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# A chronological description of the spatial development of rammed earth techniques

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## Abstract

Rammed earth has been used by man for thousands of years and is currently experiencing a revival in some parts of the world as a result of its inherent sustainability. Historic rammed earth structures are scattered around the world and much information can be derived from these structures to inform the development of modern rammed earth. This paper provides a chronological study of rammed earth distribution through observation of monumental buildings to aid the study of this building technique. It is shown that the rammed earth technique is likely to have originated independently in China and around the Mediterranean, and spread through the movement of people and ideas to many other parts of the world. Through observation of historic rammed earth sites, geographical and climatic limits can be placed on the extent of rammed earth. The different ways rammed earth has been used over time are explored, culminating in its current incarnation as a sustainable building material.



**Running head**
A chronological description of rammed earth

**Keywords**
Rammed earth, tapial, pise, earth building


## Introduction

Rammed earth is a construction technique where soil is taken from the ground and compacted to form structures. Removable formwork is installed, and the soil compacted within it. The technique is widespread but the distribution of rammed earth across the world and its development over time has not previously been fully documented. Many sources quote the same examples of the Potala Palace in Lhasa, parts of the Great Wall of China, and the Alhambra in Granada. The distribution of rammed earth is however more complex than usually portrayed, appearing to spread over the world in a number of temporal waves, each precipitated by a different set of needs.

In this paper we first present a strict definition of the rammed earth technique, identifying it by name in different languages. We show that the rammed earth technique appears to have developed independently in China and around the Mediterranean. The technique then spread with the movement of peoples to different parts of the world. Rammed earth has continually been reinvented as a building material. At times it has been used as a quick technique for the building of fortifications, a cheap way a man can build his own home, and a sustainable construction technique using only what is available on site.

The paper concentrates on monumental rather than vernacular architecture, as monumental architecture is better documented and preserved. It is assumed that rammed earth was used as a vernacular technique where it is found as monumental buildings. The examples given are taken from a wide literature review and from field visits by the authors to Spain and India. The two identified nuclei of rammed earth are dealt with separately, beginning with China. It is shown that similar techniques to those in China are found in central Asia and India. Rammed earth around the Mediterranean is then discussed, its spread into Europe, and use during the Muslim caliphates. European migration to the Americas and to Australasia spread rammed earth to regions where it did not previously exist, but now flourishes. The differences between these two schools of historic rammed earth architecture are shown. Because the technique is not found in Pre-Columbian America or Australasia prior to European settlement the spread of rammed earth from these centres explains the current geographical distribution of rammed earth.

In a study of this nature it is likely that some rammed earth architecture is missing and there may be rammed earth sites which should be added. The nature of earthen architecture means that sites are extremely vulnerable to decay, and thus historic sites may no longer exist in a useful form to be studied. Further investigation is clearly required, but it is hoped that this paper is able to broadly outline the distribution and development of what we term “historic” rammed earth.

## Defining “rammed earth”

The term rammed earth has been used to describe a large number of different processes involving the dynamic compaction of soil to form a solid mass. This has led to confusion and misdiagnosis amongst practitioners, and the following three distinct processes are therefore outlined.

1. Compaction of a large area to make level. This is known as a rammed earth floor and its use is again becoming popular in modern architecture.

2. Raising of mounds or platforms by the repeated addition and compaction of soil. Soil would be taken from the surroundings, placed and compacted to increase the height of an area. This method is seen as the production of defensive ramparts.

3. Compaction of soil between formwork boards, which are later removed. This is the process by which rammed earth walls are formed. This differs from 2 in that vertical faces of soil are formed, and remain exposed above ground. This is the definition which is used throughout the rest of this paper. This technique is known as *pise* in French, *tapial* in Spanish and *taipa* in Portuguese.

Difficulty arises when describing similar techniques in various languages. In Spanish *tapial* is used to define rammed earth, but is broadly used for placement of material between removable formwork. Many *tapial* structures in Aragon, Spain are constructed using gravel cemented with lime, but cannot be considered as rammed earth. In Central America, the word *tapial* is used to describe a technique which is actually a hybrid of rammed earth and wattle and daub (Easton 1996). The term *hangtu* is used by Chinese archaeologists to describe both rammed earth mounds and earth rammed between formwork. In Farsi *chineh* and in Uzbek *pakhsa* are the terms used for earth walls built up without formwork, known in English as *cob. A* variation on *pakhsa* described by Schroeder *et al.* (2005) involves the throwing of moist clay into formwork, which is then removed and the resulting bricks stacked to form a wall. The *layered technique* (Walls

2003) is similar to *hangtu* and *cob*, but a layer of lime is spread over a compacted layer prior to construction of the next.

## China

Warren (1993) observes that the simplest form of construction on the alluvial plains of northern China is rammed earth. Nomadic peoples in China began to form permanent settlements during the Lung-shan era (c. 2310-1810BC). These settlements became ringed with defensive walls, initially no more than mounds and ditches, but as the size of the settlements grew, so did the size and complexity of the encircling walls. Walls were initially constructed by heaping soil to form a rhomboid section wall, with the base width increasing in proportion to the height. Yunxiang (2003) describes how these initially rhomboid walls may have been cut to present a vertical exterior face. Later soil may have been heaped against a single vertical timber wall acting as formwork, which was then removed. The technique may then have developed by the placing of two parallel vertical timber walls, with soil heaped against each one, and finally the rammed earth technique defined above was developed.

The Lung-shan sites of Lianyungang, Jiangsu and Taosi, in Shanxi Province (see Figure 1 for locations) are encircled with large rammed earth mound walls. Taosi is also the site of what is considered to be the world's oldest observatory, which has a rammed earth wall of 60m diameter (Da 2003). The first definite use of formwork boards for the production of rammed earth walls comes from the walled Lung-shan settlement of Pingliangtai in Henan Province in the middle Yellow River area, where traces of small wooden boards used for formwork and ramming tools have been found (Yunxiang 2003). Pingliangtai has walls 13m wide at the base and the walls are still 3m high over 4000 years after construction. The walls here form a square around the village of side length 185m (Owen 2006). Due to the great thickness of these walls, it is thought that the walls were constructed by heaping soil against two removable timber walls.

The foundations of rammed earth walls have been found at palace complexes in Erlitou and Longwan, Hubei dated to 1900BC-1500BC (Hong 2005). Rammed earth mound walls were likely to have been used at the city of Cheng tzu-yai, Shantung where walls 9m wide and 6m high have been found (Wenke 1999). Excavations at the Shang dynasty (1600-1000BC) capital in Anyang city, Henan carried out in 1933 revealed a rammed earth wall 70m long and 2-4m wide (Houben and Guillaud 1994), and the cities of Linzi and Xiadu, built during the Warring States period (475-221BC), were encircled with massive rammed mound walls, up to 30m thick at the base (Shen 1994). The Qin dynasty (221BC-206BC) were the first to construct a wall along the northern frontier of China, using stone in the mountain ranges, and rammed earth in the plains. However it is in the Great Wall where the use of rammed earth is most recorded. The Han (206BC-202AD) and Jin (265-420) dynasties repaired or rebuilt the walls, but few sections remain, and thus it is impossible to tell the nature of their construction (Jiyao and Weitung 1990).

