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ADVANCED MASTERS IN STRUCTURAL ANALYSIS
OF MONUMENTS AND HISTORICAL CONSTRUCTIONS

Master's Thesis

Kee Young Jung

A Brief Historical Review of the Earthen Architecture of the World with a Focus on Spain and South Korea

UNIVERSITAT POLITÈCNICA DE CATALUNYA

University of Minho

Spain | 2019

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Year: 2019

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I hereby declare that the MSc Consortium responsible for the Advanced Masters in Structural Analysis of Monuments and Historical Constructions is allowed to store and make available electronically the present MSc Dissertation.

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ABSTRACT

Earth is one of the earliest materials chosen by mankind to make buildings and is still used commonly in some parts of the world. Earthen constructions are found in almost every place on the planet inhabited by people.

Both Spain and South Korea have a long, rich tradition of building with earth. The Iberian and Korean Peninsula is full of historic sites and monuments built with different earthen materials and construction techniques. However, earth has lost its place as a construction material in both countries after their rapid modernization and transition from an agricultural to industrial economy. While building with earth provides many economical and environmental benefits such as low cost, zero-waste potential, and minimum use of energy for construction, its potential has been neglected by the public and the experts.

Therefore, there are two main reasons to research earthen constructions and materials. First, since earthen constructions contain important and sometimes unknown information about the ancient and medieval culture and history, there is a need to preserve and understand them. Secondly, as they offer solution to the demand for sustainable and affordable architecture, their material properties and construction techniques should be further researched.

In order to preserve historic earthen construction of Spain and South Korea, it is important to understand how earth architecture in two different regions of the world have developed independently over time and to find similarities and differences arising from the influence of climate, geography, functional use, material composition, and culture. Thus, the aim of this thesis was to conduct state-of-the-art research on the traditional earthen construction techniques and to look into specific examples of vernacular earthen buildings of each country. Finally, the thesis concludes by briefly presenting attempts to use earthen materials in modern construction and to serve as a starting point for future researchers and architects who are interested in rediscovering earth as a building material and an architectural fabric.

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RESUMEN

La tierra es uno de los materiales más antiguamente utilizados por la humanidad, y aún sigue en uso en diversas partes del mundo. Este tipo de construcciones con tierra se encuentran en casi todos lugares habitados.

Tanto España como Corea del Sur tiene larga y rica tradición en sistemas de construcción con tierra. La península ibérica y la península coreana están plenos de lugares históricos que han sido construidos con una gran variedad de materiales en base tierra y utilizando técnicas únicas. Sin embargo, la tierra ha dejado de ser usada debido a la modernización de ambos países y la transición de economías agrícolas a economías industriales. La construcción con tierra proporciona muchos beneficios económicos y ambientales como el bajo costo, el potencial de desperdicio cero y el uso mínimo de energía para la construcción. A pesar de esto, su potencial ha sido descuidado tanto por los usuarios como por los expertos.

Por lo tanto, hay dos razones principales para investigar construcciones y materiales de tierra. Primero, dado que las construcciones de tierra contienen información importante y, a veces, desconocida sobre la historia y la cultura antigua y medieval, es necesario preservarlas y comprenderlas. En segundo lugar, sus propiedades materiales y técnicas de construcción deben investigarse más a fondo debido a que ofrecen una solución a la demanda de una arquitectura sostenible y asequible.

Para preservar la construcción de tierra histórica de España y Corea del Sur, es importante comprender cómo se ha desarrollado la arquitectura de tierra en dos regiones diferentes del mundo de manera independiente a lo largo del tiempo y encontrar similitudes y diferencias derivadas de la influencia del clima, la geografía, el uso funcional, la composición del material, y la cultura. Por lo tanto, el objetivo de esta tesis fue realizar una investigación de vanguardia sobre las técnicas tradicionales de construcción de tierra y examinar ejemplos específicos de edificios de tierra vernáculos de cada país. Finalmente, la tesis concluye presentando brevemente los intentos de utilizar materiales de tierra en la construcción moderna y de servir como punto de partida para futuros investigadores y arquitectos interesados en redescubrir la tierra como material de construcción y como tejido arquitectónico.

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초록

흙은 인간이 집을 짓기 시작할 때부터 사용했던 가장 오래된 건축 자재이며 현재까지도 세계 곳곳에서 쓰이고 있다. 흙 건축물들은 지구에서 인간이 거주했던 거의 모든 곳에서 발견되고 있다.

특히 스페인과 한국의 흙 건축은 오래된 역사를 지니고 있다. 이베리아 반도와 한반도는 다양한 흙 건축 자재와 공법들로 만든 역사 유적과 기념물들의 고장이다. 그러나 농업에 기반을 둔 두 나라가 빠르게 산업화와 근대화를 거치는 과정에서 흙은 건축 자재의 역할을 잃어버렸다. 흙으로 건물을 지을 때 그 비용과 에너지가 적게 들고 폐기물도 최소한으로 배출하는 등 흙 건축은 많은 경제적, 환경적 이점을 가져다주지만 그 가능성은 오랫동안 대중과 전문가들에게 무시되어 왔다.

흙 건축을 연구해야 할 중요한 이유를 크게 두가지로 들 수 있다. 첫째로 흙 건축물들은 고대와 중세 사회의 역사와 문화에 대한 잃어버린 기억을 간직하고 있기 때문에 그것들을 보전하고 연구해야 한다. 둘째로 흙은 친환경적이고 저렴한 건축을 향한 가능성을 제시하고 있기 때문에 그 물성과 건축공법을 자세히 들여다볼 필요가 있다.

고로 이 논문은 흙 건축에 관한 동서양의 다양한 서적 및 자료들을 정리해서 전통 흙 건축공법에 대한 보다 포괄적인 정보를 제시하고 흙을 통해서 스페인과 한국의 토착 건축의 특성을 살펴보려 한다. 스페인과 한국의 흙 건축물들을 보전하기 위해서는 두 나라의 흙 건축이 어떻게 개별적으로 발전되어왔는지와 그 과정에서 각각의 기후와 지형, 기능과 물성, 그리고 고유의 문화에 어떠한 영향을 받았는지에 대한 공통점과 차이점을 찾는 것이 중요하다. 마지막으로 이 논문은 현대 건축에서 흙을 사용한 예를 보여주고 앞으로 흙을 건축 자재로 재발견하려는 연구자들과 건축가들에게 기초를 마련해주고자 한다.

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1. OBJECT AND CONTENT OF THE THESIS

This paper presents a brief overview of earthen architecture in the world and specifically on the typologies and construction techniques of Spain and South Korea. Due to the short duration of this master's thesis, it was difficult to cover an in-depth knowledge of the topic or carry out any extensive historical surveys of regions of each country. Thus, this paper is limited to a preliminary documentary review of some information readily available online in a form of journals, thesis papers, newspaper articles, web encyclopaedias and books about historic constructions and techniques.

Chapter 2 begins by providing background information on the history of traditional earthen architecture. The first section explains the archaeological and etymological origin of each major construction techniques. It describes the basic construction processes, the materials used and their strengths and weaknesses, the functional use of the building, and issues with durability and resistance against natural and anthropogenic threats. The second section attempts to identify possible influence of the natural environmental factors on the selection and distribution of certain construction techniques. The third section compares and contrasts representative vernacular buildings from each country to see how all these factors shaped vernacular architecture.

Chapter 3 shifts the attention to how earthen buildings are being built and preserved nowadays. It describes the World Heritage Listing status and modern usage of traditional techniques in building earthen buildings from Spain and South Korea.

2. TRADITIONAL EARTHEN ARCHITECTURE

2.1 Earthen Construction Techniques

Earth is one of the oldest building materials used by mankind. One of the earliest known human settlements of Çatalhöyük in modern day Turkey was built with adobe and covered with plaster (Figure 1) and the famous Great Mosque of Djenne in Mali was piled with cob. The ancient Native American tribes of Adenans and the Hopewellians constructed burial mounds (Figure 2).

Figure 1: Left: Reconstruction of Çatalhöyük in 6000 B.C.; Right: Great Mosque of Djenne, Mali [1]

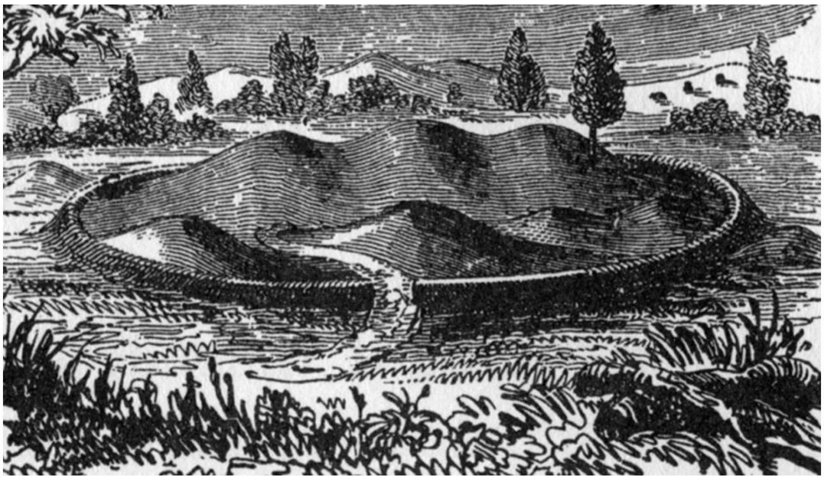


Figure 2: Drawing of earthen burial mound by Hopewell Tribe [1]

But what is the definition of earthen construction? To what extent should buildings be considered as such? The World Heritage Inventory of Earthen Architecture prepared by CRATerre in 2012 explains its criteria for the selection of "earthen heritage" [2].

Properties were selected when earth materials were used in:

- Load-bearing walls (different techniques, rammed earth, adobe, cob, hand shaped earth);
- Mortars, in stone or burnt brick walls;

- Fillings for wooden structures, mainly as part of “wattle and daub” constructions, with many variations;
- Roofs and floors, often in conjunction with wooden load-bearing structures;
- Coatings and paints, exterior or interior;
- Extensive landscaping works requiring specific engineering solutions.

However, properties with the following characteristics were not selected:

- Properties in which earth is not used specifically for the intrinsic properties the material has to offer in terms of cohesion, compressive strength, water resistance, etc. (e.g. earth fillings as part of foundations and wall bases, which would have lead to the inclusion of most built properties in the inventory);
- Properties where the main use for earth is agricultural (e.g. The Rice Terraces of the Philippine Cordilleras)

In this chapter, earthen construction will be classified into three main groups (Figure 3). The criteria for this classification are based on the size of the unit of construction. The final structure can be a one whole unit of earth, comprised of smaller individual units of different shapes and sizes, or as an infill and plaster of a main structure made of a different material.

The first group is earth in monolithic structure, including dug-out construction and rammed earth. The second group is earth structure in pieces, including cob, earth bricks, cut earth blocks, and sod. The last group is earth structure with other materials, including half-timbering and earth as masonry wall infill. Each construction method will be explained in detail regarding its origin and region, process, usage for Spain and South Korea.

It should be noted that this method of classification is arbitrary and is just one of many ways to look at earthen construction methods. For example, a study by Hind El Houari divides different construction methods into either construction by removal or addition [3]. Another way of looking at it can be achieved by focusing on the load bearing role and capacity of structures made from different construction methods.

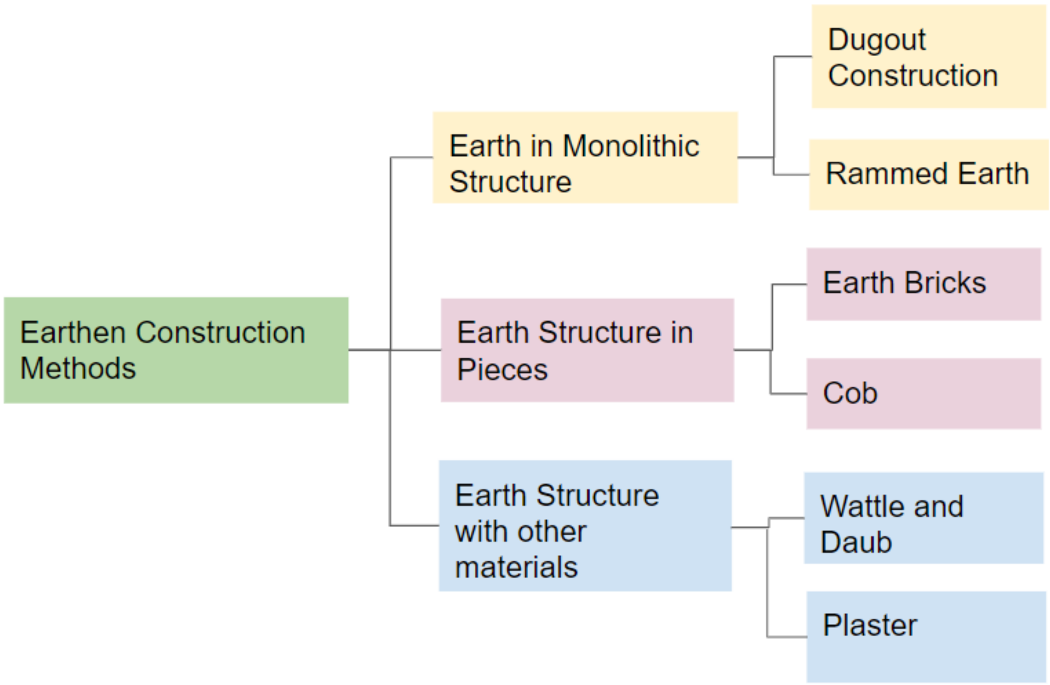


Figure 3: Classifying construction methods into three main groups

In this chapter, earthen construction was studied by grouping various construction methods into three main areas based on the size of the unit of construction. Each technique was investigated by briefly looking at the overall building typology and geometry, size, scope, and ease of construction, how building materials were procured and prepared and their physicochemical and mechanical properties, and how resistant and durable they were to natural and human actions.

Although it was not covered in depth in this paper, it was crucial to understand the history of each region as economic trade, migration, warfare and colonization led to the transfer of ideas, materials and often led to the creation of new ideas and technology.

In the case of Spain, it was helpful to research similar construction techniques of Ancient Roman, Egyptian and Arabic states in order to better understand the origin and development of Spanish construction. Ancient Egyptian knowledge of making earth bricks had to be studied as they were passed down to Arabic states and later to Spain during Muslim conquest of the Iberian Peninsula. Traces of Roman military campaign and colonization can be found in vast areas of Europe, and Spain was not an exception. A more detailed study comparing the earthen construction of Iberia and Morocco can be found in the work of Hind El Houari [3].

South Korea has a long, inseparable relationship with China. Many of its political ideas and military technology was introduced from mainland China across the plains of Manchuria and the Sea of China whether it was by war or economic trade that lasted for a millennium. Traditional architecture of South

Korea has been continuously shaped by incoming Confucianism and Buddhist ideas and culture as they can be seen in burial mounds, pagodas, temples, and pottery kiln. More evident was in the adoption of rammed earth formwork for building earthen fortresses and castles. They later modified these original ideas, mixed it with their own inventions, and then passed it down to Japan.

Yet it was difficult to find, translate, and interpret original documents detailing ancient treatise on history of construction and methods. Early humans of the Neolithic and Bronze Age and even late medieval Europeans did not leave much written records on construction methods and specifically about earthen constructions. A good number of public monuments were constructed using impromptu soil mix and did not follow a standardized system. Techniques used in vernacular buildings were even less standardized and shows greater variation for each region.

Scarcely any original documents exist for this type of information so this paper relies heavily on archaeological evidence and findings to estimate and understand traditional earthen techniques. To make the situation worse, relatively few numbers of earthen buildings have survived over the course of human history, and of them few have been excavated, preserved, and researched by scholars to carry out field investigation and draw out any meaningful information. Sometimes a lack of information for Spanish construction was substituted from known information in the neighboring countries of France, Portugal, or even the United Kingdom, and China and Japan for Korean construction.

A special attention was paid to the etymology of each technique. Some words such as Arabic “at-tûb” and Spanish “adobe” had a similar sound and showed that how the transfer of technology from one culture to another was evident in names in each language. Korean terms were easier to guess its meaning as many of them were spelled directly from a Chinese character.

It was also interesting to see how sometimes the translation of the names of the technique revealed the emphasis on certain parts or procedure of the technique. For example, the French term pise de Terre and the Chinese hangtu literally translates to rammed earth and focuses on the act of ramming, while the Spanish term Tapia and the Korean panchuk translates into scaffolding/wooden board and highlights the use of formwork used to make rammed earth. Both “pared de mano” and muro amasado” are spanish names for cob construction, yet pared de mano means heaped up earth and muro amasado refers to the act of kneading and shaping the balls by hand. Therefore, the presence of variety of names for a common technique aided in the understanding about the origin and process of the technique in the absence of proper documentation.

2.1.1 Earth as a monolithic structure

2.1.1.1 DUG-OUT ARCHITECTURE

Dug-out architecture is probably the oldest type of construction method since mankind moved out of the caves to settle down in their permanent houses at the end of the Paleolithic period. Between the Neolithic period and the Bronze Age, people started to dig vertical holes in the ground in the shape of a rectangle or a circle and placed a roof over it (Figure 4). A circular plan was used for hunter-gatherers and a rectangular plan seems to have been more preferred for a farming community [4]. An area of 4m by 6m was dug up to a depth of 1m in cold areas and 50 cm in warm areas, and the bottom was straightened. The concept of a wall did not yet exist in this period so a natural ground wall and a sloped straw roof formed a building envelope and protected people from rain, wind, and sunlight. The roof was usually supported by a timber frame or two to four wooden poles in the center. The roof was covered with straw, tree barks or small branches which were widely available, light and easily moldable, and durable against water and wind (Figure 5). A small opening was made in the corner to serve as a door which was connected to a small staircase or a ramp from the bottom.

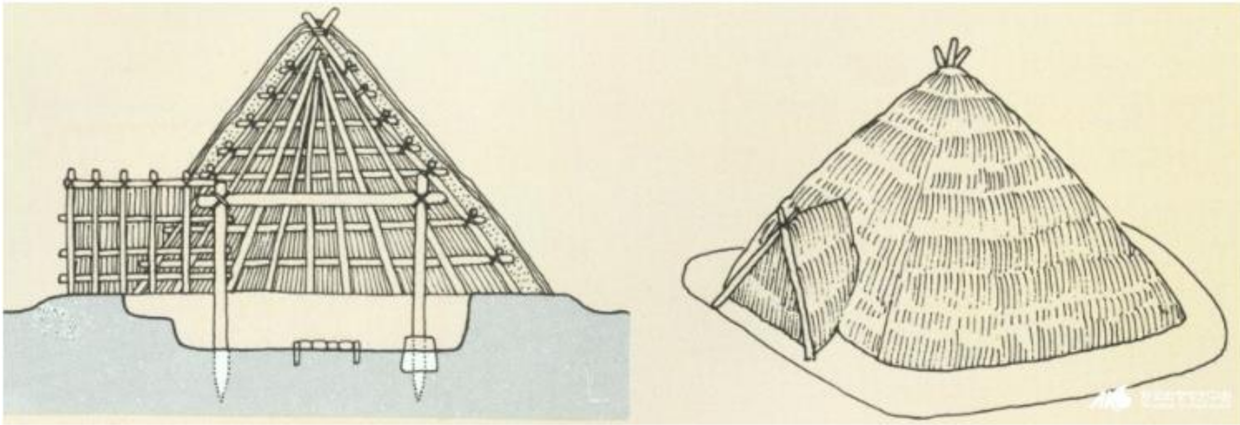


Figure 4: Reconstructed drawing of a Um in Korea. [4]

Figure 5: Hut with straw cover in Seung-ju, Korea (left) and tree bark in Maruyama, Japan(right). [5]

A typical pit house or a hut was called um or um-mak (움집, 움막집) in Korea. These houses were occupied by a family of 5 to 6 people as shown in Figure 6. In the center, a furnace was placed for cooking and heating and a part of it was dug to store and preserve food. Women stayed in the center while the men slept in the periphery close to the entrance. Since there was no window to brighten the room and circulate the air and it was difficult to prevent the cold rising from the ground, it later became necessary to build a house on a leveled ground [6].

