a systematic methodology of social science which comprises of extracting general theoretical results from collected data (Strauss and Corbin, 1998). Thoroughly elaborating the experts’ qualitative interviews and answers in questionnaires with the use of Grounded theory, it was the way to identify the potential of natural buildings for Crete.

## 5.2.Methodology Discussion

### 5.2.1. What kind of Research

Any question can be answered by designing a good research plan, collecting the appropriate data and analyzing it carefully. Every one of us is conducting research regularly by asking questions, listening to anecdotes, watching others and engaging in discursive dialogues. This kind of research is called qualitative research. In opposition to quantitative research which requires large samples and it answers with numerical data, qualitative research focuses in ''quality'' drawing conclusions by approaching and comprehending an idea with critical interrogations through a specific context (Tracy Sarah, 2011). A statistical method might be preferable when the subject is common and homogenous but since natural building in Crete is particular and alternative, the present case is different. Human beliefs and concepts emerge naturally with qualitative research while quantitative data cannot do that (Tracy Sarah, 2011). Here the author aims to define the general context of natural structures in Crete by interviewing key people and evaluating case studies.

On the other hand, one of the biggest qualities of qualitative research is self-reflexivity which means that there is a high risk of bias and opinionated results. The author observes, participates and interviews through their own eyes, deeply influenced by their background and experience. But:

'How can it be different when the qualitative researcher literally serves as an instrument of absorbing and interpreting the data?' (Tracy, 2013)

'Everyone is entitled to his own opinion, but not his own facts' (Senator Patrick Moynihan)

All in all, as far as trustworthiness and authenticity are core elements of a proper qualitative research, the results will be genuine (Bryman Al., 2001).

### 5.2.2. The qualitative research

Architects, engineers, occupants, self-builders and owners of natural buildings in Crete were contacted for answering a short list of questions in the form of short structured interviews. The questions were sent by e-mail in "Microsoft word" since it would facilitate the approach of people from various distant places. Also, this would give them time to think and answer in their own time and the author to copy and translate their answers more effectively. According to Bryman (2001), computer assisting interviews improve the control over the process and enhance standardization of the asking and recording answers.

The questions slightly differentiate according to the experience and expertise of each participant. The answers were categorized under names A, B, C… so that each person's answer could be aggregated with other respondents' answers to find out the frequency of certain issues and reach to some general conclusions. This procedure is called coding and it is actually a stage of quantitative research (Bryman, 2001). But in our case the interviewees are not as many as would be appropriate for a quantitative research and this tool is just borrowed for facilitating our qualitative research.

Moreover, there were two charts of evaluation which were identical for everybody. The participants had to evaluate in a climax from “1” to “5” a list of characteristics related with natural materials and ecological building.

The participants were chosen out of a wide range of people in order to represent the different aspects of: green architects, conventional civil engineers, self-builders and occupants. They were chosen carefully out of the circle of people the author knew or have heard of according to their connection with natural building or/and their overall experience in constructions. By using targeted professionals it is possible to record how these key actors see the situation in Crete today.

### 5.2.3. The Case Studies

In the many forms it can take, "a case study is generically a story; it presents the concrete narrative detail of actual, or at least realistic events, it has a plot, exposition, characters, and sometimes even dialogue" (Boehrer, 1990)

Case study research focuses at a small pool of examples using observations, interviews, protocols, tests, examination of records. It is ideal when dealing with “creativity, innovation, and context” (Tracy Sarah, 2011) which describes the current situation of natural buildings in Crete.

The investigation of 2 case studies contributes to the research first-hand experience of natural homes in the island. A primary step is conducting “thick description” which is gathering some general background information of the people and context of the particular cases (Tracy Sarah, 2011). The peculiarity of case study method is that the researcher can only draw conclusions about that participant or group and only in the specific context (Bronwyn Becker, 2012). Therefore, grounded theory cannot be combined with case study analysis as the results extracted are only referred to the specific case studies (Tracy Sarah, 2011).

Case study research may contain bias risk and entails fear of generalization while the focus should be placed on exploring and describing a specific case (Flyvbbjerk, 2006). Despite this, Flyvbbjerk persists that case studies can have general value results indeed which are unbiased and objective. He also demonstrates 2 more reasons why researches can be benefitted from investigating a real-life situation with case study research:

- Evolution of an image of the reality
- Researcher’s own learning process in developing skills for good research

Taking into account the above, the author decided to proceed in the investigation of two already existing natural buildings in Crete which are typical cases of self-build, alternative dwellings. As already mentioned, the author estimates that in Crete at the moment there are approximately 6 already constructed modern natural dwellings. After visiting all of them, two case studies were selected to be part of the present study: the first case is a strawbale building on the seaside of Paleokastro and the second case is a light clay dwelling in Archanes, on the foothills of Youchtas Mountain. The reasons for choosing these cases among others were:

- Similar surface size
- Both were Self-built with community engagement
- Two different techniques
- Different climate (seaside Vs Mountain)
- Already occupants living inside for 1-2 years
- Approachable and helpful owners
- Data was collected by visiting and observing directly the site while reflection notes were taken during the author's presence as a volunteer on site, too.

The owners were very approachable, communicative and willing to cooperate. Semi-structured interviews and/or flexible conversations allowed spontaneity and trustworthiness and they were generated in a friendly atmosphere. A "guide" with bullet points-issues to be discussed stimulated deep narrative answers about the steps of the construction, the selection of materials, the green features, the community engagement but also the hardships of each project. Of course, the choice to build with natural materials usually is the choice of environmental conscious people. So there might be a bias in the fact that these people have a positive attitude towards this kind of buildings in any case. There was an effort to judge objectively and from a distance their statements.

# Section A:

# 6.Perspectives on natural building materials

Intro

Within the frame of this research, representative professionals and occupants of natural building in Crete were asked to give their perspective. They have been interviewed briefly most of them with structured interviews though e-mails. Moreover, evaluation forms were sent to them via e-mail in order to gather representative data on what *natural materials* and *green building* means for them. Not everyone who was contacted was available or willing to participate but finally, 11 people took part in this qualitative research: 4 architects, 3 structural engineers, 4 self-builders and occupants. This section A is divided in two parts: presentation and analysis of the data.

I. Presentation of Data:

a) The interviews

b) The evaluative questionnaires

II. Analysis of the Data:

a) Discussion of the interviews

b) Findings of the questionnaires

## 6.1. Presentation of Data

### 6.1.1.Interviews

*The participants:*

1. Antwnia Diamantaki, architect of strawbale building,
2. Giorgos Ritsakis, self-builder ,occupant of light clay,
3. Tasos Andreadakis, structural engineer,
4. Michael Katakis, occupant of light clay,
5. Christos Choraitis, architect, self-builder, occupant of strawbale
6. Claire Oiry, earth buildings specialist-architect
7. Herbert Gruber, constructor, founder of ASBN
8. Christina Charamountani architect specialized in natural materials,
9. Yannis Kalaitzis, structural engineer specialized in timber
10. Theodosia Kakavelaki, structural engineer
11. Axel Trillhaase, constructor
12. Apostolos Mousourakis, architect of light clay

**Christos Choraitis** is the architect, builder, owner and occupant of a strawbale house in Paliokastro. He choose to build with strawbales and clay for various reasons: healthy environment, comfort, beauty, time and money budget. He says it was cheaper than conventional building techniques but with an important prerequisite: that it is self-built. Natural construction materials are not expensive: "Crete has abundant resources like earth, clay, sand which are very cheap or even free as contractors have problems as to what to do with the excavation products" he says. According to him, straw is not the definite ecological solution for Crete because there is not abundant. But surely it is one of the high choices for well-being because of its insulation properties and the healthy indoor environment achieved through the breathing walls. He considers thermal mass inside the walls as a plaster is enough to keep out the fluctuation of the temperatures during day and night. Although he pointed out that the most sustainable choice for Greeks is renovating existing abandoned houses with natural materials. It is far the most ecological solution, he mentioned. Despite the difficulties of working with natural materials (which are analyzed in section 2), he would choose to build with strawbales again without doubt.

**Herbert Gruber** is conscious about fuel poverty and climate change. He believes that construction industry has to move into more ecological practices claiming that "Living in a clean from chemicals indoor environment is good but not enough: it should not be ignored that healthy living can only be on a healthy planet".

Moreover, a basic motivation to build with strawbales in his opinion is the fact that it is a relatively easy and comprehensible technique that anyone can take up quickly. Then, he adds that there is the possibility for self-build house, an option that saves money and engages the community in a process of learning and mutual help. The community of self-builders is a very valuable part of his life and professionally it helps the progress of the natural building technique. It is something like a family net, he adds.

When he was asked why he thinks that strawbales and earth are not popular building materials amongst Cretan people, he claimed the nonexistent tradition. "People never built with strawbales before, so it is not a surprise they do not build now". Professionals or not, the people who have now experience with it must make the information available and spread the word through TV, Newspapers, Radio etc. On the other hand, he expressed doubts on whether straw is the ideal ecological solution for Crete because of the fact that it is not a very abundant material:

With strawbales, sounds and weather conditions are kept outside the building whereas the natural plaster controls the moisture by allowing the breathing of the wall. But is only insulation appropriate for the Mediterranean climate? There are intense day to night temperature fluctuations. In that query, Herb.Gruber answered that a plaster 3-5 mm inside would be more than enough to keep heat outside during the day by slowly absorbing it and later release the heat inside during the night.

He noted that the exceptional insulation of strawbale walls are mainly a result of the thickness of the bales, as it could be a wall of 60 cm pure insulative material of any kind. But what makes it special is its environmental attributes. "Strawbales is a cheap and easily available ecological alternative material in most countries of north Europe and maybe north Crete. On the other hand, this is not the case for Crete. The specific material is not abundant in Crete since the mountainous terrain does not permit large cultivating tillage." Consequently, it can be difficult to find the desirable quality of bales and since the production is limited, most of the times it is overpriced (it can reach 7-8 euros per bale). Also, he said that "the environmental impacts will be higher if the bales have to be transported from far away", leaving a space for other natural materials or different techniques.

Fig. 21 H. Gruber
(source: baubiologie.com)

**Antonia Diamantaki** has built with strawbales respecting the environmental consciousness of her client, the harmony with the surrounding natural landscape and caring for the healthy and comfortable indoor environment. Also she adds: “I am conscious of climate change and I do care for finding new ways to construct houses with the least impact possible”. Aesthetics is a major reason for her to build with natural materials, too.

Asking her about the difficulties she faced during the realization of the project, she said “there were many”. One of the major problems she found was that she could not find like-minded environmentally conscious builders to work on site. The contractor and builders were not experienced with bales and not environmentally conscious so it was not an easy cooperation. Diamantaki says “this is a general situation as builders and contractors in Greece are not trained in eco-buildings and in many cases they are not willing to learn as learning requires more work or taking risk.” An architect or owner who designs an ecological project has to be there supervising and leading the procedure all the time otherwise mistakes are likely to happen, which is quite risky with natural organic materials.

Also, the fact that professional contractor was employed to build the strawbale building raised the cost significantly: “Even if materials cost less, the labor costs more and in the end it is the same thing”. A very important difficulty related with issuing the energy performance certificate of KENAK was that there is no certification for U-value of strawbales and earth they had to look for indicative numbers in German insulation regulations.

As far as the satisfaction from the thermal environment of her client, A. Diamantaki says that it is a success. When insulation is combined with passive solar design, rain proofing, air ventilation and right application of the material, the result is more than satisfying. Under these circumstances, she would definitely recommend it again.

Fig. 22 European Sustainability Academy, a strawbale building (source: www.esa.org)
Fig. 23 Antonia Diamantaki, the architect (source: www.esa.org)
http://eurosustainability.org/building.php

Fig. 24 T. Andreadakis (source: T.Andreadakis )

**Tasos Andreadakis** (Fig.24) was asked for the anti-seismic potential of strawbale or light clay as infill materials, he assured that as far as a load bearing skeleton is calculated and designed on the safe side, there is indeed structural sufficiency. Tasos considers that earth and straw are not suitable for the mainstream and he would recommend this kind of natural buildings to people who want to enjoy a more rural, natural lifestyle. "This kind of buildings are "alternative" as their materials, they can be used for a rural dwelling or a summer house. But again, the investment would be taken only by a client that is really conscious about" he concluded. The fact that there is not a long history of straw and clay homes in Crete casts a dark shade: "The lack of long lasting contemporary examples is a drawback at the moment. Contemporary applications up to now are still under the investigation process and they will be tested through time."

**Theodosia Kakavelaki**'s personal perspective about alternative natural materials: "Buildings from earth and straw are going to share only a small portion of the housing sector. People are not used to consider these kind of building as an option maybe because of the negative images they have from the villages in the countryside: old abandoned earthen wrecks of the last century. Especially straw has not extended use in the island and it is hard to trust something without memory."

"The greek culture dictates to invest in construction for safety and long term but not innovating. Earth or straw could be the solution for a holiday home or a second home somewhere in the nature or the suburbs. It is not eligible for multifamily building of many floors. Average people do not dream of a strawbale home, they even do not know it exists.”