Houben and Guillaud (1994) argue that a 'true' rammed earth technique was first developed during the Three Kingdoms Period (221AD to 581AD), where formwork was held in place by long poles driven into the ground. This type of construction was used by the Hakka people, who originated in the Henan and Shanxi provinces. The Sui dynasty (581-618) reunited northern and southern China, and was followed by the Tang dynasty (618-907) which came under attack from Turkic tribes to the north of China. The Tang dynasty built cities (for example Jiahoe, Gaochang and Xi'an) along the Silk Route, each encircled with large rammed earth walls (Jiyao and Weitung 1990). The Tang fort of Baishui, at the western end of the Silk Route is constructed wholly in rammed earth (Xinhua 2007). Upheaval at the end of the Tang dynasty led to the southward migration of the Hakka, who moved to Guangdong, Jiangxi and Fujian provinces. The influx of the Hakka into these regions drove them into conflict with their new neighbours and they constructed the fortified farms known as *Tu lou* (meaning earthen structures). The *Tu lou* are large round or square rammed earth structures, which take many years to build and often house the whole family. There is only one entrance and no windows at ground level, making the structure easily defensible. The *Tu lou* are usually over 4 storeys high,

with walls over 1m thick, and can be between 60 and 90m in diameter. The highest concentration of *Tu lou* is in Nanjing County, Fujian, where within a radius of 25km, there are over 2000 such buildings (Aaberg-Jørgensen 2000).

The Ming dynasty (1368–1644) arose from the defeat of the Jin empire by the Mongols, and saw a period of Chinese expansionism. Constant trouble from the Mongols on the northern borders led to the upgrade and repair of the Great Wall at this time. Sections of the Ming wall were stronger than previous walls, being built in fired brick and stone, such as the famous section north of Beijing, but sections in the far west of China continued to be constructed in rammed earth. The walls of Xi'an, the Ming capital city, were initially constructed in rammed earth, and are 18m wide at the base and 12m high. In 1558 they were faced with brick, and so the rammed earth is now invisible (Jiyao and Weitung 1990). The town of Cockcrow, north of Beijing was established in 1420 and has a massive masonry fronted rammed earth wall now under the protection of the World Monument Fund (Evarts 2006). The greatest lengths of rammed earth in the Ming Great Wall occur in Ningxia province (Evarts 2006; Smith 2006), where sections of wall originally 9m high are constructed in layers of 15 to 30cm high, to form a rhomboid shaped wall (Figure 5). A number of forts are constructed along the wall at for example Jiayuguan and Hexibao. Jiayuguan Fort was begun in 1372 and the bottom 6m of walls are rammed earth, but were raised using adobe bricks to their current height of 9m (Fletcher and Nicholas 2007). The use of rammed earth as a monumental building material in China appears to decline following the construction of the Ming wall. Rammed earth may have been extensively used in Tibet, and is certainly found at the Potala Palace in the capital Lhasa (Hurd 2006), and may thus have spread south to the Himalayas.

## Himalayas

Rammed earth is found extensively in the Himalayan kingdoms of Ladakh, Mustang (part of Nepal) and Bhutan (Figures 10 & 11). These kingdoms trace much of their history from Tibet and China to north, rather than India to the south. It is possible that

the same rammed earth techniques used in China and Central Asia were also used in the Himalayas. Rammed earth is considered to be the oldest construction technique in Ladakh, its use preceding that of sun dried mud brick (Jest *et al.* 1990). Evidence of the historic use of rammed earth in the Himalaya is provided by a rammed earth fortress at Basgo, Ladakh which was constructed before 1357 (Howard 1995). Lo Manthang the capital of Mustang in Nepal is surrounded by a rammed earth wall which was built in 1380 (UNITAR 2006). Much of the monumental and vernacular architecture in western Bhutan is rammed earth (Nock 1995). Rammed earth was a successful construction technique used for Muslim fortifications in north Africa and Spain from the 8$^{th}$ century. Although the initial Muslim expansion (in 712AD) did not reach the Himalayas, there were repeated incursions into Ladakh during the 15$^{th}$ century. These incursions destroyed much of the monumental architecture, making it impossible to know if rammed earth was present prior to this period (Rizvi 1996). An Indo-Muslim manuscript written in Urdu (date unknown), details rammed earth construction (Acedo 2006 pp 51). Following the Muslim incursions into Ladakh, rammed earth was used for fortress construction at the towns of Shey and Leh. The technique is still used today where corrugated steel sheeting is seen to have been used as formwork, producing corrugated rammed earth walls.

## Middle East and Central Asia

Evidence of rammed earth in the Middle East is very scarce. Ochsenschlager (1998) is convinced that the rammed earth used by modern Iraqi Marsh Arabs was used in antiquity, but a lack of archaeological investigation of the region means that identification of historic rammed earth is currently unlikely. Walls (2003, 2004) identifies the *layered technique* used in Oman and Iran, but this technique is more similar to cob. At Bam in Iran, a highly studied site following the 2003 earthquake, the majority of construction is in adobe or *chineh* with only a few examples of rammed earth (Langenbach 2004). In Uzbekistan *pakhsa* walls are found (Schroeder *et al.* 2005) which involve no formwork, but *pakhsa* walls observed by Cooke (2005b) appear to have been constructed using formwork, in a manner which would be described as rammed earth. Construction in rammed earth in these regions is hampered by the lack of available timber for formwork

(Schroeder *et al.* 2005), and as such any earth construction would take the form of cob, adobe or similar which do not require large timber formwork. Locations of these sites are shown in Figure 1.

Jest *et al.* (1990) argue that remnants of rammed earth walls and houses have been found at Qinghai, Tsaidam between Tibet and Central Asia, which are thought to date from the Muomhong period (2000-500BC). Marshak (1990) and Turkekulova (2005) cite the mud brick city of Penjikent (Tajikistan) as the highlight of pre-Islamic culture on the Silk Route. The city, established in the 5$^{th}$ century AD, is surrounded by earthen walls, and the ground floors of many buildings are constructed in rammed earth. The city was razed by the Muslim expansion in 722 and is now a working archaeological site, but many of the uncovered earth buildings quickly disintegrate once exposed. The Muslim expansion brought the destruction of many earthen sites in Central Asia, and further archaeological investigation is required to establish the building techniques used (Stevens & Talon-Noppe 1983). City walls and buildings constructed in rammed earth at Khar Balgas city in Mongolia, capital of the Uyghur Empire (745 - 840) were uncovered by Russian archaeologists in 1949 but only a small amount of investigation has taken place. The site was declared a World Heritage site in 2004 (ICOMOS 2002; UNESCO 2003). Many Silk Route sites which survived the Muslim expansion were later razed by Genghis Khan in his campaigns in the 13$^{th}$ century. The fragile nature of earthen construction means that little remains of many central Asian historic sites (Turkekulova 2005).