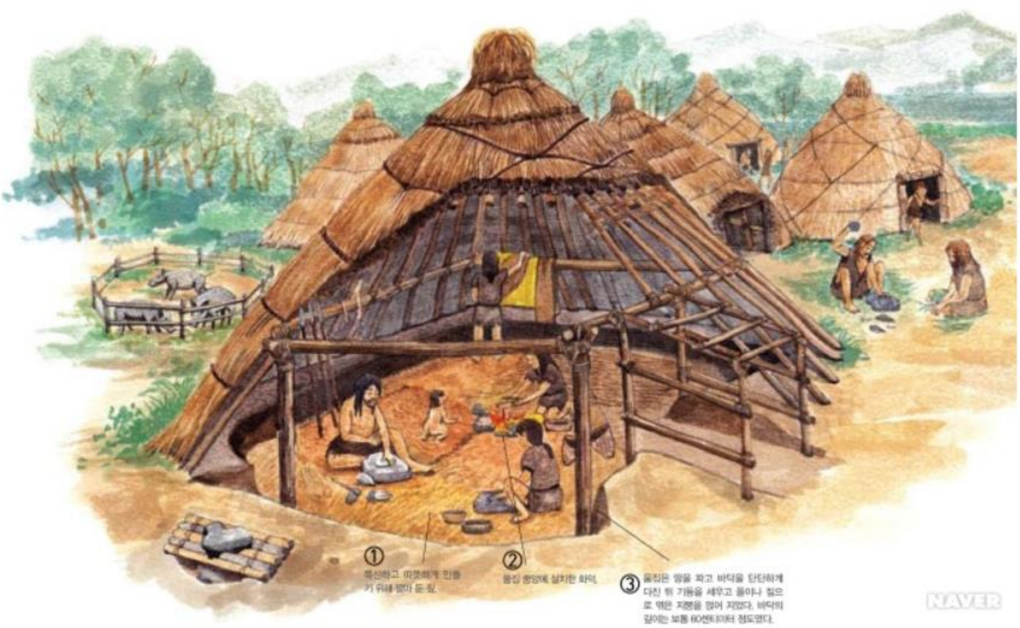


Figure 6: Typical Um for a family of five**.** [6]

While dug out construction was mainly for residential pit houses, it has also been used to store food - as wine cellars, ice pits, and spaces for growing mushrooms, curing certain cheeses. These underground spaces can be found throughout Spain, especially in Andalusia, Castile-León, Navarre, Aragon and a broad strip of the east of the peninsula, including some notable sites in Castile-La Mancha [3].

Ditches were also a common dug out construction that surrounded tribal villages in the Bronze Age. Earthen ditches were dug to 1 to 3 meters deep with a V or U shaped cross-sections as shown in Figure 7. The dug out soil were not carried away but piled next to the holes to raise the height of the ditch. A wooden pole was driven at certain intervals to prevent these piled earths from collapsing [7]. Later, a wooden board must have been placed at these wooden poles to raise walls evenly and allow ramming. Earthen fortresses built with rammed earth technique might have evolved from these ditches.

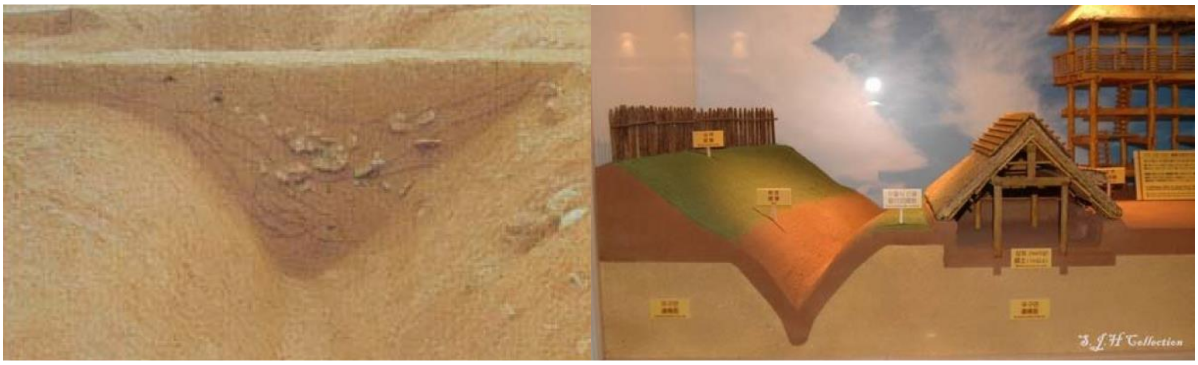


Figure 7: Left: Photograph of the excavated V-shaped ditch of Gumdanli, Korea; Right: Diagram of the reconstructed cross section of the earthen ditch of Oshinogari, Japan. [7]

These ditches served many purposes. Its main and foremost role was to prevent access from the outsiders into the village and dwellings of the inhabitants. Therefore, it has a circular perimeter if seen from above as shown in Figure 8. A strip of opening between each ditch was gates that allowed people to enter and exit the village. Raised walls along the ditch were used as a trench to hide the soldiers and weapons during battles [7].

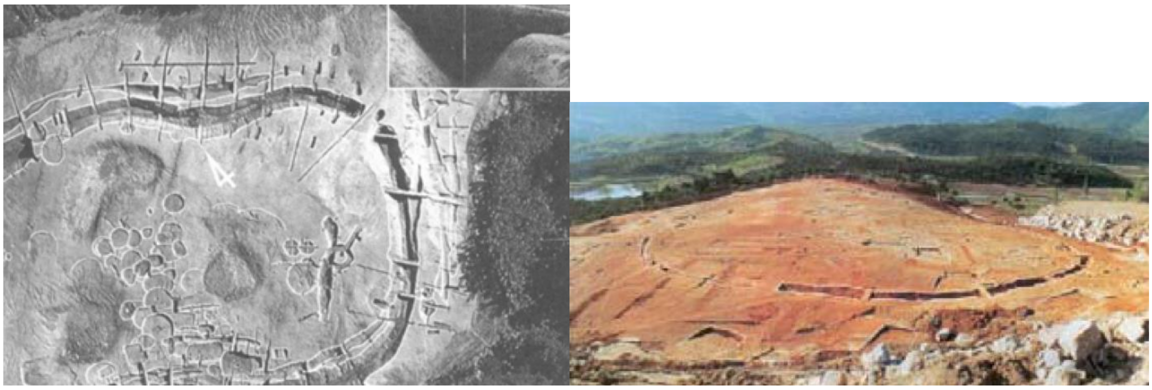


Figure 8: Photograph of the excavated site of ancient village of Gumdan-li (Left) and Ulsan Seosang-dong (Right) surrounded by a ditch. [7]

Secondly, the ditches were an efficient draining system for the whole village. Since they were dug at the lower part of the sloped hill, water flowed into these ditches through natural gradation. Also, since these ditches were dug deeper than the pit houses by one meter or so, any excess rain water that was absorbed into the ground ended up in these ditches. The water collected in the ditch was used to irrigate crops in the nearby farms or further prevented invasions by acting as a moat [7].

2.1.1.2 RAMMED EARTH

Large scale earthen constructions were built mostly for military fortification to surround and protect the city from invasions as shown in Figure 9 and Figure 10. As written in Figure 11, R. Azuar Ruiz explains the reason for selection in his ”Las tecnicas constructivas en Al-Andalus. El origen de la silleria y del hormigon de tapia” (Construction techniques of the Islamic Spain. Origin of the ashlar masonry and rammed earth wall) [8]. Although masonry is an iconic historic fabric for castles and walls are, earth was preferred over masonry due to its economic feasibility and ease of construction. Cutting, transporting, and placing large stone blocks on top of each other required the expertise of stone masons and heavy labor and planning in construction by the authority. On the other hand, building walls with rammed earth technique allowed the workers to collect soil onsite and raise them quickly with simple formwork and tamping.

Figure 9: Northern perimeter wall of Jairán at Alcazaba in Almería, Province of Almería in Andalucia, Spain. [8]

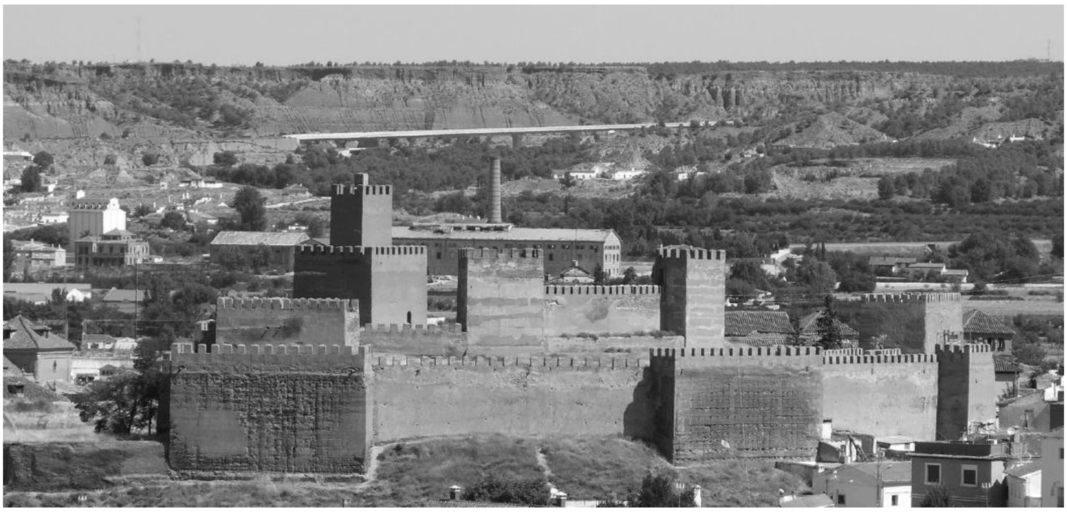


Figure 10: Rammed earth walls in the palacial area of Alcazaba in Guadix, Province of Granada, Andalucia, Spain. [8]

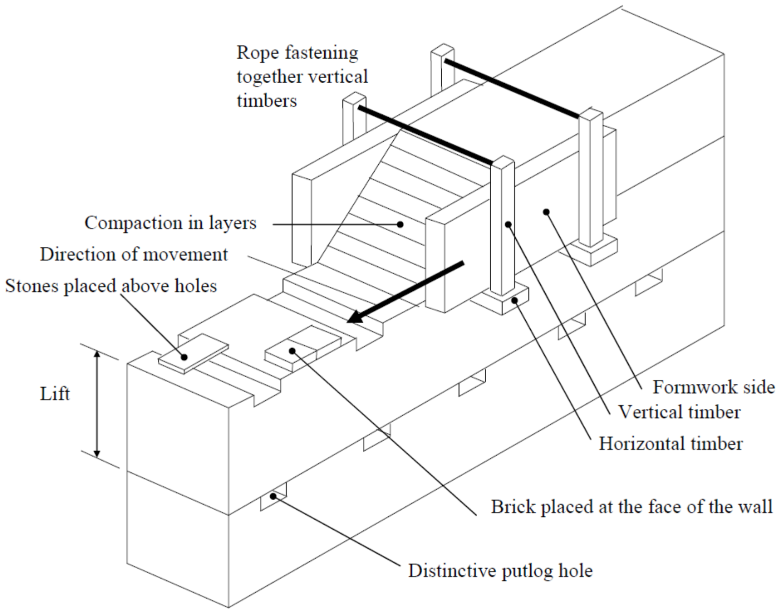
"It is evident that, for the determination of the use of one or other technique, there should be economic criteria: the use of ashlar masonry or rammed earth assumes different investment in work, time and fiscal resources. That is: the construction of a walled enclosure will be cheaper with rammed earth than with ashlar masonry. The material – earth – will be found in each locality, it does not need to be transported from distant quarries and the construction process can be executed almost without specialized skills. That is not the case with ashlar construction because this requires specialization and various processes of extraction, shaping and placement. All these issues... allow the use of rammed earth to be easily defended in the face of edicts from the State. They were able to build fortresses in a short time and with few resources; also the work could be abandoned at any time and built differently. In other words: the use and adaptability of rammed-earth construction offer highly flexible solutions."

Figure 11: Translation by Ignacio-Javier Gil-Crespo [8]

Rammed earth is a technique commonly practiced all over the world with different names and styles. Thus, its definition differs by culture. Generally in Europe and America, rammed earth is known as a technique of compacting earth between formwork to make a homogeneous mass wall. By compacting moist earth layer by layer in a temporary wooden form and then removing the forms, the earth dries until it fully gains its strength. One of the earliest documentation of this technique was by Romans who later introduced it to Southern Europe and England during their period of military campaigns [9]. Rammed earth continued to be used for building public and vernacular houses as Portugal, Spain, and France (Figure 12). Much later in 1791, this technique was reintroduced as Pisé de terre in Lyon, France by François Cointereaux who published numerous writings advocating its use for residential housings. His works were translated into many different languages and played an important role in revitalizing rammed earth in Europe [10]. He also encouraged Thomas Jefferson to adopt this technique in America, but Jefferson rejected this idea as he thought rammed earth was not fit for harsh North American climate [9].

Figure 12: Left: Drawing of a rammed earth wall depicted in the 12th century Cantigos of Alfonso X the Wise [3]; Right: Photograph of the imprints of the construction process of the tapial wall of Torres Belmejas of Alhambra Fortress

Rammed earth is known as Tapia in Spain. Tapia by definition is a rammed earth wall made with a formwork called tapial, which means quarterdeck in Spanish. The term tapia comes from the Berber word “tabiya” which means formwork and was used in Maghreb al-Aqsa, the western area of the Arab control in North Africa [11]. A formwork is typically made from two parallel long wooden boards that are placed in the shape of a box. The wooden boards are usually made of two or more lines of planks. This panel of wooden planks held together by tying the vertical timber with ropes (Figure 13) or they can be leaned against an external scaffolding of wooden poles that are fixed on the ground in certain intervals. The vertical timbers rest on horizontal timbers that pass through the wall [12].



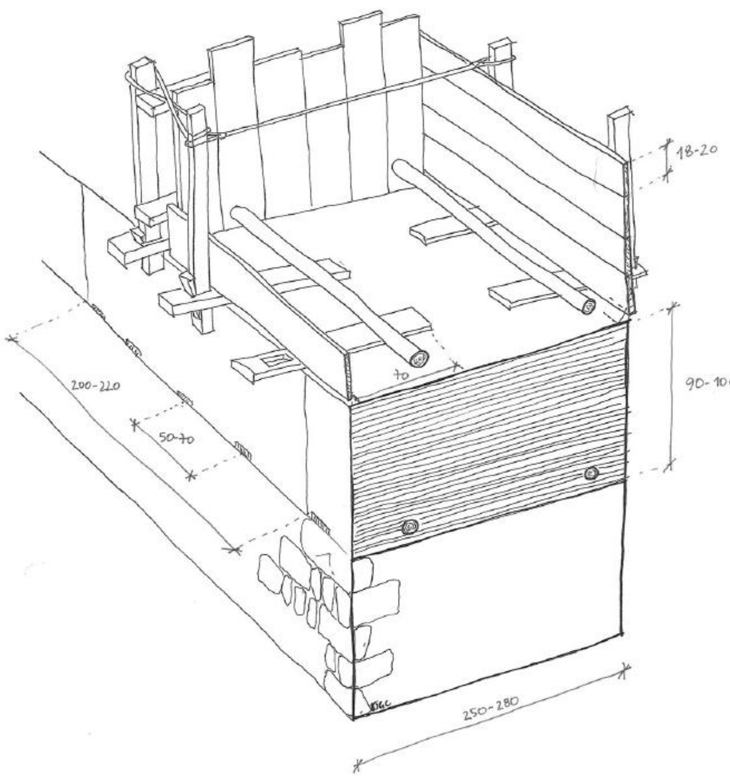


Figure 13: Features of typical historic rammed earth formwork in Spain. Top is a Christian model [12] and bottom is an Islamic model [8]

Once the formwork is assembled, it is filled with a soil mix. The mix usually comprises of a sieved soil combined with additives such as straw or lime. The layer of soil mix of an average height of 150 mm is compacted with a rammer [12]. Then, another layer is placed on top of the previous one and compacted again. This process is repeated until the formwork is completely filled and one lift is reached.

The formwork is removed and reassembled on the next level. For a smaller structure that requires one or two lifts, the wooden boards will be placed on the edge of the newly rammed earth. This results in a narrower width of the wall on the second lift. Otherwise, the wooden boards will be placed on a new horizontal timber before the next lift is rammed. Once ramming is complete, the horizontal timbers are removed and leave a putlog hole called mechinales in Spanish [12]. If no putlog hole is found in the wall, it can be assumed that the formwork was supported using external scaffolding. There is a clear difference between the formwork of Christian and Islamic fortresses in Spain. Unlike the Christian model whose horizontal timber penetrates the entire cross-section of the wall, the one of the Islamic model is disconnected in the middle and does not extend from one side to the other [8].

As much of Southern and Central Spain has an arid climate, earthen fortresses remained popular since the Roman colonization during the Punic wars until the 15th century [11]. Many large scale fortresses in Spain were constructed during the Islamic dominion of Spain from 700 to 1492 full reconquest of Iberian Peninsula as shown in Figure 14. In order to construct cheap and quick defense system, rammed earth was selected by Arabic nations and used in ad hoc manner.

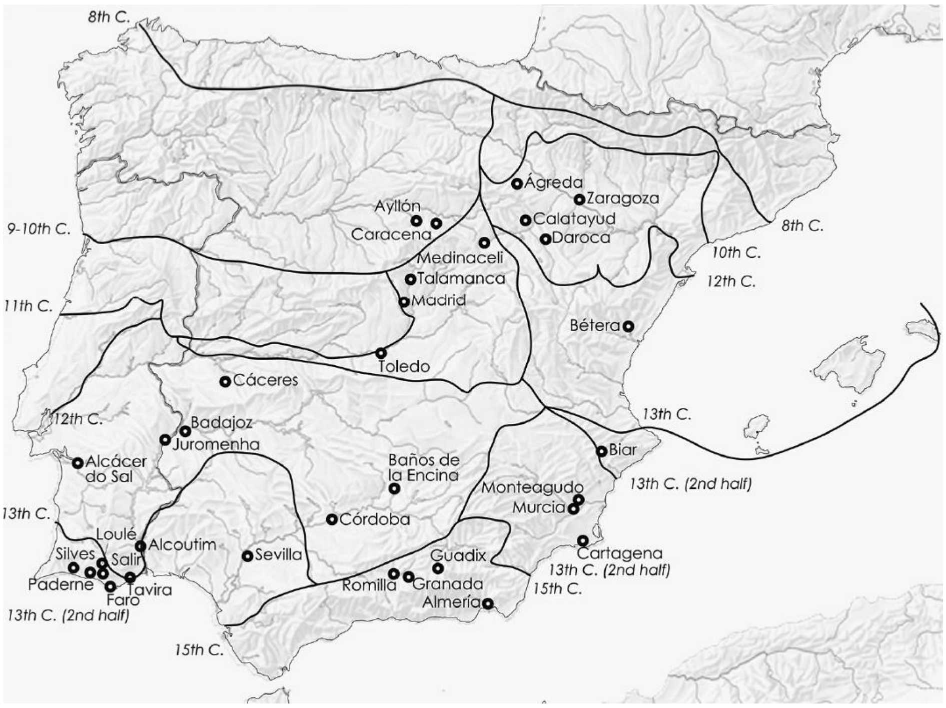


Figure 14: Map of the Iberian Peninsula with black lines marking the stages of southern expansion of the Christian forces into the Islamic territories at each century [8]

The high density of historic rammed earth structures in the Iberian Peninsula is likely due to the Muslim presence there from the 8th century onwards. Initial expansion, a period of civil war and eventual defeat by Christians led to the construction of a large number of fortifications, many constructed in rammed earth. A famous example is the Alhambra at Granada, but there are hundreds of smaller sites throughout Spain. By the end of the 15th century Christians had replaced Muslims through most of Spain, but rammed earth continued to be used in both vernacular and monumental architecture.