According to her, finding trained builders with experience in natural buildings is not an easy task. “There are not any ready available contactors at the moment, it is something new for everyone”. Therefore, self-build is the most common way to do it which is not possible or desirable for the majority. On the other hand, it is not difficult to find people who work with stonemasonry, says T.Kakavelaki. Because of the long tradition in Crete, there are a lot of good stone masons. “If someone prefers natural materials, why not to use stone instead?” Stone is a high thermal mass material which, if used correctly e.g. with passive solar design, can have excellent results in the thermal comfort of the building. Let’s not forget the rocky Cretan landscape and that stone was an abundant material here which explains the number of stone built vernacular homes

**Yannis Kalaitzis** is a structural engineer based in Crete with an Msc in Structural Timber from Napier University. He says: “Natural materials are used as wall infill elements and they do not contribute nearly at all in the rigidity of the wall, whether it operates isolated as a cantilever or transversal with others as part of a mechanism. Therefore, they are not taken into account for the design of the load bearing elements of construction”

“Despite the fact that walls do not support the load of the superstructure this does not mean that the sided and variable loads, such as wind and earthquake should be ignored.” Once they are designed to take these loads, according to Kalaitzis the walls will be absolutely safe, especially when reinforced by using drywall (plasterboard), plywood (plywood), and particle board (OSB) on the sides. Alternatively, the necessary layer of mortar could be combined with suitable aggregates and fibers for tensile strength. The plastering could be just on the outer side of the wall or both the inner and outer side simultaneously. In case of using only simple overcoat plaster, a tool for extra strength is to place suitable vertical wooden piles. In the case of high walls, Kalaitzis recommends an installation of wooden cement rings in slots (creation of a reinforcement band) - particularly in the case of loam which is a brittle material. He finally adds that is crucial to ensure that the loads are successfully transferred to the load bearing structure through the appropriate steel connections.

To conclude, that natural materials are safe to use within a calculated loadbearing skeleton. Perhaps slight cracks are formed over coat / mortar / plaster board, but this is a matter of daily functional use rather than construction failure, and hence there is not safety issue here. Essentially, the design should consider seismic forces and wind.

**Ritsakis Giorgos** is a self-builder, occupant and owner of a light clay house in Crete. The hardships he encountered were related to the people he employed to work for him for the building. This time the problems were on the paperwork: the public engineers were delaying for the building permission, the architects employed were unaware on how to issue the papers without troubles. Most importantly, the regulations for energy efficiency required calculation of U-values of the wall. They had never before considered straw as a building material. So, a sample of the wall 40cm*40cm was sent to the official national laboratory in Athens to identify the thermal characteristics of the specific block. Successfully it was measured and it was set as an example of “light clay” for consequent cases. He notes that alternative building materials like straw and clay make the construction more affordable especially in conjunction with self-built practices. With the help of friends or volunteers one can save a lot in daily labor costs.

Fig. 25 Ritsakis G. building his own house with light clay (source: Manos Ximeris)

**Katakis Michael** is occupant and owner of a light-clay home who spent a lot of working days helping on site during the construction. Principally choose that way for a healthier living environment for him and his family. He did not face any particular difficulties for the realization of the project but it would be interesting to mention that his contractor was German and he was experienced in natural building. He lives there 2 years already with his family and he claims to be very content of the thermal behavior of the house all year round and he would not doubt to recommend it or do it again if he had the chance. It even cost less than a similar conventional house, as it is not a status quo yet in Greece. Apparently, he also spend a lot of days working himself on site.

**Axel Trilhaase**, has built Katakis Michael’s light clay home and was involved in one more light clay building construction. He is specialized in natural building but most of his projects are conventional. He is optimist that natural building advantages will disseminate in the future. According to him earth and straw are not popular materials yet because of the lack of knowledge. According to him, building with earth and straw incorporates low construction costs because of the price of the materials but also lower operational costs thanks to their properties. He concludes: “This information must be spread so people will appreciate the healthy indoor environment that alternative natural materials have to offer”.


Fig.25 Katakis Michalis' light clay home built in 2013 (source: Piliko team)

**Apostolis Mousourakis** (fig.26) is an architect and founder of PILIKO team. The primal concern as an architect is to offer to his clients a" healthy indoor environment to live happily" but also, he feels he ought to respect the natural environment. The most appealing characteristic of natural building is the low occupational cost while achieving a better thermal environment naturally. He also believes that construction costs are lower than conventional building. He would not find any special difficulties for realizing his projects, although it would be necessary to mention that they were mainly experimental educational activities with adobe, rammed earth, light clay and natural plasters.

**Christina Charamountani**, architect, was asked about the cost of such constructions she said: "In Greece, although natural materials are found in traditional architecture, there is not the know-how for building new with strawbales or earth. A very good research has to be conducted in all fields beforehand, which increases the cost and time of implementation. Natural building somewhere with expertise and appropriate infrastructure would be cheaper. However, we can always hope that this is the future here since the increase in demand would lower the cost." She added that the cost is also related with the method used. She adds that natural buildings have plenty of possibilities but also many limitations (ps. concerning the loads of the building which do not permit multilevel structures).

**Claire Oiry**, architect, used vernacular, traditional materials like earth and straw for renovating a stone building with the purpose to disseminate their value to the people of the area. This project had a social dimension since it engaged many volunteers and it had educational purposes. She mentions that working with earth and straw requires more people or more working hours on site than conventional materials e.g.cement and therefore it is normally more expensive. Plus the fact that there is not experience in the field means that some training is anticipated, too. This undoubtedly rises the costs if it's a professional job for clients. There is an alternative but common process, to make it self-build with the help of volunteers. This would lower the cost but the question is…is this for everyone?

Fig.28

Fig.29

Fig.28 Claire Oiry during renovation with natural materials in Gavdos (source: Claire Oiry)

Fig.29 Renovating with the help of the community in Gavdos (source: Claire Oiry)

Fig.26 Renovation with natural materials in Gavdos, Crete by Claire Oiry (source: Claire Oiry)

## Summary

The 11 structured interviews gave the context of the situation for natural buildings with earth and straw in Crete. The participants expressed their views on the benefits and the drawbacks of these materials and how they estimate the future in Crete. In general, the majority of the people had positive attitude towards natural building. The major assets of natural buildings could be consciousness for the environmental degradation, the priority to live in a healthier indoor environment, self-built as an act of cost efficiency and self-sufficiency. The negative points are mainly connected with the difficulties during their implementation and they will be analysed further in paragraph 6.2.1.

## 6.1.2.Evaluative Questionnaires

Apart from the interviews, the eleven participants were asked to fill in three evaluative questionnaires regarding natural building materials and their perception on green building. Everyone sent back their evaluations via e-mail, except from Yannis Kalaitzis, civil engineer who did not complete it. The questions were:

"What are the reasons for you to build with natural materials?"

"What are the most essential elements of a green building?"

"What are the features of earth and straw that you consider as the most important?"

The evaluation tables were sent by e-mail to the interviewees asking them to grade with points from **1** (not so important) to **5** (very important) the different options provided on the left side of the chart with an "x". The total score for each question is presented here and there is an analytic table of what every person voted in the appendix. The total is calculated in the last raw by multiplying the votes with the respective marks.

Table 1: "What are the reasons for you to build with natural materials?"

| Reasons to build with natural materials (straw/ clay) | | | | | | |
|---|---|---|---|---|---|---|
| **Reasons to build with natural materials** | 1 | 2 | 3 | 4 | 5 | Total Points |
| lower $CO_2$ emissions | 1 | 2 | 1 | 2 | 5 | 41 |
| thermal comfort | | | | 2 | 9 | 53 |
| healthy environment | | | 2 | 1 | 8 | 50 |
| aesthetics | 2 | | 2 | 4 | 3 | 39 |
| construction costs | 2 | 1 | 2 | 3 | 3 | 37 |
| occupational costs | | | 1 | 5 | 5 | 48 |
| innovation | 4 | 2 | 3 | 2 | | 25 |

Table 2: "What are the essential elements of a green building?"

| The most essential elements of a green building | | | | | | |
|---|---|---|---|---|---|---|
| **Essential green building elements** | 1 | 2 | 3 | 4 | 5 | Total Points |
| natural materials | | | 1 | | 10 | 53 |
| water management | | 2 | 2 | 2 | 5 | 43 |
| energy efficiency | | 1 | | 4 | 6 | 48 |
| healthy environment | 1 | | 1 | 2 | 7 | 47 |
| aesthetics | 3 | 1 | 3 | 2 | 2 | 32 |
| landscape architecture | | 1 | 3 | 4 | 3 | 42 |
| community empowerment | 1 | 4 | 2 | 2 | 2 | 33 |
| bioclimatic design | | | 1 | 2 | 8 | 51 |
| garbage management | | 1 | 3 | 3 | 4 | 43 |

Table 3: “What are the features of earth and straw that you consider as the most important?”

| Evaluation of earth and straw features | | | | | | |
|---|---|---|---|---|---|---|
| **Features of earth & straw** | 1 | 2 | 3 | 4 | 5 | Total Points |
| local materials | | 2 | 2 | 3 | 4 | 42 |
| natural materials | | | 2 | 3 | 6 | 48 |
| humidity response | 2 | 1 | | 3 | 5 | 41 |
| opportunity for self-built | 1 | 1 | 4 | 2 | 3 | 38 |
| Recyclable | 1 | 1 | 3 | 1 | 5 | 41 |

The results of the questionnaires could be regarded as an identical sample of opinions from people who are pertinent to ecological construction in Crete but within a wide frame of professions and qualities. The analysis that follows in paragraph 6.2.2 is an intention to understand better the findings.

## 6.2.Analysis of the data

### 6.2.1.Discussion over the Interviews

The reasons for impediment of natural building houses in Crete is defined by the interviewing of key local people. The engineers were more reserved for the future of alternative natural building materials. For them, straw and clay will be in the margins of the construction market as the majority of the people would never consider it as a primary housing solution. The static engineers are responsible for the safety of the structures so they are less open to take risks, especially in a seismogenic area like Crete. Traditionally, they represent the conservative part of the construction site. It seems that earth and straw are not perceived as important as conventional concrete, even if the safety of the structure is guaranteed against earthquakes by an approved load bearing timber skeleton.

On the other hand, it is remarkable that the people who have already built or lived in natural buildings of straw and earth etc., say they would re-live/ re-build again in the same environment despite the difficulties. They note several benefits like minor environmental impact, thermal comfort and healthy environment. Although, there is not professional experience, there are willing volunteers who want to learn by practising. This has already occurred for the cases of Choraitis, Ritsakis and Diamantaki who had people helping voluntarily. It could be claimed that natural building entails community support and encourages social bonds through mutual help and exchange.

The emerging issues for the restraints of using earth and straw are summarised and coded with capital letters:

A. Skills Gap is mentioned by 6 people

B. Legislation Limits is mentioned by two people 3

C. Cost Implications was mentioned by 3

D. Social Acceptance was mentioned by 2

E. Straw and timber was mentioned by 2

<u>Analysis of emerging issues</u>

A) SKILLS GAP. The interviews revealed that there is a serious lack in experienced people to work with alternative building materials in Crete. This broad Skills Gap signifies there are not enough trained builders, technicians or engineers/architects to undertake natural building or just to promote this kind of projects in the market. This lack is mainly mentioned by architects of the field. As it is expectable, the self-builders were not very concerned about it. Nevertheless, even with self-built projects, there must be a technical supervisor who is aware of the subject and leads the process. It will take time and money to learn and acquire experience in the field but it should be considered an investment for the future.

B) LEGISLATION LIMITS. The regulation for energy efficiency in buildings “KENAK”, which does not include U or λ co-efficient for strawbale or earth walls. The procedure for identifying them is costly and time consuming and includes sending a sample to the national laboratory in Athens. Also, another essential limitation is that regulations allow only post and beam natural constructions excluding load bearing approach. Although it costs more, both for materials and labor, it offers more reliability and safety against earthquakes according to the engineers’ opinion.

C) COST IMPLICATIONS. At the moment there is not an economical advantage in the market even if earth and straw can be found cheaply. This is mainly due to the fact that it is an innovative, uncommon technique but also it has an artisanal handcrafted character. Therefore, it requires long hours of manual work. At the moment, the only solution for realistically lowering prices is to go through the self-build construction path along with the help of volunteers, family etc. This would lower the costs significantly as reported by self-builders like Christos, Michalis, Giorgos and Axel. However, author’s assumption is that self-build approach is not a very common option up to now and it may need some time to be embraced by the majority.

D) SOCIAL ACCEPTANCE. The deterioration of poorly designed and maintained natural houses (earth, straw) of the past results in depreciation of these materials in the eyes of the public. There is lack of “social acceptance” for natural buildings as they are considered unsafe, temporary or unstable. There is also the idea that this kind of buildings are not for the majority, they are considered appropriate for people with alternative lifestyle, those who like rural life or just for those who want to be different. This concern was mainly expressed by the structural engineers.

