1 Adobe making in the 21st century, New Mexico, United States (photo: Vegas & Mileto).
2 Lime-washed earthen dovecote, Hawara, Egypt (photo: Vegas & Mileto).
3 Ruined earthen dovecote, Ampudia, Spain (photo: Vegas & Mileto).

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Earthen architecture: sustainability and heritage

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The economic crisis linked to the increase of oil prices in 1973 brought about a renewed interest in earthen architecture, given its low cost and advantages as a building material.
As well as being readily available, earth is a highly resistant, ductile and chemically stable material, which is easy to extract and execute and can be completely recycled after use, without losing its properties. The use of earth in construction also guarantees a high level of indoor comfort in buildings, because of its acoustic insulation capacity and its optimum bioclimatic behaviour, linked to thermal inertia, permeability and thermo-hygrometric properties, which greatly reduce the use of heating and air conditioning, leading to noticeable energy savings.
Using the above as starting points, several research centres began experimentation programs using earth as a constructive material for a more sustainable and inexpensive architecture at all stages of its lifecycle, from construction to destruction, including its operation during its useful life. Based on their research, the most important and innovative international institutes in this field are: Forschungslabor für experimentelles Bauen at the University of Kassel, in Germany (founded by Gernot Minke in the 1970s); CRATerre at the University of Grenoble, in France (founded in 1979); Auroville Earth Institute, in India (founded by Satprem Maïni in the 1980s); the Earth Building Research Forum at the University of Technology of Sydney (founded by K. Heathcote and G. Moor in 1999); Amaco, an institute shared by the University of Grenoble, the University of Lyon and the ESPCI University in Paris (founded in 2012).
The research carried out in all these centres has confirmed the values of earth as a constructive material: *economic value* (immediate availability as earth can be found anywhere; simple or no transformation required; easy execution as it is simple to handle and requires no specialized labour); *constructive values* (high resistance, elasticity and adherence; it is not flammable; it is durable as it is chemically stable; it is ductile and therefore malleable); *bioecological values* (it guarantees a good level of comfort thanks to its acoustic insulation capacity; its thermal inertia and permeability enable thermal control and a good transpirability and regulation

4 Earthen mosque at Djenné, Mali (photo: Sánchez-Heredero).
5 Beehive domes made of adobes laid in a single spiral course at El Raheib, Syria (photo: Vegas & Mileto).
6 Interior of a beehive dome made of corbelling adobes in a single spiral course at Fah, Syria (photo: Vegas & Mileto).
7 Half-timber building filled with adobe at Hameln, Germany, home of the mythical Pied Piper (photo: Vegas & Mileto).

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of steam; it has no radioactive or toxic load); *environmental values* (it integrates well into its settings, without affecting the landscape; it guarantees greater energy efficiency thanks to energy savings linked to transport, extraction and transformation processes and to the savings in heating or air conditioning; its use reduces waste as it is fully recyclable).

Earthen architecture: a global heritage

Earth is the most abundant and accessible material on the planet. It is a ubiquitous material, available next to building sites and it can be used to produce from the simplest to the most complex architectures with direct forms of handling and execution techniques.
The spread of earthen architecture was recorded in the map produced in the late 1980s by CRATerre, on which the subsequent studies were based. This map was later incorporated locally through numerous initiatives developing more specific themed atlases by continent or region (as in the case of the European atlas, published in the *Terra Europae* book).
In the late 1980s a third of the world's population lived in earthen habitats, a proportion which is now higher, according to the more recent statistics provided by UN/Habitat and other international organizations. When examining these figures, it could be assumed that these earthen dwellings are simple shelters or shacks where the poor and marginalized world population lives. However, most of these dwellings are examples of vernacular architecture that are perfectly adapted to the climate and to the inhabitant demands, to different forms of use and cultures, scattered or grouped into the landscape in symbiosis with nature, transcending the use of material and bringing local residents closer to the use of the territory.
Habitats where earthen architecture is developed embrace the fertile central European plains, such as the Pannonian plain along the Danube (Austria, Slovenia, Czech Republic, Slovakia, Hungary and Romania), the oases of the desert, with the dwellings on the fringes of palm groves in northern Africa (Morocco, Algeria, Tunisia), the plateaus of South America (Peru), the villages clinging to the peaks of the *mesas* that jut out of the plains or the enclaves sheltered in the irregular rocky cliffs of the southwest >

8 Earthen-dug excavated patio houses with stone façades at Matmata, Tunis (photo: Vegas & Mileto).
9 Adobe wall at Fuensalida, Spain (photo: Vegas & Mileto).
10 Adobe wall, Sardinia, Italy (photo: Vegas & Mileto).
11 The excavated city of Guadix, Granada, Spain (photo: Vegas & Mileto).
12 The whole Islamic Alhambra is built with rammed earth walls and bricks and earthen mortar walls, Granada, Spain (photo: Vegas & Mileto).

