Concrete Chapter—Mary Ann Eaverly


Abstract

The most popular building material in the world today, concrete was first developed and exploited by the ancient Romans who used it to create monumental public spaces such as the Colosseum. The design of Roman concrete structures reinforced Roman ideas about social status and imperial power. This chapter explores the rich history of concrete and its legacy in the modern world, touching upon the role of concrete in ancient Rome, today's technical advances in concrete construction, and concrete's environmental drawbacks. The chapter also examines how concrete construction is shaped by societal ideals today, just as it was by societal ideas in ancient Rome.


# Engineering Society through Social Spaces: Concrete Construction

## Introduction

Figure 1. The Guggenheim Museum, New York City

Pourable, moldable, durable, waterproof, and relatively easy and inexpensive to manufacture, concrete is the world's most popular building material. We live, work, and play on and in buildings and roads constructed from it. Architects exploit its properties to create artistic tour de forces as well as utilitarian monuments **(FIGURE 1).**

Concrete is such a part of our daily lives that we may not stop to think about who invented it or why builders create certain types of buildings from it and not others. Is there a connection between buildings and larger societal forces? Have you ever wondered why we use concrete the way we do? Do buildings reflect a society's ideals for social organization? To try to answer these questions we need to examine the role concrete played in the society that first developed it— ancient Rome. This chapter explores how concrete structures have historically been connected to social organization.

MT. VESUVIUS and POMPEII

In AD 79, long after Vitruvius's death, Mount Vesuvius erupted and destroyed the Roman city of Pompeii, preserving its buildings and construction practices (as well as many of its human inhabitants and even a few dogs) for modern archaeologists to study. Find out more at

[www.cyark.org/projects/pompeii/overview](www.cyark.org/projects/pompeii/overview)



## Origin of Concrete

As far a back as the sixth millennium (6000-5000 BC), the ancient Mesopotamians knew that heating calcium carbonate, a substance occurring naturally in limestone rocks, creates a new substance, known today as quicklime, in a process described chemically as $CACO_3$ + heat(1000° C) =$CO_2$ + CaO. This chemical reaction releases carbon dioxide into the atmosphere (more on this later). The resulting material, when mixed with water, bonds to other surfaces. The early residents of Çatalhöyük, an ancient city in modern-day Turkey, used this substance to coat their walls, providing a surface for painted decoration. The Egyptians of the third millennium (3000-2000 BC) used quicklime for mortar in stone construction.[i] In neither case was concrete the primary building material. It was used for decoration or as an adhesive. However, in the third century BC the Romans discovered that by mixing quicklime and sand with a local volcanic stone—pozzulana—they could create something much stronger than simple quick lime **(FIGURE 2).** The Romans called their new material—the forerunner of modern concrete— *opus caementicum*. Because of

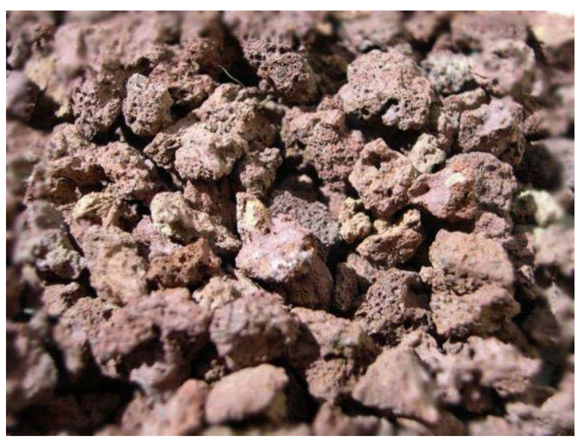

Figure 2. Pozzulana from the Area of Vesuvius

its durability, many ancient Roman buildings still stand, providing evidence of the strength of Roman concrete and of Roman construction practices.

Fortunately, we also have ancient testimony concerning Roman buildings from the Roman architect Vitruvius, who wrote during the reign of the emperor Augustus (27 BC-AD 14). Vitruvius wrote a ten-volume history of Roman architecture—*De Architectura*. An architect himself and a former catapult operator (catapults hurled projectiles at walls during sieges) in the Roman army, he was interested in many of the practical aspects of Roman construction. In the second volume of his history, Vitruvius describes building materials, including concrete. About pozzulana, the additive that makes Roman concrete possible, he says: "There is also a type of powder that brings about marvelous things naturally. It occurs in the region of Baiae and in the countryside that belongs to the towns around Mount Vesuvius." (*De Architectura*, II, 6, 1) [ii] Since Italy is a volcanic region, pozzulana was not hard to find.