E) LOCALITY OF THE RESOURCES. Strawbale building is an ecological, sustainable practice to use the bales instead of wasting them. However in Crete, there are not enough cereal crops to satisfy a wide demand for natural building. The same applies to timber. Following the rule of vernacular architecture that “we build with what we have”, in Crete people would use mostly stone. Cereal cultivation is not favored by the small tillage and the extended dry periods.

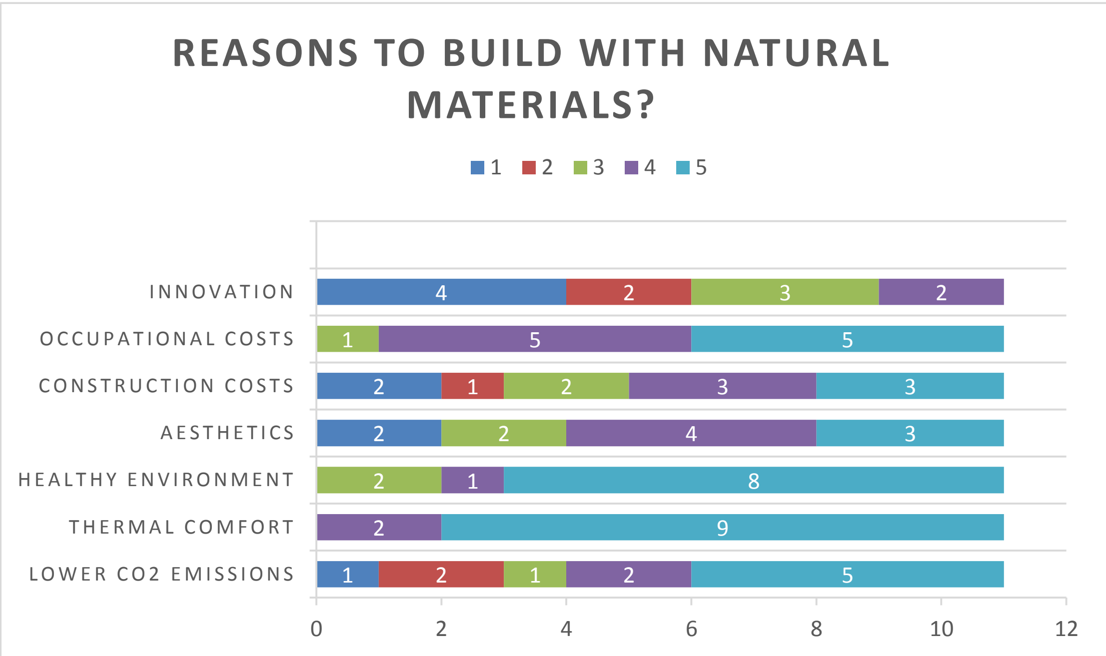
Good quality bales for construction can be purchased from the north of Greece but this results in more expensive construction and also more embodied carbon due to transportation.

### 6.2.2. Results of the Questionnaires

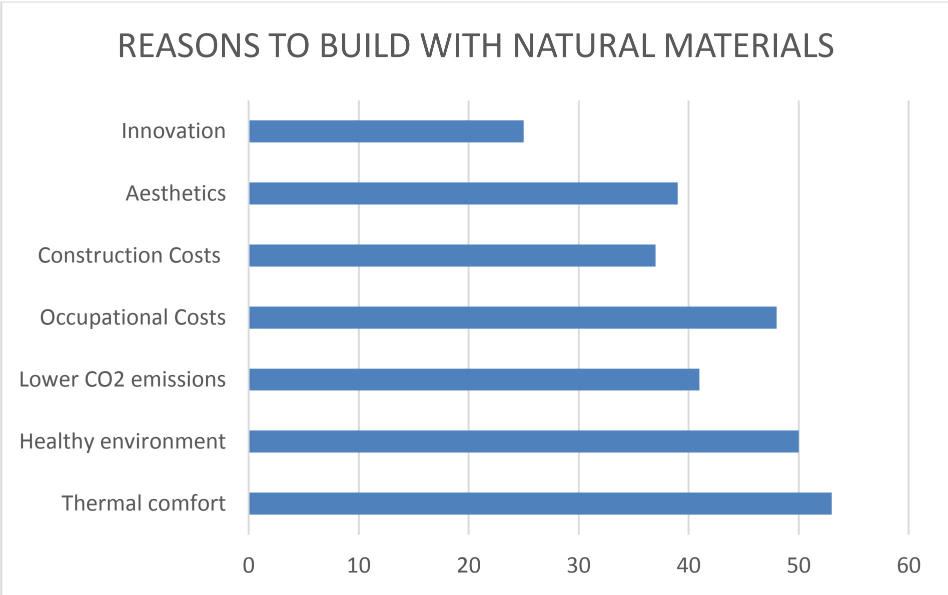
The results of each of the three tables are demonstrated with two graphic representations: the first showing the actual votes and the second one showing the total evaluation marks (1 to 5 is multiplied with the corresponding votes, for example when there are 11 votes of 5, it's 11*5=55). The elements with the maximum points are considered to be the most important. Interestingly, some features concentrate very diverse marks.

The participants evaluated the reasons to build with natural materials and their responses are concentrated in Table 1. The results are presented in Graph.1 which shows that "thermal comfort" is clearly the most important priority with "healthy indoor environment" (related with airborne toxins, humidity absorption etc) following very close. The third priority is the "occupational costs" which stand for occupants' expenses, e.g. electricity bills.

Graph.1 "Reasons to build with natural materials" Graphic representation for votes (source: author)



Graph.2 "Reasons to build with natural materials" Graphic Representation for points (source: author)




Furthermore, the reduction of "$CO_2$ emissions" shows environmental consciousness and awareness of the impact of buildings in climate change. This was mainly the vote of architects and engineers whereas more practically orientated participants didn't consider it as a priority (C. Choraitis, M. Katakis). Most (self-) builders choose to invest in natural materials with first priority their need or preference to live in a healthy, comfortable, low cost home. It makes sense as they dedicate personal time and they want it to comply with their requisites. Mining deeper the data, Katakis, occupant and owner of light clay, voted "1" for $CO_2$ emissions and innovation and "5" for aesthetics whereas Ritsakis, occupant-owner-builder of light clay, exceptionally gave "4" to lower emissions and innovation and "3" for aesthetics. The diversity shows that personal motivations for building and living in a natural home are very different among different occupants.

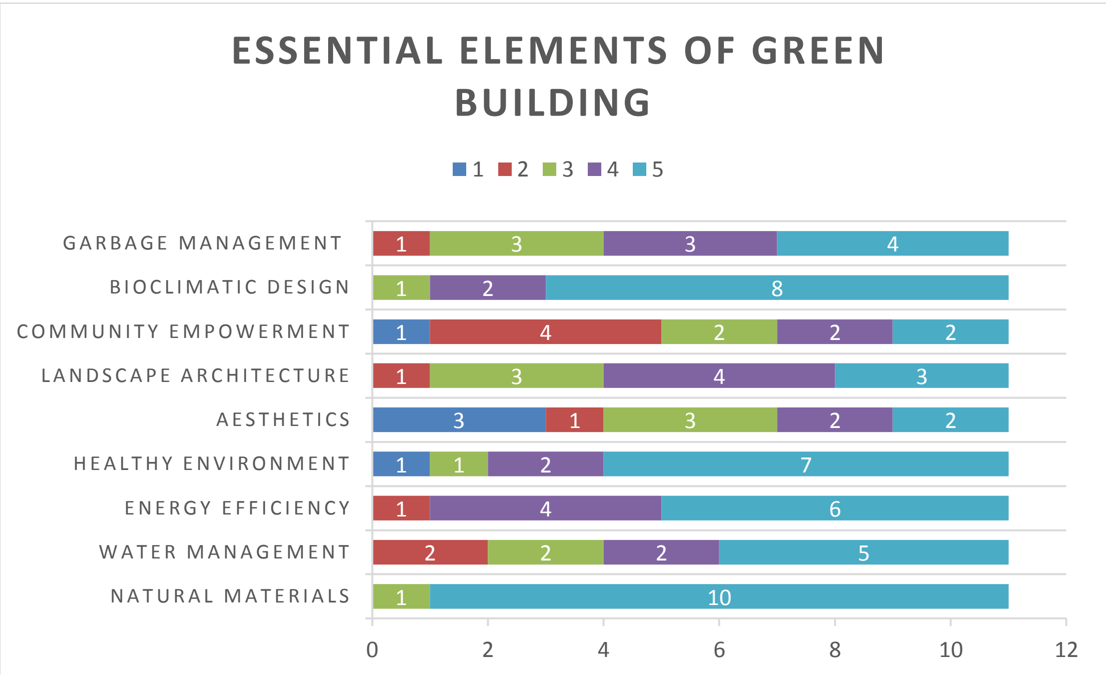
Aesthetics is highly appreciated among those who have built and live already in natural homes (Katakis, Choraitis, Ritsakis, Trilhaase) but also architects (Diamantaki, Charamoutani, Choraitis) whereas contractors, builders and more ecologically orientated persons (Gruber, Oiry) ignore aesthetics and stress the need for the lower carbon emissions from building. Last but not least, "innovation" seems to be a minor priority. The people who gave it 3 or 4 marks are professionals (e.g. Tasos Andreadakis, Herber Gruber, Ap. Mousourakis) and they may have ambitions for natural building as an opportunity for work in the future.

"Construction costs" are the last elements in the hierarchy as can be assumed from Graph.2. This factors was not so preferred by the architects. Probably, they consider that due to the skills gap and lack of expertise, there will be consequently more workload and therefore higher prices. Also, they may see it from the perspective of the professional who has more awareness of the detail and not the owner/client. On the other hand, self-builders, constructors and owners think that it is cheaper maybe because they consider no working expenses and low-price (or free) natural resources.

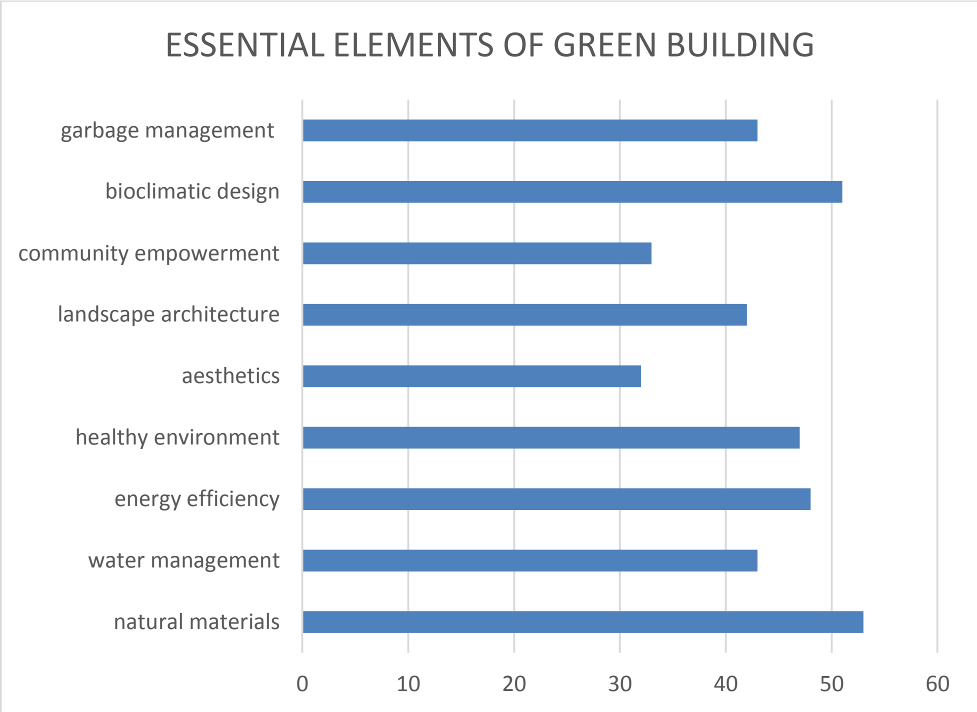
The essential elements of green building are evaluated in the second questionnaire (Table 2). The use of "natural materials" and the implementation of "Bioclimatic design" are graded as the most important aspects of an eco-home. "Energy efficiency" follows but it is closely related with bioclimatic design anyway, as already shown in page 35, Fig.3 since solar energy is used for saving energy expenses. However energy efficiency embraces more parameters like insulation, renewable energy etc. Kakavelaki Th., structural engineer, voted "2" for energy efficiency maybe considering the environmental impacts of heavy industrial materials or embodied energy to achieve it.