## Mediterranean (Figure 2)

Rammed earth appears to first have been used in Phoenician settlements around the Mediterranean. The Phoenicians spread from modern Lebanon, founding numerous cities along the Mediterranean including the Carthage in 814BC. Excavations of Phoenician settlements suggest the use of rammed earth both in north Africa (Carthage, Kerouane and Utique (Houben and Guillaud 1994)) and in Spain (Morro de Mequitilla (Chazelles 1993)). Michon (1990) argues that the art of rammed earth building was

practised by in north African by oasis dwellers. Pliny the Elder describes rammed earth towers constructed by the Carthaginian general Hannibal (invader of Iberia 218BC):

> ‘Moreover, are there not in Africa and Spain walls made of earth that are called framed walls, because they are made by packing a frame enclosed between two boards, one on each side, and so are stuffed rather than built, and do they not last for ages, undamaged by rain, wind and fire, and stronger than quarry stone? Spain still sees the watchtowers of Hannibal and turrets of earth placed on mountain ridges’ (Pliny and Healy, 1991).

The Romans admired rammed earth from a distance, using pozzolanic based concrete in preference to rammed earth, but Vitruvius’ *De architectura,* a systematic compilation of the construction techniques known to the Romans and written between 27 and 23 BC reports rammed earth used in the city of Marseilles. Recent excavations of 3rd century AD sites at La Lagaste, Entremont, Martigues, Marignane, Mouries, Ruscino and Lyon in southern France have all uncovered sections of rammed earth walls (Houben and Guillaud 1994). The Latin verb *pinsere* is coined for the action of ramming earth and has passed into French as *pise*.

## Muslim expansion

While it is obvious that rammed earth was used as a construction technique before and during Roman times, the use of rammed earth may have increased through the expansion of Islam. Following the death of Muhammad in 632, Muslim armies spread quickly from the Arabian Peninsula, controlling Persia by 656. The Armenian city of Yerevan was taken in 658, and is now surrounded by a historic rammed earth wall (Hurd 2006). By 705 modern Afghanistan was Muslim, and the Indus River, the most easterly point of the empire, was reached in 712.

The Iberian peninsula was invaded in 711, and the maximum extent of the occupation occurred around 756. There has been a continued presence of Islam in Persia, the

Arabian Peninsula and north Africa since the initial expansion, and in Iberia a Muslim presence lasted until 1492.

The use of rammed earth may have increased with the growth of the Muslim Almoravid and Almohade Berber dynasties which originated from the Sahara and ruled north Africa and Iberia. The famous Berber Kasbahs in the Draa and Dades valleys of Aït Ben Haddou and Tamnougalt are now World Heritage sites but the date of their construction is unknown. In Marrakesh the city walls and the El Badi Palace, constructed in 1578 are constructed mainly in rammed earth. Much of the vernacular architecture in Morocco is still rammed earth.

Azuar-Ruiz (1995) argues that a lack of evidence means that it is not possible to trace the use of rammed earth prior to the 9$^{th}$ century in Iberia. The first rammed earth may have been the castle of Badajoz, built in 874, of which nothing now remains. However town fortifications in Calatayud and Pla d'Almata dated to 884 have been uncovered. Graciani-García &Tabales-Rodríguez (2003) argue that the oldest walls in the Alcazar of Seville (circa 914) constructed as dressed stone with a compacted mortar fill, are rammed earth, but this is considered to be the Roman technique of *opus quadratum* rather than rammed earth.

Internal political strife in Iberia at the end of the 10$^{th}$ century led to the construction of castles (for example Baños de la Encina, Figure 6) which were built using rammed earth as a speedy construction method which producing durable fortifications. During this period separate kingdoms (*Taifas*) ruled small parts of the peninsula, constructing many fortifications (for example the Alcazar in Granada, Figure 7). Following repeated Christian incursions, the Iberian Muslims requested the assistance of the Almohade rulers of north Africa. The majority of rammed earth castle sites in southern Spain are associated with the Almohade era (for example Castle of la Atalaya, Villena, Figure 8), although dating the initial construction of these sites is extremely difficult. The technique was widespread during the 11$^{th}$ and 12$^{th}$ centuries, and Moses Maimonides, a Jewish

writer and philosopher, born in Cordoba in 1135, but residing in Morocco, Egypt and Israel wrote of rammed earth:

> The builders take two boards, about six cubits long and two cubits high and place them parallel to each other on their edges, as far apart as the thickness of the wall they wish to build; they steady these boards with pieces of wood fastened with cords. The space between the boards is then filled with earth, which is beaten down firmly with hammers or stampers; this is continued until the wall reaches the requisite height and the boards are withdrawn. Moses Maimonides, cited Cooke (2005a)

## Late Medieval Europe

The Muslim rule in Spain waned, and the last Muslim king of Granada was removed in 1492. The Christian rulers of Spain initially employed the Muslim population as craftsmen and artisans, and the rammed earth technique is found throughout Christian Spain. Fired brick began to be mixed with rammed earth (Gerrard 2003), and the introduction of artillery led to the cladding of rammed earth walls in masonry. Some strategic military structures were strengthened and enlarged in stone by the Christians (Figure 8), but rammed earth continued to be used for both strategic and vernacular architecture (Jaquin *et al.* 2007). In Spain rammed earth was used for military architecture (e.g. Figure 9) and vernacular architecture until the 19$^{th}$ century (Font & Hidalgo 1991; Gerrard 2003).

Vernacular rammed earth in southern France may have been prevalent in Christian medieval France, because rammed earth was introduced into Switzerland from the Lyon region of France around 1660 where the alluvial soils proved ideal for rammed earth construction. The oldest Swiss rammed earth constructions are Gonzenbach castle outbuildings near Geneva (Kleespies 2000).

## Expansion to the Americas (Figure 3)

Rammed earth was not found in the Americas prior to 1492. In 1549 Manuel da Nobrega, a Jesuit missionary sent a request to Europe to send 'artisans able to handle loam, and carpenters, for the construction of a rammed earth wall'. Jose de Anchieta, a Spanish Jesuit arrived, and supervised the construction of Colegio da Companhia de Jesus in Piratininga, São Paulo, Brazil (Puccioni 1993). Tibbets (1989) and Easton (1996) argue that the first rammed earth in North America used a soil and sea shell mix, compacted in heavy formwork, found in St Augustine, Florida and built in 1556.