A survey of 60 historic rammed earth sites in Spain constructed between 967 and 1837 AD was done by Paul Jaquin, Charles Augarde and Christopher Gerrard who were researchers at the University of Durham at the time [12]. They classified rammed earth techniques in the Iberian Peninsula largely into three different groups: Calicaraedo, Tapial Real (translated as royal) and plain. Each group has distinct mix designs of varying contents of lime and earth. The first two groups of mix designs are identified by Gallego Roca and Valverde Espinosa in their paper “The city walls of Granada (Spain), Use, Conservation and Restoration”[12]. Each also uses a different ramming technique and produces distinctive external appearances, although it is difficult to distinguish when a face is rendered or badly eroded.

Calicaraedo is a rammed earth technique that uses a lime and earth mixture called “careado”, in which the mixture is spread along the edge formwork while the interior is filled with a strong sand gravel mixture. This allows the wall to become more durable at its exterior due to its high lime content and still maintain reasonable strength through its inner core of sand gravel. The external face is usually plastered with lime regularly to prevent moisture ingress and to protect the wall from further erosions. It has been observed in a number of sites that the wall core erodes quickly when the lime surface is removed.

Tapial Real rammed earth is also known as Arab-concrete. It is a rammed earth technique with a mix design consisting of lime to earth ratio of 1:3. Due to the high lime content in the mix, the wall does not require regular plastering and makes it more expensive than other mix designs. It has been used in the walls constructed in the 8th century in Alcazaba, Cadima in Granada.

Plain rammed earth is almost indistinguishable from Tapial Real by naked eye. However, it has significantly lower lime content than Tapial Real mix and closely resembles the unstabilized rammed earth technique used at Eden Project in Cornwall, UK.

Figure 15: Map of rammed earth sites in Spain visited by researchers at the University of Durham [12]

Another database compiling information of 230 restored rammed earth sites in the Iberian Peninsula were created by researchers at the Polytechnic University of Valencia [11]. Quite a number of rammed earth techniques exist in Spain and Portugal are shown in Figure 15. Rammed earth built between brick masonry buttresses (Technique 4) and with stone and lime mortar infill (Technique 5) seems to be most common in Spain. Other techniques include rammed earth built between forms, reinforced with layers of lime mortar, reinforced with layers of brick bonded with lime mortar, built between brick masonry buttresses, with stone and lime mortar infill, reinforced with bricks on outer surface, with ashlar masonry basement, coffered masonry with lime mortar, with gypsum mortar, reinforced with layers of adobe masonry bonded with lime mortar. So far ten techniques have been identified and since the research is ongoing, more techniques might be discovered in the near future.

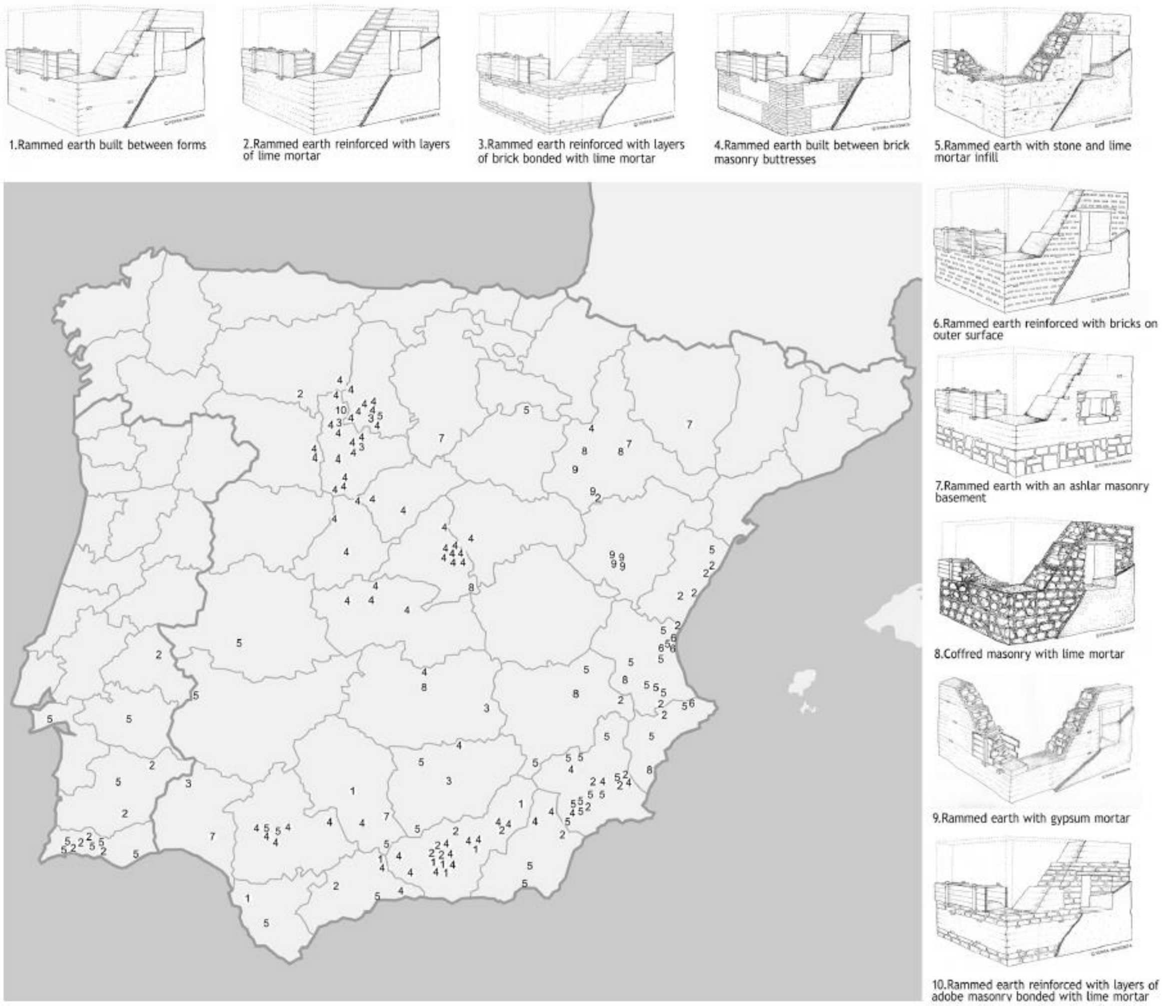


Figure 16: Map of location of different rammed earth construction techniques identified in the Iberian Peninsula [11]

In North East Asia, rammed earth has two different definitions (Figure 17). Ancient Chinese defined hangtu (夯土) as tamping the earth with a rammer without the use of formwork. If a wooden formwork was used, it was called banzhu (版築).

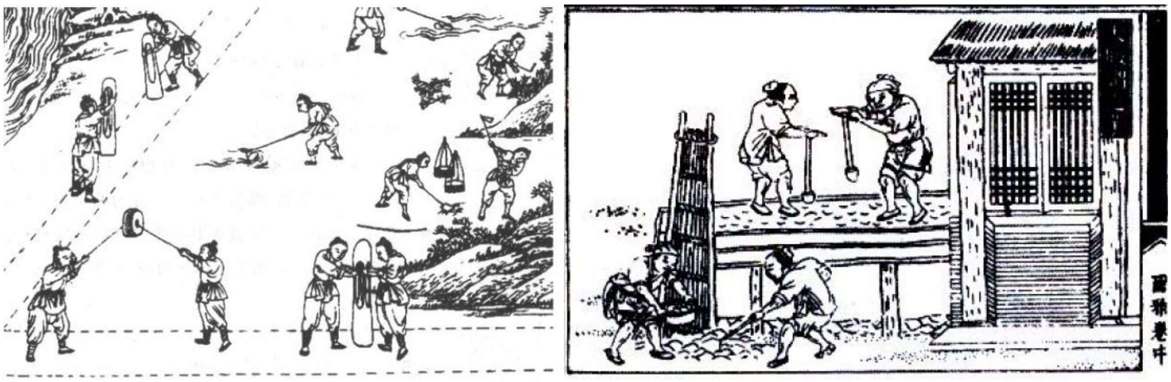
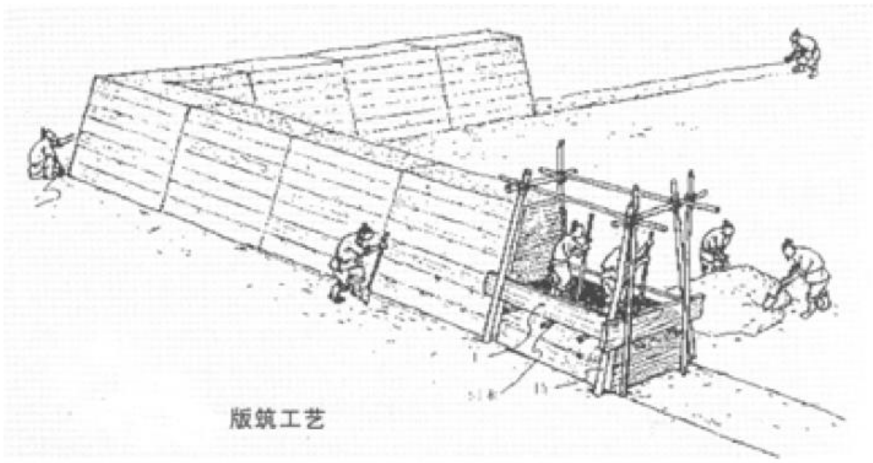


Figure 17: Ancient drawing of hangtu (left) and banzhu (right) [7]

Hangtu was mainly used for preparing the foundation by removing any vegetation and flattening the ground before building large structures such as a pagoda. Banzhu, although the term is frequently misused as hangtu, should involve a wooden formwork [13]. Figure 18 shows two different types of wooden formwork used in China in which one has a trapezoidal cross-section whose width of the wall decreases along the height and the other with a constant rectangular cross-section. The right image closely resembles the Spanish formwork (Figure 13) with a wooden tie instead of a rope to hold two boards together.



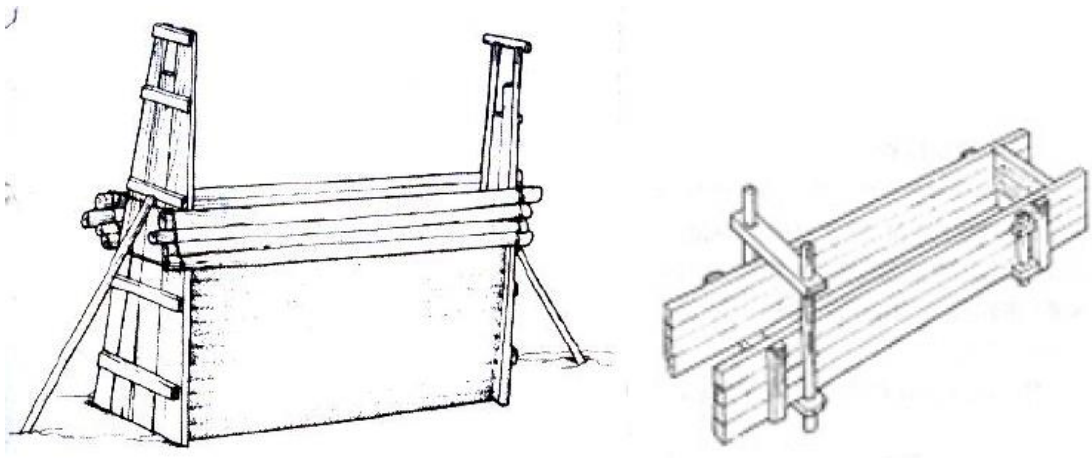


Figure 18: Ancient Chinese drawing of banzhu formwork. Top drawing shows how a wall is constructed using the formwork while the bottom left and right drawing shows a formwork with a trapezoidal and rectangular cross-section. [7]

Not much is known about heuk dajim (흙다짐), a rammed earth technique in Korea. This term is a literal translation of rammed earth used by some scholars as “heuk” means soil in Korean and “dajim” means rammed or smoothened out. Similar to the problem in China, most scholars confuse the concept of ramming with and without a formwork [13]. Like hangtu, dalgujil (달구질) is the process of ramming the earth with a long hammer called dalgo (달고) as shown in the left image of Figure 19. This hammer is also commonly referred to as julgo gongi (절구공이), a tool for grinding grains, as they are similar in shape. If a wooden formwork was used, the technique should be called panchuk (판축) which is a korean translation of the chinese word banzhu.

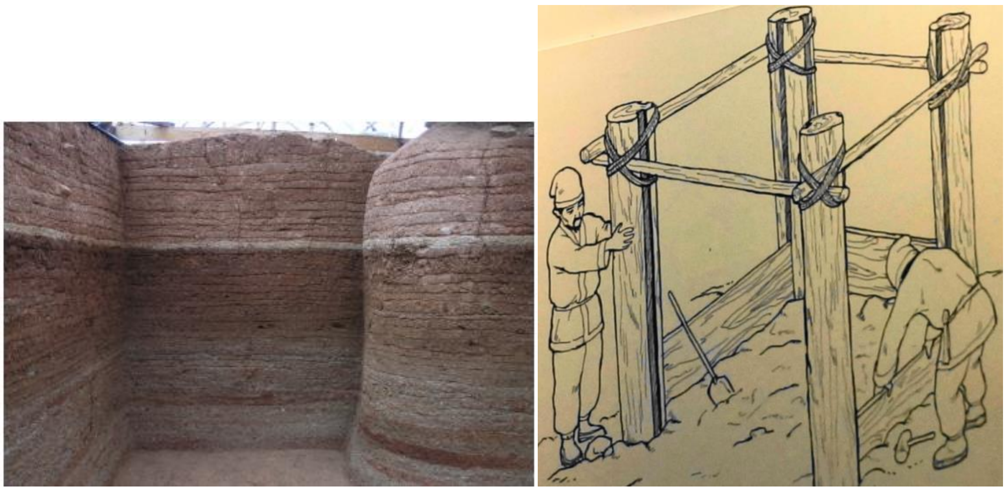


Figure 19: Left: Image of foundation work done by dalgujil under a stone pagoda in Iksan; Right: Reconstructed drawing of Panchuk from Baekje dynasty in Korea. [13]

The right image of Figure 19 shows how panchuk might have looked like during the Three Kingdom Period in Korea. A formwork is made of wooden board slid into a hole in each of the wooden poles which are connected to one another by wooden beams and fastened by a rope. A soil is put inside and compressed by dalgo until it reaches a certain height. This system seems more efficient than the traditional Spanish formwork as the configuration does not have to be altered until 5 or 6 lifts are reached and because it does not leave any trace of putlog holes.

Major earthen fortresses called tosung (토성) shown in Figure 20 were constructed by Baekje dynasty which ruled the left southern region of Korea during the Three Kingdoms period. Baekje maintained a friendly relationship with China as a major economic trading partner and a political alliance against the other two Korean kingdoms of Goguryeo and Silla. It is assumed and widely accepted by scholars that Baekje adopted the rammed earth technique from China which was originally developed to raise a fortress in the open plain of certain parts of China [14]. Baekje later modified it to fit their needs and many fortresses are located near a plain near a large, wide river or a hillside slope. On the contrary, most fortresses of Goguryeo in the northern region of the peninsula were constructed with rubble stone masonry collected from abundant quarries in the high mountains. This suggests that the choice of material for fortification walls was dictated by local availability. Main type of soil used for construction was called Hwang-to (황토) which is a typical mud loam that is rich in silt and low in clay and sand [15]. A detailed research on the property of this soil is explained by Hyeju Hwang in his "Strength characteristics of rammed Earth using hwangto Binder".

Figure 20: Map of the major earthen fortresses built with rammed earth technique in South Korea [7]

Due to the heavily rainy climate of Korea in the summer season, earthen fortresses eventually evolved into a mixed earth and stone structure or stone fortresses with the advent of stronger tools and a unification of the Korean peninsula by a single dynasty of Goryeo and Chosun [16]. Figure 21 shows the present remain of the sloped walls of Pungnap and Mongchon fortresses. These remains are covered with grass and trees and are hard to distinguish from natural hills as the earthen walls are no longer exposed.

Figure 21: Remain of walls of Pungnap (left) [17] and Mongchon (right) [18] fortress in Seoul, Korea

2.1.2 Earth Structure in Pieces

2.1.2.1 Cob

Cob is a technique of mixing the subsoil with fibers and water and placing them on top of each other as pieces of ball or lump to make a structure [19]. Although the process might appear similar to rammed earth, it is distinguished by its use of wet soil and absence of formwork.

The name “cob” has an Anglo-Saxon origin and is also referred to as clob in Cornwall, witchert in Buckinghamshire, mud walling in the Midlands, clay dad in Scotland, and clom in Wales [20]. Abundance of names inside UK indicates that this technique was and still is widely practiced in the UK. In fact, cob is one of the most representative building typologies of British vernacular architecture.

Cob construction can also be found abundantly in other parts of Europe with a name bauge in France, weller in Germany, and terre cue or massone in Italy [20]. However, cob techniques called pared de mano, muro amasado, and tierra apilada are not so common in Spain. Pared de mano by translation means heaped up earth and the name muro amasado comes from the act of kneading and shaping the balls by hand [21]. A variation of this technique is called chamizo which is a wall kneaded earth placed on a timber or cane substructure, so it should be classified as earth with half-timber filling in the later section.

Subsoil is the layer of material below the organic top soil and above the bedrock. It is believed that a good mix for cob construction is 30 to 40% gravel, 25 to 30% sand, 10 to 20% silt and 10 to 25% clay [20]. Once the subsoil is extracted from the ground, vegetable fibers such as straw or grain is added to create a clayey mixture that can be easily shaped. They are mixed well together with feet or a shovel on the ground as shown in Figure 22. Water is added if deemed necessary by the builder depending on the moisture content of the subsoil. Fibers play an important role as a degreaser and reinforcement in preventing cracking and retractions of the structure during the drying process.

Figure 22: Left: Mixing of subsoil with feet; Right: Adding straws with a shovel in UK [20]

The mixture is then kneaded and shaped into a ball (or pelladas in Spanish) as shown in Figure 23. These balls are piled on top of each other to form a layer of wall with an average thickness of 50 to 200 cm. There is a maximum allowed height of 50 to 60 cm per day for these walls to allow the layer to gain sufficient strength and bonding overnight before a new layer of material can be placed on top of it [21]. The bonding is ensured by water and fiber and does not require the use of mortar or other additives. Since the layer does not have to be rammed as it is naturally compacted by the weight of the material alone, this technique is less labor intensive than the rammed earth technique.

Figure 23: Left: The shaping of a ball [22]; Right: Constructing a cob wall on a masonry base in France [21]

The cob wall is easily attacked by insects and animals, rain, and wind. Therefore, it is usually built on a masonry foundation in order to avoid the issue of a rising damp and covered by a long eave of a roof to minimize contact with the rain. A surface finishing with lime is also applied to both the interior and exterior walls which give them a white color (Figure 24). Furthermore, a formwork can be used in areas with poor soil quality that does not have a good cohesive property of the mixture. Since the formwork is rarely used in cob construction, this process is less time consuming and complicated than other methods.

Figure 24: Left: Old Devon Farmhouse from 1920 with cob walls in Devon, UK [23]; Right: Cob wall with adobe reinforcements and a timber lintel in Zamora, Spain [21]

It is very difficult to find a cob wall in Korea. The name “almae heuk” (알매흙) refers to a mud kneaded and grinded on a wooden board to fix the tiles on the roof (Figure 25). The name itself suggests that cob was not used as a principal load bearing structure in Korean buildings, but more as a supplementary structure that connects the rafters and the roof clay tiles. The composition of almae heuk is approximately a 3:1 ratio of hwangto and coarse sand [24].

Figure 25: Placing of almae heuk on a roof in traditional hanok in Seoul, Korea [25]

2.1.2.1 EARTH BRICK

An earth brick is simply defined as an unbaked brick made of soil that is cut directly from a source as a block or shaped either by a hand or a mold and dried in natural air. It exists in many different forms - adobe, cut or hand shaped earth blocks, and sod.

Adobe is a sun-dried mud brick that is formed by hand or placing an earth mixture in a mold. It is one of the oldest and most well-known earthen construction techniques in the world. Archaeological evidence suggests that the buildings from the second settlement of Jericho in the Jordan Valley of the Mesopotamia region were made with mud bricks [24]. In fact, a sample of adobe was identified in the fortress of Jericho and was dated to be hand shaped around 8000 BCE. The granaries of the Ramasseum were built by Ramses II (from the 19th dynasty) around 1300 BC and are still standing in a place called Western Thebes (Figure 26) [26].