Besides, next important element is "healthy environment" with an interesting "1" mark by C. Choraitis who probably thinks that *green* should not only define the occupants well-being but mainly the building's general environmental impact. Interestingly, "water management" is not one of the priorities, despite the fact that Crete is affected seriously by climate change with reduced precipitation and prolonged droughts (Koutroulis A., 2013). Then is "landscape architecture" with a lot of points in the middle ("3", "4") and enforced mainly by architects while less interesting for builders and contractors. This could be expected since architects are trained to have a more holistic view of a building project. Community empowerment shows interesting sparsity in the opinions but again this is easily defined by the different qualities of the participants. The civil engineers and surprisingly the owners/occupants believe less in this part of green building whereas the architects proved to have a more social vision about it. Aesthetics seems to be a little bit indifferent for evaluating a building on its greenness. However, Kakavelaki Th., engineer and Diamantaki A. gave "5" pointing it as a very important element

Graph.3 "Essential elements of Green Building" Graphic representation for votes (source: author)



Graph.4 “Essential elements of Green Building” Graphic Representation for points (source: author)

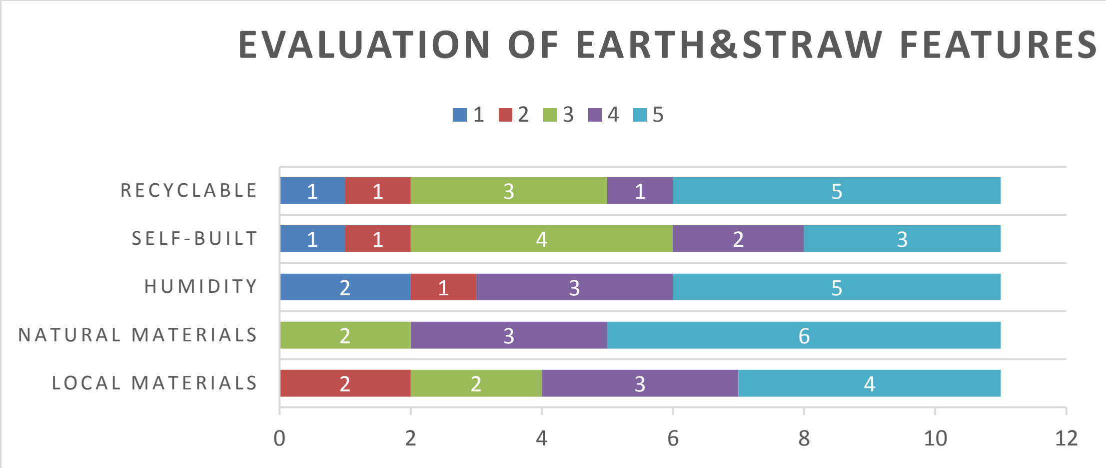



Regarding the evaluation of earth and straw features (table 3), the results are presented graphically in Graphs 5 and 6. The fact that earth and straw are “natural” and “local” materials is highly appreciated. The locality of these materials is not so important for the engineer Kakavelaki Th. and owner Katakis Michael, who, judging from their answers, are generally more interested in the performance of the buildings and the occupants’ satisfaction.

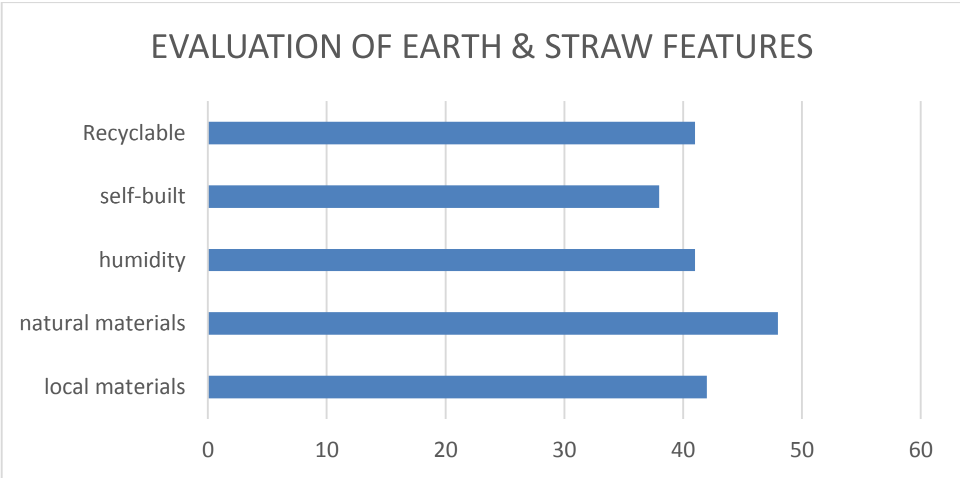
The opportunity for “self-build” homes even if not generally highly evaluated, it is highly rated by the self-builders (Ritsakis G., Choraitis C.) and contractors (Herbert Gruber, Axel Trilhaase) and also Claire Oiry, an architect who has been involved in social projects. Notably, the three of the five higher marks were given by people who are from countries of wealthier economies (Germany, Austria and France) according to global financial indicators (source: www.principalglobalindicators.org) but at the moment they have chosen Greece to stay and work, despite the big financial crisis (Hatzis A., 2015). Maybe this could be an indication that natural building materials are a preference for people who want to live self-sufficiently, to be creative and to help and be helped within the community.

The behavior of these materials to humidity rates has brought some controversy. It is interesting that Cretan people have voted high, especially all the owners-occupants-builders who have experience with living in specific houses. The “1” votes come from Herbert Gruber (Austria) and Claire Oiry (North France) who possibly were evaluating considering a climate with more rain and definitely not so long dry periods like the Cretan climate.

Graph.5 "What are the features of earth and straw that you consider as the most important?" Graphic representation for votes (source: author)




Graph.6 "What are the features of earth and straw that you consider as the most important?" Graphic Representation for points (source: author)




## 6.2.3. Summary

To sum up, there are two sides: the "environmentally conscious" are those who evaluate high the $CO_2$ reduction, thermal comfort and innovation whereas others value more the healthy indoor environment and construction costs and see natural materials as a highly appreciated part of the beauty of a building project. However, the top-3 priorities are qualities related with the personal life and well-being of the occupants. Natural materials and energy conservation through bioclimatic design are the benchmarks of green building according to the participants. The straw and earth in buildings are mainly appreciated for being natural, local and recyclable. However, the diversity of answers allows broad margins of interpretation.

## Section B:

# 7.The case studies

The second part of the research includes two case studies: a strawbale timber framed building and a light clay building.

1. Paleokastro: strawbale
2. Archanes: light clay

They are both contemporary examples of natural buildings in Crete and therefore a kind of pioneers. Their occupants are also owners and self-builders and they have seen all parts of rising an alternative natural home: from conception to living in it.

## 7.1. Paleokastro: The strawbale project

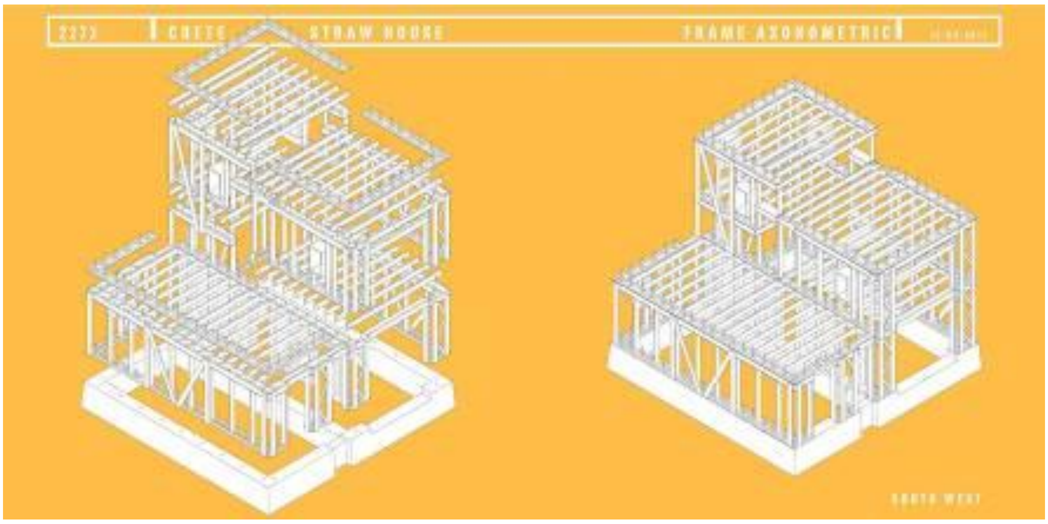



Fig. 31 Strawbale building in Paleokastro: Ballon Frame Skeleton (source: Ch.Choraitis)

In the summer of 2011, architect Christos Choraitis begun the self-built construction of his own strawbale building in Paleokastro, a seaside village 15 km west of Heraklion. The main motivation behind this choice was consciousness about environmental degradation. His ideology of “lightly step on the earth” led him to design a place of holistic sustainable living: a strawbale building with its own energy generator, organic garden, water collector and sewage treatment system. As he mentioned, strawbale construction was not a single factor to claim his position on the existing ecological crisis.

## 7.1.2. The building construction

The construction is a timber framed strawbale building in two floors while the total surface of the building is 126 m2 and total height is 6 meters. It incorporates wooden floors and wooden roofs, all insulated with 10 cm pumice stone. There is a green roof while the top roof holds the installed photovoltaics. The structural design of the construction is “balloon frame”, which is a way to build faster, cheaper and without necessarily the skills of an expert woodworker (Sidler S., 2012). Balloon frame means lighter wood beams and nailed connections, smaller but denser posts. Additionally, Toby McLean, structural engineer (TALL engineers) suggested the placing of two beams in *diagonal bracing* to connect large surfaces and hold the structure together in any extreme load from winds or earthquake.

Following the ecological approach, the foundations were laid without concrete but solely with the use hydraulic lime as a binder. Compacted gravel in a trench 1,00 m. * 0,70 m. covered with geotextile , hydraulic lime as a ring beam all around the trench 0,40m x 0,70m and stone wall 0.60 m*0,60 m on the top which raises the whole structure mainly to protect it from the silt soil due to the nearby river.

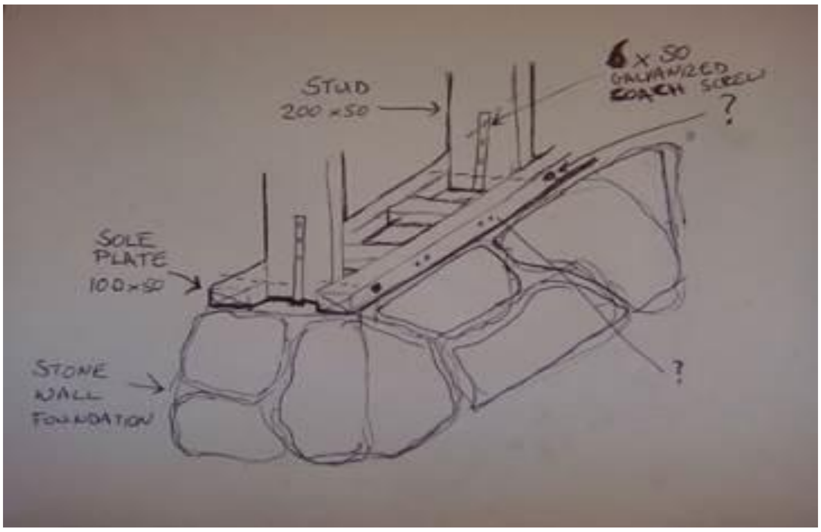



Fig.32 Sketch of the foundations by Ch.Choraitis

Fig.33 The trench made with local stone and geotextile. Photo by Ch.Choraitis

Fig.34 Christos Choraitis fixing the Ballon Frame Construction (source: C.Choraitis)

When Christos was asked why he preferred the strawbale technique in comparison to the light-clay, he answered that it is much faster but also easier and safer for beginners in self-construction. The strawbales were pinched onto sticks that were vertically nailed onto the timber frame. When the bales reached the height of the wall, they were tightened with a strap and the free space on the top was filled with more straw. The diagonal and vertical beams were often an obstacle and strawbales required modification (shortening or trimming), which made the process to last longer. According to B.Jones (2011), the load bearing walls are more suitable to the strawbale building technique because the walls rise much faster and the roof top only comes to compress the bales downwards (B. Jones, 2011). On the other hand, a strawbale building without a load bearing skeleton would be impossible to realize in Greece because of the planning regulations according to Eurocode 8 for earthquake resistance. So even if the building process is a bit harder, the timber frame technique is the one to choose in Greece.

Fig. 35&36 Straw was used to insulate the ceiling of ground floor (source: C.Choraitis)

Fig.37&38 Floor and Roof were insulated with 10 cm pumice stone layer (source: C.Choraitis)

Plastering with natural materials is highly recommended because of their hygroscopic nature they allow breathing and any traces of humidity would eventually evaporate. In Paleokastro, three distinct layers of natural plasters were applied with varying proportions of clay, lime and sand and as we move up to the final finish, lime proportion is rising until the last layer that was just Hydraulic Lime. There was also an extra “key coat” in the beginning which is a thin layer of clay mixture with water used to brush the surface of the bale and help the next layer of plaster to stick on the wall. The “recipe” for the mixtures was decided after experimenting with the application of different proportions and origins of lime, clay and straw. The best mix was the one that appeared with small and short cracks so that the next layer would have good absorption and also if the plaster would crack along the line of the wood.