While *opus caementicum* had many of the properties of modern concrete—it was strong, moldable, and light in weight (at least compared to stone), it lacked the smooth pourable consistency we take for granted with concrete today. In addition to *pozzulana,* the mix included aggregate—rubble, pieces of rough stone, and broken brick. These materials were not blended into one seamless product, but were instead bound in a rough mass. The resulting mixture then had to be laid by hand rather than poured. The Romans found its rough appearance unsightly and covered (faced) it with other materials, usually a surface layer (veneer) of either brick or fine marble. Yet, even with the added veneer, concrete construction proved much more economical than the previous reliance on stone for large-scale buildings. Stone carving required highly skilled laborers. Transporting blocks from the quarry to the building site was time consuming and expensive, as we shall see later in this chapter. Concrete, in contrast, could be made on site and laid by less-skilled workers, who could be organized into quickly working groups[iii]. By covering buildings with a veneer of fine marble or other exotic stones, the Romans achieved the appearance of an expensive solid stone structure cheaply and efficiently.

## Roman Concrete Revolution

Concrete freed the Romans from the constraints of traditional architecture. Before concrete, buildings made of wood or stone used what was known as *the post-and-lintel construction system*, in which vertical elements (posts) support .horizontal elements (lintels).You can see the post-and-lintel construction in the columns of such

Figure 3. Post-and-Lintel Construction. The Parthenon, Temple of Athena, 5 Century BC, Athens, Greece


Figure 4. The Pantheon, Rome (2nd Century AD)

famous ancient Greek columns of such famous ancient Greek temples as the Parthenon in Athens[iv] **(FIGURE 3).** With this system it is almost impossible to create a large unsupported roofed space. While some Greek temples were massive (the Temple of Apollo at Didyma[v] in modern Turkey had a total area of 18,000 square feet and columns that were 64 feet tall), their usable interior space was limited  because of the need for  internal roof supports (columns or posts), which took up much floor space.

Because of its light weight and moldability, concrete roofing systems did not need to be supported. By using concrete to create intersecting arches and vaults, the Romans designed interior spaces on a far grander scale than post-and-lintel construction allowed.

Archaeologists call the Roman exploitation of concrete arches, vaults, and domes to create interior space the 'concrete revolution.' Among the most dramatic of these buildings is the Pantheon in Rome **(FIGURE 4).**



The Pantheon

From the exterior the Pantheon looks like a traditional temple with columns for support, but the interior is a spectacular domed space. Compare its interior with that of the Parthenon, considered the most perfect of Greek temples **(FIGURES 5 and 6).** Because the diameter and the height of the Pantheon are the same, the building's interior encloses a complete sphere of space, which may be an allusion to the totality of the gods (the word *pantheon,* derived from ancient Greek, means "all of the gods") since a circle is a complete form[vi].  While columns

Figure 5. The Pantheon Interior, Rome (2nd Century AD)

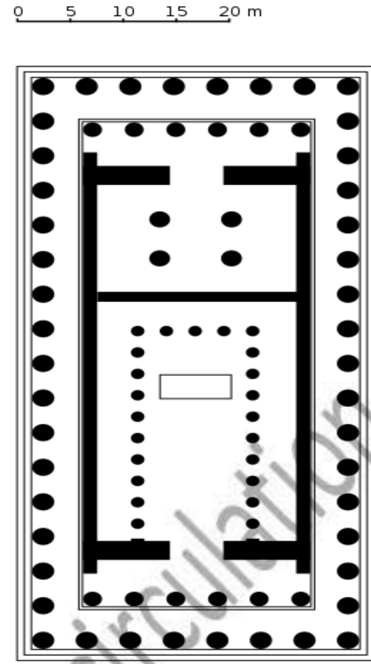


Figure 6. Plan of the Interior of the Parthenon. Each dot represents a column.

built into the walls appear to support the ceiling, concrete arches and vaults actually bear the weight. By using increasingly lighter materials in the concrete aggregate as they moved to the top of the dome, the builders were able to ensure that it did not collapse. Until the twenty-first century the Pantheon was the largest unsupported dome in the world. All of the structural, load-bearing work of the concrete is hidden beneath elaborately colored marble veneer. Note that despite its 'revolutionary' interior the Romans gave the building the outward appearance of traditional post-and-lintel building style. Because they admired the architectural achievements of the Greeks, they retained the column styles that the Greeks had created (Doric, Ionic, and Corinthian), even when these columns had no true structural role in a building. This tradition continues today in modern buildings, such as banks or government offices, in which ancient Greek architectural elements on concrete buildings evoke the perceived glory of the Classical past.