Rammed earth was used in the Goiás and Minas Geras areas of Brazil (Oliver 1997; Justi-Pisani 2004), In São Paulo the cathedral of Taubaté was constructed from rammed earth in 1645 (Alvarenga 1993; Pereira 1993; Vinuales 1993) and the Church of Our Lady of the Rosary in 1720 (Pecoraro 1993). In São João del Rei the Basilica of Our Lady of Pillar was built sometime in the early 18$^{th}$ century (Lima and Puccioni 1990). In Goiás, the House of the Chamber constructed in 1776 is of very similar architecture to that found in Portugal in the late 18$^{th}$ century (McHenry 1984). Rammed earth use was widespread in São Paulo and the surrounding during the 18$^{th}$ and early 19$^{th}$ century. However in 1850 following flooding in the city a public campaign against the use of rammed earth led to a reduction in the use and demolition of much of the rammed earth architecture (Pecoraro 1993; Pereira 1993; Justi-Pisani 2004). A small number of examples of rammed earth architecture still exist, such as the Chapel of Morumbi which was built in 1850 on farmland outside of São Paulo and is now a national monument.

## 18$^{th}$ century Europe

The prevailing political climate in Europe at the end of the 18$^{th}$ century was of revolution and for a rise in status of the common worker. Rammed earth began to be championed as a low cost owner-builder construction technique. In France G C Goiffon published *Art du macon piseur* in Le Jai, an obscure Paris journal in 1772 and in 1786 François Boulard published an article on rammed earth in Cours Complet d'Architecture (Cody 1990). Neither article was as successful as the series of pamphlets published by François Cointeraux in 1791. Cointeraux lived in Lyon and "rediscovered" the rammed

earth legacy left by the Phoenicians almost 2000 years earlier. Cointeraux conducted a number of experiments on rammed earth, detailed in four documents (Cointeraux 1791; Figure 12) which were distributed around Europe. Gilly (1798) translated the works into German and Guiseppe del Rosso, an architect in Toscana, Italy published a rammed earth construction manual probably inspired by the work of Cointeraux (Bertagnin 1993). English translations of Cointeraux's work were published in 1798 in England by Holland and Salmon (1798) and in the United States by Johnson (1806).

A large number of barns and agricultural buildings were constructed to Cointeraux's specifications in rammed earth and can be found in the Lyon area of France (CRATerre 2006). In the rest of Europe, known surviving large buildings include a three storey hotel in Marcon, France, constructed in 1790 (McHenry 1984). In Germany a fire resistant house was constructed in 1795 by the head of the local fire service in Meldof, Schleswig-Holstein, who wanted an alternative to timber construction. Haus Rath in Weilburg an der Lahn, was constructed in 1828 which climbs to five storeys (Guntzel 1990; Steingass 2005).

In the early 18$^{th}$ century a group of craftsmen travelled through Norway and Sweden building in rammed earth using fixed formwork filled with lime mortar and slag of pebbles and stone. The increase in popularity of rammed earth was brought about by the perceived ecological crisis engulfing Europe at the time, which was seeking alternatives to timber construction to prevent deforestation in Europe (Palmgreen 2005). A Swedish mining engineer built houses in Hartz (1735) and Falun (1739). Lime production led to the construction of rammed lime buildings in the middle of the 19$^{th}$ century. In Sweden outbuildings of the Karlsborg Fortress in Stockholm were built from rammed earth in 1842 and parts of the summer residence of the Queen of Norway was constructed in rammed earth at Kongsvinger in 1890. However following the introduction of locally produced Portland cement in Scandinavia at the turn of the 20$^{th}$ century, rammed earth fell into decline (Palmgreen 2005).

## 18th and 19th century migration

The late 18th and 19th centuries saw the first truly mass migrations of peoples. Movement of peoples to North America, Australia and New Zealand brought previously unknown skills and customs to these lands. Rammed earth spread from rural to urban China, and from China and Europe to America. European settlers to Australia and New Zealand experimented in rammed earth. Rammed earth did not succeed everywhere, but there are many examples of historic rammed earth structures built by these immigrants.

Hoi Pa Village, Hong Kong, grew up in the 18th and 19th centuries built by Hakka peoples who had migrated south. The Fan Sin Kung temple in Hong Kong was constructed in 1790 and Holmes (2000) states that it was common in this period for buildings in Hong Kong to have at least one wall (usually the rear) constructed in rammed earth. A good example of traditional southern Chinese village architecture is the Old House, built in 1904 and now preserved as an Environmental Resource Centre (AMO 2004).

A depression in China, and the lure of gold mining, led to large migration to California in the mid 19th century. In Fiddletown, California Chinese immigrants constructed a small rammed earth herb shop (The Chew Kee Store) around 1850, which was recently repaired to become a museum (Easton 1993; Easton 2007). In Palo Alto, a business woman named Juana Briones built a rammed earth type house around the same time (Camarillo 2005).

On the east coast of the United States a rammed earth construction manual was published in New Jersey (Johnson 1806) which drew heavily on the work of Holland and Cointeraux. Johnson built a house near Trenton, New Jersey, hoping to provide a model to newly arrived Americans looking to settle new farm land. Tibbets (1989) argues that German immigrants built in rammed earth in New York and Pennsylvania, and that Thomas Jefferson built his home (Monticello, Virginia) in rammed earth. Another well documented structure, Hilltop House, was constructed in 1773 in

Washington DC. Bushrod Washington (nephew of George Washington) built rammed earth lodges on his estate at Mount Vernon in 1812 (Pogue 2007). In 1819 John Stuart Skinner, editor of *The American Farmer* published a translation of Holland's work, and later several other articles on rammed earth construction experiments taking place in North America, notably John Hartwell Cocke's slave quarters at his plantation in Bremo, New Canton, Virginia (Johnston *et al.* 1969). Dr. William W. Anderson of Stateborough, South Carolina, recounted his experimentation with rammed earth construction, which had begun with the construction of a small dairy in April 1821. Pleased with the results, Anderson constructed rammed earth servants quarters in July 1823. Gilman (1839) published a treatise extolling the virtues of rammed earth, and John Stephen Wright, editor of *Prairie Farmer* published 40 references to rammed earth in this periodical between 1843 and 1855 (Cody 1990). In 1842 St Thomas Church in Shanty Bay Ontario was built and in 1850 Dr Anderson began the *Episcopal Church of the Holy Cross* in Sumter County, South Carolina (Easton 1996).

European settlers in Australasia in the mid 19$^{th}$ century experimented with a wide range of building techniques (see Figure 4 for site locations) . The first reference to rammed earth may be a notice by the Agricultural Society in May 1823 on the front page of the Hobart Town Gazette, Tasmania.

> 'Resolved that the mode of building in pise, or rammed earth, appearing to this Society to be both economical and expeditious, the Society earnestly recommend its adoption in Van Diemen's Land' (Moor & Heathcote 2002).