Fig.39 Plastering included many trials of different mixes (source: C.Choraitis)

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Fig. 40 Rounding the edges with plastic net frame (source: author)
Fig.41 Second layer of plaster. (source: author)
Fig.42 Cracks along the wood is a good sign. (source: author)
Fig.43 Plastering with earth and straw (source: author)

| Element | Description (from external to internal surface) | U-value |
|---|---|---|
| Roof | Grass roof; filter medium; root protection foil; formaldehyde free chip-board; timber beams; battens; airtight polyethylene foil; wood-chip wallpaper; cavity (445 mm) fully filled with straw. | 0.1 W/(m²K) |
| External wall | Strawbale density; 50 mm sand lime plastering; 10 mm lime plaster covering all internal surfaces; | 0.14 W/(m²K) |
| Windows | Double low-e glazing type Solaire. Aluminium window frames with additional PU-foam insulation | 0.7 W/(m²K) |

Fig. 44 Constructive details

### 7.1.3. Materials

Christos travelled around Greece in search of the perfect bales for his building construction. He finally chose bales from a small scale farm in Thiva (Mainland Greece), where the density and dimensions were checked manually every tenth bale. The initial calculations indicated 400 bales but to be on the safe side, Christos ordered 650 bales. They were shipped to Crete with a truck running a distance of 100 km on the road and 342 in a cargo ship. Most of the extra bales were finally used in the construction because the rain destroyed big part of the walls. Nevertheless, a lot of the extra straw ended up covering the surface of the vegetable garden (mulching). The excess straw that was bought but not used for its primary purpose involved excess $CO_2$ emissions mainly from its transportation and it rises the EE of the house. However, the fact that it was used in the garden as compost material and not wasted, means actually carbon sequestration and "justifies" partly the extra purchasing.

The clay and sand are materials which are very abundant in the area of Heraklion so it was an easy task to gather these materials from close by very cheaply or even for free. The wood was bought locally but it was imported oak.

### 7.1.4. Environmental design

Paleokastro project is designed to be self-sufficient. At the moment, there is not any external energy input apart from the occurring energy streams of natural resources: the already installed PV and in the future a small wind turbine.

"Everything is a challenge towards self-reliance, independence and community development through knowledge" (Christos Choraitis, 2014)

The building has been designed with bioclimatic principles so as to use wisely the solar energy. Large facades have south-east orientation for the solar gains during winter, while a large overhang protects the interior from overheating when the sun is higher during the summer. The use of high performance glazing was a way to enhance solar gains. Christos used *"solair"* glass for his openings, a hi-tech product which allows sunlight to pass through a window or façade while reflecting away a large degree of the sun's radiative heat. The indoor space stays bright and much cooler than it would be if normal glass was used. The double glazing type "Solaire" has a void of 2.30 cm in between the glass sheets filled with air for extra insulation whereas the inside of the glazing is a solar filter that reflects glare. Moreover, the building has turned its back to the north cold breezes by incorporating only the necessary small openings in the north which allow air flow through the house for naturally acquired fresh air circulation.

On the other hand, for keeping a wide open space, the design did not foresee any entrance hall. According to Pelsmaker S.(2012), the lobbies are an essential part of a low energy house because it protects from direct air and draughts from the external environment. The Paleokastro building does not have this, so with every opening of the door, the external air temperature easily affects the interior. Also for architectural reasons, Christos did not proceed to put outside shutters or indoor covers (curtains, blinds etc) at the openings. However, such elements protect significantly the interior from excessive heat during intense solar irradiation in the summer but also help keeping steady indoor temperatures during winter nights (Visilia Anna Maria, 2008).

For personal arrangement of the thermal comfort if needed there is a ceiling fan in the living room, a stove mass heater bench in the kitchen and a wood burning stove in the center of the living room where an aluminum chimney transfers the heat wave at the first and second floor.

45. 

46. 

Fig. 45 The PV panels on the top roof

Fig. 46 The stage before the green roof.

47  48 

49  50 

Fig.47 South facing glazing for solar energy (source: author)
Fig.48 South facing glazing for solar energy (source: author)
Fig.49  Small North openings allow air circulation (source: author)
Fig.50 The building has turned its back at the north and the street noise (source: author)

## 7.1.5. Social Sustainability

Christos: "A self-built strawbale building is hard work, but it is possible to get help by people who want to learn and participate voluntarily. Of course, they will need induction or supervising but it is a fruitful procedure that both sides give and take a lot of things" Christos mentioned that strong social bonds and inspirational encounters were the side effects of the workshops that were conducted in his place. The strawbale walls were done with volunteers under the induction of Barbara Jones, the founding member and director of Amazonails (now Straw works). During a 10-day workshop, at least 20-25 people worked together to fill up the walls with straw. A bit later, two more workshops on plastering were to follow with participants from all over Greece. Moreover, friends and relatives visited the site to help, too. After this event, people in Crete learnt about the technique and it could be possible in the future to desire their own strawbale house.

A workshop on tadelakt (a natural plastering technique for waterproofing surfaces) took place in Paleokastro accepting international participants. Notably, this last workshop brought about another seminar just on the other side of the street. Herbert Gruber, the founder of the Austrian Strawbale Network, participated in this workshop only to discover another project 10 meters away. The abandoned hotel "Gabriella's Garden" at Christos' neighborhood was the subject of renovation with natural materials: insulation with straw and natural plastering by a group of volunteers. The goal is to become later an open space for creation, workshops and gatherings. Also, Annicka who had participated in the first seminar of wall infill decided to build her own strawbale home which is on issuing the building permission at the moment.

Fig. 51-54 Workshops were conducted during different phases of the building procedure (source: C.Choraitis)

All in all, the building project of Paleokastro has been a busy place for working and having fun, exchanging knowledge and acquiring new skills. The bonds created through it are valuable community cells of today's social dynamics under a fragile economy.


Fig.55 The first workshop brought a second one at Gabriella's garden, Paleokastro (source: Herbert Gruber)

## 7.1.6. Temperatures and Relative Humidity

### 7.1.6.1. Measurement results

Digital thermometers were installed in order to examine whether the building acts as a good thermal insulator and provides a comfortable indoor environment. One was placed inside the building and the other outside. Christos, since he lives there, was asked to mark the temperatures and relative humidity twice daily for ten days: once in the morning at 8.00a.m., once in the afternoon at 8.00 p.m. The aim of the measurements was to examine the variation of the indoor and outdoor conditions. The noted facts are presented in tables' fig.33&33 and their related graphics are in fig.22&22:

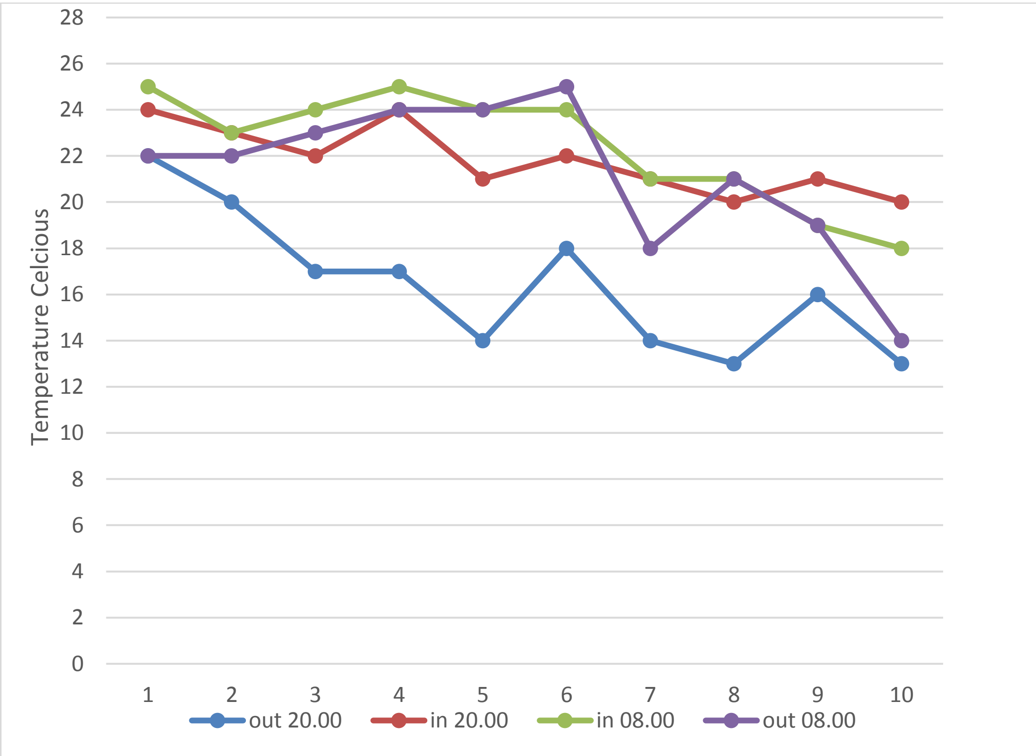

Fig.56 Digital Thermometers were installed inside and outside of the strawbale building (source:web)

Table 4. The temperature measurements during 10 days (source: author)

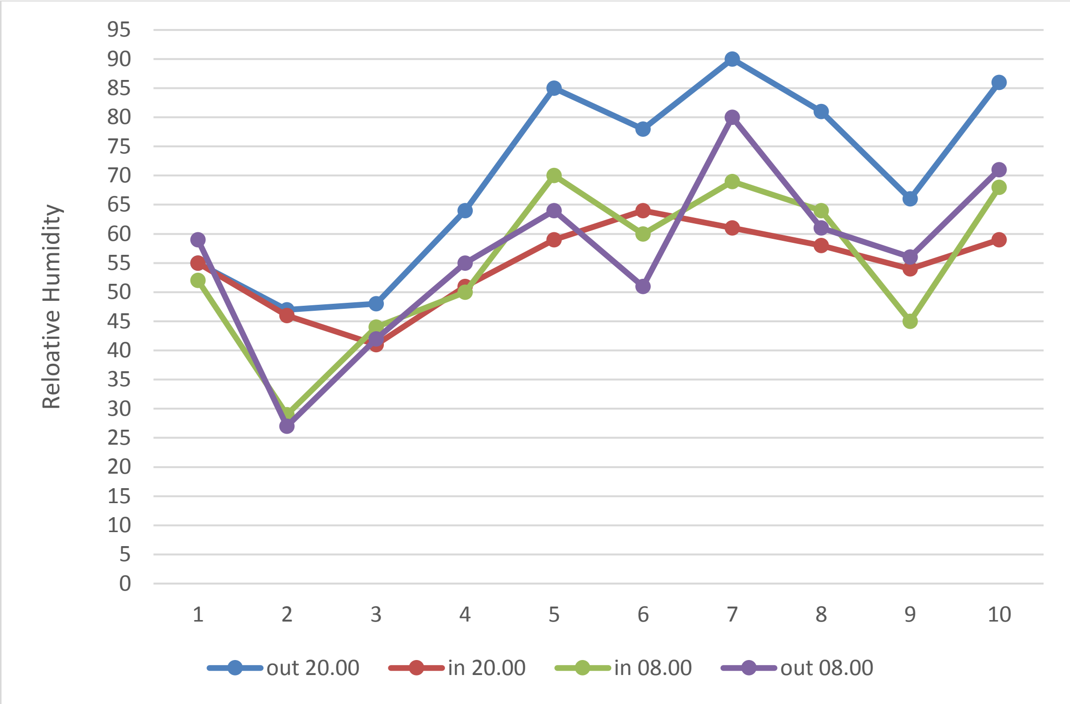
| TEMPERATURES | DAYS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| morning outside | 22 | 22 | 23 | 24 | 24 | 25 | 14 | 18 | 18 | 21 |
| morning inside | 25 | 23 | 24 | 25 | 24 | 24 | 21 | 22 | 21 | 21 |
| Evening outside | 22 | 20 | 17 | 17 | 14 | 18 | 24 | 14 | 13 | 16 |
| Evening inside | 24 | 23 | 22 | 24 | 21 | 22 | 24 | 21 | 20 | 21 |

Table 5. The relative humidity measurements during 10 days (source: author)

| RELATIVE HUMIDITY | DAYS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 08.00 outside | 59 | 27 | 42 | 55 | 85 | 78 | 80 | 61 | 80 | 71 |
| 08.00 inside | 52 | 29 | 44 | 50 | 59 | 64 | 69 | 64 | 65 | 60 |
| 20.00 outside | 55 | 47 | 48 | 64 | 64 | 90 | 81 | 66 | 66 | 86 |
| 20.00 inside | 55 | 46 | 41 | 51 | 70 | 61 | 58 | 54 | 54 | 59 |




Graph.7. Graphic representation of temperature measurements during the last 10 days of May (source: author)




Graph.8. Graphic representation of relative humidity measurements during the last 10 days of May (source: author)

### 7.1.6.2. Discussion of the findings

In order to have satisfying thermal comfort indoors and also to avoid mould growth the relative humidity is acceptable between 40 to 70 % and ideal temperatures are 20-24 in winter and 22-27 in the summer (Pelsmaker S., 2012). As one can see, the strawbale walls insulate sufficiently and fulfill the indications given by the environmental design guide of Pelsmaker (2012).