The exterior columns of the Pantheon were not, as is typical in ancient temples, made from segments, but were instead each carved from a single block of granite brought to Rome from Egypt. Costly and difficult to carve and transport, they, along with the exotic marble veneers inside the building, emphasized the reach and power of the Roman Empire. Using concrete cut down considerably on construction time. Even with the time consumed by transporting the columns from Egypt the Pantheon took just six years to complete (AD 118 to AD125), while the Greek (all-stone) temple of Apollo at Didyma took almost five hundred years (332 BC to AD 130).

Bread and Circuses

As impressive an engineering feat as the Pantheon is, temples did not provide the impetus for Roman exploitation of concrete. Instead, spectacles, bath complexes, and military operations drove the development of this technology. As archaeologist Lynn Lancaster writes: “The two cultural institutions that had the greatest effect on the advances in vaulted technology during the imperial period were public bathing and public entertainment.”[vii] Ancient Roman writers attest to the importance of these cultural practices. In the second century AD, the Roman writer Juvenal, despairing of what he perceived as the decline of the Roman national character, states in *Satires*:

… the people that once bestowed commands, consulships, legions and all else, now meddles no more and longs eagerly for just two things—Bread and Games. (*Satires*, 10.81)[viii]



This phrase, usually translated as “bread and circuses,” refers to the government-sponsored daily distribution of free bread to the populace and spectacles such as gladiatorial games that took place in amphitheaters, large concrete structures designed to house such events. What role did these games play in Roman society, and how did they contribute to the rise of concrete technology?

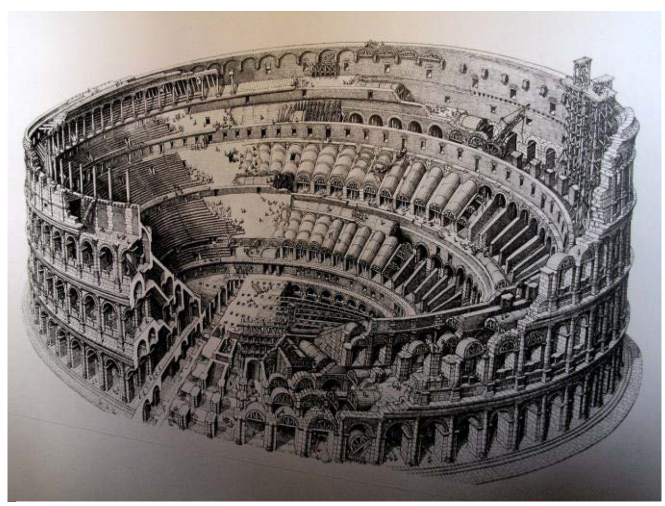

Figure 7. Drawing of the Colosseum, Rome. In the cut-away sections, note the use of vaults and arches for support.

The Colosseum and Roman Gladiatorial Games

The most enduring statement of the Roman love of spectacle is the Colosseum in Rome **(FIGURE 7).** Designed to hold 50,000 spectators, the building covers an area of 615 ft x 512 ft, almost 315,000 square feet, and is 159 feet tall. Eighty exits made for facilitated easy entrance and exit. The building fully exploits the properties of concrete. While from the exterior it looks as if columns, a feature of post-and-lintel construction, are doing the supporting work, they are simply a façade (a decorative surface) covering the actual structural elements—concrete arches and vaults that support the sloped (stadium) seating. These arches and vaults allowed the Romans, unlike the Greeks, to build stadium seating in the round. While the Greeks had developed stadium seating for their theaters, they needed a hillside to provide the inclined angle for the seats. Concrete obviated the need for a naturally occurring slope[ix].

GLADIATORS

Highly trained combatants wearing different types of specialized armor fought against each other in single combat. For example, a heavily armored man with a sword (Myrmillo) would fight a lightly armored man with a net and three-pronged pitchfork (Retiarius). The net man had the advantage of speed and the armored man the advantage of protection. The Romans enjoyed seeing each man exercise his skill against the other. The loser was killed by his opponent, although if he had fought well he might be spared by the administrator of the games to fight again. The combat always paused for the moment when the loser confronted his own death. The crowd admired those who faced their death bravely.

**ACTIVITY –Take an aerial tour of the Colosseum**

https://search.yahoo.com/yhs/search?p=aerial+tour+of+colosseum+in+rome&ei=UTF-8&hspart=mozilla&hsimp=yhs-003

Begun in AD 72 and completed in AD 80, this amphitheater hosted one of the favorite forms of Roman entertainment—gladiatorial games **(FIGURE 8).**