The *Southern Australian* reported in 1839 that '*nearly thirty houses have been erected, they are mostly built of pise'.* In Rushworth, a gold rush town in Victoria, rammed earth was used as a speedy construction technique and in Harden, Australian Capital Territories, a rammed earth barn and stables are now a heritage monument (ACT 2004). Much of the original settler architecture in Oberon (Gemmell-Smith 2004), and Penrith (NSWCR 1991) New South Wales was constructed in rammed earth, and though much

has been demolished, a small number of historic examples remain. On the west coast, the village of Moora contains a large number of rammed earth structures, constructed between 1847 and 1869 (Laurie 1995). Earth building in New Zealand began with the first European settlers in 1840, but all forms of masonry construction fell out of favour following earthquakes in 1846 and 1855 (Walker & Morris 1997). The best known example of historic rammed earth in New Zealand is Pompallier House in Russell which was completed in 1842 and has recently undergone conservation work (Bowman 2000).

## 20th century

The two World Wars in the 20th century both saw rammed earth suggested as a solution to the housing and labour shortages which followed each war. In the UK following the First World War, Welsh architect Clough William-Ellis 'discovered' earth buildings hidden beneath plaster veneers of historic cottages. His father-in-law St. Loe Strachey, an ideologue aristocrat and media mogul, ran a campaign in *The Spectator* magazine, both for information and to promote rammed earth as a building material in the UK. Following the campaign, William-Ellis published a book (William-Ellis 1919) explaining earth building techniques for use in the UK, and the Board of Agriculture constructed a series of prototype cottages at Amesbury, Wiltshire, some in rammed earth, others in brick and others in rammed chalk. The rammed earth cottages, while initially popular, did succeed due to the differential costs of labour and materials following the collapse of the post war boom (Easton 1996; Swenarton 2003; Walker *et al.* 2005).

In the United States Karl Ellington published a book (Ellington 1924) with a preface by William-Ellis, and in 1926 Thomas Miller of the US Department of Agriculture was sent to investigate the *Church of the Holy Cross* in South Carolina, and as a result published *Farmers Bulletin No 1500*, which detailed rammed earth construction methods. Harry Baker Humphrey, a senior member of the Department of Agriculture, was impressed with the technique and built his rammed earth home in 1926. Many others followed suit, using the *Farmers Bulletin* to construct their own homes in rammed earth. Academic research was carried out by Ralph Patty and Henry Delong of South Dakota State College, with many publications produced for example Patty (1936). As part of President

Roosevelt's New Deal programme, a number of intentionally labour intensive homestead projects were initiated. In 1932 Thomas Hibben built seven experimental rammed earth houses at Gardendale, Alabama, all of which stand today. Elbert Hubbell, continuing the work of Patty, built a many rammed earth structures on an Indian reservation in North Dakota, and together with Miller and Hibben, Hubbell conducted tests on a number of earth building systems. They published the Building Materials and Structures report (BMS78) which concluded that all of the earth building methods tested were suitable for the construction of single or two storey structures (Tibbets 1989; Easton 1996). A single reference (Kornouchow 1933) suggests that rammed earth may also have been investigated in the Soviet Union as a solution to social housing during this period.

Following the Second World War, rammed earth was used in East Germany as a cheap and widely available construction material for immediate post-war reconstruction (Steingass 2005) and Building Standards documents covering rammed earth construction were published between 1947 and 1956 (Houben and Guillaud 1994). A similar revival was seen in Scandinavia at the same time with two books on rammed earth being published and a number of constructions (Palmgreen 2005). In Australia an English trained architect, G F Middleton was employed by the Commonwealth Experimental Building Station in Sydney and conducted a large number of tests on rammed earth and other earth building techniques. His initial reports (Middleton 1952) and his *Build Your House of Earth* book (Middleton 1953) were until recently the accepted standard reference in Australian earth building (Moor and Heathcote 2002).

In the mid 1970s, a number of different groups began reinvestigating rammed earth, and established themselves as builders or academics to spread the rammed earth message. In the United States, David Easton and Tom Schmidt began to build in rammed earth, in Australia Giles Hohnen and Stephen Dobson founded companies offering rammed earth homes. Architecture graduates Hugo Houben and Patrice Doat founded CRATerre at the University of Grenoble, for the study of earth building materials. Following those pioneers, the use of rammed earth has grown and shrunk in different parts of the world, but is now enjoying a growth, and reinvention as a sustainable and environmentally

friendly building technique. Rammed earth is now a well established construction technique in Western Australia and the south west United States where cement stabilised rammed earth is gaining mainstream use. In Europe and other parts of the world rammed earth is now being suggested as a sustainable construction material.

## Conclusions

The discussion above has detailed the development of rammed earth (as defined at the start of this paper) across time and over specified regions. This is summarised in a timeline in Table 1 supplemented by Figure 13 which indicates the most significant movements of rammed earth methods over time. A development of the technique in China was explained, and it is possible that rammed earth developed from the heaping of soil against vertical formwork in many parts of the world. Two independent schools can be observed: one around the Mediterranean and one centred on China.

Rammed earth in China developed as a necessary construction technique where few building materials were available. Yunxiang (2003) shows that heaping of soil may have developed into compacting between formwork as a method of producing a vertical face. The technique was successfully used for long sections of defensive walls built by successive empires, eventually becoming known as the Great Wall of China. The technique is certainly used by the Hakka people originally from central China, and may have been used in Tibet. Rammed earth is currently found in southern China as a result of Hakka migration, and in the Himalayan kingdoms of Ladakh, Mustang and Bhutan.

Rammed earth around the Mediterranean appears to be present in Phoenician and later Carthaginian settlements, such as those of Hannibal described by Pliny and Healy (1991). This appears to be independent from the rammed earth technique practiced by the ‘oasis dwellers’ of north Africa’ described by Michon (1990). The explosion of Islam in the 8$^{th}$ century led to the second introduction of rammed earth into Europe, this time from north Africa, and many rammed earth fortifications in southern Spain are a result of this spread. Evidence in Central Asia is scarce, rammed earth is found in Penjikent in Tajikistan, dated to the 5$^{th}$ century, and rammed earth walls at Yerevan in Armenia exist,

but the date of their construction is unknown. Muslim technology and architecture spread east with the armies, but it is probable that rammed earth already existed in central Asia prior to this.

There is no evidence of rammed earth in the Americas or Australasia prior to European settlement, even though rammed earth is now flourishing in those parts of the world. 16th century migration took the technique from Spain and Portugal to South America. 18th and 19th century migrants to North America and Australasia tried rammed earth amongst a wide range of building techniques, and a small number of historic examples have been highlighted. Chinese migration to the west coast of north America may have been responsible for the Chew Kee store in California (Easton 1996).

Rammed earth use in Europe was revitalised by the publications of Cointeraux, and translations of his work helped to spread the message far. In the 20th century rammed earth was again revived as a solution to the housing and labour shortages following each World War. Recently rammed earth has once again seen a revival in interest, this time as a sustainable building material.