Following the green and red lines for indoor temperatures in graph.7, it can be seen that the building interior had maintained relative stability of inddor thermal comfort at 08.00 and 20.00. The maximum difference was 2-3 degrees on days that probably the door was open. For comparison, the blue and purple lines that indicate outside temperatures, have much greater variances for morning and evening temperatures.

Now comparing the inside with the outside, the pair of lines: red-blue (for evenings) and purple-green (for mornings) mirror each other: they are steadily less for 2-3 degrees in the mornings while the gap grows in the evening with even 7 degrees difference. Findings show clearly that strawbale walls insulate very well and the house offers steady thermal comfort inside. However with a prerequisite: the occupants' care for closing the doors and windows, especially during days with uncomfortable conditions outside. It seems that irrespectively of the building envelope, the behavior of the occupants should not be ignored for keeping satisfactory thermal comfort inside with low energy expenses (Pelsmaker S., 2012)

Christos said he was often leaving the door open because he would work in the garden and he had to cross over the door all the time. As a consequence the frequency of opening doors and the duration of leaving them wide open has affected the results.

For example the 1st day in the evening and the 5th and 6th day in the morning the fluctuation of the measurements are not as usual. It is noticeable that something unscheduled happened and affected the flow of results with a great tendency to have similar or same results. Christos said he would leave the doors open on those specific days. Also, Christos was taking measurements but maybe not the same time every day as it was during his busy daily routine. Nevertheless, this would not affect seriously the overall results

The results of the measurements were generally satisfying. It seems that the strawbale walls are effectively weatherproofing the interior thanks to their insulation properties. A factor that appears to be important is the impacts of the occupants' behavior in maintaining a good temperature inside by actively participating in isolation of the space from the external conditions (closing doors, curtains, shutters etc)

## 7.7. Practical Restraints

The infill with strawbales started in October, when it is likely to rain. Therefore the outside surfaces had to be covered as soon as possible so as to protect the bales from water. Humidity is a serious cause of rot if it succeeds to penetrate more than 20% of the bale (Goodhew S., 2003). During the wall filling, there was indeed heavy rain which lasted during 4-5 days and even if there was protection cover, many bales were wasted. Also, later in winter a whole wall had to be replaced because the humidity had been deep inside the bales. Also, Christos mentioned some problems that could come along with strawbales if plastering will not happen soon: mice were present in the place, creating holes in the bales. He had to evacuate them and fill the gaps before the plastering. But all these are typical of building with natural materials according to Christos: "You have to be ready to face these things when using natural materials. I was not disappointed, I was ready for that" he says.

He also found difficulties with plaster which often cracked and he had to demolish the parts that would not adhere to the bales. Since he used bulk natural materials which he found for free in the nature (mountain sand, clay) he had to experiment a lot and modify the original recipes which is normal when the exact consistency is not known. Also, he had to fill too many gaps in the walls with a mix of clay and loose straw because the bales would not absolutely fit the timber frame. That was a lot of labor, long hours and all in all a disheartening job. But with this way, the desirable thermal mass of clay was adduced later as a thick 3-5cm plaster on the inside surface of the strawbale walls.

Greek legislation does not include regulations for the use of strawbales as a building material. Of course this does not mean they do not allow it since wall infill has not material specifications for the building department. The structural skeleton which is obligatory is responsible for the stability and anti-earthquake properties. However, KENAK -the Greek energy efficiency regulation- requires characteristics like U and λ values. To overcome the lack of certification was maybe the biggest difficulty concerning regulations. Christos unfold his way of thinking about doing things "We don't have always to go with the rules. Regulations can change by successful experiments"

Fig.62 The south face of the building has views to the garden (source: Herbert Gruber)

## 7.2 Archanes: The Light - Clay Project

### 7.2.1. The project

The building is lying in the suburbs of Archanes, on the valley along the foothills of mountain Youchtas, southern of Heraklion. Giorgos Ritsakis is the owner, self-builder and manager of the project who immersed himself in creating an ecological low-energy dwelling with wise use of local natural materials.

Fig.63 Archanes project: light clay self-built dwelling (source: author)

Fig.64 Archanes project: light clay self-built dwelling (source: author)

### 7.2.2. The building construction

The construction started in 2011 with a post and beam skeleton with light clay infill. “Straw is a highly isolative material, ideal for the climate of Crete” he says. After long research, he finally chose “light clay” as the most appropriate technique. It’s a mixture of loose straw soaked with clay-water mixture which is placed in between two thin wood boards and being pressed downwards and let dry only to reveal part of the wall a bit later. He did not select the strawbale technique because he was not sure about their behavior in a climatic environment with intense humidity and heat, like this in Archanes. He considered that it could incorporate a serious risk of rot.

Structurally, it consists of a timber frame to support the loads of the construction and walls are made with straw-clay infill and plastered with a natural mixture of sand-clay-straw. They also added donkey manure in the mix from the nearby horse riding center for the outer shell plastering.

An exceptional characteristic of the house is that it incorporates two techniques: apart from “light clay” for the most surface of the envelope, the southern external wall was made up of adobe bricks that were handmade on site (Fig.70,71). The reason is that thermal mass is particularly beneficial when facing south. It absorbs the solar irradiation during the daytime keeping the interior cool and release it slowly during the night when the temperature drops. “This bioclimatic characteristic maximizes the sun’s benefits for the occupants” Giorgos says.

In order to avoid water penetration, the outer shell of the envelope was finished with linseed oil to waterproof. This blocked the breathing of the walls and as a result, the water which had penetrated the envelope would not find its way out. These are the remarkable stains on the outer envelope of the building (fig.63). Giorgos considered the use of linseed oil for the outer shell of the building as a mistake and he added: “The pores of the envelope should remain open by using appropriate plaster i.e. lime. The walls have to breathe so that any existing humidity can eventually find the way out of the bale”.

### 7.2.3. Materials

Fig.65 The south façade of the Archanes Project (source: G.Ritsakis)

The straw was bought from Crete even if the price was a bit raised in comparison with straw from mainland Greece. Even if the straw is used in loose form for the mix, it should be transported in the form of bales to the construction site to minimize work and volume in transport. On the other hand, it was sourced very close to the building site and like that transportation costs have minimized. Also, the clay and the soil used for the plasters were collected from the environs of the village. The donkey poo was collected from the horse riding center in Heraklion and it was added mainly for cohesion to the mixture. The energy expenditure for clay is only the transport from mine to the construction site.

The roof was insulated with mineral wool material, specifically KNAUF ECOSE which had a good price/quality ratio instead of the very expensive pure sheep's wool. It is a formaldehyde free, environmentally friendly material with low embodied energy. The foundations contain cement as a binder, under the instructions of the engineer. Although the house was built on a massive rock, which means extra stability for the structure, the structural engineer insisted on using cement between the rocks.

66.  67. 

Fig.66 Timber skeleton with horizontal shafts to hold the infill material (source: G.Ritsakis)

Fig.67 G.Ritsakis used Ecological insulation material "Ecose" which was sponsored by KNAUF (source: author)

The timber is originated from the mainland of Greece, near the town of Larissa. The low cost was the main incentive for buying it from there but in the end, the additional cost of transportation and also travelling north to do the research has raised the cost almost as would be to buy it from Crete. Of course the embodied energy of the material was significantly raised with that choice. It is much preferable though than buying it from abroad as most Greek contractors do nowadays. (Kakaras I., 2009). Besides, the timber frame was over the border for safety of constructions within a seismogenic zone. Crete is a place within a seismogenic zone (Sharedata map, WP 3.2) so all the statics are calculated under this consideration. The engineer's calculations were fine with less wood but he was afraid because of the new type of construction and he raised the wood dimensions (calculations were asking for 8*8 but the engineer decided for 10*10). Of course, in this case more raw material raised the cost as well as the embodied energy in the end.

Table 7. Material identity of the construction (source: author)

| **Material identity of the construction** | |
|---|---|
| Frame = | *Timber* |
| Walls = | *Clay+straw* |
| Plaster = | *Sand + Straw + Clay + Donkey Manure* |

Fig.69 The timber frame skeleton is based on stone foundations (source: G.Ritsakis)

### 7.2.4. Environmental design

The house is connected to the grid at the moment but the goal is to install solar panels which will provide the 100% of the necessary electrical power to the house. Giorgos believes that Crete gets enough amount of daily sunshine to sustain the necessities of a residence, especially during the extended summer months. As he says, he is not in favor of any form of combustion (burning) in the house to get energy from, even for cooking purposes (gas) or space-heating. As an exception, he would consider building a rocket stove massive heater since it is an economic wood burner and very efficient, too. Though the main idea for heating is incorporating infrared heating panels under the floor which will be using energy from the solar panels.

The field was ideal for the building orientation according to bioclimatic principles. It has large openings in the south-east and small windows in the north. The living room, kitchen and bedrooms have large south-east facades which allow winter's low-angle sun to get in and in the form of solar thermal energy to be stored in the floor mass. Double glazing is a major contributor of the passive cooling and passive heating of the space because it lets the sun in but it keeps out the fluctuation of the outdoor temperatures.

Although there are not overhangs on the top of the southern openings to protect from the summer sun, according to Giorgos Ritsakis, the indoor temperatures were more than pleasant during the summer even with 10-12 people living in the house. He did not like aesthetically the idea of overhangs outside the house so he just used indoor movable measures like curtains and shutters. However, he mentioned that he seriously thinks of putting overhangs for maximizing the thermal performance of the house for the next summer.

Fig.70 Adobe bricks were handmade on site (source: G.Ritsakis)

Fig.71 Adobe bricks in the making process (G. Ritsakis)

Waste management

Giorgos Ritsakis mentioned that the landfill waste from this building project was minimal since local materials (soil, sand and straw) have minimal packaging and almost whatever is left, it is natural and it can be recycled easily in the nature.

### 7.2.5. Social Sustainability

Soon after the beginning of the construction, people were available to volunteer and learn the process of building with earth and straw by helping the owner. They formed a group in 2012 and according to Giorgos Ritsakis: "Through workshops, publications and community events the team offers information, support and inspiration for natural, healthy buildings." After having set up the timber frame, a group of international volunteers came to help with the wall infill. "There was no requisite for experienced workers at this stage, we were all learning by doing. Even me, I was a beginner", Giorgos added. The straw and clay were mixed in a gasoline powered mixer to save time and then set on big plastic containers to distribute on the shaped wall containers.

Fig. 72 & 73 Volunteers helped during all phases of the building (source: G.Ritsakis)

It is a common belief that strawbale building will cost less than a conventional one. When Giorgos was asked about the price of the strawbale house he was clear that this is not true. If all the parts of the house are concluded normally in the price then the cost will be the same.

He would count for excavations, architect and supervisor for the building permission bureaucracy, electrician, plumber, openings, roof, insulation, plastering, painting, heating and cooling systems, kitchen, bathroom, landscape. For all these, the cost is the same no matter what type of construction one chooses. "The fact is that for filling your walls with earth and straw you need less money to buy them but then it is more labour intensive to build it and you need more working days. The idea was principally to gather your family and friends and do it altogether because it is not a complicated a job. It is the way for the construction to be cheaper" says Giorgos.

### 7.2.6. Practical Restraints

Natural organic materials like earth and straw are hard to classify with U values. The most complicated part of the case was to get the Energy Performance Certificate by KENAK regulation because it requires certified building products with λ so as to calculate U-values etc. The straw and clay walls could not be certified as usual because they were handmade from locally sourced materials. Notably, it was the first case in Greece that was asking certification for these materials. A sample from the wall had to travel as far as Athens only to identify its U-value. Finally the "Archanes project" has achieved an A, which is the highest achievable grade for its energy performance certificate (EPC).

According to the energy strategy of KENAK, there is a compulsory provision for air conditioning for all dwellings. Giorgos does not acknowledge this need and most probably he is not going to consent with this scheme. He already lives in the house for one year and the bioclimatic design and provision for ventilation as well as the isolative roof and walls is sufficient.

# 8. Conclusions

## 8.1. Synopsis of the findings

This study aims to explore the potentials of earth and straw as building materials in Crete with qualitative research methodology and two case studies. The use of online structured interviews with key personel coupled with the completion of evaluating questionnaires were the basic tools in not only defining the emerging social, legal and financial barriers but also the benefits of these materials in the Cretan context. Two contemporary natural building examples in Paleokastro and Archanes were analyzed with the help of interviews and data measurements. The conclusions of this research are presented below:

In modern day Crete, the use of straw and earth as building materials is very limited. There is a “skills gap” amongst building professionals is most likely a hinderance for wider applications of these materials. Builders, architects and engineers could be trained to be ready to take up natural building projects. In addition, there is lack of awareness from the intended market i.e. potential clients. It is a common misconception that earth and straw are materials of low value and people dismiss their good qualities due to the existing badly-preserved examples or simply because these materials are not industrially manufactured and often considered waste in the modern society. However, they have proven to contribute to a healthier, more comfortable building environment according to today’s occupants of natural buildings in Crete.