The games included not only man-to-man combat, but a day-long program comprised of public executions, man-vs.-beast and animal-vs.-animal contests, and even mock naval battles in which participants fought to the death. While scholars debate the origin of these blood sports, most believe that they derive from early funeral rituals involving games and blood sacrifice offered to appease the spirits of the dead. By the time of the Colosseum, however, these activities were intended to reinforce social and imperial identity throughout the empire. How did this work? First, where one sat was determined by one's social class. Roman society had four sharply delineated main divisions. The patricians—hereditary noble families—formed the top (aristocratic) class. The most important member of this group was, of course, the Emperor, absolute ruler of a vast empire. **(FIGURE 9**) Next in importance were the plebeians—the majority of Roman citizens (free-born but not patrician). They were followed by freedmen—individuals who had once been slaves but who had, through various means, earned their freedom. Finally, slaves formed the lowest level. This group included prisoners captured in Rome's many wars throughout the ancient Mediterranean, but also included Romans who had been sold into slavery because of debt and those who had been

Figure 8. *Pollice Verso*, by Jean-Léon Gérôme. This 19th-century painting attempts to recreate the moment of death for a defeated gladiator. The crowd is condemning him to death by pointing thumbs down. We do not, however, actually know what gesture was used to determine life or death

born of slave parents. The best seats, in the Colosseum and other Roman amphitheaters, near the arena floor and thus closest to the action, belonged to the patricians. The remainder of the spectators sat in descending order of importance (plebeians, freedmen, and slaves). The higher the seats, the lower the status. Women—who were not eligible to vote or participate in government— sat at the very top with the slaves, indicating their inferior status regardless of social class. Amphitheaters were a vital part of every Roman town and this arrangement was repeated throughout the empire. Gathered to watch the games, Romans could, while surveying the audience, re-affirm their own place in society. Seating provided physical and visual confirmation of society'[s rules. Compare the Colosseum with one of our modern stadiums. If, for example, we look at the University of Florida football stadium during a Saturday football game, we can see that some status functions are also at work, although in this case we see that our seating reverses Roman practice.  In American football stadiums the most expensive seats (and therefore those that belong to what might be called "the most important people") are the sky boxes at the *top* of the stadium. **(FIGURE 10).** These are enclosed and provide food, beverages, and the best view of the game.

Figure 9.  Map of the Roman Empire at its greatest extent. The darkest areas (green) on this map was controlled by the Romans.

Yet, in at least one respect, the Colosseum had innovations lacking in the modern world. While only a few American football stadiums are domed, the Colosseum and many local Roman amphitheaters provided a retractable awning called a *velarium* to protect the audience from the sun.  American professional basketball arenas, where the seats do follow the Colosseum pattern, also inform us about status in the modern world.  In this case, the ‘patricians’, seated closest to the action, are those our society seems to value most—celebrities from the film and recording industries.

Figure 10. “The Swamp.” Ben Hill Griffin Stadium, University of Florida, Gainesville Florida

The Colosseum performed a further function. By showcasing creatures from all parts of the ancient world (elephants from Africa, tigers from India, etc.) in the animal combats, the emperor showed the people the extent of the empire and the power of an emperor who was able to control such a vast territory. While acknowledging the emperor’s authority, they could take pride in belonging to a society that had seemingly mastered the entire world (or at least the world as they knew it).

The message of unity presented at the Colosseum also finds echoes in the modern American college football stadium. Students and alumni gathered at the Swamp (as the University of Florida’s stadium is called) or at any college football stadium confirm their identity and unity as members of a collegiate community, despite their different majors, academic programs, and class year. Professional football teams can unite the disparate members of a city as well when fans fill the stadium on a Sunday to cheer their team. World Cup Soccer fever shows the intensity of the connection between athletics and national pride today.  Concrete stadiums and arenas reinforce social ideals.

The Colosseum itself was propaganda supporting the Emperor Vespasian. It was a public building placed over the demolished remains of the private villa of Vespasian's hated predecessor, Nero. The land had originally been the site of Roman private homes. Nero had confiscated it for his own private pleasure palace after a tragic fire destroyed much of Rome in AD 64. The building takes its name not from its size, but from its proximity to a colossal statue of Nero, in the guise of the sun-god, which Vespasian left standing. The contrast between the two monuments (a public place of entertainment and an ego-enhancing statue that once decorated a private luxury palace) provided a continued reinforcement of Vespasian's message of benevolence towards the people of Rome.



Mock naval battles (*naumachia*) in the Colosseum provided another affirmation of the power of the emperor. Ancient sources tell us that the Colosseum floor could in fact be flooded. (Remember the waterproof nature of concrete). These battles did not re-enact contemporary Roman victories, but instead depicted battles from the past. By choosing historical battles, the emperor showed that not only did he have control over the physical terrain of his empire, but that he also had control over time.