Rammed earth is not a ubiquitous construction technique, instead finding niches in different parts of the world. Rammed earth is found only where certain criteria are fulfilled. The building material, namely soil, must be suitable, and the wide range of different suitable soils is testament to different mixtures which can be used. If a soil is predominantly clay, then it is more likely that moulded sun dried clay bricks will be made. If the soil is too sandy, then any attempt to make rammed earth will ultimately fail. The availability of timber is paramount. If timber is freely available, then it will be used for construction, but formwork cannot be produced if it is wholly absent. The climate in which rammed earth will survive is the source of much debate. Rammed earth is found in regions with a Mediterranean climate, which includes western Australia and the south west United States.

This paper has provided a chronological account of rammed earth in different locations around the world. Monumental architecture has been used as references, and it is assumed that vernacular rammed earth existed where monumental rammed earth is found. It may be likely that rammed earth may be discovered at sites not yet investigated, but the fragile nature of rammed earth means that many sites may no longer exist.

Rammed earth has been used for the quick construction of fortifications, and is used where few other building materials are available. Rammed earth flourishes where labour is comparatively cheap, and has repeatedly been proposed as a solution for owner-builder construction. Most recently rammed earth has been suggested as a sustainable building technique, and it is hoped that the rich heritage of historic sites are able to inform modern construction.

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**Figure Captions**

Figure 1: Selected rammed earth sites in China and Central Asia

Figure 2: Selected rammed earth sites in Europe

Figure 3: Selected rammed earth sites in North America

Figure 4: Selected rammed earth sites in Australasia

Figure 5: Great Wall in Ningxia. (Photograph: Smith 2006)

Figure 6: Castle of Banos de la Encina, Andalucia. Constructed 967. (Photograph Jaquin 2007)

Figure 7: The Keep, Alhambra, Granada, Andalucia. Constructed around the 10th century (Photograph Jaquin 2007)

Figure 8: Castle of la Atalaya, Villena, Alicante. Almohade Muslim base constructed around 1172, Christian masonry above constructed after 1240 (Photograph Jaquin 2007)

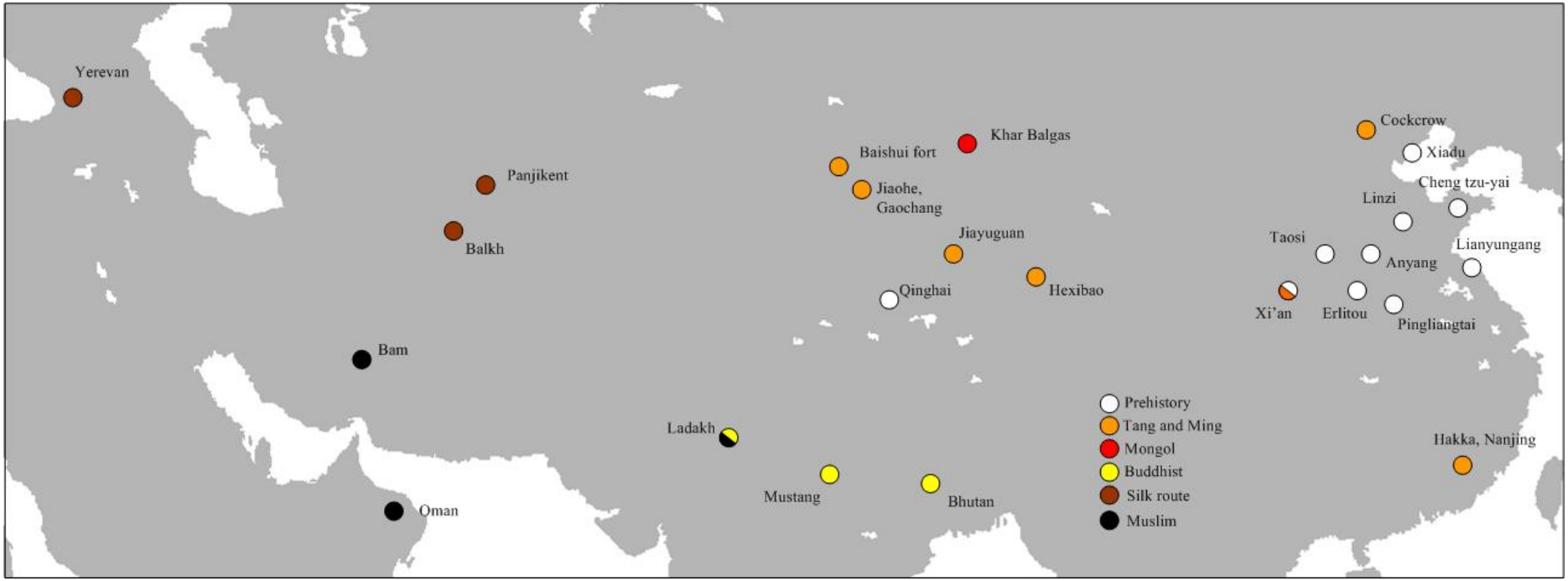
Figure 9: Rammed earth wall, Daroca. Constructed 1837, windows are rifle ports. (Photograph Jaquin 2007)

Figure 10: Shey Palace, Ladakh. Constructed around 1357. (Photograph Jaquin 2006)

Figure 11: Namgyal Tsempo, Leh, Ladakh. Constructed around 1550. (Photograph Jaquin 2006)

Figure 12: Example of a rammed earth home (from Cointeraux 1791)