Figure 26: Left: Remains from the walls of Jericho, Turkey; Right: Granaries of the Ramasseum in Western Thebes, Egypt [26]

Records of adobe appear frequently in the tombs of the royal Egyptian families. As shown in Figure 27, a detailed process of adobe making was found inside the Tomb of Rekhmire in Thebes, Egypt [27]. The fresco depicts the workers collecting mud from the lake near the trees, mixing and molding the bricks to transporting them to the construction site.

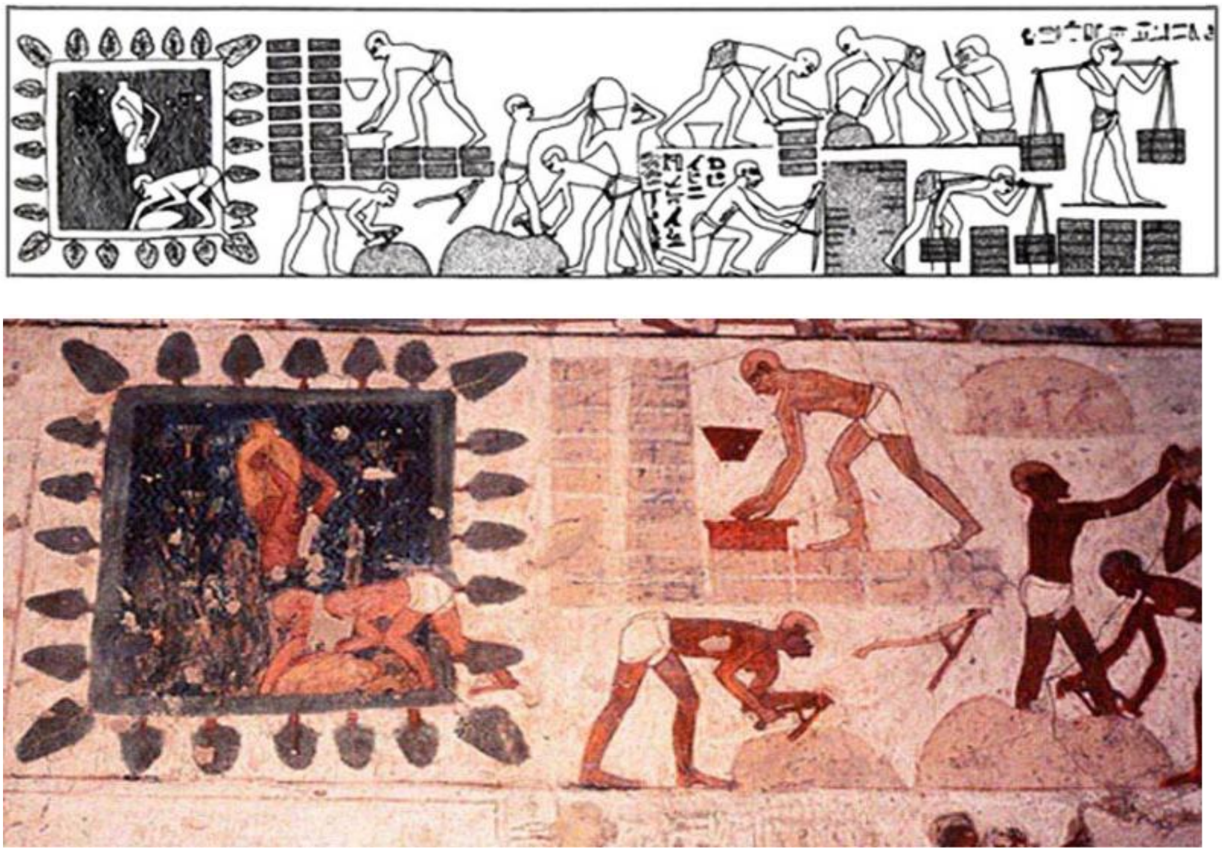


Figure 27: Adobe making shown in Fresco inside the Tomb of Rekhmire in Thebes, Egypt [27]

The oldest documentation of the adobe technique is in the Egyptian hieroglyph “dbt”, meaning brick (Figure 28). This word was transformed from “τωωβε” in Coptic to “Al-ţŭb” in Arabic. Then, during the Moorish occupation of the Iberian peninsula, "at-tûb" or "at-tûba" in Arabic (translates to a block or a brick) became “adobe” in Spanish [27]. The name has other variation in Spanish such as gasson, adoba, arrobero, de cabeza, menguao, chiquito, adogue, or zabaleta [3]. It is usually formed as a straight rectangular parallelepipeds, although a variety of other shapes are possible.

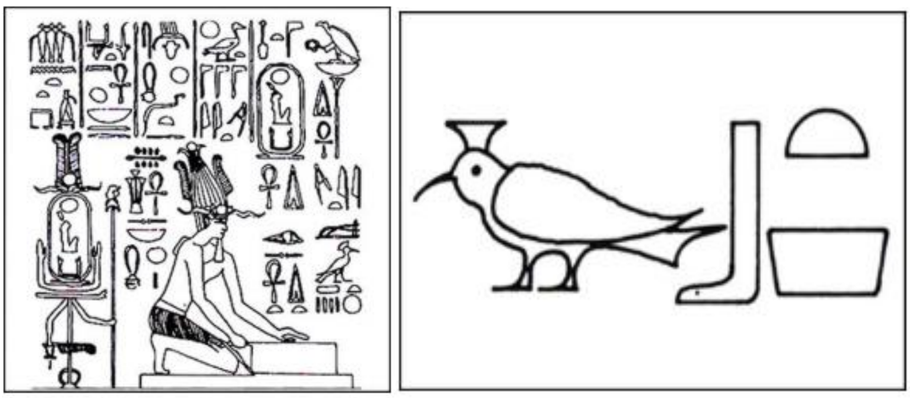


Figure 28: Left: Drawing of adobe making in Tomb of Queen Hatshepsut in Egypt ; Right: Egyptian hieroglyph “dbt” meaning brick [27]

Mineralogy of the adobe brick needs to be studied in depth as they play an important role in determining the physicochemical and mechanical properties of the structure. It is commonly misunderstood that soil used to make a traditional adobe brick usually has high clay and silt content since it is difficult to hold its shape with sand. However, it is actually made with poorly sorted soil with a uniform mixture of sand, silt, and clay. It is true that there should be sufficient amount of clay minerals present for the bricks to gain adequate strength, but excessive clay content will result in shrinkage and cracking problems. In detail, high percentage of expandable clay minerals provides strength but causes shrinkage and cracking problems. Therefore, a balanced amount of expandable (smectite and mixed layer illite-smectite) and non-expandable (illite and kaolinite) clay minerals should be present to allow the clay to act as a binder for the adobe [28].

The actual amount of mineral composition for the abode varies greatly depending on the geology of the region of construction, but it is generally accepted that an average adobe brick contains 15 to 20 percent of silt, 15 to 25 percent of clay, plus a remainder of sand and coarser particles. Maximum size of the coarse gravel usually does not exceed more than 2.5 inches. It is important to remember that local people making the adobe bricks did not spend significant time sieving the materials to achieve a proper mix proportion.

As in cob and rammed earth technique, a natural fiber such as a straw and grass or an additional binder material was sometimes mixed with soil to provide better cohesion between the soil particles (Figure 29). Straw also acts to prevent cracking while the bricks are being cured. Even if the adobe walls develop cracks over time, same soil mix for the original can be used to repair the walls. Once the structure is repaired carefully, it will be as strong as the original structure.

Figure 29: Straw present in adobe [29]

The soil mix is prepared by mixing all ingredients with hand. Then, it is placed in a simple rectangular wooden mold without a bottom (Figure 30). When the mix is still damp but hard enough to retain its shape, the mold was lifted and taken away to make more bricks. The damp brick was left in the sun to dry for the next 4 to 5 weeks until it fully gained its strength [30]. Mortar should be made of the same material as the brick spread evenly on the interface between bricks

Figure 30: Left: Lifting the mold [30]; Right: Adobe house in Villasandino, Spain [31]

A less complicated type of earth bricks were made by cutting turf or sod into a block. This was probably easier than cutting and transporting large stone blocks with limited tools and shortage of laborers in a smaller civilization. As shown in Figure 31, blocks of 7 x 7 x 14 inches of size are cut from sod or soil with grass roots with a shovel or a garden spade with a flattened blade [32]. Once they are dried, tough and durable walls can be built from these blocks.

Figure 31: Cutting of sod into blocks [32]

In tropical regions with a lateritic soil that contain carbonates, the soil was highly cohesive and was easily cut in a block to be used as a brick. This technique is still used widely in parts of southwestern United States and South America where there are plenty of swamps and boggy river bottom lands. It is hard to find these structures in Spain since there is no lateritic soil, but irregular blocks without grass called terrones or tabones (marls) are found occasionally. Terrones were commonly used to build dykes, small walls and defensive embankments in the past, especially in the northern part of the peninsula in regions of Asturias, León, Zamora, Palencia, Burgos, and Galicia [3].

On the other hand, people living in regions with a loose soil had to use topsoil and grass instead to cut blocks and stack them on top of each other. This was more popular in England with a name sod, and also used extensively in Scandinavia. In South Korea, this method was used for a different purpose for covering a tomb mound.

Earth bricks are also found in South Korea with a name heuk byukdol (흙벽돌). In the past, the government recommended city dwellings to be built with fired bricks to prevent massive fires from spreading. However, they were only used in parts of the royal palace or residence of the rich aristocrats due to scarcity of coal and firing wood. Average people who couldn't afford fired bricks turned to earth bricks as a cheap alternative.

Figure 32: Soil bricks of Fence of Hahoe Village of Korea [33]

Earth bricks were commonly used to build walls and fences in the town. As South Korea is humid in the summer, earthen walls were often reinforced with stone blocks or fragments of tiles. Figure 32 shows a typical earth brick fence in a historic Hahoe village in Korea.

Traditional Korean bricks are made in a similar fashion to adobe. However, they are not sun dried but left to dry in the shade for the first five days of curing. They should also not be exposed to heavy rain for a minimum of 10 to 14 days of curing. The usual size of the brick measure 30 cm in length, 18cm in height and 15 cm in width. Earth brick walls were often covered with a surface finishing called samhwato (삼화토), which is a mix of lime and soil [16].

2.1.3 Earth as a Component of a Structure

2.1.3.1 WATTLE AND DAUB

Wattle and daub is a technique of building a structure by weaving twigs and branches and covering the framework with mud. This might have appeared soon after mankind started digging underground to make a more permanent home. Its appearance resembles that of a primitive hut that now stands on the ground. While dug out construction used a natural ground as a wall, wattle and daub raised its wall with a mix of mud and timber structure. Excavations of ancient settlement sites such as Jericho and Catalhoyuk have revealed the use of wattle and daub structure along with earth bricks and rammed earth. There are not many surviving examples in the world since the structure is not very durable and easily destroyed by fire and many other factors.

The difference between the two techniques is that dugout construction used a process of removal to create space underground and covered the open area with a roof made of wooden rafters and vegetable fiber while wattle and daub used a process of addition by raising the structure above ground with wooden poles (Figure 33). Both typologies are found almost universally in most places of the world, yet the distribution may be affected by the level of precipitation of each region. Dugout construction is susceptible to ponding during high rainfall or floods, so it is likely that it was more widely used in arid regions.

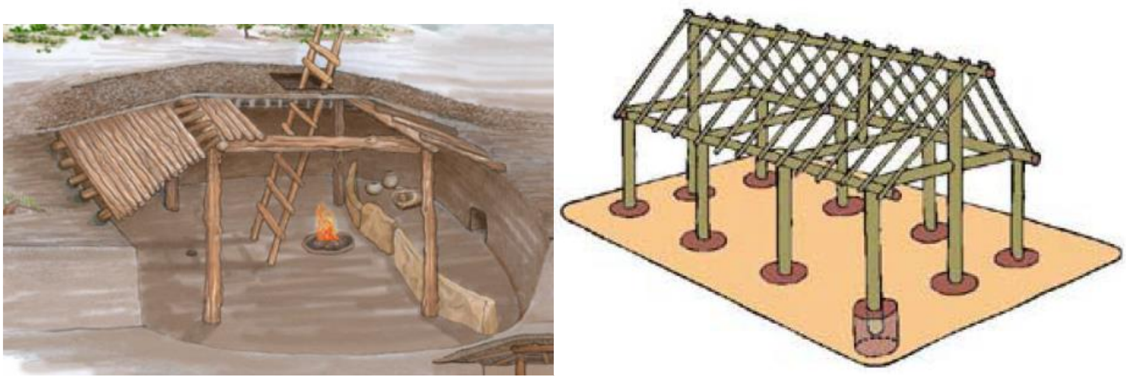


Figure 33: Framing of Underground pit house and level wattle and daub house. [4]

The name wattle and daub implies the partition of this technique into two distinct parts. Wattle is a woven framework of twigs and branches, and daub is a mud covering applied over the framework as shown in Figure 34.

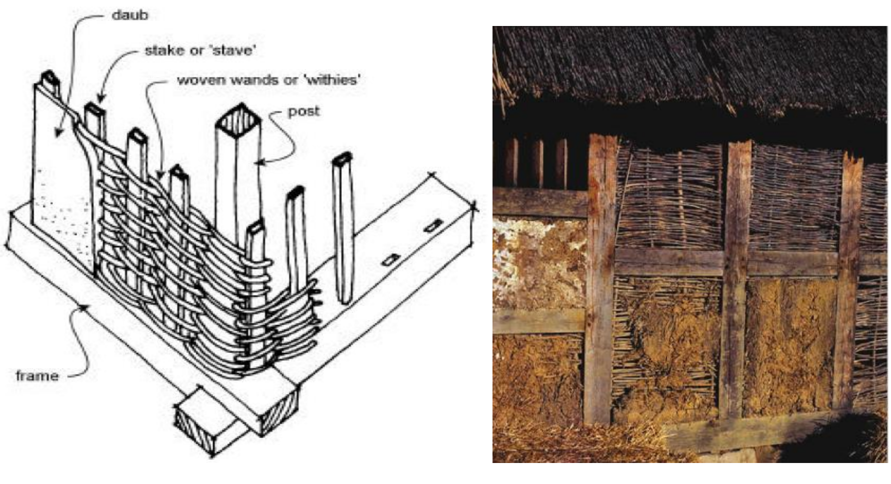


Figure 34: Drawing (Left) and Image (Right) of a Wattle and daub structure [34]

This technique was probably preferred by hunter gatherers who needed to build a quick settlement with materials easily procured from their surroundings. Lacking tools and woodworking skills to build a complicated timber structure, early nomadic villages built a simple, lightweight, but reasonably strong framework with thin tree branches and small twigs. Sometimes wattle was made with reeds or bamboo depending on local availability. Remains from Meare near Glastonbury in Somerset shows how later in the Iron age, twigs were woven on the vertical poles and wooden stakes that were driven directly into the ground or connected to the horizontal timber frame to better support the wattle [35]. This gradually evolved into a technique of half-timbering and was used widely in Europe until recently.

To prevent wind, rain, and sunlight from penetrating into their home, people plastered and filled the voids of the woven framework first with straw, moss, and leaves then later with earth. Turf and topsoil was used at first for easy layering, but they were soon replaced with mud as it was easier to press them into place.

Mud mixture for daub is similar to one used for making earth bricks but with smaller aggregates. Dung is commonly used as an organic binder to make sure the mud does not crack and adheres properly to the wood. Straw, hay, animal hair was also used as reinforcements. Daub is applied thoroughly to the wattle by hand until all the voids are filled and the surface is completely covered and smoothened out. Sometimes the wall is whitewashed with lime to better protect the house from rain and insects. Occasionally in some places, daub was found burnt. Whether this was done by accident or on purpose, it hardened the surface like fired pottery and resulted in a fire resistant and more durable structure.

Unlike other earthen construction techniques, earth is not the main structural component in wattle and daub structure. A wooden framework serves as a load bearing element while the mud is used solely as a plaster. Also, since the wattle and daub wall is very thin, it does not have good thermal mass properties like the structures built with rammed earth or earth bricks. The woven structure is also flexible and is less vulnerable to earthquakes than other earthen constructions. The disadvantages of using wattle and daub is explained explicitly by Roman scholar Vitruvius (Figure 35), which implies that the technique was developed independently by each region in Europe with minimum Roman intervention [34].

‘As for "wattle and daub" I could wish that it had never been invented. The more it saves in time and gains in space, the greater and the more general is the disaster that it may cause; for it is made to catch fire, like torches. It seems better, therefore, to spend on walls of burnt brick, and be at the expense, than to save with "wattle and daub," and be in danger. And, in stucco [plaster] covering, too, it makes cracks from the inside by the arrangement of its studs and girts [rails]. For these swell with moisture as they are daubed, and then contract as they dry, and, by their shrinking, cause the solid stucco to split. But since some are obliged to use it either to save time or money, or for partitions on an unsupported span, the proper method of construction is as follows. Give it a high foundation so that it may nowhere come in contact with the broken stone-work composing the floor; for if it is sunk in this, it rots in course of time, then settles and sags forward, and so breaks through the surface of the stucco covering.'

Figure 35: Text by Vitruvius [34]

2.2 Natural environment and its influence on earthen architecture

Natural environment is one of the most influential factors that shape the traditional earthen architecture. Earth is one of the most commonly used materials throughout the history and nature has pushed its inhabitants to optimize their resources and develop their unique construction techniques in order to adapt to and overcome their climate, temperature, precipitation, geographical features, soil distribution, and earthquakes.

2.2.1 Climate, Precipitation, and Geographical features

There are few methods to divide the regions of the world into different climate zones. Koppen-Geiger is the most widely accepted climate classification method. According to this methodology, the world can be divided into roughly five regions of Tropical, Arid, Temperate, Cold, and Polar [36]. Figure 36 shows the map of the areas with tradition of earthen construction, and it is quite clear that the majority of the cultures in all continents have passed down the tradition of building with earth. Figure 37 shows that earthen architecture has thrived and has been passed down in most areas of the globe inhabited by people despite the drastic difference in their climate. This means that even if the climate plays a role in deciding the shape, location, configuration of the traditional buildings, it cannot limit the type of material used in construction.