Water Supply

The naumachia were supplied with water by aqueducts, another feature of Roman engineering connected to concrete. An aqueduct is a water transport system. To bring water from its source (a spring or lake) over long distances required keeping the water

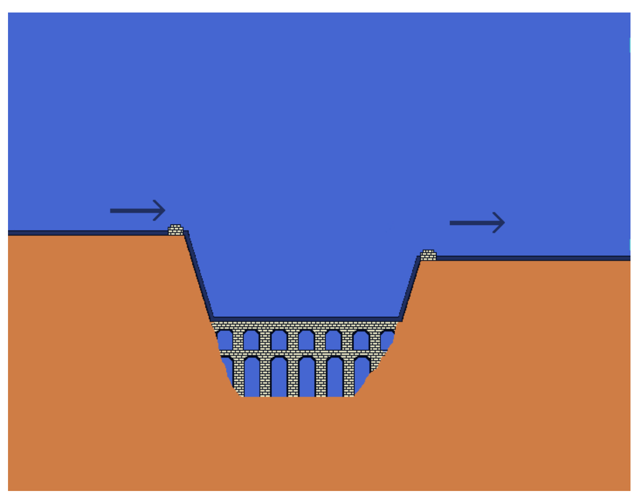

Figure 11. Diagram showing how aqueducts keep water flowing across obstacles such as valleys. The angle of descent was carefully calculated so that the water would continue moving without pumps.

constantly flowing. Lacking modern electrical pumps, the Romans relied on raising and lowering the water's level **(FIGURE 11).** Aqueducts, carried on arched stone or concrete substructures, spanned valleys and other topographical obstacles to keep water moving. They supplied an enormous volume of water to the city. At the height of Rome's population (1,000,000 people) eleven aqueducts supplied the city with the equivalent of 540 liters (or about 142 gallons) of water per person per day[x]. While you might think that this meant every Roman had running water at home, and while water did flow at public fountains, the Romans used piped water in domestic settings primarily for lavish fountain displays in gardens in the homes of the wealthy, as we can see in the remains of the fountain from the home of an aristocrat in Pompeii that has been preserved by the eruption of Vesuvius. By having a purely decorative water display in their homes, these aristocrats proclaimed their power and wealth **(FIGURE 12).**

While such display was important in promoting status, a primary function of the aqueducts was supplying water to the public bath houses, another major factor in the development of Roman concrete technology. One of the earliest domed concrete structures in the Roman world is a second-century-BC bath complex in the Italian city of Baiae. The need for water was two-fold. Baths, which exploited concrete in their construction, needed water not only for bathing Once again societal needs for public spaces drive concrete construction.

Figure 12. Water Feature from the Gardens of Loreius Tiburtinus, Pompeii, 1st Century AD. Water flowed through this channel to create a man-made river in this aristocratic home.

For the Romans, bathing in public bath houses was a vital daily activity. A first-century-BC Roman felt that such baths were so important that he inscribed the following on his tombstone:

“Wine, sex, and baths ruin our bodies, but they are the stuff of life.[xi]” Every city had numerous baths. Bathing required followed a progression through rooms of different temperatures, from cool to hot and then back to cool. Patrons could also exercise, buy snacks, and partake of beauty treatments, such as hair plucking, similar to modern health-and-fitness centers. The hottest rooms were heated by a hypocaust system—raised floors and tile pipes—that allowed air heated by furnaces beneath the floors to rise through pipes in the walls. The air was forced from the furnaces by bellows, hand-pumped devices that produced a strong current of air when squeezed. The addition of water in some rooms created steam. There were also unheated pools for plunging. The fact that concrete is waterproof made it ideal for bath buildings. Not only did baths provide for public cleanliness,

Figure 13. Baths of Caracalla, Rome 2nd Century AD. Note the fragments of mosaic decoration.

but they also functioned as a social safety valve. While the Colosseum, and life in general, emphasized class distinctions, the baths allowed for a temporary dissolution of those same social levels. Everyone, regardless of social class (men in one section and women in another or in separate facilities), “got naked together.” These buildings were designed to be luxurious and a large domed hot room (caldarium) became a standard feature. Beginning with the emperor Titus in the first century BC, emperors sponsored lavish imperial bath buildings in Rome. Such elaborate constructions curried favor with an often restless population by emphasizing the emperor’s benevolence (or seeming benevolence, since many emperors were violent, unstable individuals), but also highlighted the power and expanse of the empire he controlled.

Like the Pantheon, these buildings often used expensive and exotic marble veneer to cover the concrete. Succeeding emperors tried to outdo each other by building larger and larger complexes. One of the grandest of these (portions of which still stand) was constructed during the reign of the emperor Caracalla in the second century AD. Elaborately decorated with colossal mythological statues, it enclosed an area 1315 ft. by 1076 ft. Its size and grandeur continued the tradition of imperial display and provided a needed social outlet for Rome's populace **(FIGURE 13).** Even the poorest Roman could briefly enjoy beautiful—and, in winter, warm—surroundings thanks to the emperor.