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of the United States and Northwest of Mexico, the settlements clustered on the mountain slopes of the valleys of Tibet or the architectures found scattered or grouped on the banks of the major rivers which manage to create life in the desert, as is the case of the Nile (Egypt), Euphrates (Syria), Rio Grande (United States), on the fertile band resulting from a geological fault in the middle of the savannah, like the Bandiagara Cliff (Mali) and, finally, in the green enclaves of the fjords and rivers of the north of Europe (Iceland). This variety of landscapes and settlements constitutes the testimony of the adaptation of humans to nature, as well as their capacity to work on it and manipulate it to develop their life practically anywhere on the planet.
A very broad sample of this type of architectural heritage in Europe is compiled in the book *Terra Europae* (2008), including: the wealth of isolated or grouped dwellings present in the whole Iberian Peninsula and in the South of France, the half-timber dwellings of the small and medium-sized historic nuclei of central Europe, the countless dwellings of the Pannonian plain, the cottages of the United Kingdom and Ireland, the Mediterranean architectures with courtyards in Sardinia (Italy), the dwellings scattered throughout the fields of the north of Europe or in the green landscape of Iceland. As well as offering an important overview of the earthen architecture of EU countries, the book *Terra Europae* includes an atlas reflecting 4 families (rammed earth, half-timber, adobe and cob), covering a total of 72 constructive techniques.
Often the technical-constructive variety of earthen architecture in Europe and the diverse cultural landscapes in which its examples are found continue to surprise, as earthen architecture is not directly connected with the European continent and tends to be associated with arid climates with no rain. However, this architecture is found in almost all corners of Europe and represents a large part of the continent's vernacular and heritage architecture.
Nevertheless, beyond Europe there are notable examples of independent and grouped vernacular dwellings. Some of the most exceptional examples of these are the excavated dwellings in Matmata (Tunisia), Zhog Tou (China) and Guadix (Spain); the polychrome dwellings of the Kassenain Tiebele, Burkina Faso or in the region of Gujarat in India; the

13 Adobe house at Nuévalos, Spain (photo: Vegas & Mileto).
14 The village of Aït Ben Haddou, built with rammed earth and adobe, Morocco (photo: Vegas & Mileto).
15 Wall with brick and adobe alternated courses, Baté, Hungary (photo: Vegas & Mileto).
16 Taos Pueblo, New Mexico, United States (photo: Vegas & Mileto).

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domed dwellings of the Mousgoum in Cameroon; the dwellings with false domes in southeast Aleppo (Syria) or in Oruro (Bolivia); the dwellings with different shaped groupings of the Dogon (Mali) and groupings by aggregation of the Pueblo Indians (United States); the circular aggregations of the Toulouin the province of Fujian and many of the rural peoples of Yunnan, as in the case of Lijiang (China). There are often buildings linked to local production and food associated to these dwellings, as in the case of the grain stores at the shelter of the Bandiagara Cliff in Dogon country (Mali), the gigantic grain stores of the peoples of Niger, the dovecot towers of the Banks of the Nile (Egypt), the circular or square dovecots of Tierra de Campos in Spain, the *cuescomate* grainstores in Mexico, the huge *yakhchal* coolers in Iran or the family ovens found in almost all cultures.
In addition, in some cases the grouping of these dwellings into rural settlements of different sizes matches the size of major cities, as attested by the city of Shibam, dubbed the Manhattan of the desert in Yemen (16th century), the city of Bam in Iran (around 2,000 years old) or many of the cities and settlements of northern Africa, from major cities like Marrakesh (Morocco) or Ghadamis (Tunisia), to numerous small *ksour* and *kasbahs* in the south of Morocco, Algeria, Tunisia (with such spectacular specimens as those found in the Draa Valley or Tataouine in Tunisia) and Sub-Saharan Africa, including Djenné and Mopti (Mali). However, other continents have also seen the development of compact settlements which offered protection from harsh climates or human incursions, creating striking unitary groups. This is the case of settlements clustered on mountain slopes and sheltered from the force of rivers (villages such as Shegar in the valleys of Tibet, Kagbeni in Nepal or others like Chinceros and Ollantaytambo in the Sacred Valley of the Incas in Peru) protected and unreachable at the top of a mountain (like the Acoma Pueblo in New Mexico, United States) or creating artificial levels, as in the case of Taos in New Mexico (United States).
Earth, used worldwide to build dwellings and settlements, has made it possible to build spectacular public buildings including religious and funerary buildings (burial mounds, pyramids, temples, churches, mosques, etc.), representative palaces and defensive buildings (walls, towers and fortresses), >

17 Mesa Verde old settlement built with stone walls laid with earthen mortar (photo: Vegas & Mileto).
18 Kuri village, Rajastan, India (photo: Vegas & Mileto).
19 Khiva city walls, Uzbekistan (photo: Sánchez-Heredero).
20-21 Sod house at Keldur, Iceland (photo: Vegas & Mileto).