Figure 13: Major movements of the rammed earth technique

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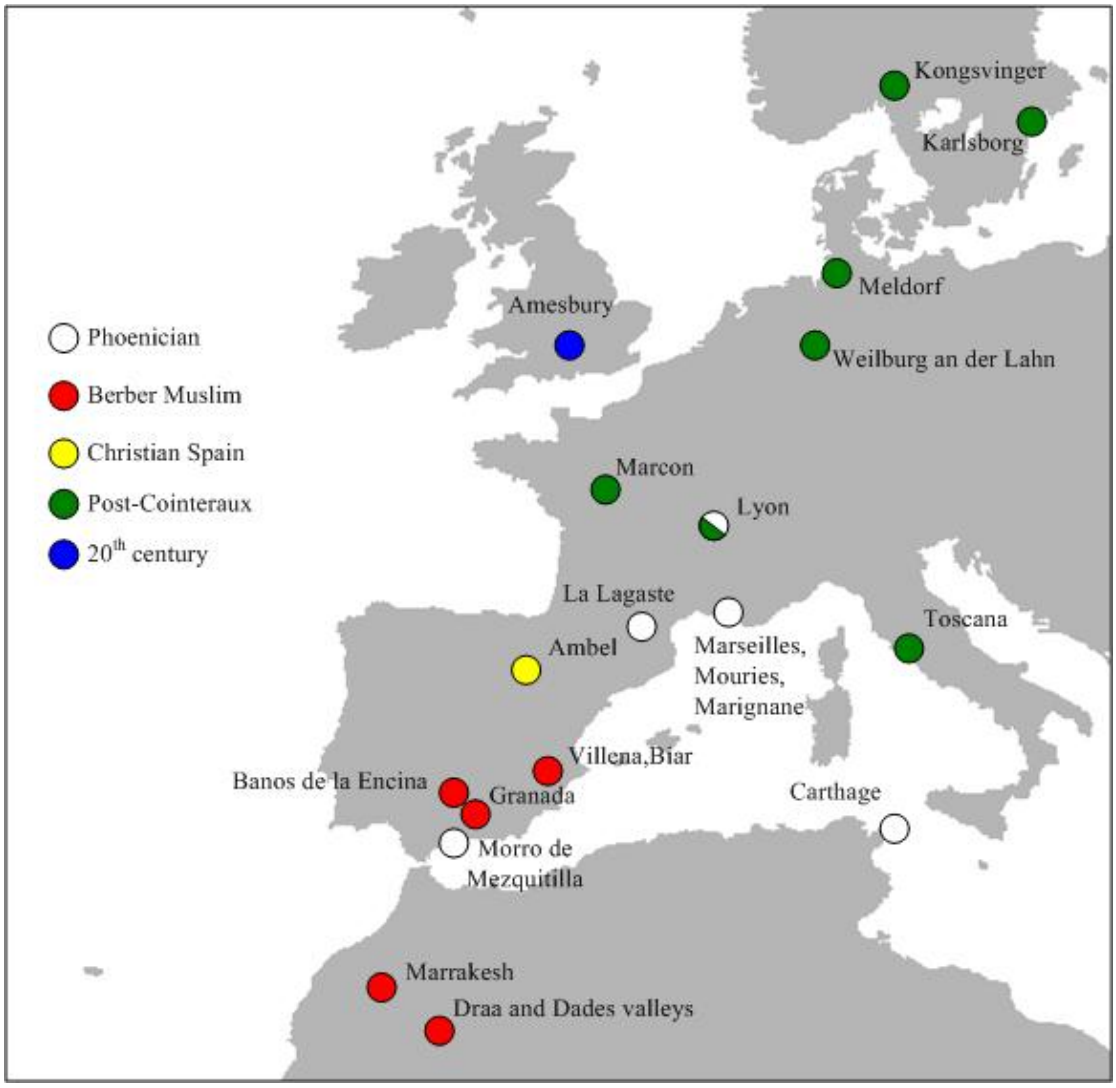



Figure 2: Selected rammed earth sites in Europe

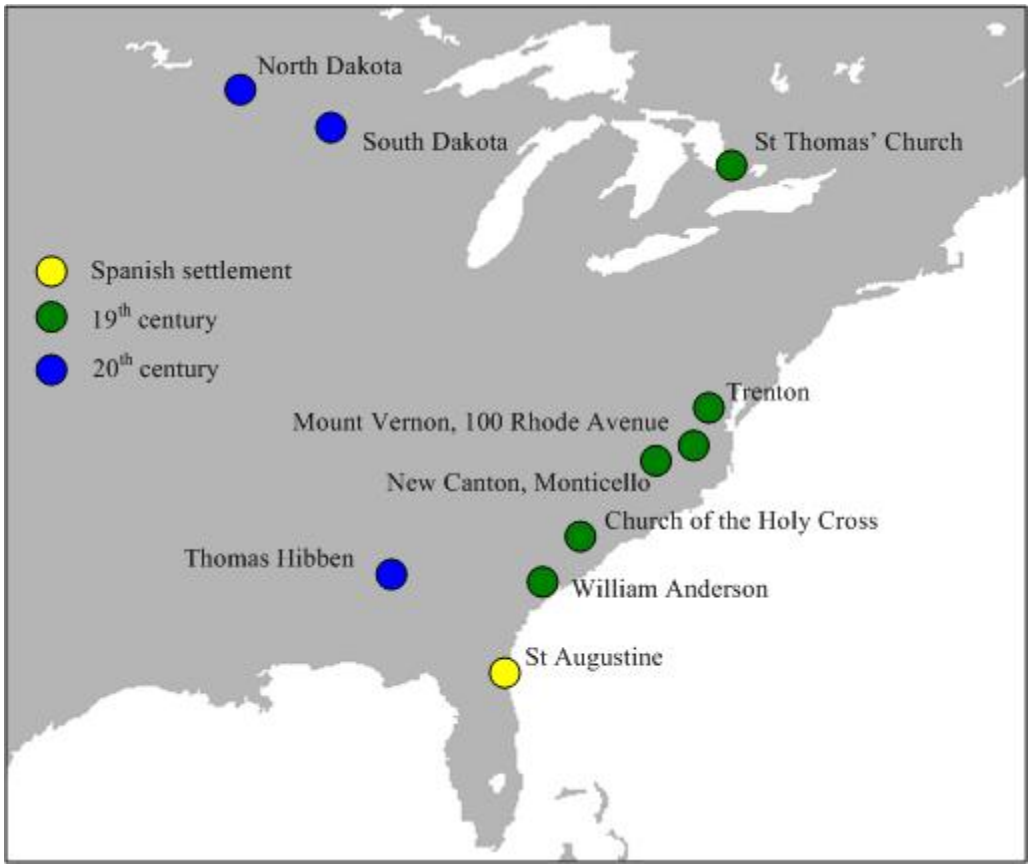
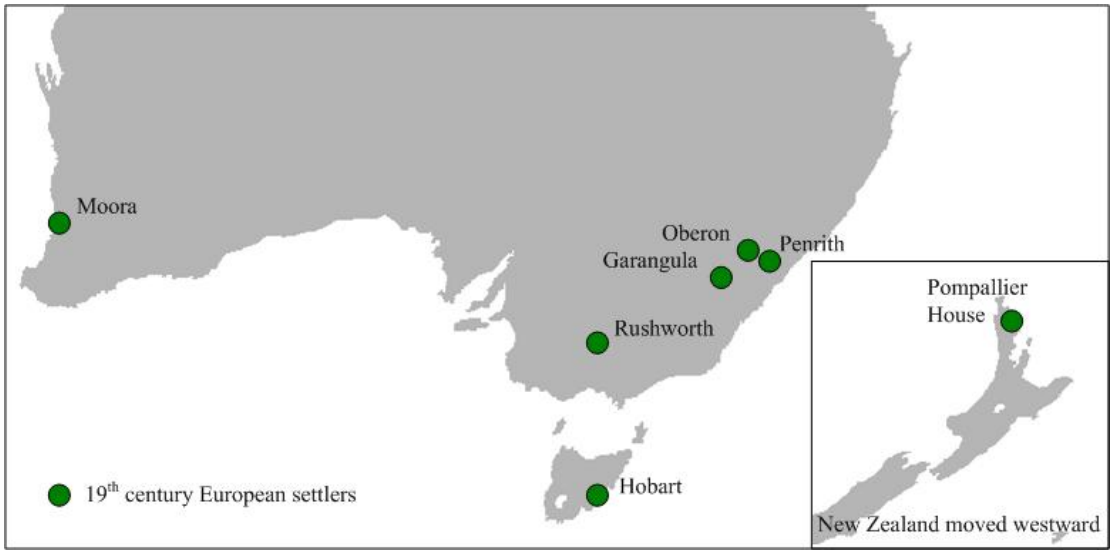