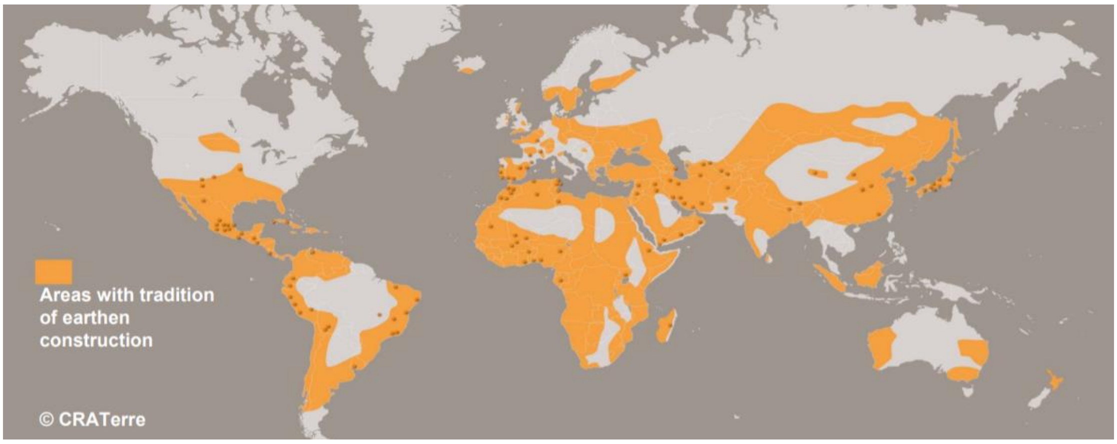


Figure 36: Map of the areas with tradition of earthen construction [2]

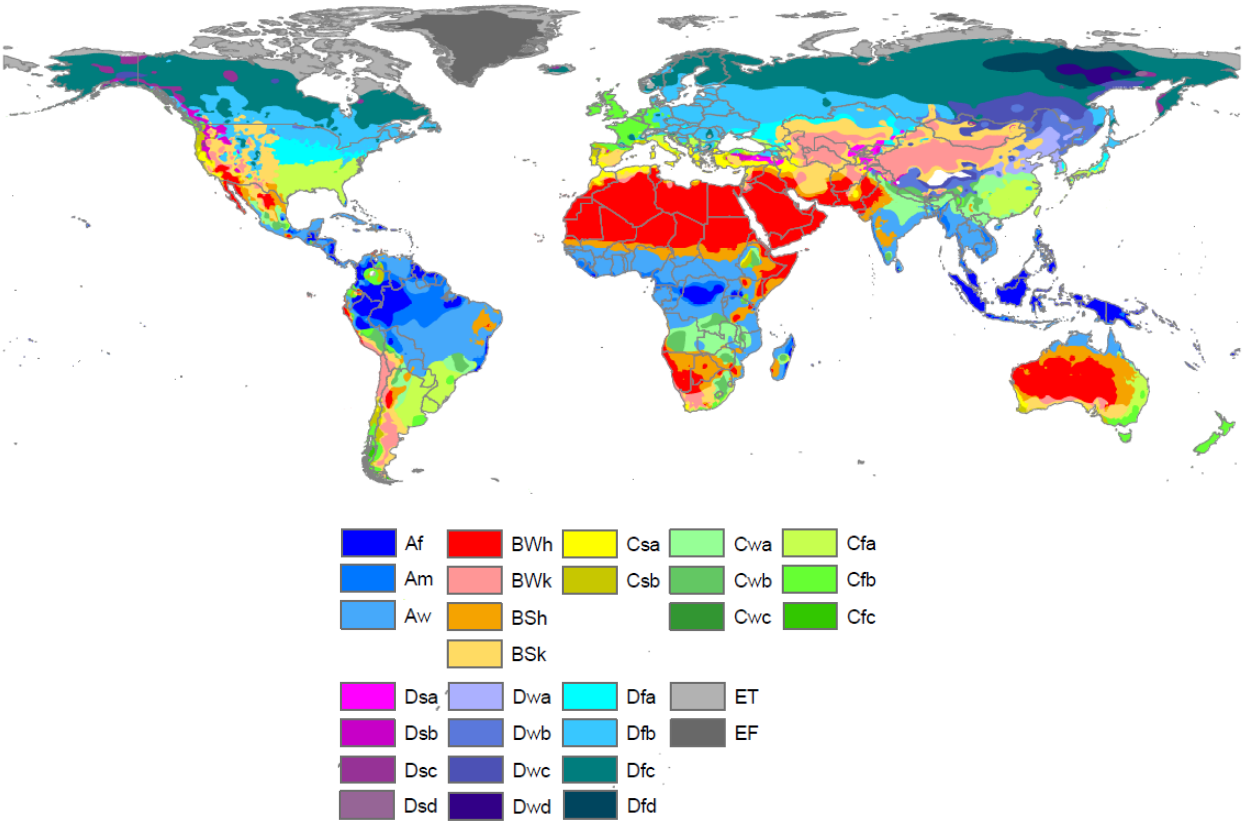


Table 1. Description of Köppen climate symbols and defining criteria.

1st	2nd	3rd	Description	Criteria*
A			Tropical	$T_{cold} \geq 18$
	f		- Rainforest	$P_{dry} \geq 60$
	m		- Monsoon	Not (Af) & $P_{dry} \geq 100 - MAP/25$
	w		- Savannah	Not (Af) & $P_{dry} < 100 - MAP/25$
B			Arid	$MAP < 10 \times P_{threshold}$
	W		- Desert	$MAP < 5 \times P_{threshold}$
	S		- Steppe	$MAP \geq 5 \times P_{threshold}$
		h	- Hot	$MAT \geq 18$
		k	- Cold	$MAT < 18$
C			Temperate	$T_{hot} > 10$ & $0 < T_{cold} < 18$
	s		- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
	w		- Dry Winter	$P_{wdry} < P_{swet}/10$
	f		- Without dry season	Not (Cs) or (Cw)
		a	- Hot Summer	$T_{hot} \geq 22$
		b	- Warm Summer	Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a or b) & $1 \leq T_{mon10} < 4$
D			Cold	$T_{hot} > 10$ & $T_{cold} \leq 0$
	s		- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
	w		- Dry Winter	$P_{wdry} < P_{swet}/10$
	f		- Without dry season	Not (Ds) or (Dw)
		a	- Hot Summer	$T_{hot} \geq 22$
		b	- Warm Summer	Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a, b or d)
		d	- Very Cold Winter	Not (a or b) & $T_{cold} < -38$
E			Polar	$T_{hot} < 10$
	T		- Tundra	$T_{hot} > 0$
	F		- Frost	$T_{hot} \leq 0$

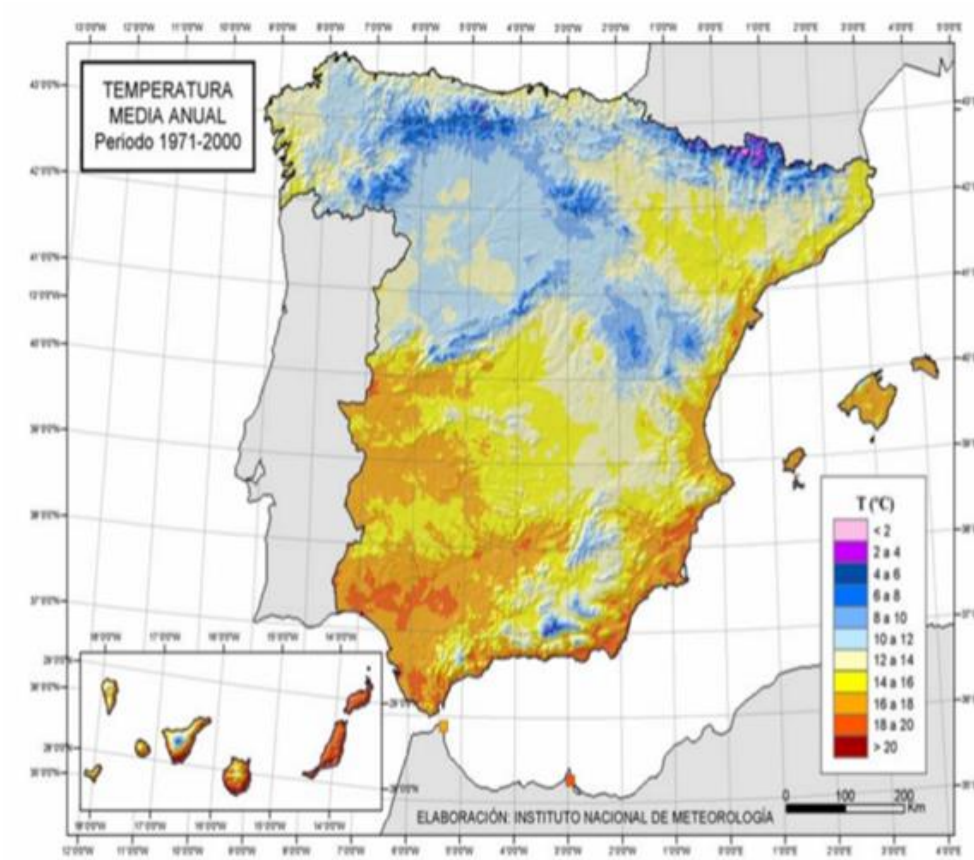
*MAP = mean annual precipitation, MAT = mean annual temperature, T_{hot} = temperature of the hottest month, T_{cold} = temperature of the coldest month, T_{mon10} = number of months where the temperature is above 10, P_{dry} = precipitation of the driest month, P_{sdry} = precipitation of the driest month in summer, P_{wdry} = precipitation of the driest month in winter, P_{swet} = precipitation of the wettest month in summer, P_{wwet} = precipitation of the wettest month in winter, $P_{threshold}$ = varies according to the following rules (if 70% of MAP occurs in winter then $P_{threshold}$ = 2 x MAT, if 70% of MAP occurs in summer then $P_{threshold}$ = 2 x MAT + 28, otherwise $P_{threshold}$ = 2 x MAT + 14). Summer (winter) is defined as the warmer (cooler) six month period of ONDJFM and AMJJAS.

Figure 37: Koppen Classification map and index [36]

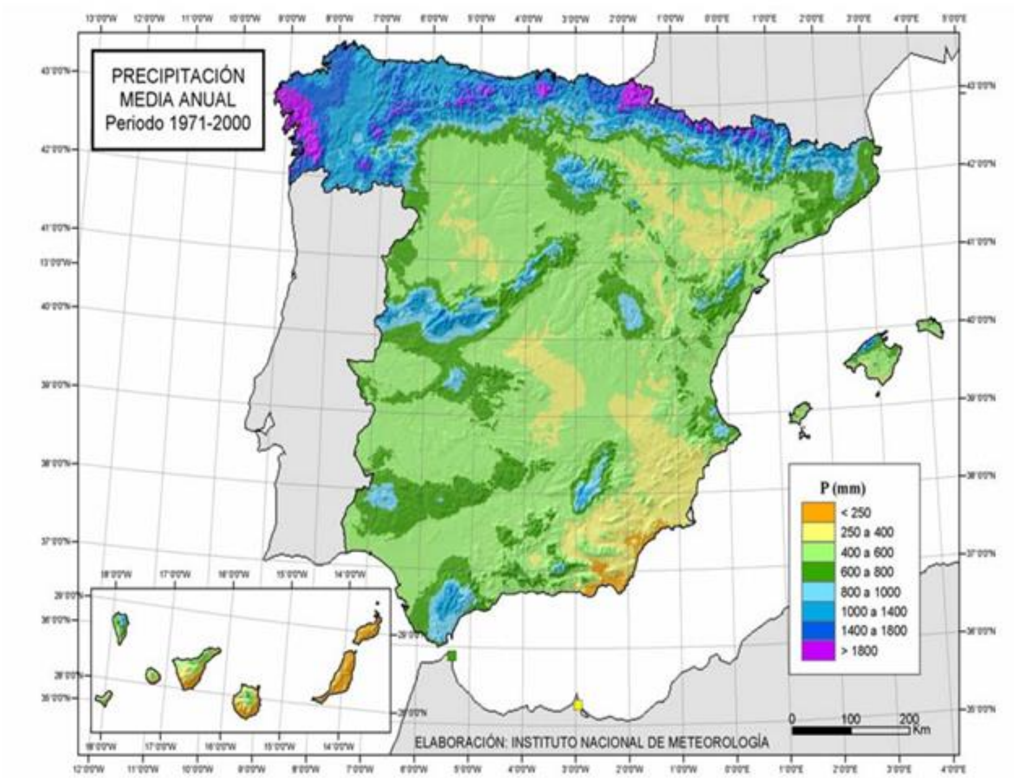
Although earthen constructions built with different techniques are found all over Spain, some techniques appear more frequently than others in each region. This uneven distribution is a result of choices made by the inhabitants of the land who were influenced by complex interaction of culture, technology, and nature over the history.

Most areas of the Iberian Peninsula are temperate and have a dry summer while its northern part having a bit of warm summer. The peninsula is made up of large plains along its coast and several mountainous regions that extend from northern to central to southern regions of Spain (a of Figure 38). The northern and western edge of the peninsula is subject to high precipitation (c of Figure 38).

a)


TEMPERATURA
MEDIA ANUAL
Periodo 1971-2000
T (°C)
< 2
2 a 4
4 a 6
6 a 8
8 a 10
10 a 12
12 a 14
14 a 16
16 a 18
18 a 20
> 20
ELABORACIÓN: INSTITUTO NACIONAL DE METEOROLOGÍA

b)


PRECIPITACIÓN
MEDIA ANUAL
Periodo 1971-2000
P (mm)
< 250
250 a 400
400 a 600
600 a 800
800 a 1000
1000 a 1400
1400 a 1800
> 1800
ELABORACIÓN: INSTITUTO NACIONAL DE METEOROLOGÍA

c)

Figure 38: a) Geographical map of Spain; b) Map of annual mean temperature (°C) and c) Map of annual mean precipitation (mm) of Spain from 1971-2000 by Spanish Meteorological Institute [37]

A study was carried out by team of researchers from the Polytechnic University of Valencia [38] in which they tried to find a correlation between the geographical distribution of earthen buildings and various factors such as climate, precipitation, altitude, and geology of regions in Spain.

According to their survey, despite the varying climates and temperatures (b of Figure 38), rammed earth construction is found almost everywhere in Spain and South of Portugal. It covers a broad area between the South of Andalusia and the Northern sub plateau (Figure 38). However, few of these buildings exist in the North and Northwest since high rainfall in this region (c of Figure 38). As the durability of rammed earth buildings are severely affected by rain, especially when there are not sufficient protections such as a sloped roof or lime washing against water infiltration, none of the localized cases from the survey are in areas with relatively high precipitation. They are also not found in steep mountainous areas (a of Figure 38) such as the Pyrenees, the Central Mountain System or the Cantabrian Mountains [38].

Figure 39: Location of Rammed Earth Construction in the Iberian peninsula [11]

Adobe construction can also be found in most of the Iberian Peninsula except the Cantabrian corridor, the South of the Peninsula, and the east of Portugal [38]. The study explains that this typology appears frequently in the Northern half of the peninsula where mean temperatures are lower than in the South (b of Figure 38). Adobe constructions are found at varied altitudes, from the coast (Central region of Portugal or Valencia) to areas of considerable altitude (a of Figure 38) such as the Iberian Mountainous System [38]. However, similar to the rammed earth buildings, these earthen constructions are not common at the high and steep mountainous areas. Furthermore, the use of adobe is limited in the northern and western regions with a higher rainfall.

In contrast, half-timber buildings are found in mountainous areas with an average altitude above 600m and cold climates (a of Figure 38). They are found in areas with plentiful wood needed for timber construction except in the Northern plateau in Castille and León [38]. Half-timbering are also found in cold climates or areas with high rainfall such as the north of the Iberian Peninsula and Portugal and in Sierra de Gredos. Northern Spain receives between 800 to 1400 mm of rainfall every year (c of Figure 38), which provides optimum condition for trees to grow.

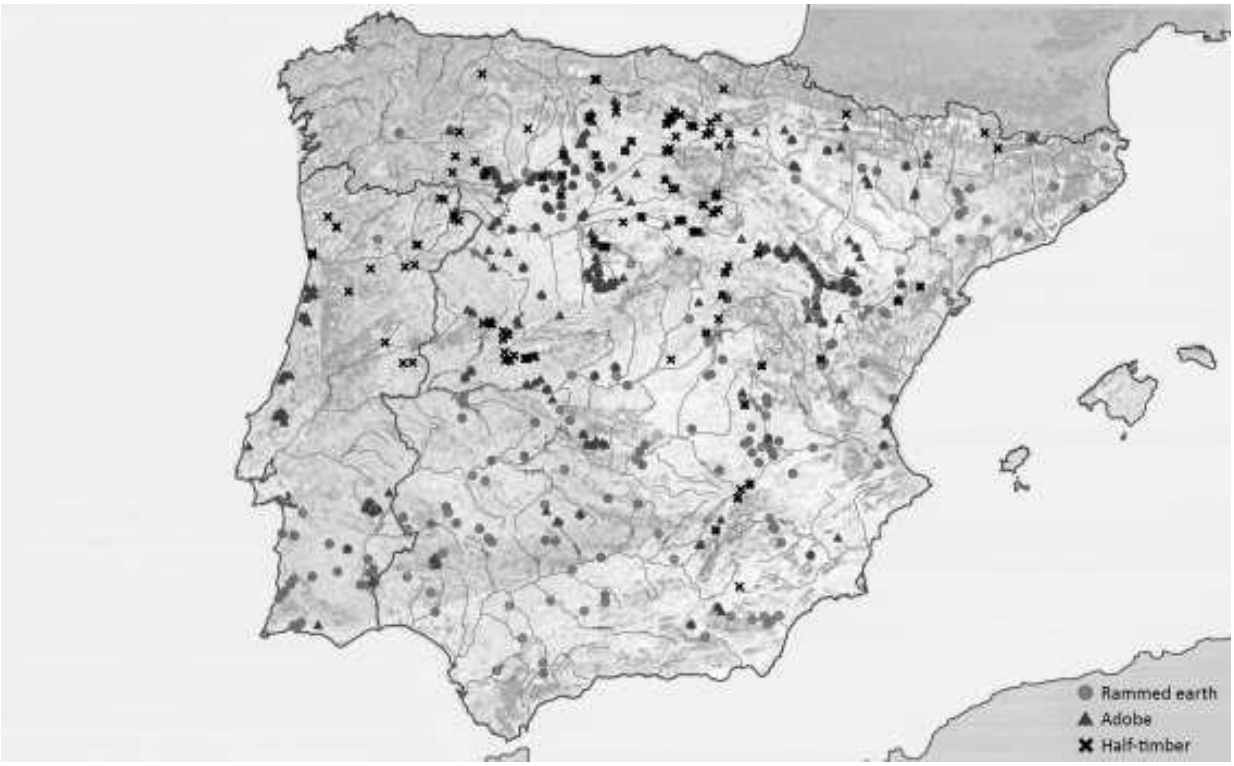


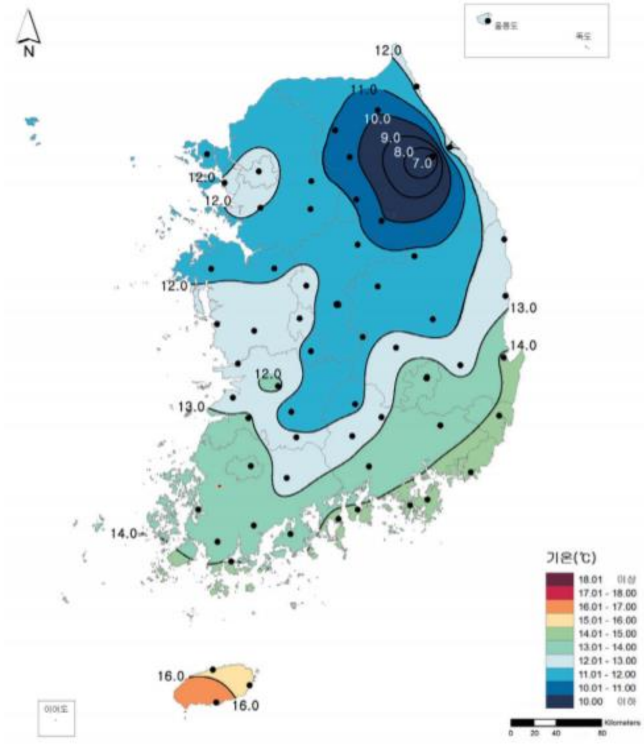
Figure 40: Location of earthen buildings built with three main techniques of rammed earth, adobe, and half-timber in the Iberian peninsula [38]

Finally, the study also presents a case analysis of distribution of earthen constructions in the Iberian Peninsula by geographical features such as rivers, plains, hills, mountains, and dry valleys. The results showed that the highest number of earthen constructions is found near river valleys (40%) where people can have an easy access a source of water for living and clay sediments to build their settlements [38].

The second most frequent geographical feature where earthen constructions were found was near a plain (28%) where rain-fed crops were harvested in farms for large settlements. Areas near hills (15%) and mountains (12%) did contain a number of earthen constructions, but these buildings were usually supplemented with larges stones that were easily procurable from these features. Finally, dry valleys (5%) the least amount of earthen construction most likely due to the fact that large settlements avoided areas with limited access to water.