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and buildings for production (kilns, coolers, etc.). One only has to think of such notable examples as the Great Wall of China, in the part of the province of Gansu, the Alhambra in Granada and a large number of fortresses from the Islamic and Christian periods in Spain, the castles and fortresses of Iran (including the castles of Rayenand Nerein and the citadel of Goorthan, etc.; the monasteries, palaces and fortresses of Tibet and Ladakh (including the Gyantse fortress in Tibet, the Leh Palace or the Basgo Monastery in Ladakh); the mosques of Western Africa, the mosques of the river Niger, the most spectacular of which are probably those of Djennéand Timbuktu in Mali and those of Bobo Diolasso and Bani in Burkina Faso; the churches of New Mexico (United States), the first missions in Texas (United States) and the walled cities of Khiva and Bukhara (Uzbekistan).

This is also true for major archaeological sites whose architecture is still imposing, including: the pyramid of Senusret II in el-Lahunin Egypt (19th century BC), the ziggurat of Chogha Zanbil in Iran (12th century BC), the citadel of Merv in Turkmenistan (6th century AD), the pre-Columbian city of Chan Chan (15th century), the Temple of Raqchi (14th century) and the Huacas del Sol y de la Luna in Peru (1st century AD), the Great House in Casa Grande (United States), the pre-Columbian city of Paquiméin Casas Grandes in Mexico (1200-1450 AD).

Techniques and variants

The wealth of earthen architecture is also linked to the potential of the use of earth in construction. Due to its composition, earth varies in colour, granulometry and texture and it has traditionally been used in construction with a wide range of techniques and models, which have led, in turn, to the development of numerous constructive cultures, linked to different climates and locations worldwide, from east to west and from north to south. The first full classification of these techniques was completed in the 1980s by investigators from the CRATerre research centre (France) and was published in the treatise on earthen construction in 1989. This classification established 12 forms of use for earth in construction: excavated, as covering, as filling, cut, compacted, manipulated, piled, moulded, extruded, sieved, with straw and as a finish.

22-23 Cob houses at the Tiébéle village of the Kassena tribe, Burkina Fasso (photo: Vegas & Mileto).
24 Detail of the wedge-shaped cob courses at the houses of Samsana village of the Lobi tribe, Burkina Fasso (photo: Vegas & Mileto).
25 Detail of a courtyard house at Samsana village of the Lobi tribe, Burkina Fasso (photo: Vegas & Mileto).
26-27 Half-timber filled with adobe, Navapalos, Soria, Spain (photo: Vegas & Mileto).

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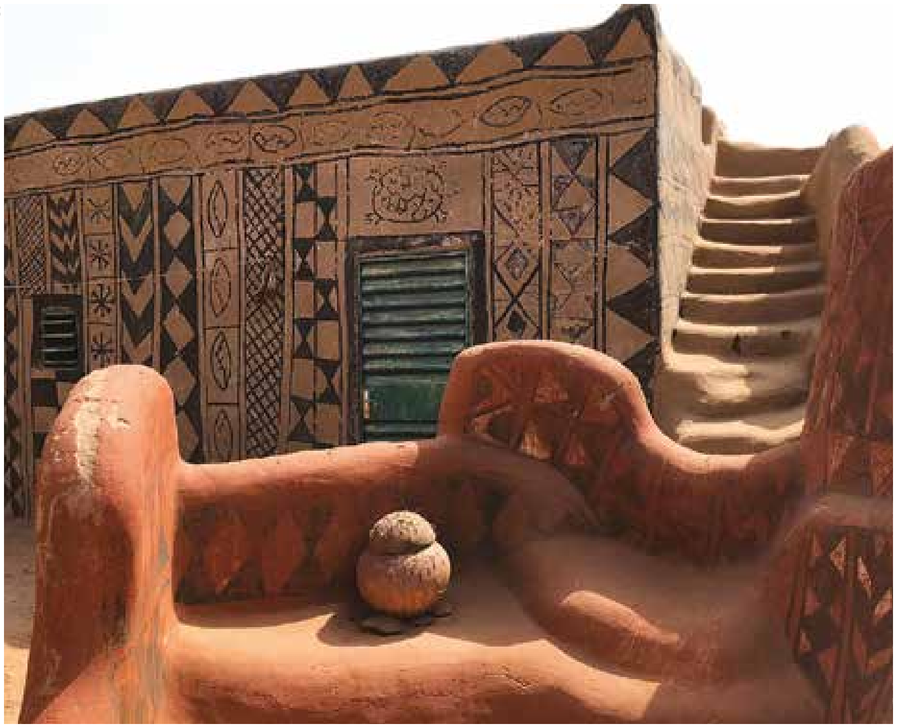