**ACTIVITY—Tour the Baths of Caracalla and learn more about Roman bathing.**



http://www.pbs.org/wgbh/nova/lostempires/roman/day.html

Military expansion and trade made possible the vast empire celebrated in imperial buildings such as the Colosseum and the Baths of Caracalla. Concrete was also exploited for these goals. Because concrete could set underwater, it was perfect for creating ports that needed strong underwater substructures. Vitruvius does not fail to mention this important characteristic of the composition of *opus caementicum*:

Hence, when these three ingredients (lime, fired rubble, and pozzolana), forged ,in similar fashion , by fire's intensity, meet in a single mixture, when this mixture is put into contact with water the ingredients cling together as one and, stiffened by water, quickly solidify. Neither waves nor the force of water can dissolve them. (*De Architectura*, II, 6, 1)[xii]

Thus, secure, deep pilings could be put in place for ports throughout the Roman world. Concrete allowed the Romans to spread their military forces and to develop trade routes by creating ports in areas that did not naturally have adequate facilities. Ports provided part of the infrastructure for expanding, consolidating, and ruling the vast territories that comprised the Roman Empire. Along with baths and amphitheaters, these man-made harbors reflect the societal values that dominated the development and exploitation of concrete's inherent properties[xiii] **(FIGURE 14).**

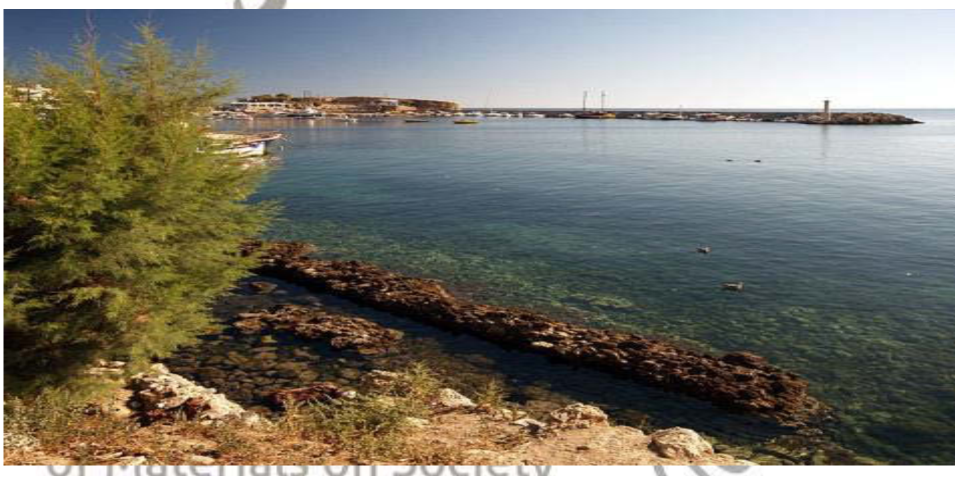

Figure 14. Traces of Roman Port at Hersonisos, Crete

The emperor's desire for control is evident in the Colosseum and imperial bath complexes. Social class is emphasized in the Colosseum and social tensions are relaxed in the baths. By creating concrete ports, Romans controlled distant territories through transport of troops for military campaigns and movement of goods through trade. They were thus able to spread their values and social organization throughout the ancient Mediterranean world. Their particular world view shaped the ways in which concrete could be used. While we might expect other types of monuments—durable public housing, perhaps, or water delivered directly to every home—these were not important to the Romans and thus were not among the reasons for their development of concrete forms. The Colosseum, baths, and port facilities promoted Roman identity and power. Although the Roman Empire eventually collapsed, its concrete structures endure. In fact, modern engineers and archaeologists are studying Roman port construction to see if these installations can teach us something about durability.

## Modern Concrete

We have seen how concrete technology was driven in certain directions by Roman social forces. What about us? What societal factors determine concrete's use today? We use concrete for many types of buildings and infrastructure—museums, houses, and bridges, for example. Some of these remain much the same in style and form as those the Romans created. For example, modern athletic complexes are startlingly similar in shape and seat arrangement to ancient amphitheaters. **(FIGURE 15).** Although our athletes do not literally fight to the death, we continue to place a high value on athletic competition and venues designed to showcase it.