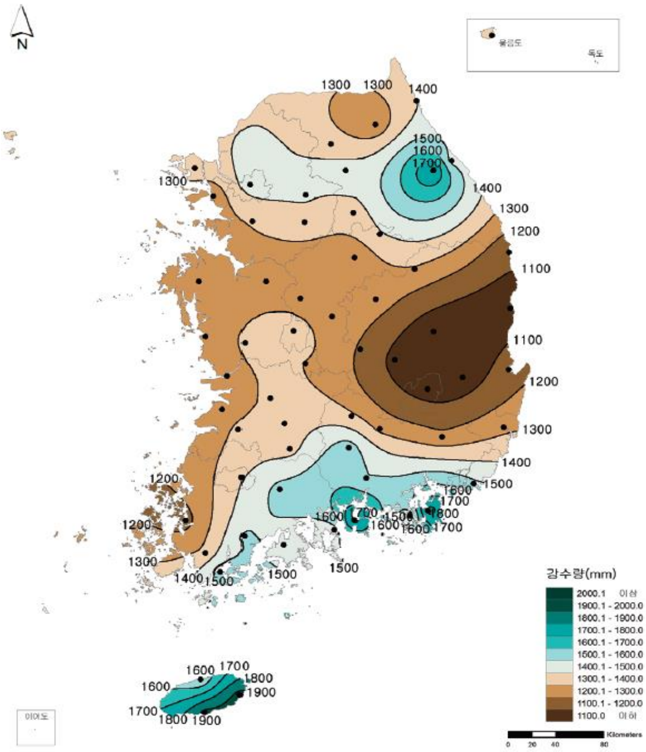
There is no existing survey on the identification and distribution of different typologies of historic earthen constructions in South Korea like the case study carried out by Spanish researchers. It is only possible to estimate their distribution by carefully observing the geography of the Korean peninsula and drawing from the example of Spain.

a)



b)

그림 2-1. 우리나라의 연평균기온(1981~2010년)



c)

그림 2-8. 우리나라의 연강수량 분포(1981~2010년)

Figure 41: a) Geographical map of South Korea; b) Map of mean annual temperature (°C) and c) Map of mean annual precipitation (mm) of South Korea from 1981-2010 by Korean Meteorological Administration [39]

South Korea is highly mountainous with 70 percent of the land covered by mountains (a of Figure 41) and receives heavy rainfall with an annual mean precipitation of 1308 mm (c of Figure 41), which is much higher when compared to 665 mm of Spain. Monsoon season hits the summer.

Most areas of the Korean peninsula are cold with dry winter while its southern coastal tip is temperate with hot summer (Figure 42). This shows that the Iberian Peninsula generally has a warmer climate than the Korean peninsula. This is also supported when looking at the annual mean temperature of each country recorded by their respective meteorological institute (b of Figure 38 and b of Figure 41).

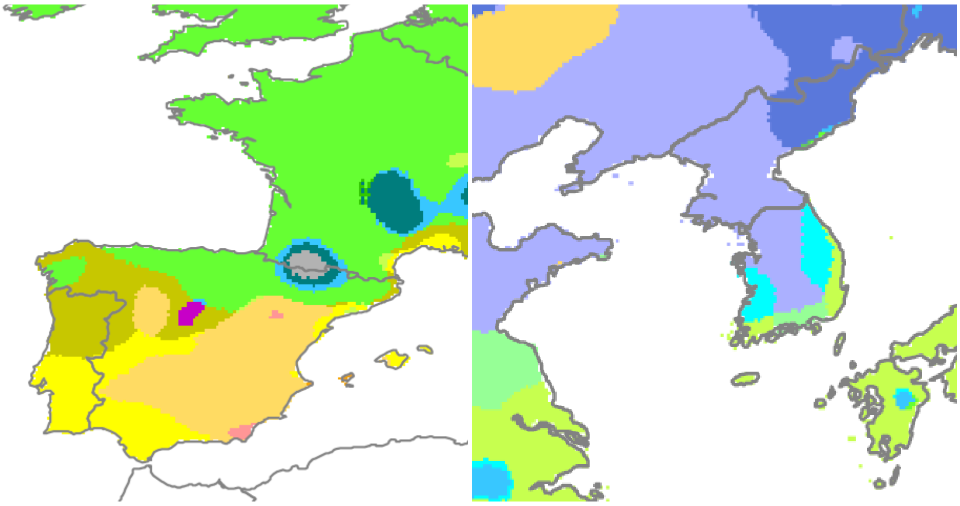


Figure 42: Zoomed in map of Koppen Climate Classification of Spain and South Korea [36]

Literature review suggests that rammed earth may be the most commonly employed techniques in the Korean peninsula. Half-timbering can also be found quite frequently while there are not so many adobe used for construction. Yet there has not been any detailed surveys conducted in Korea that supports these claim. Assuming that natural factors such as climate, precipitation, altitude, and geographical features play a huge role in deciding the use and distribution of earthen constructions in South Korea, it is likely that rammed earth is used in most regions except in the coastal plains of southern most regions that receives excessively high amount of rainfall. The eastern half of the peninsula should find a considerable number of half-timbered houses along the mountainous areas with colder temperatures.

2.2.2 Regional Soil Distribution

Soil plays an important role as a prime ingredient of earthen constructions. Every earthen building is a product of unique mix designs and construction techniques, and some are more affected by the property of the soil than the others. Thus, it is important to study the characteristic of the local soil to better understand how it shaped the way people chose certain techniques and mix designs over others.

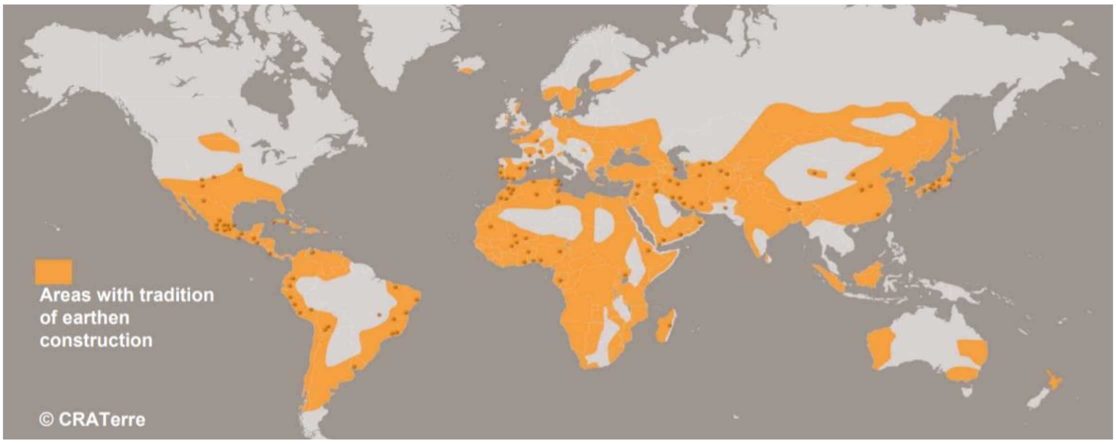


Figure 43: Map of the areas with tradition of earthen construction [2]

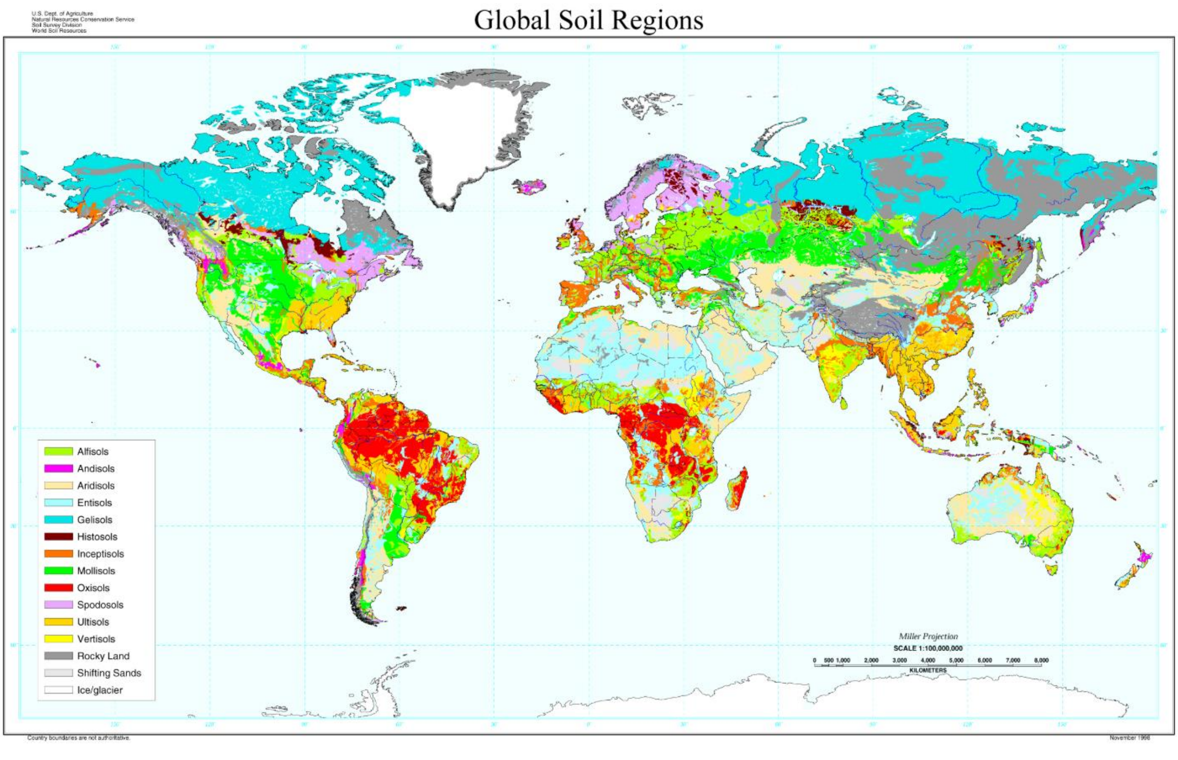


Figure 44: Global soil regions map by USDA [40]

Comparing the map of the areas with tradition of earthen construction (Figure 36) and the global soil regions map (Figure 44) may reveal something that was not possible to observe by comparing the former with the Koppen classification map of climates in the world. It is evident that no earthen constructions can be found on a rocky land (gray) or on land with gelisols (Darker blue) that contain permafrost in Russia and Canada. There is a scarce distribution of earthen buildings on land with highly acidic spodosols (magenta) in North America and Scandinavia and oxisols (red) in the tropical rainforest of Brazil and Central Africa that contain a high percentage of oxides.

Looking closer in the map, the Iberian and the Korean Peninsula shows a stark contrast in their soil distribution. While most of the Iberian Peninsula is dominated by the presence of Inceptisols (orange) and few Alfisols (light green) and Entisols (light blue), the Korean Peninsula is covered with Entisols (light blue) and some Ultisols (gold) along the western coast and rocky land in the north.

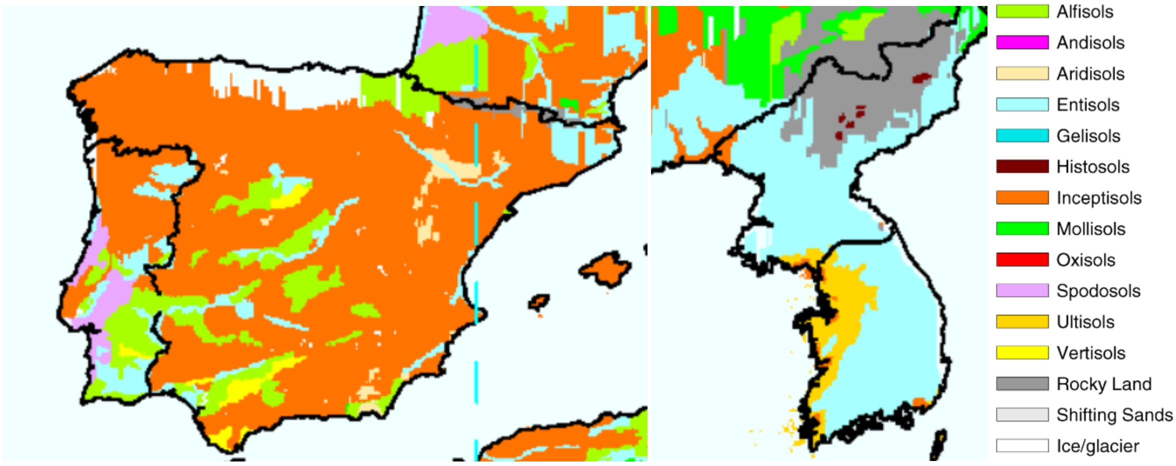
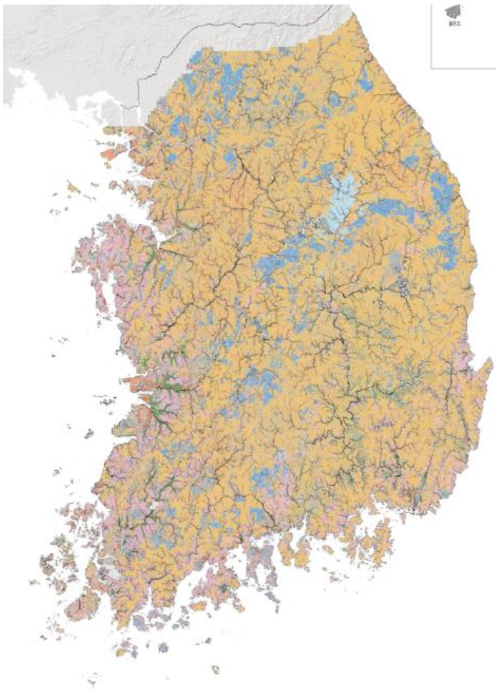


Figure 45: Zoomed in map of global soil regions of Iberian and Korean peninsula [40]

However, a recent geologic survey conducted by the Rural Development Administration of South Korea reveals a quite different soil distribution [41]. The soil map in Figure 46 shows the national prevalence of inceptisols indicated by color yellow. There are also some entisols (blue) in the mountainous area and ultisols (pink) along the coast. This suggests that Spain and South Korea may actually share similar soil characteristic. Inceptisols are soils that do not show any concentration of a specific soil element such as clays, iron oxide, aluminium oxide or organic matter but rather shows a somewhat even proportion of elements. A detailed soil analysis of earthen buildings in both countries is crucial to determine if there is any correlation between the choice of construction technique and regional soil properties. Yet there seems to be a global trend of low appearance of earthen constructions in those regions in extreme environment where soils show a high concentration of a specific element such as oxisols or spodosols.



토양 유형별 분포 면적

목(7)	아목(17)	토양통(405)	면적(ha)
인셉티솔 (Inceptisols)	아쿠엡트(Aquepts)	54	529,809
	유드엡트(Udepts)	97	5,602,668
엔티솔 (Entisols)	아쿠엔트(Aquents)	11	28,001
	플루벤트(Fluvents)	6	45,230
	오르스엔트(Orthents)	29	956,984
	쌈엔트(Psamments)	12	35,969
울티솔 (Ultisols)	아쿠울트(Aquults)	5	36,316
	휴울트(Humults)	10	50,322
	유드울트(Udults)	50	1,159,747
알피솔 (Alfisols)	아쿠알프(Aqualfs)	22	441,661
	유드알프(Udalfs)	47	378,585
안디솔 (Andisols)	유드안드(Udands)	42	129,093
	비트안드(Vitrands)	1	71
몰리솔 (Mollisols)	아쿠올(Aquolls)	2	308
	유드올(Udolls)	15	62,080
히스토솔 (Histosols)	싸프리스트(Saprists)	1	50
	헤미스트(Hemists)	1	359

농촌진흥청(2015)

Figure 46: Soil map of South Korea and a table showing the distribution of each soil group by area (ha). Index is not shown but color yellow indicates inceptisols, blue entisols, and pink ultisols. [41]

The same study by the Polytechnic University of Valencia mentioned in the earlier section has made some interesting conclusions about the relationship between clayey and siliceous areas and the type of construction techniques employed [38]. For example, adobe has the greatest correspondence with clayey areas in the Iberian Peninsula. This is probably due to the fact that the mix design for adobe brick requires more clay than rammed earth to hold individual bricks in place. Also, mesh fillings of half-timbered constructions are found more frequently in siliceous areas as the North of Portugal, Galicia and Zamora. As usual, rammed earth constructions are uniformly distributed in clayey, limey, and siliceous areas.

2.2.3 SEISMICITY

Seismicity is not a determining factor in the design of traditional earthen architecture since they were not designed to resist earthquakes in the first place. When earthquakes occurred in the ancient times, people simply rebuilt their homes and infrastructure. Furthermore, the Korean Peninsula is located outside the Ring of Fire in the Pacific Ocean and has reported very few major earthquakes in the past millennium. Although Spain is in the Mediterranean region with frequent earthquakes, the intensity of earthquake it experiences is far less than that of Italy, Greece, and Turkey. Therefore, this paper will not consider seismicity as a major agent in influencing the typology of earthen constructions in Spain and South Korea.

2.3 Earth as a medium for vernacular architecture

In section 2.1, each type of earthen construction techniques were classified and explained in detail. Then, section 2.2 attempted to explain their different uses and geographical distribution by observing how climate and other natural factors might have limited the use of materials and techniques in certain areas in Spain and South Korea. In this section, the focus will be on how individuals have responded to environmental and economic situations through their choice of construction techniques.

2.3.1 Case Study of Choga and Barraca

Vernacular housing of Korea and Spain is an interesting topic to study in the context of earthen architecture. It shows how common people have slowly but continuously adopted different construction methods and utilized local and new materials to improve their living conditions. The evolution of housing typology in each country reveals that traditional earthen construction methods cannot be dealt as separate entities but rather a complex interaction of various social, economic, natural, and technological factors. This section will introduce the choga of South Korea and the baracca of Valencia, Spain and try to find similarities and differences in their typology and function.

Although hanok is considered the standard as a Korean vernacular architecture, the most widespread type of dwelling for the common people was the type of thatched house called a choga (초가) shown in Figure 47.

Figure 47: Private choga residence of Lee Hanho Family in Nak-an, Korea [42]

This type of thatched house is also seen in the neighboring countries such as Japan (Figure 48). The thatched house is believed to have evolved from the Neolithic huts. In the earlier times, people dug the ground and placed a grass covering over it, and this house gradually changed its shape over time as the roof was then supported by earthen or stone walls, then later by wooden poles and beams. The origin of a choga is not well known due to lack of proper documentation throughout the history, but it is written during the Three Kingdoms period that this type of building already existed and was dwelled even by the first King of Silla, Kim Suro [24].

Figure 48: Wada house of Shirakawa-ko in Japan [43]

A barraca is a typical dwelling of farmers and fishermen in the countryside of Valencia, Spain. It is characterized by its steep, thatched roof and whitewashed clay walls (Figure 49). Its appearance, especially the high and steep roof, resembles more of the thatched house of Japan more than that of Korea. This type of housing is most prevalent along the coastal area of Valencia, specifically in l'Horta, the coasts of La Plana and the fertile lowlands of Orihuela [21]. Yet a similar typology can also found in Italy and the Mediterranean region and other Spanish colonies.

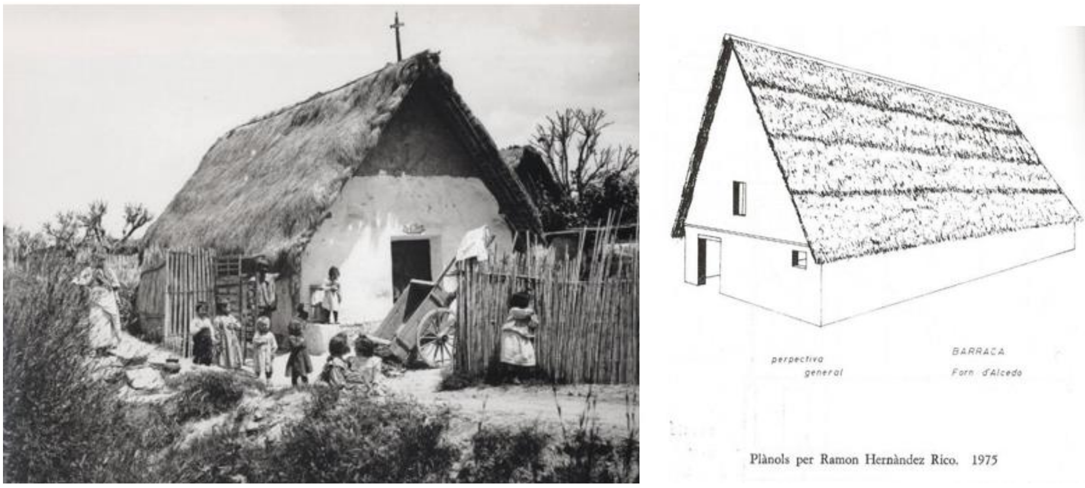


Figure 49: A photograph (left) [1] and drawing (right) of a typical Valencian barraca [44]

The origin of these buildings are uncertain - they can be traced back to Roman times, but their simple typology suggests it might have evolved from primitive huts just like the choga. These buildings were constructed until the Moorish invasion during the 16th and 17th century which forces the inhabitants to retreat to the walls within the city [45]. Later in the 18th century barracas were rebuilt and continued to serve as a main dwelling of the rural Valencians until the early 20th century when industrialization and modernization ended the era of traditional houses.