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In recent years, following studies and extensive efforts have been done to classify and name all the techniques and variants found in heritage, especially after the experience of the *Terra Europae* project (2011). In the case of Spain (although applicable in other contexts), it is suggested to group techniques into major families that can be internationally used: construction by removal (caves and excavations), monolithic construction (cob, piled earth, rammed earth, poured rammed earth, etc.), construction by pieces (clod, adobe, sod, cut earthen blocks, CEBs, etc.), mixed construction with wood, earth and fibres (half-timber, hay, wattle, etc.) and earth as an auxiliary material (aggregate in mortars, reinforcements, renderings, etc.). In each of these families the different techniques can also be divided into numerous variants depending on the available materials, local traditions or climatic and environmental needs. A single technique, such as rammed earth, can have tens of variants resulting from the adaptation to a given location and to the demands of the population, while also offering an interesting constructive and aesthetic range.

There are so many constructive variants found in built heritage that it is impossible to cover this topic comprehensively. In this general context, which aims to show the offer variety in the world of traditional earthen construction as a heritage value, it is worth remembering the constructive principles underlying the main techniques, in order to show a wide, though not exhaustive, visual range of the possibilities which can be found and, again, make it possible to gauge the wealth of this architecture.

Constructions by removal consist in the creation of architectural spaces by excavating the natural land. Due to their nature, these constructions present vaulted spaces and can have parts which are built underground or externally.

Monolithic constructions are executed by piling earth directly on the site to build the walls. Piled earth can be consolidated with or without the use of formwork, in the form of rammed earth or cob respectively. Both techniques offer numerous variants in terms of execution, composition of the mix used and the materials added to it (stone, brick, lime, gypsum, ceramic, etc.). In rammed earth, the formwork used – known as tapial – can be straight or >

28 House with rammed earth walls, Rupià, Spain (project: Auquer i Prats Arquitectes, photo: Jordi Can, courtesy of Lluis Auquer).
29 Indoor swimming pool within rammed earth walls, Toro, Spain (project: Vier Arquitectos, photo: Vier Arquitectos).
30 Half-timber walls filled with stones and half-timber with cob, La Cuenca, Soria, Spain (photo: Vegas & Mileto).
31 Building a rammed earth wall, Mgoun valley, Morocco (photo: José Manuel López Osorio).

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curved and continuous or organized in modules. The earth is tamped by layers inside the tapial. In cob the layers are stacked manually and can be smoothed, cut, etc. at a later stage. In this group it is also worth remembering mixed techniques, such as piled rammed earth or poured rammed earth, where a mix is poured into the formwork.
Construction with pieces is executed bonding pieces which have been prepared beforehand. These pieces may have been air-dried earlier (adobe) or executed while still damp (clod), manually modelling the earth in different ways (manual adobe can be parallelepiped, conical, truncated cone, cylindrical, flat, etc.) or shaped with a wooden mould (adobe), executed directly cutting the earth into blocks (cut earthen blocks) or earth with grass (sod). The pieces produced are combined with different bonds and types of execution in the construction of walls or even vaults.
Mixed constructions with wood structures and earth are executed with a wooden load bearing structure, made up of vertical studs, horizontal and sloping elements transoms, plates, etc.), forming a half-timber construction, where empty sections between wooden elements are filled with pieces or monolithic element in a wide range of modalities and bonds. The wooden structure is built with numerous variants depending on the position, interaxis and rhythm of the elements, on the composition of the whole, etc. This group also includes the constructions which use structures woven with plant fibres (reeds, branches, rushes, etc.), rendered in earth on one or both faces and filling the gaps between two plant screens with earth, etc.
Finally, earth is used as an auxiliary material in other types of construction. For instance, this is the case of earth mortar used in the construction of adobe walls, as well as in stone masonry walls. Earth is often used as a rendering material, usually mixed with straw and limewashed, on both earthen walls (rammed earth, adobe, half-timber, etc.) and masonry walls. In constructions using wooden logs, earth is used to render the interior and to close the gaps between logs on the outside. Due to its insulation and waterproofing qualities, earth is used in its various forms to produce the finishing layer of flat roofs (usually with a tamping process) or with sod on sloping roofs.

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