The construction costs clearly play an important role in Greece during the current economic climate. Opinions are divided on the issue of the expenditures as some reports say that natural dwellings are cheaper whereas others report that they are more expensive than conventional. The fact remains that constructing a building by employing a contractor and workers will not be cheap since it is not market competent yet. The builders should be trained competently and supervised appropriately with additional technical advice. Also, the labour is more time-consuming and intensive in comparison to concrete and steel. Building with strawbales will not be as cheap compared to those places with plenty of cereal crops. However, it will still be cheaper than conventional constructions in the case of self-constructed buildings.

Nevertheless, these materials allow possibilities for a self-building approach which according to the interviewees can lower the cost significantly. The labour is the most significant percentage of the expenditures since materials, especially earth, can be found in low price. At the moment, organizing workshops and accepting volunteers are ways to proceed faster with self-building. Moreover they encourage social bonding and community empowerment through help exchange. The case studies showed there is, indeed, an interest for this kind of help in exchange for learning. In conclusion, the cost of natural building is fundamentally a decision based on whether the owners would like to be personally involved in the construction process.

Another essential limitation is the legislation barrier of KENAK because it does not acknowledge earth and straw as building materials. This implies that the regulation for energy efficiency in buildings does not include U or lambda coefficients for strawbale or earth walls and the actual problem is issuing the Energy Performance Certificate. In order to proceed, a sample from the walls needs to be sent to the National laboratory in Athens for certification. However, this is costly and time consuming. Earth and straw houses will only have a wider acceptance in Greece as soon as legislative problems are solved.

Different teams around natural building interest have been formed in Crete which is a sign that there is a growing interest in that sector. “Piliko” team is based in Chania and has contributed with the first practical workshops, presentations and seminars with good effects. Architects of the team have issued building permissions for strawbale and light clay on the island. There is one more recent team formed after the completion of the light-clay dwelling in Archanes called “Natural building in Greece”, which is based in Archanes. These organizations are the contact references for those wanting to build with earth or straw in the island which is a first step to facilitate their broader potential.

To conclude, there some difficulties for the wider use of earth and straw but also there are advantages which most people dismiss. New findings and innovative examples should move the world forward in new sustainable ways. The earth and straw buildings are appropriate for Crete and even if strawbales are not abundant in the island, their import from mainland Greece can be environmentally justified. The first steps of alternative natural building methods have already been made in Crete and it seems that the future belongs to more sustainable, green buildings and natural materials.

## 8.2.Implications to the existing orthodoxy

Learning how to build with earth and straw means investing time, money and enthusiasm. In the L.R. it was mentioned how simple and easy it is to build with these materials providing the possibility for self-building by beginners. Having this in mind, it would be even easier for experienced builders and contractors to be trained and acquire these new skills. Maybe apart from carpentry for the load bearing skeleton, all the other technical issues can be fast and easily learnt. However, this requires willingness to make the move towards this direction. Then, any new project would be an exemplary case for the future and it will probably encourage new investments.

The lack of information should be covered by educating people for the value of these materials. Informing the people about the possibility to build with these materials could be aided from organizations like Piliko team, educational institutions like the Technical University of Crete and of course professionals who want to work in such projects. Dissemination of knowledge through the web (social media and advertising) or in the form of articles and reports in mass media (TV or newspapers) can be accessible to the majority of the people regardless of their work, status, age etc. To a considerable extent, wise marketing would help to make these materials more popular.

The economic crisis that Greece is facing during the last 5 years, has brought deep cuts in the construction market and changes in society ideology with respect to …. In the quest of limiting expenses and living with less income, people do not invest in construction like the past and many choose to leave the urban centers for the countryside. When living and working closer to the land in pursuit of self-sufficiency, natural buildings can be a compatible alternative option. They can be self-made and also helps to empower the community spirit in terms of help-exchange and inspiring self-sustenance. Under these circumstances, the building cost is lower and moreover they have a better performance for thermal comfort which means lower occupancy cost in the long-term. All in all, natural materials could be particularly beneficial in modern day Crete and Greece.

## 8.3.Limitations to the study

First of all, the author's background and personal opinions, as she has participated in many workshops and has volunteered for the existing natural buildings in Crete, may have biased the results. In addition, the interpretation of what was being said during the interviews and the speculations on findings could also introduce a bias due to the author's personal perspective.

In addition, the 11 people who were asked to participate in the qualitative research reflects a small sample size. A larger sample would provide a more representative conclusion. The sample size was further limited as it was sourced from individuals that the author new herself or through her work. Furthermore, the number of occupants and experienced builders are small on the island, whereas there are more plentiful architects and engineers with whom to contact. However this would imply a much broader time frame than the available time for the present study. The author tried to maintain as far as possible a balance between supporters of natural buildings and more conservative building professionals.

Furthermore, the qualitative questionnaires were kept short in order to ensure that they would not be time-consuming and the contacted people would not hesitate to answer. The interviews were conducted online and via telephone which might be a reason for shorter answers and limited analysis. However, the contained truth remains the same.

Moreover, the opportunity to conduct a proper post occupancy evaluation (POE) for the existing natural buildings would be restricted in the frame of the present study. The location of the case studies were at a considerable distance and the author would have to be based closer to the data source. The occupants were happy to talk and explain their situation with direct lively conversations but it would be hard for them to work for POE results longer. Notably, in the first case, the house was not connected to the grid so there were not any energy bills to look at.

Christos Choraitis, the occupant of the case study 1, was responsible for the measurements of temperature and RH, as he would have daily access to the thermometer. He was asked to take notes every 8.00 am and every 8.00 pm, but this time pattern was not followed strictly. Nevertheless, the daily morning and daily evening plan was maintained. Some days that Christos was working outside, the door would have been open for long periods which ruined the linearity of the findings. On the other hand, this kind of fault shows the serious level of responsibility of the occupants for the indoor thermal behavior of the house.

The use of tools like Life Cycle Assessment and Embodied Energy or Embodied Carbon Emissions would facilitate the evaluation of the case studies through more accurate numerical data. However the handling of these tools require a large pool of data which were not available to the author. The research was conducted under qualitative discourse dialogues generated in friendly, unstructured visits to the building locations and therefore did not permit exhaustive demand of information from the owners.

Finally, the *future potential* may be a too wide frame for the evolution-or not- of natural buildings. Climate change impacts hinder any kind of prediction for the people's needs or availabilities in the long run. Also the dynamics of the current economic crisis introduces an element of insecurity and instability nationally which may also influence the findings presented here. Hence the reason why the results should be considered proper and acceptable only in the short term a predictable frame of changes.

## 8.4.Recommendations for further research

The availability and willingness of technical professions and economic implications for filling the skills gap could be an interesting research subject. It appears that one of the most important drawbacks of natural building is that workers have to be trained from the beginning assuming no prior technical knowledge base. How could we invest in these novices to acquire the appropriate skills? Are they willing to learn? Will this take forward natural building to a wider audience?

An rising issue could be to further explore the possibility of planting cereal crops, now that people are aware of its use an alternative source in construction. Moreover, a comparative research on a stone traditional building and a straw and earth building as far as embodied and operational energy as well as the costs would be interesting.

# APPENDIX

## a) The participants of the interviews

**Herbert Gruber** is the founder of austrian strawbale network (ASBN) and his contribution to strawbale building spread in Austria is fundamental through the network. He came to Crete to participate in Christos Choraitis' plastering workshop in December 2014. Later on, he organised another natural building workshop in Heraklion.

**Antonia Diamantaki** is an architect and founder of PILIKO team, a team of professionals dedicated to earth buildings in Crete. She has run a lot of workshops and done experimental structures of natural materials (earth, straw, bamboo) all around eastern Crete. She has issued the permission, designed and managed the construction of a strawbale building in Chania. It is the building of European sustainability Academy that hosts a variety of actions and social events like seminars and conferences.

**Apostolis Mousourakis** is an architect and founder of PILIKO team, a team of professionals dedicated to earth buildings in Crete. He has issued two permission of light clay home for clients by this time and he has led a lot of workshops and the creation of experimental structures of natural materials (earth, straw, bamboo). He works closely with the Technical university of Crete for the investigation of natural materials.

**Tasos Andreadakis** is an experienced structural engineer based in Chania, Crete. He has calculated and designed the timber frame of ESA strawbale building and also light clay homes that are still in the design phase in Crete.

**Theodosia Kakavelaki** is a structural engineer who has long experience in concrete and steel buildings and has supervised, calculated and designed a significant number of private and public buildings. She stands for the average Greek engineer with the perspective of someone who, in spite of 35 years of experience, she was never involved in earth or straw buildings.

**Yannis Kalaitzis** is a structural engineer based in Crete with an Msc in Timber from Napier University.

**Axel Trillhaase** is a German constructor and builder but lives in Crete since 2007. He has his own firm "Ecohouse a.t." specializing in ecological building and he has built two light clay buildings in Crete up to now.

**Ritsakis Giorgos** is a self-builder, occupant and owner of a light clay house in Crete. Giorgos is deeply environmentally conscious and also he is aware of the advantages offered by this type of building. He met a lot of difficulties on the way but they did not discourage him from his choice to build with earth and straw.

**Katakis Michael** is self-builder, occupant and owner of a light-clay home who principally choose that way for a healthier living environment for him and his family.

**Christina Charamountani** is a Greek architect with 10 years practice in constructions in Greece and lately her focus is to promote natural buildings through workshops. She represents the new generation of architects.

**Claire Oiry** is a French architect specialized in earthen buildings and natural plasters from Crateure Institution. In Crete, her project was a renovation of an old ruin from stone solely with local earth and a little bit of straw trimmings. It is not a new building project, but the fact that natural materials were sourced locally and most of them for free make this case belong to the margins of the survey. The place is isolated and there was no electricity there so the work had to be done without mechanical means which was very time consuming and required the help of a group of people to see good results.

### b) The evaluation questionnaires

The questionnaires for evaluating natural building materials and ecological building are presented below with analytical results of the votes of each participant. The letters in the marking tables correspond to the following names of participants:

x=Axel Trilhaase

H=Herbert Gruber

C=Christos Choraitis

R=Christina Charamountani

M=Michael Katakis

u=Theodosia Kakavelaki

G=Giorgos Ritsakis

T=Tasos Andreadakis

a=Antonia Diamantaki

p=Apostolis Mousourakis

O=Claire Oiry

**Table 1: The answers of the participants for "What are the reasons for you to build with natural materials(straw/clay)?"**

| Why natural materials? | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| lower CO2 emissions | M | xH | C | RG | uTaPO |
| thermal comfort | | | | uP | OaTGMHCxR |
| healthy environment | | | Hu | P | OTRCxMGa |
| aesthetics | HO | | GT | PCxR | Mua |
| construction costs | aO | u | RP | HMG | xCT |
| occupational costs | | | u | RMGPO | xaCTH |
| innovation | CRMu | xa | HPO | GT | |

**Table 2: The answers of the participants for "What features of straw and earth buildings you evaluate the most?"**

| Straw& earth features | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| natural materials | | | HT | CRu | xMGTaP |
| use of local resources | | Mu | CT | RGP | HxaO |
| recyclable materials | M | H | xCR | G | uTaPO |
| humidity | HO | u | | GTP | xCRMa |
| opportunity for self built | u | a | RMTP | HG | xCO |
| community empowerment | u | Ra | xCMP | HG | O |

**Table 3: The answers of the participants for "What are the essential factors to perceive a building as ecological?"**

| Ecological building factors | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| bioclimatic orientation | | | H | GP | OuxCRMTa |
| natural materials | | | C | | OGuxHRMTaP |
| water management | | xu | HM | TP | CRGaO |
| energy efficiency | | u | | CMTP | xHRGaO |
| healthy environment | C | | u | TP | MHxRGaO |
| Aesthetics | CHG | M | xTO | RP | ua |
| garbage management | | M | uTa | HPR | xCGO |
| community empowerment | u | CGTa | xM | HR | PO |
| landscape architecture | | H | xCG | RMuT | aPO |

### c) Heat Loss Calculation for Paleokastro Strawbale

The temperature measurements inside and outside the building in Paleokastro allow us to calculate the heat loss rate of the envelope as far as the U values are known. The formula for heat loss is:

P=U*A*DT (in watts) (McMullan,1983)

A=surface
DT= temperature difference
On a specific day, for example on day 3 from graph.8, the evening temperature outside is 17 C˚ whereas inside it is 22 C˚. So the temperature difference is 5 C˚.