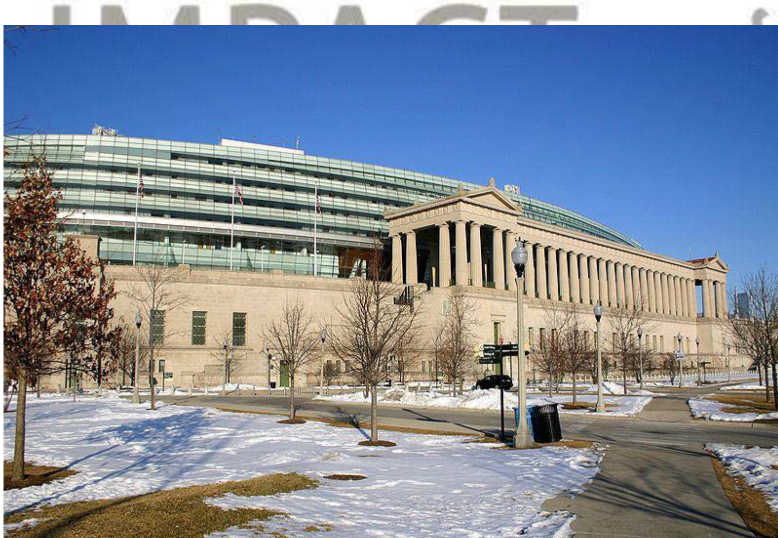

Figure 15. Soldier Field, Chicago, Illinois. Note the combination of modern concrete and classical columns.

Universities and cities pride themselves on their multi-million-dollar sports complexes. Professional teams can threaten to leave cities if the tax-payers do not pay for updates to their stadiums or for new stadiums. Modern consumer culture drives other types of concrete structures, such as shopping malls. Transportation needs promote airport construction. Concrete continues to be—as it was for the Romans—a relatively inexpensive and time-saving material. Yet, in the modern world, it has tremendous hidden costs.

## Problems and Challenges

Despite more highly mechanized manufacturing techniques, the process of creating concrete still relies on the basic chemical reaction exploited by the Romans, the reaction that releases carbon dioxide, a major pollutant, into the atmosphere. The absence of many other manmade pollutants in ancient times and the Romans smaller manufacturing scale meant that they did not suffer from pollution to the same degree we do. Today, the world's yearly production of 1.6 billion tons of concrete is responsible for 7% of the carbon dioxide released into the air[xiv]. As even more concrete is produced, the amount of carbon dioxide will also rise unless we develop smarter, greener methods of production. Concrete manufacturers recognize this problem, but any solution will have to be cost effective for worldwide adoption to take place.

An additional cost of manufacturing concrete is the need for sand as a component of the finished product. Today, sand is becoming an increasingly rare and sought-after commodity. As the Romans knew, only sand worn by water (river or ocean sand), not sand that has been exposed to the elements (desert sand), is suitable. As Vitruvius states:

…when sand beds lie exposed for any stretch of time after they have been worked, subjected to sun and moon and frost, they break down and become earthy. And thus when such sands are mixed into the mortar, they cannot hold the rubble together. Instead, the rubble comes loose, and the weight of the masonry, which the walls can no longer sustain, collapses. (*De Architectura*, II, 4, 3)[xv]

The vast deserts of the world cannot supply the right kind of sand. Excessive removal of river and sea sand is already destroying fragile ecosystems. Modern battles over this dwindling resource have resulted in murder in some parts of the world. Residents opposed to sand mining in one community in India were killed by groups controlling the manufacture of concrete for shopping malls and stadiums[xvi].

While these problems are connected with new construction, older concrete structures pose other issues. Most modern concrete is reinforced by metal bars, leading to eventual cracking as the metal expands or contracts. Can we recycle ruined concrete buildings? How can we stabilize and repair buildings? Engineers are working to develop new technologies that can sense imminent structural issues before a bridge or building collapses. To prevent damage in new construction, engineers developed Smartcrete, a form of concrete that can repair itself. New methods of concrete construction such as Ductal®, which requires no metal, and the use of cloth as a framing material are also potential answers to this problem.



Although some striking modern architectural monuments have been built from concrete, the Guggenheim Museum in New York, for example, many consider modern concrete stark and ugly because of the many utilitarian buildings constructed from it. Because, unlike the Romans, we can make concrete with a smooth surface, it is not necessary for us to cover it with other materials. After World War II, when a devastated Europe was in need of quick and cheap housing, architects turned toward concrete[xvii]. They created structures which, while answering a key societal need and advancing the idea of an affordable and equal form of housing for everyone, created cities filled with identical unappealing structures.