Barracas were mainly built on huerta type farms. The word “huerta” can be translated as orchard or garden in Spanish [46]. Huerta farms are large complexes that grew fruits and vegetables on artificially irrigated farms. Therefore, barracas were built not as a single entity but in groups for a large community (Figure 50). Huertas were typically located near coastal plains that provided sources of water with its small rivers and deltas. Sometimes a barraca was inhabited by local fishermen, but this was limited to the Bay of Valencia where people supplemented their income through small huertas.

Figure 50: Rows of Valencian barracas next to the huerta farms in Valencia, Spain [45]

Similar to the barraca, choga continued to be the most common dwelling for the working class and poorer scholars. As most of the peasant class living outside of the capital worked as farmers and fishers, choga was prevalent till the late 20th century. Figure 51 shows a photograph of a choga standing in front of a modern apartment complex in the heart of Seoul. Although Korea was going through rapid modernization, this photograph shows that a considerable number of low income class still lived in a traditional choga.

Figure 51: Photograph of a choga taken in 1981 by Kwon Taekyun in Seoul, Korea. In the background is Eunma apartment complex of Gangnam, Seoul that was completed in 1979. [47]

Both the choga and the barraca are prime examples of vernacular architecture have evolved throughout history and incorporated various earthen construction techniques to fit the needs of the region and the community. The wall of the choga is commonly made using earth brick, rammed earth, or wattle and daub technique, and the wall of the barraca have evolved from using wattle and daub to cob to earth brick.

Navarro and Dato explains that the barraca went through five main stages of variation in its typology [1]. The first stage was using the canes and mud where a bundle of cane was tied with reed and driven into the ground to form a single space of wall and a roof. This whole framework was plastered with mud inside and out. Cane and reed was readily available and easily collected from the river bank of the coastal plain of Valencia. The second stage was an upgrade of the wall from cane to sun dried hard branches and a replacement of the mud roof with bundles of reed which can be identified as a classical wattle and daub structure. The third stage was a combination of the first and the second stage where canes were inserted and tied between timber posts with ropes and covered with mud and several types of reeds to increase the durability. The walls were plastered with lime which is now regarded as a typical barraca appearance.

The fourth stage of the barraca was a shift to cob technique as straw became widely available through the harvest of wheat and rice. External walls were thickened and made stronger with layers of 10 to 20 cm strips by the pared de mano technique (Figure 52). This technique was also named as fang remugat by Josep Escrivà in 1976 and translates to crushed mud. The final enclosure was a wall of an average thickness of 50 cm and a height between 50 to 120 cm. Sometimes wood trunks were inserted in the cob layers as a reinforcement.

Figure 52: Wall of the barraca built with cob technique [21]

Similarly, earlier models of the choga were constructed with wattle and daub technique. Wall of the house is usually made of wooden poles filled with highly clayey soil mixed with chopped straw (4 to 5 cm long) to prevent cracking due to high clay content [48]. The roof of the house is covered with straw from rice or wheat or strong vegetable fiber such as a grass. Choga by translation means house made of grass, so it is named by its roof.

Figure 53: Replacing of the straw covering in the roof of Choga in Nak-an, Korea [49]

Roof and the wall prevents outside air from dramatically influencing temperature of the inside. Use of rice straw estimated back to Three kingdom period (삼국시대) when they started cultivating rice [42]. Using straw as a building membrane gives an advantage of a good insulation, as the straw prevents the outside temperature from influencing that of the inside. Rice straw is hollow inside so the air trapped in it acts as a natural insulator by blocking sunlight and preventing inside heat from escaping the house [48]. Also, its slippery surface does not absorb water from rain. Shape of the roof and the way it was weaved varies by region and climate. Straw is replaced once a year to prepare for the annual summer monsoon season, and it was a community effort that required the help of men from the neighborhood as shown in Figure 53.

Unlike the barraca, cob did not replace wattle and daub of choga. Instead, as Korean society became more structured with the advent of various kingdoms and dynasties, rammed earth became a popular method of constructing a choga [48].

Figure 54: Rammed earth wall (left) and fence (right) of Choga [48]

Panchuk was used mainly for building earthen fortresses during the war between three kingdoms. The idea of using a wooden formwork was probably passed on from China to Baekje, and went through improvements over time to achieve better efficiency. Later, this technique was reduced in scale and modified by the rich aristocrats of Yangban to build low earthen walls of todam (토담) around their houses (Figure 54). It was very difficult for peasants or slaves to find a huge tree for wooden column or beam or even have time to construct a house, so they borrowed the damtle from their owner to build the small dwelling called a todam House [50]. The structure was simple as it was a rectangular plan of todam walls with a rafter (서까래) resting on the wall to form a roof and covered by straw or tiles.

“To” means earth and “Dam” is a Korean word for a small fence-like wall. A formwork was called “damtle” (담틀) and its actual shape varied by the skill of the carpenter in each town. The wall was built in two steps - the bottom wall was about 80 cm wide and the top wall was about 60 cm wide [16]. The inner part of the wall was trimmed to smooth out the surface.

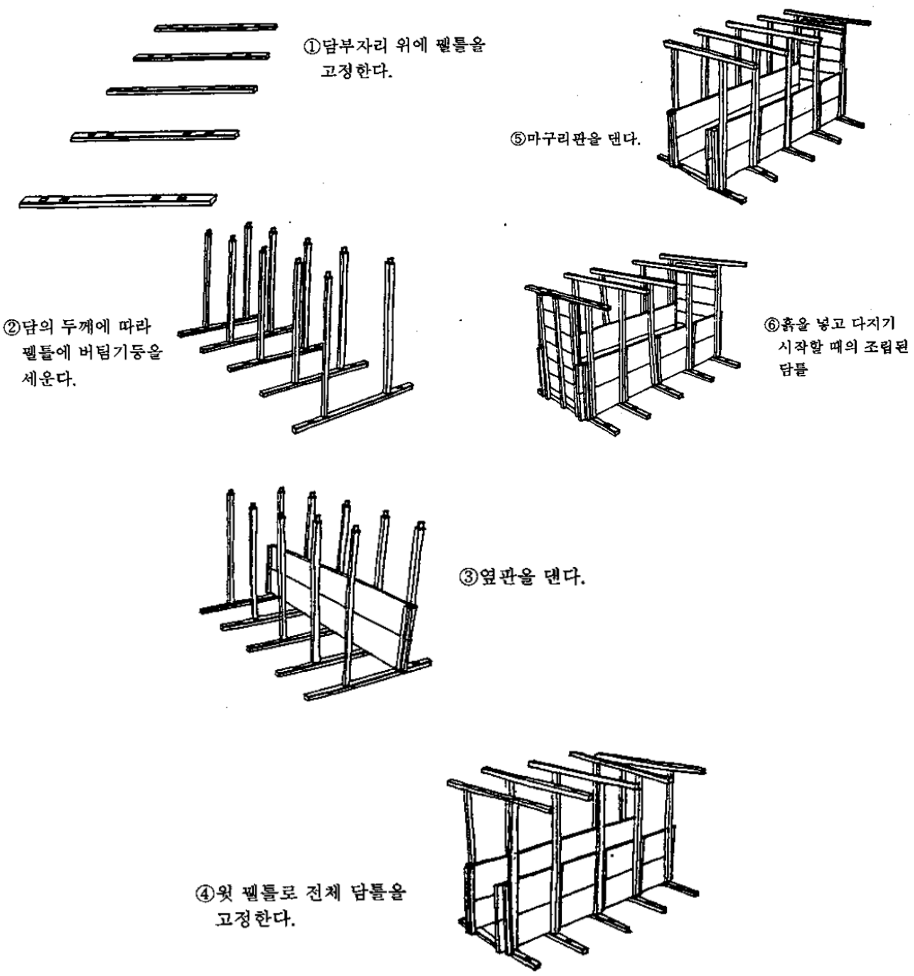


Figure 55: Process of making a damtle formwork [50]

Architect Kiyong Jung carried out an extensive survey of traditional earthen construction technique in South Korea in 1980s and explains the process of making a formwork for damtle construction in Yesan style (Figure 55) [50]:

1. Bottom horizontal pieces are laid out in rows.
2. Support wooden poles are inserted to the holes of the bottom pieces. The distance between the rows of poles depends on the width of the wall.
3. Wooden boards are laid next to the poles.
4. Top horizontal pieces are connected to the wooden poles and hold the whole formwork in place.
5. Bottom plank is laid on top of the bottom horizontal pieces.
6. Earth is poured into the formwork and is ready for ramming.

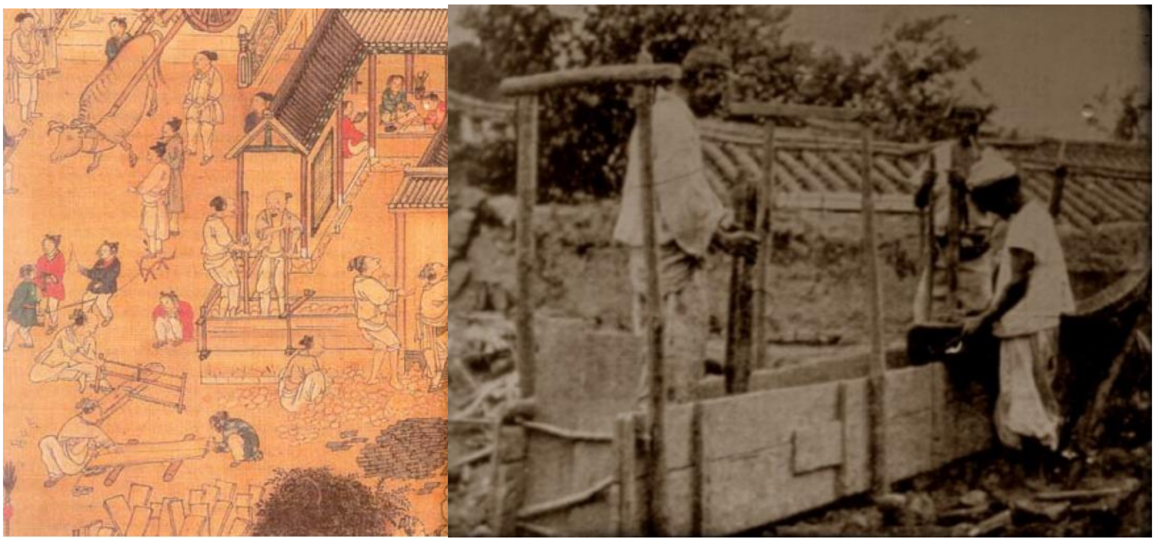


Figure 56: Historic painting of 태평성시도 (Left) and a photograph (Right) from 19th century Chosun dynasty [16]

There was usually one mold in a town, and building a todam is labor intensive as it requires a number of men to ram the earth, so it was a community effort to build a house (Figure 56). When a new person will settle in a town, they will have to rent a room for about 3 years, and once he earns recognition of townspeople, they will lend him a mold and man power on a small plot of land to help him build his house (Figure 58). Most villages were located next to a mountain as shown in Figure 57.

Figure 57: Photograph of a typical historic village in Nak-an, South Korea

Figure 58: Building a todam with damtle in a typical village in Korea. A photograph is taken by foreign missionaries in the early 20th century.

Since peasants were not allowed to have free time during the day, todam house had to be built over couple of night with torches, thus it was also called “Thief house” since it was built without a notice [50].

Barraca was also a product of community effort. Huerta was a highly organized agricultural village which aimed for maximum efficiency, the farmers needed to live close to the huerta and to each other (Figure 59). The barraca was built by the farmer with the aid of a barraquer (a builder of barraca) [45].

Figure 59: A photograph of view of the Peri-urban Vegetable Garden, West of Valencia, Spain [51]

The fifth and the final stage of the barraca saw a jump towards a more advanced technique of earth bricks (Figure 60) [1]. The walls were now made of polyhedral adobe bricks of dimension 40 x 35 x 6 cm. The adobe wall was coursed on a tamped foundation to a height of 2.5 meters using a “punter i boser” bond with one adobe in a long run and another across. Finally, the wall was plastered with mud and sometimes lime.

Figure 60: Photograph of earth brick wall of a baracca (left) and a choga (right)

Earth bricks were also commonly used in South Korea. However, earth bricks can be seen more often in a fence around the house or around the village called “damjang” (담장). Figure 61 shows various types of fences made with rammed earth and earth brick in Andong Hahue Village of South Korea.

Figure 61: Various types of fences in Andong Hahue village of South Korea [52]

3. EARTHEN ARCHITECTURE NOWDAYS

3.1 World Heritage Listing

As mentioned in an earlier chapter, the World Heritage Inventory of Earthen Architecture prepared by CRATerre in 2012 is a very useful document that contains the most updated list and statistics that were compiled from a survey of types and modes of earthen construction from each region of the world.

It is part of the World Heritage Program on Earthen architecture (WHEAP) which was launched in 2008 “as an initiative to address pressing concerns through the development of policies for the conservation, revitalization and valorization of earthen architecture properties, enhancing capacities at the regional, national and site levels for both management authorities and technical experts.” [2]

Surprisingly, one third of the properties in this list are from Asia and the Pacific region (51 out of 150 properties), while Europe has less than half of their heritage listed (19 out of 150) as shown in Figure 62. This statistics by no means indicate the actual number of earthen construction in each region, but shows that earthen construction in Asia are not well known to the public compared to that of other regions, such as the famous Great Mosque of Djenne of Mali or the Alhambra of Granada.

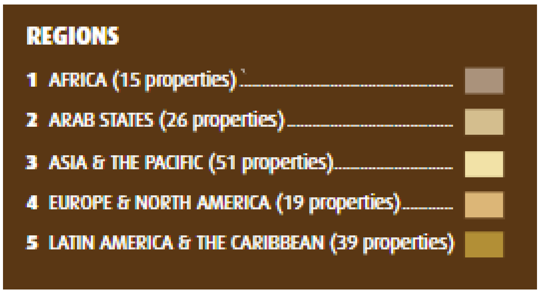


Figure 62: Number of listed properties on the World Heritage List by regions [2]

Also, as to confirm belief that earthen construction is strongly associated with the concept of vernacularism, almost one third of the total properties are classified as vernacular architecture. And although this paper presents the most amount of information on the rammed earth technique, adobe is the most dominant type of construction method in the world according to these statistics (Figure 63).

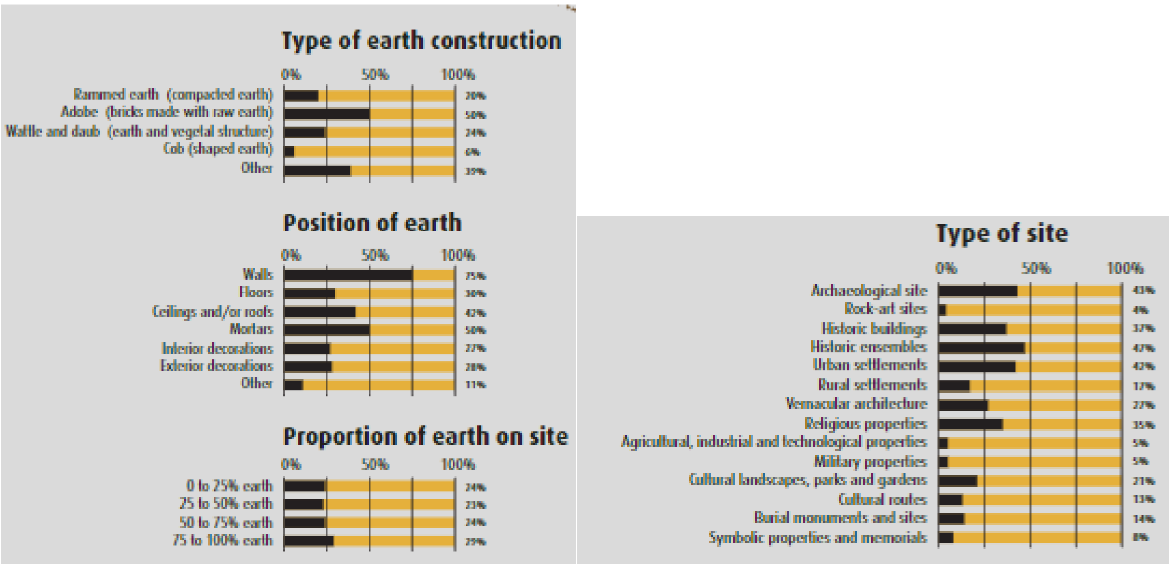


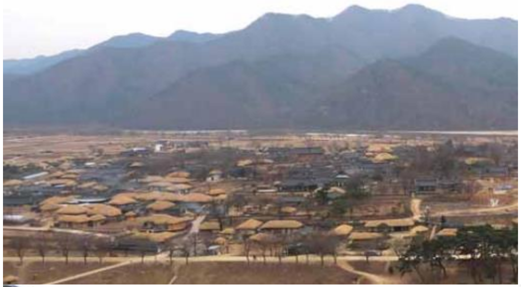
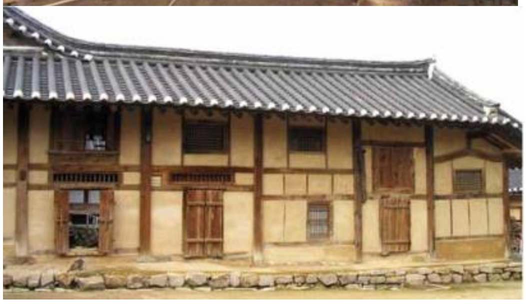
Figure 63: Statistics of properties in the World Heritage List [2]

According to these criteria, a total of 8 heritage sites and buildings from the Korean peninsula were included in the list - one from North Korea and the rest from South Korea. The complete list and the description of each property are shown in Table 1:

Table 1: List of property of South Korea and their description [2]

Property Name and Image	**Role of Earth**	**Date of Construction (Century)**
Changdeokgung Palace Complex 	filling is made of burnt bricks in the lower parts and wattle and daub in the upper parts. These mud “panels” are themselves covered with several layers of mud and a final coating of white-colored lime or red paint. Earth is also used for roofing, in thick layers supporting the tiles	15th

		
Gyeongju Historic Areas 	Many tombs of the rulers of the kingdom of Silla form mounds consisting of a wooden burial chamber covered with a first layer of stones and a second thick layer of grassy earth.	1st BC to 9th AD
Haeinsa Temple Janggyeong Panjeon, the Depositories for the Tripitaka Koreana Woodblocks 	Wattle and daub for the partition walls of the buildings, cob associated with horizontal layers of tiles for the enclosure walls and in thick layers of earth under the roofing tiles.	13th
Historic Villages of Korea: Hahoe and	Aristocratic and commoner houses, pavilions and Confucian academies.	14th to 20th

Yangdong  	Earth is present in various forms: adobe for the partition walls of the buildings, adobe or cob combined with horizontal layers of tiles for the enclosure walls and for the thick layer of earth mixed with straw on which the roofing tiles are laid.	
Jongmyo Shrine 	Wattle and daub is used to fill the voids in the wooden frames of the shrine. These mud 'panels' are themselves covered with several layers of clay and a final coating of lime painted red. Earth has also been used for the roofing. A thick layer is laid over the wooden structure before installing the roofing tiles.	16th
Royal tombs of Joseon dynasty 	These tombs, forming funerary mounds, are made up of a wooden burial chamber covered with a first layer of stones and a second thick layer of grassy earth.	15th to 20th
Seokguram Grotto and Bulguksa Temple	Wattle and daub is used to fill the voids in the wooden frames of the temple. These mud 'panels' are themselves covered with several layers of clay and a final coating of lime painted yellow. Earth has also	8th

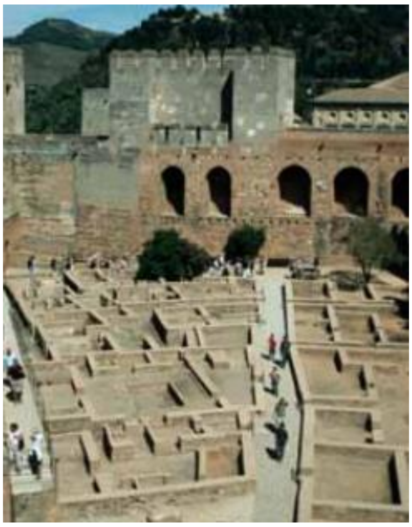
 	been used in the roofing, in thick layers between the ceiling and the tiles.	