The dimensions of window and door openings are noted in the following table

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2.30*0.90 | 2.07 | 9 | 0.90*0.50 | 0.45 |
| 2 | 2.00*0.90 | 1.8 | 10 | 0.90*0.50 | 0.45 |
| 3 | 2.30*0.80 | 1.84 | 11 | 2.30*0.90 | 2.07 |
| 4 | 2.30*1.00 | 2.3 | 12 | 0.90*0.50 | 0.45 |
| 5 | 2.30*0.80 | 1.84 | 13 | 1.80*3.00 | 5.4 |
| 6 | 2.30*3.00 | 6.9 | 14 | 0.60*2.00 | 1.2 |
| 7 | 2.30*0.90 | 2.07 | 15 | 1.80*0.50 | 0.9 |
| 8 | 0.90*0.90 | 0.81 | 16 | 1.80*0.50 | 0.9 |

*TOTAL GLAZING SURFACE G=31, 45 m2*

The outside surfaces of the walls including the strawbales are

Ground floor 4 walls *9 m *2.5 m = 90 $m^2$

First floor 2 walls *9 m *3.5 m +2 walls *5 m*3.5 m= 63+35=98 $m^2$

Total surface with glazing E= 188 $m^2$

*Total strawbale surface without glazing E'=188-31.45 = 156.55 m2*

U-Value is a measure of heat flow (Watts) pass through 1 m2 of construction for every degree difference from inside to outside.*

*U value is measured in W/$m^2$ K

U value of Strawbale wall + U value of 5 cm natural plaster = 0,14 W/$m^2$ K
U value of solair glass= 0,7 W/$m^2$ K

# REFERENCES

Ashour, Heiko Georg, Wei Wuc (2011) “Performance of straw bale wall: A case of study” Energy and Buildings 43, pages 1960–1967. Accessed at http://www.ti.bund.de/media/institute/ol/Infrastruktur_MS/Publikationsdateien/625_OEL_Georg__Straw_bale_wall_Journal_of_Energy_and_Buildings.pdf

Alapetite Julien (2010), “A Benchmark to Assess Local Ecological Footprint Account”, The State of the Art in Ecological Footprint Theory and Applications. Accessed at: www.footprintnetwork.org/images/uploads/Academic_Conference_Book_of_Abastracts.pdf

Alcorn A., Donn Michael (2010), “Life cycle potential of strawbale and timber for carbon sequestration in house construction”, Coventry university and The University of Wisconsin Milwaukee Centre for by-products utilization, Second international conference on sustainable construction materials and technologies June 28-30, 2010. Available at http://www.claisse.info/2010%20papers/m23.pdf (Accessed: 1 June 2015)

Balaras C.A. ,Gaglia A. G., “European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings”, Building and Environment 42 (2007) 1298–1314 (www.sciencedirect.org)

Berger Warren (2009), Glimmer ,USA Penguin press

Bignozzi Maria Chiara “Sustainable cements for green building construction” 2011 International Conference on Green Buildings and Sustainable Cities, Procedia engineering 21 (2011) 939-942 (www.sciencedirect.org)

Bokalders Varis, Block Maria (2010), The whole building Handbook, London: Earthscan

Brojani L., Petric A., Clouston P. (2013) “A comparative study of brick and strawbale wall systems from environmental economical and energy perspectives”, ARPN Journal of engineering and Applied Sciences, Vol.8,No.11 ISSN 1819-6608,Available at www.arpnjournals.com (Accessed : 1 July 2015)

Bronwyn Becker, Patrick Dawson, Karen Devine, Carla Hannum, Steve Hill, Jon

Brundtland, O., 1987, *Our Common Future,* World Commission on Environment and Development (Oxford University Press).

Cabeza L., Barreneche C., Miró L., Morera J., Bartolí E., Fernández Ines(2013) “Low carbon and low embodied energy materials in buildings: A review” Renewable and Sustainable Energy Reviews 23, p.536–542Available at: www.sciencedirect.com

Coch H., (1998) “Bioclimatism in vernacular Architecture”, Renewable and Sustainable Energy Reviews 2, pp 67-87, Elsevier Science Ltd, Available at www.scopus.com , (Accessed : 1 December 2011)

Ding G.K.C., 2008 “Sustainable construction—The role of environmental assessment tools” / Journal of Environmental Management 86, p. 451–464, Accessed at www.sciencedirect.com on March 2015

Godfaurd John, Derek Clements-Croome, George Jeronimidis (2004) “Sustainable building solutions: a review of lessons from the natural world”
Accessed at: 27 May 2015

Galli A., Wiedmann T., Ercin E.,Knoblauch D., Ewing B., Stefan Giljum S., Integrating Ecological, Carbon and Water footprint into a “Footprint Family” of Indicators: Definition and role in tracking human pressure on the planet, Ecological Indicators 16, p.100–112
Accessed at www.sciencedirect.com on March 2015

Franzoni Eliza (2011) “Materials selection for green buildings: which tools for engineers and architects? (2011) International Conference on Green Buildings and Sustainable Cities, Accessed at www.sciencedirect.com on March 2015

Flyvbjerg Bent, "Five Misunderstandings About Case-Study Research," Qualitative Inquiry, vol. 12, no. 2, April 2006, pp. 219-245. DOI: 10.1177/1077800405284363 Available at: http://arxiv.org/ftp/arxiv/papers/1304/1304.1186.pdf

Howard Frumkin (2001), “Beyond Toxicity Human Health and the Natural Environment”, Medical Subject Headings (MeSH): animals, ecology, environmental health, nature, plants, trees (Am J Prev Med 2001;20(3):234–240) American Journal of Preventive Medicine

Harris C. & Borer P. (1998) ‘The whole House Book’, Centre of Alternative Technology, Machynlleth, Great Britain: Cambrian Printers

Hall Min (2012), Thesis on “Investigation and potential of straw and earth buildings” New Zealand

Hatzis Aristides (2015), “Greece Needs Broader Structural Reforms than Syriza Has Proposed”, Article in New York Times, Accessed at: http://www.greekcrisis.net/

Harris Cindy (2009) “Environmental Impacts of buildings”, MSc: AEES DL, Module CEM150, Environmental Impacts of Buildings

Giesekam J. et al. (2014) “The greenhouse gas emissions and mitigation options for materials used in UK construction” Energy and Buildings 78 (2014) 202 Accessed at www.sciencedirect.com on January 21st.

Jaquin Paul (2009), “Humidity regulation in earth buildings” *Ramboll Technical Forum*. London November 2009

Jimenez Delgado MC, Guerrero IC. (2007) The selection of soils forun-stabilised earth building: a normative review. Construction and Building Materials 21, p.237–251. Accessed at www.sciencedirect.com on January 21st of 2015

Jones Barbara (2002) Building with strawbales, Green Books, Foxhole, Dartington, Totnes, Devon TQ96EB

Kalogiannaki Evangelia (2014) Interview with architect Christos Choraitis recorded.

Kalogiannaki Evangelia (2014) Interview with architect Giorgos Ritsakis recorded.

Koundouri P., Karakousakis K., Jeffrey P. (2006), Water management in Arid and semi-arid regions, Edward Elgar Publishing Limited Cheltenham UK

Koutroulis A., Tsanis A., Daliakopoulos I., Jacob D. (2012), Impact of climate change on water resources status: A case study for Crete Island, Greece, Journal of Hydrology 479, p. 146-158. Accessed at: www.sciencedirect.com on January 21st of 2015

Saunders T., (2008) A discussion document comparing international environmental assessment methods for buildings. BRE Global. Retrieved on May 14, 2010 at

Leydens, Debbie Matuskevich, Carol Traver, and Mike Palmquist (1994 -2012). Case Studies. Writing@CSU. Colorado State University. Available at: http://writing.colostate.edu/guides/guide.cfm?guideid=60

Lee Bruno, Trcka Marija, Hensen Jan (2011), Embodied energy of building materials and green building rating systems—A case study for industrial halls, Sustainable Cities and Society 1 (2011) p. 67– 71, Accessed at www.sciencedirect.com on January 21st.

Magwood Chris, Mack Peter, Therrien Tina (2005) "More Straw bale Building. A complete guide to Designing and building with straw"

Makropoulos Kostas, Burton Paul (1984) "Greek tectonics and seismicity" Tectonophysics, 106 (1984) 275-304 Elsevier Science Publishers B.V.. Amsterdam - Printed in The Netherlands Accessed at: http://www.geophysics.geol.uoa.gr/papers/makro/makro017.pdf

McLean Toby (2011), "TALL engineers", personal comment

McMullan R., (1983), "Environmental science in building", 6th edition, UK, England: Palgrave Macmillan

McDonogh, W& Braungart,M. (2002) Cradle to cradle:remaking the way we make things

Morel J.C., Mesbah A., Oggero M., Walker P.(2001) "Building houses with local materials: means to drastically reduce the environmental impact of construction" Building and Environment 36 / 1119–1126 Accessed at www.sciencedirect.com on January 21st.

McEnroe John, (2010) "Architecture of Minoan Crete: Constructing Identity in the Aegean Bronze Age"

Minke G. (2006) Building with earth, design and technology of a sustainable architecture. Basel, Berlin, Boston: Birkhäuser Publishers for Architecture;

Minke, G. (2001), "Construction manual for earthquake-resistant houses built of earth", Gate Basin (Building Advisory Service and Information Network)

Millen Y.K. (2008), "Ecopsychology", CEM 162, Msc Architecture: Advanced Environment and Energy Studies, Graduate School of the Environment, Centre for Alternative Technology, Machynlleth

New Building Code, Article 11, The ministry of the Environment and Energy Accessed at: http://www.opengov.gr/minenv/?p=3938

Nodarou Eleni, Frederick Charles, Hein Anno (2008) "Another (mud)brick in the wall: scientific analysis of Bronze Age earthen construction materials from East Crete", Journal of Archaeological Science Vol.35, Issue 11, November 2008, pg 2997–3015 Accessed at www.sciencedirect.com on January 21st.

Niroumand Hamed, MZain M., Jamil Maslina "A guideline for assessing of critical parameters on Earth architecture and Earth buildings as a sustainable architecture in various countries" Renewable and Sustainable Energy Reviews 28 (2013)130–165 Accessed at www.sciencedirect.com on January 21st.

Papamanolis N.(2004) The main constructional characteristics of contemporary urban residential buildings in Greece, Building and Environment 40 (2005) 391–398, Elsevier. Accessed at www.sciencedirect.com on January 21st.

Roaf Sue, (2001) Ecohouse2: A design Guide, 2nd edition, Oxford UK: Elsevier Ltd

Roaf Sue, Fuentes Manuel, Stephanie Thomas (2003), Ecohouse2 A design guide, Oxford: Elsevier Ltd

Randle D. (2008) 'Introduction to climate change and the implications for UK buildings', Msc Architecture: Advanced Environmental and Energy Studies by DL, Graduate School of Environment, Centre of Alternative technology, Machynlleth

Scott Sidler (2012), "Timber, ballon or Platform frame?" Accesed at http://thecraftsmanblog.com/

Venkatarama Reddy B.V., Jagadish K.S.(2003), "Embodied energy of common and alternative building materials and technologies" Energy and Buildings 35 / 129–137 Elsevier. Accessed at www.sciencedirect.com

Vissilia Anna-Maria, (2009) "Evaluation of sustainable Greek vernacular settlement and its landscape: architectural typology and building physics", Building and Environment 44, pp 1095-1106, Available at www.scopus.com, (Accessed: 1 Dec. 2011)

Pan Feng (2011), "Brief Discussion of Green Buildings", 2011 International Conference on Green Buildings and sustainable cities , Procedia engineering 21, p.939-942 Accessed at www.sciencedirect.com on January 21st.

Parra-Saldivar and Batty W., "Thermal behavior of adobe constructions", Building and Environment Vol.41(2006) pg 1892-1904, Elsevier Science Ltd, Available at www.sciencedirect.com, (Accessed : 1 March 2013)

Pelsmakers Sofie (2012), The environmental design pocketbook, London: RIBA Publishing

Stephen Vardy, Colin MacDougall (*2006*) “Compressive Testing and Analysis of Plastered Straw Bales”. Journal of Green Building: Winter 2006, Vol. 1, No. 1, pp. 63-79. Accessed at http://osbbc.memberlodge.org

Strauss A. and Corbin (1990) Basics of qualitative research: Grounded theory Procedures and Techniques, Newbury Park, Calif. Sage

Tucker Simon (2010) “Zero and low carbon housing”, MSc: AEES DL, Module CEM150, Environmental Impacts of Buildings

Thoreau Henri David (1860) Familiar letters, Letter to Harrison Blake on May 20, 1860
Accessed at http://www.quoteyard.com/ on 3 March 2015

Turrent, D. (2007). Sustainable Architecture, London: RIBA. Available online via this route: www.openathens.net > My Athens>

USGBC. (2009). LEED 2009 for new construction & major renovations. U.S. Green Building Council.

Web Links:

Anelixis Organisation www.anelixis.org

Destination Crete http://www.destinationcrete.gr/en/archaoi-chronoi/neolitihki-epochi

http://eurosustainability.org/building.php

Whole Building design guide http://www.wbdg.org/

Piliko team http://www.piliko.gr/

Kakaras Ioannis (2009) Wooden structures and Greek reality http://www.wands.gr/gr/articles/148-2010-02-17-07-56-31.html

The european database of seismogenic faults:

http://diss.rm.ingv.it/share-edsf/sharedata/SHARE_WP3.2_Map.html

Agriculture and horticulture in numbers/ Greece

http://www.climateadaptation.eu/greece/agriculture-and-horticulture/

Principal Global Indicators

http://www.principalglobalindicators.org/Pages/Default.aspx

Ximeris Manos (2012) The Archanes Project Photo Gallery. Accessed at:
https://picasaweb.google.com/112394548819939228851/TheArchanesProject