Figure 3: Selected rammed earth sites in North America

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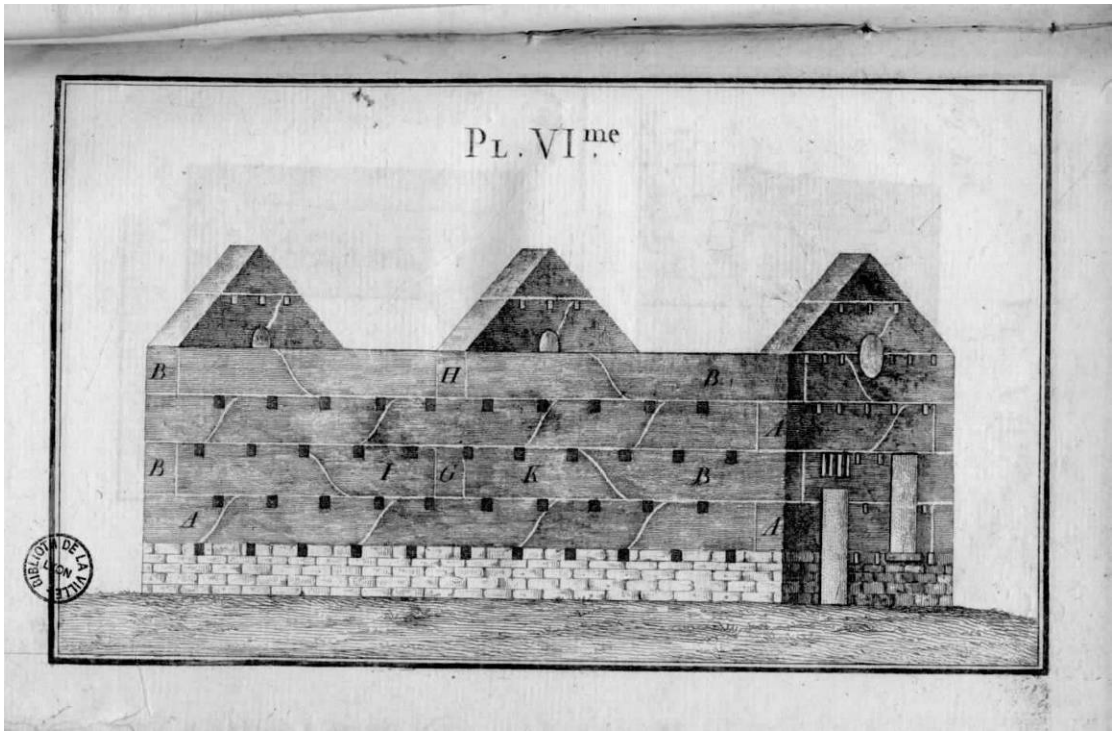


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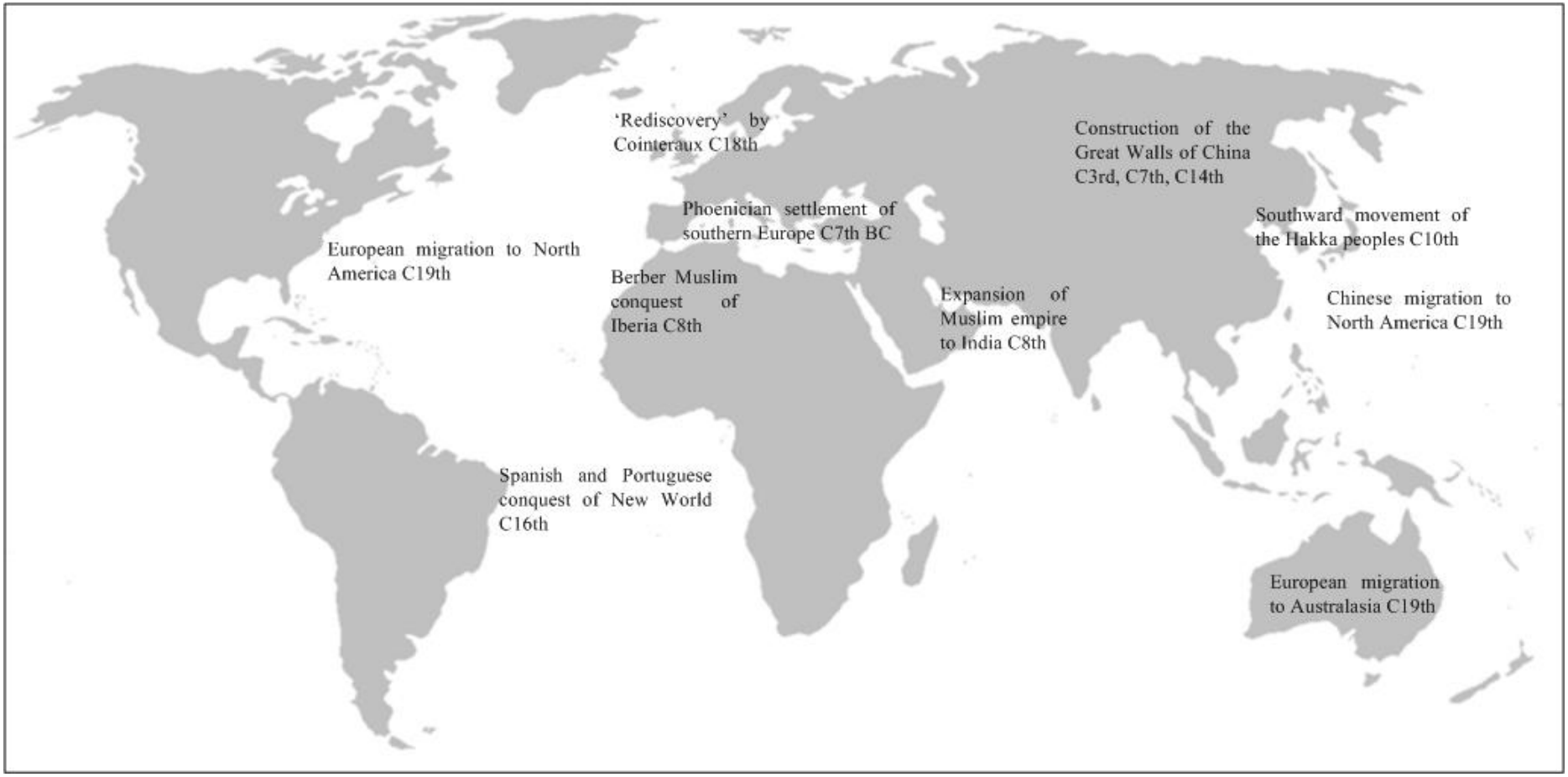


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