Unfortunately, these 8 properties are not the most comprehensive nor representative sample of existing earthen construction in the Korean peninsula.

On the other hand, Spain only has four of its heritage listed and their descriptions are shown in Table 2:

Table 2: List of property of Spain and their description [2]

Property Name and Image	**Role of Earth**	**Date of Construction (Century)**
Alhambra, Generalife and Albayzín, Granada	The walls of the Alhambra Palace, built from the Almohad period, are largely constructed in rammed earth. The name of this	13th to 16th

 	palace, from the Arabic Al Hamra, meaning «red», is in reference to the color reflected by earthen walls at sunset.	
Cathedral, Alcázar and Archivo de Indias in Seville 	The Alcázar of Seville has some walls or parts of walls built of rammed earth, using a technique widely available in Spain during the Almohad period.	13th to 16th
Historic Center of Cordoba	The use of earth can be seen in the ancient fabric of the city of Cordoba	3rd BC to 14th AD

		
Old town of Caceres 	The Desmochada Tower, part of the Almohad enclosure of the city of Caceres, reflects the rise of the technique of rammed earth during this period in Spain. The use of rammed earth and adobe is also found in the vernacular fabric of the ancient city.	13th to 16th

3.2 Research and Restoration Efforts

Accelerated and uncontrolled industrialization and urban development led to environmental destruction, loss of cultural heritage buildings and sites, traditional construction materials techniques. Modernization and urbanization movement changed the cityscape into skyscrapers, apartments, and commercial building complex that are uniform and mundane. High energy consumption of concrete and steel resulted in massive air pollution in the country and emissions from cement buildings and wall paints created the new house disease. Finally, lack of natural resources such as metals and fossil fuels needed for construction caused some countries to be dependent on others as its suppliers.

Most vernacular earthen constructions in Korea were destroyed after 1970 New Town Movement (Figure 64) which pushed for modernization of the country by President Park Jung Hee. Every major town building was replaced with concrete and steel, and container box, roof tiles were replaced with metal sheets. The perception of earthen construction suddenly was degraded into architecture for the poor and was regarded as a symbol of ignorance, poverty, and the uncivilized [53].

Figure 64: Demolition of earthen buildings in Korea in the 1970s

Earth was erased from architectural movement in Korea. It is no longer considered as a viable building medium. School of civil engineering and architecture no longer delivers lectures on earth and research projects only focus on reinforced concrete and steel. Naturally this led to the lack of interest and documentation of earthen construction, compared to wooden and masonry heritage. Very recently, Professor Hwang Hye-ju from Mokpo National University in Jeon-la Province have been carrying out research focusing on rediscovering the benefits and properties of soil and earthen buildings and developing new soil materials and construction techniques for modern usage. He has published papers such as “Eco-architecture technology utilized Traditional Building Materials” and established a chapter of CRATerre in South Korea called Terra Korea which became the first earth research center in the country. The department of architecture in the Mokpo National University became the first college in Korea to offer lectures and studio classes on earthen architecture.

Yet there is a need to identify and categorize historical earthen construction, techniques, and materials in Korea. Some buildings and sites are listed as National Heritage by Cultural Heritage Administration of Korea, but there is no comprehensive research on the use of soil in historical constructions. Most description of buildings focus on the artifacts discovered onsite or their importance in history, without paying serious attention to their construction techniques and architectural meaning.

There has been more progress made in Spain in terms of studying and developing new earthen materials and conserving traditional materials and techniques. Instituto Eduardo Torroja de Ciencias de la Construccion (IETcc) is a national research center working on earth as a construction material in which they developed a project called ‘‘Materials, Technologies and Low Cost Dwelling Prototypes’’ [54]. The study focused on testing the weathering resistance capacity of the earth in order to prove that earth is a viable construction material for today supported by the existing knowledge of built heritage. This project marks the beginning of the study of earth as a construction material from a scientific point of view in Spain. IETcc has not made any significant contribution to earth research since the project.

Other notable institutions are Navapalos Center and Inter-Accion [54]. Inter-Accion was established as an organization to preserve rich Spanish architectural heritage in earth. Navapalos Center was founded in 1984 in Navapalos, an abandoned town in Soria, to research earthen construction. Since then, more than ten Navapalos International Work Meetings on ‘‘earth as a building material’’ have been held. The meetings discussed some cases of repairs of old buildings, self-building projects, improvement of materials, soils and blocks characterization, analysis of existing normative or knowledge about traditional architecture.

Since the 1980s, more and more interventions have been carried out on rammed earth constructions all over the Peninsula in terms of both monumental and vernacular buildings. This changed happened after the arrival of democracy and the political and administrative changes that came about in both Spain and Portugal and the different intervention policy on monuments that ensued regarding the criteria and the professionals involved [54].

A major project “La restauración de la arquitectura de tapia en la Península Ibérica. Criterios, técnicas, resultados y perspectivas” (The restoration of rammed earth architecture in the Iberian Peninsula) was granted by the Ministry of Science and Innovation under the National Grant Scheme for the year 2010 [11]. The research aims to analyze the restoration works carried out from the eighties until the present in order to evaluate the criteria and techniques used and the results obtained over the years, along with the evolution these criteria and techniques. The analysis has been carried out from a multi-disciplinary point of view, involving researchers and collaborators from different fields such as architects, quantity surveyors, archaeologists, historians, art historians, restorers, engineers, petrologists, and many others.

3.3 Attempts to use traditional techniques in modern architecture

Several case studies of architects and engineers from around the world who tried to incorporate traditional earthen materials and construction techniques in their work will be introduced in this section.

3.3.1 New Gourna Village Project

In 1945, a renowned Egyptian architect Hassan Fathy was commissioned by the Egyptian Department of Antiquities to plan and build a new village to relocate inhabitants of Old Gourna which was to be developed into a major tourism site with its pharaonic history [55]. Fathy used this opportunity to revalorize the lifestyle and tradition of poor, rural Egyptians by studying and revitalizing historic vernacular Egyptian architecture. His innovative mixed use plan for the village included houses and public centers built with mud bricks as shown in Figure 65.

Figure 65: Mudbrick Fabrication in the yard of a Fathy building now under renovation [55]

Although only part of this grand plan to house 20,000 inhabitants was realized and about 40 percent of those original buildings have survived, Fathy is still accredited for his integration of traditional materials with modern architectural principles" [55]. He is one of the pioneers to experiment with earthen architecture in an attempt to preserve and pass down the knowledge of traditional building technique and historic building fabric to the present and future generation.

3.3.2 Architect Kiyong Jung

Fathy was a social architect who advocated the humanity of the rural poor, and his beliefs can be seen clearly in his publication "Architecture for the Poor: An experiment in Rural Egypt" where he explained that he "wanted in the public buildings of Gourna to provide for all the communal needs of the villagers – for their work and trade, for their education, for their amusement, and for their worship" [55]. He inspired new generation of young architects, one of them being the Korean Architect Kiyong Jung.

In early 1970s, Jung graduated from the Seoul University Graduate School of Applied Fine Arts and left to France to study architecture [56]. There he heard about the New Gourna Village Project and was reminded of the disappearing traditional earthen buildings and techniques of his motherland. When he returned to South Korea in 1981, he was gravely disappointed by the complete replacement of choga by cement and slate roof all over the country.

Jung firmly believed that earthen architecture should be the answer to revitalizing rural landscape of South Korea. He researched documents and photographs of historic earthen buildings as a starting point, only to find out that barely any information existed on this topic.

While Jung was struggling to find a simple image of a formwork for damtle construction which was the basis of most choga houses in the country, he came into contact with Young-hoon Shin who was a member of the committee for the Korean National Cultural Heritage at the time [50]. Shin informed Jung that there were a couple traditional earthen buildings remaining in Wonmadal-li near the city of Jeong-eup in Jeolla province.

Excited by his first encounter with a 40 year old earthen building, Jung started to travel around the country to discover traditional earthen construction techniques of Korea. From his numerous site visits to Andong Hahoe Historic Villages, he was exposed to traces of earthen construction from one thousand years ago. He learned how to make and use a damtle formwork from an old man from Yesan in Chongcheong province (Figure 66) [50].

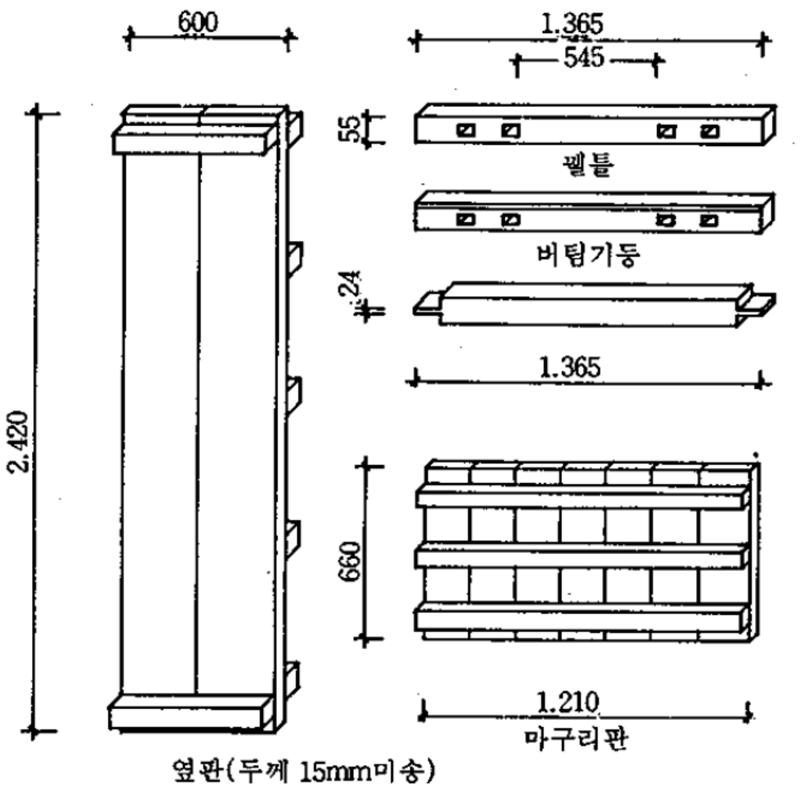


Figure 66: Diagram showing the dimension of each part of the damtle formwork created by Kiyong Jung [50]

Shortly after, on November 11th of 1988, Jung organized the “Earthen Architecture Festival” in Mapo. The festival comprised of three main parts: Photography exhibition of world’s earthen architecture, Event on reproducing traditional earthen construction, and finally Earth Dance event. The festival was opened to celebrate the publication of the translation of the book “Story of Gourna Village”.

Jung finally earned his opportunity to experiment with earthen architecture when he was involved with Muju Public Construction Project. One of the projects called Jindo-li community building became the first public building built with earth (Figure 67). When the architect first showed his draft to the community, most inhabitants of the village rejected the idea since they were worried that the building would not be strong enough and smell like dirt. Jung took the townspeople on a visit to other buildings built successfully with earth to explain the benefit of earthen buildings. Due to constant complaints from the townspeople and problem with the constructor, the community building took 2 years to build.

Figure 67: Jindo-li Community Building [57]

Architect Jung continued to incorporate earthen material in his works. The most famous is the private residence of the ex-president Noh. The wall of this house was built with rammed earth technique and can be seen clearly from the outside due to its exposed texture as shown in Figure 68. The president was deeply impressed and satisfied with the use of earth and timber for his house as he did not want anything fancy or luxurious [58]. It was a perfect place for him to return to Bongha village in 2008 and spend his years after his difficult presidency where he fought for the rights of everyday Koreans and tried to reestablish and protect democracy that was threatened and distorted by past dictatorships and big trusts such as Samsung and Hyundai.

Figure 68: Private Residence of the ex-president Noh in the town of Bongha was built with rammed earth technique [59]

There are also very few examples of other Korean architects who experimented with earthen material in their projects as shown in Figure 69 and Figure 70.

Figure 69: House of Eung-no Lee built part of the exterior walls with rammed earth technique [59]

Figure 70: DMZ(Demilitarized zone) Peace Life Park in Korea built with a mix of rammed earth technique, concrete, and corten [59]

7.5. Modern Earthen Buildings in Spain

In 1988, Architect Estudi Mirall designed a municipal theater in Balaguer that was later constructed with earth in 1996 as shown in Figure 71 [54]. The entire structural walls were built with rammed earth technique and they reached a maximum height of 15 m with 50cm of thickness. The light metal roof rests on the walls while the interior terraces are prefabricated with concrete. It was possible to design, calculate, and build the walls with earth since there was plenty of earthen built heritages in the area that served as a reference. The tradition of rammed earth technique was still being used by locals to build agricultural warehouses in Cataluña. However, while traditional Catalan rammed earth uses only 5 percent of cement in the soil mix, the actual dosage of white cement for this building was increased to 10 percent to be classified as a poor plain concrete in order to comply with the public building code for concrete buildings.

Figure 71: Municipal theater in Balaguer, Cataluna [60]

Shortly after in 1998, a rural house from the 19th century was renovated into a hotel [54]. Casa Pinariega, located in a town of Navapalos, Soria of Castilla Leon has a mixed wall of stone and adobe masonry and adobe partly within timber framing (Figure 72). Adobe units of traditional size were replicated with local soils mixed with barley straws. However, the rehabilitation effort met an unexpected problem as training inexperienced masons increased the labor cost.

Figure 72: Pinariega house in Navapalos, Soria of Castilla Leon [54]

Similar attempt to revitalize vernacular architecture can be seen in the ecovillage project in a small town called Amayuelas [54]. Ten houses were built with a rammed earth ground floor with either adobe or compressed earth block wall in the first floor (Figure 73). These two story houses were planned by various architects from Architects without Border to accommodate tourists visiting the rural area. The roofs were covered with traditional ceramic tiles resting on thick earth mortar and most of the walls were plastered with straw and lime mortar.

Figure 73: Left: Earth walled houses in ecovillage Amayuelas, Palencia; Right: Luis Salazar house in Uruena, Castilla-Leon. [54]

4. CONCLUSION AND FUTURE WORKS

4.1 Conclusion

Some conclusions can be drawn from the observations made in each chapter.

First of all, it is quite clear that some methods seem to have appeared earlier than other methods. There is abundant archaeological evidence and radiocarbon dating that supports the claim that dug out construction and earlier prototype of wattle and daub has appeared first out of all types of buildings. The typology of these buildings suggests that early mankind preferred not to build an entire structure out of earth. This may be due to the fact that they were still transitioning from hunter-gatherer to farmers and thus needed a temporary settlement which could be assembled quickly and easily by a few number of men from a single tribe.

Next stage of techniques that appeared was probably cob and piled earth. From an anthropological perspective, the presence of a complex architecture in a region suggests that it was once inhabited by a highly developed civilization. This is especially true for historic structures that are limited by an ease of construction, amount of labor force, availability of local materials and the ability to import foreign materials.

For example, preparing a sample of cob is far less time consuming and complicated than molding and drying an earth block. Mixing mud and straw and piling a blob of cob on top of each other requires less expertise and skill than layering earth brick walls. Cob walls can be laid in disorderly and with irregular thickness while mortar needs to be spread evenly between the interface of bricks and coursing should be done properly to ensure interlocking of the bricks. Therefore, techniques such as cob or piled earth construction do not display a high level of sophistication and might have appeared earlier than earth bricks or rammed earth.

Earth brick and rammed earth technique seems to have appeared lastly. Frequent use of earth bricks and rammed earth for tall towers and large fortresses suggests that these techniques became prevalent as human society became more sophisticated and were able to mobilize a high number of laborers and resources for large scale construction. At this point, people probably had a good understanding of the property of the earth through numerous trial and errors with different mortars, binders, and additives.

Rammed earth and adobe constructions are found almost anywhere in the Iberian Peninsula except in the North and Northwest due to the high level of precipitation in these regions. In contrast, half-timbering are also found in cold climates or areas with high rainfall such as the north of the Iberian Peninsula. Studies showed that earthen constructions were likely to be distributed near a source of water such as river valleys or plains where people can have an easy access a source of water for living and clay sediments to build their settlements and irrigate their crops.

There seems to be a global trend of low appearance of earthen constructions in those regions in extreme environment where soils show a high concentration of a specific element such as oxisols or spodosols. Adobe construction has the greatest correspondence with clayey areas in the Iberian Peninsula since mix design for adobe brick requires more clay than rammed earth. Mesh fillings of half-timbered constructions are found more frequently in siliceous areas as the North of Portugal, Galicia and Zamora while rammed earth constructions are uniformly distributed in clayey, limey, and siliceous areas. Seismicity was not a determining factor in the design of traditional earthen architecture since they were not designed to resist earthquakes in the first place. It was not possible to compare the observations made on the influence of the natural environment on the selection of certain construction techniques of regions in Spain and South Korea due to lack of studies carried out in this field, but it would be interesting to find their similarities and differences in the future.

Both choga and barraca are prime examples of vernacular architecture have evolved throughout history and incorporated various earthen construction techniques to fit the needs of the region and the community. The wall of choga is commonly made using earth brick, rammed earth, or wattle and daub technique, and the wall of barraca have evolved from using wattle and daub to cob to earth brick.

They also attempted overcome the disadvantage of using earth as a main construction material by using straw roof to protect it from the rain and whitewashing the walls with lime or covering them with paper. This was possible since the vernacular houses were small scale and was regularly maintained by its inhabitants as the roof was replaced annually and the walls and joints were repaired and plastered frequently. Because of their flexibility and ease of construction, choga and barraca have thrived as the main dwelling of the rural and common class of Korea and Spain until the early 20th century when industrialization and modernization ended the era of traditional houses.

Accelerated and uncontrolled industrialization and urban development led to an environmental destruction and the loss of cultural heritage buildings and sites, traditional construction materials techniques worldwide. Since the 1980s, more and more interventions have been carried out on rammed earth constructions in Spain, while South Korea while most vernacular earthen constructions in Korea were destroyed after the 1970 New Town Movement.

A total of 7 heritage sites and buildings from the South Korea and 4 from Spain were included in the World Heritage List and several architects and engineers from around the world including Spain and South Korea are now slowly incorporating traditional earthen materials and construction techniques in their work. Thus, there is a need to further identify and categorize relatively unknown and forgotten historical earthen construction, techniques, and materials in order to bring back earth as a main construction material and an architectural fabric.

4.2 Future Works

The paper hopes to contribute to research on earthen architecture by providing somewhat of a starting point for future scholars and students who are just collecting data on their respective topics. The paper collected and compiled elementary information on the origin and development of major earthen construction techniques, notably on dugout construction, rammed earth, cob, earth bricks, and wattle and daub.

It is important to carry out further research on each of the techniques by looking up ancient and medieval sources containing texts and images that may reveal missing information that has been lost over the history. A site visit to various provinces and towns of Spain and South Korea with earthen heritage sites and documenting and collecting information on their typology, material use and property, function, history, vulnerability, maintenance and repair efforts will be necessary to have a more wider and comprehensive understanding of the nature of earthen construction in their countries. If possible, a survey on the geographical distribution of earthen constructions in South Korea and a study on their climate, geographical features, and soil will be helpful in determining the influence of the natural environments on the use and selection of different construction techniques and materials in each culture.

Finally, funding and opportunities for research on traditional earthen architecture may only progress if they are deemed useful for application on future constructions. A study on the structural, thermal, acoustic capacity and serviceability of historic and modern rammed earth walls, adobe and compressed earth bricks, and half-timbered framings should be tested to see how traditional construction knowledge can help advance our approach to building future homes and built environment. An innovative research on developing 3D printing application of soil will also suggest new possibilities for earth as a medium and solution for low cost, sustainable construction.

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