*Liquid Stone: New Architecture in Concrete*, an exhibition held in 2004-2006 at the National Building Museum in Washington, DC, identified a new design direction in concrete architecture, a movement toward more dramatic and aesthetically pleasing buildings. Using fabric to mold concrete, creating translucent concrete, and embedding

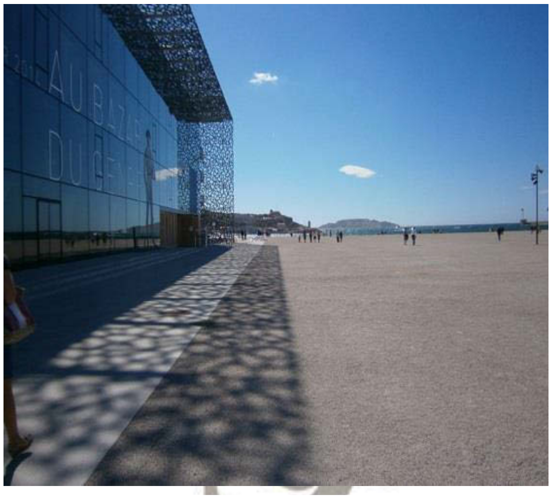


Figure 16. Musée des Civilisations de l'Europe et de la Méditerranée, Marseille, France. Note the use of Ductal® for the lacy lattice work.

fiber-optics in concrete all create dramatic new visual effects. In addition, newer forms of concrete can create sculptural embellishments for buildings at a fraction of the cost of stone[xviii] **(FIGURE 16).** New concrete technologies continue to emerge. Among the possibilities is concrete laid by robots[xix]. Acknowledging the close link between buildings and social structure allows us to wonder if there might be hidden costs to this technology. What types of work-force changes would occur if machines took over this aspect of building construction? Would using robots free humans to do other things or would it merely eliminate a large category of jobs?

Future of Concrete

Concrete's connection to social organization continues. For completion by 2020, a group of environmentalists, marine biologists, and nautical engineers is designing a floating city (seastead) on concrete piers. The city will be inhabited by 300 people focused on examining pressing world problems such as hunger and health issues.

**ACTIVITY—READ about the floating city**

Read more: http://www.dailymail.co.uk/sciencetech/article-3153412/Will-cities-future-FLOAT-167-million-project-using-concrete-platforms-home-300-people-2020.html#ixzz3k1FtozpE
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Building construction remains the primary use of concrete today. Like the Romans, we limit concrete to certain types of applications that fit our society's needs. We build apartments, shopping malls, stadiums, and airports.

Might there not be other uses for such a versatile material beyond architecture? Architects, engineers and others are beginning to address this question. For example, kitchen designers are using concrete for countertops, taking advantage of its durability, cost effectiveness, modern appearance, and ability to resist water.

With the aim of encouraging thinking about a common material in a different light, the *American Society for Civil Engineering* sponsors an annual concrete canoe contest .This challenge forces students to broaden their ideas about possible applications for this common material.



Engineering students from across the Unites States attempt to build and race a concrete canoe. They are judged not only on the results of the race, but also on their design concept. Concrete is certainly not the first material that comes to mind when thinking about canoes, although it is, after all, waterproof. But a concrete canoe suggests that if we think beyond the limits imposed on the use of concrete by our societal world-view and historical traditions, we may be able to find newer and more effective ways to use this versatile material.

**ACTIVITY – VIEW the 2015 Concrete Canoe Competition**

http://blogs.asce.org/university-of-florida-wins-national-concrete-canoe-competition/?_ga=1.25210936.425862622.1437670850

Questions for You

What new uses can you think of for concrete? Is there anything in its inherent properties that limits it to current uses or are other avenues waiting to be explored? What additional societal needs could concrete fill?  Are there social problems new forms of concrete could help solve? If it cannot be produced more cleanly, does its environmental impact mean that concrete is not worth the cost?



**Key Terms**

aqueduct

amphitheater

concrete revolution

hypocaust

*opus caementicum*

post-and-lintel construction

pozzulana

**Suggestions for Further Reading**

Jean-Pierre Adam, *Roman Building: Materials and Techniques*, trans. Anthony Matthews (Bloomington: University of Indiana Press, 1994).

J.Badcock and G.I.F. Tingay, *These Were the Romans*, (Chester Springs, PA: Dufour Editions 1986).

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Nancy H. Ramage and Andrew Ramage, Roman Art: Romulus to Constantine (Upper Saddle River New Jersey: Pearson Education, Inc., 2009).

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Jo-Ann Shelton, *As the Romans Did: A Source Book in Roman Social History* (New York: Oxford University Press 1988).



**Endnotes**

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[i] Jean-Pierre Adam*, Roman Building: Materials and Techniques*, trans. Anthony Matthews (Bloomington: University of Indiana Press, 1994), 65

[ii] Ingrid D. Rowland, trans., *Vitruvius: Ten Books on Architecture* (New York: Cambridge University Press, 1999), 37-38.

[iii] On this point see Lynne C. Lancaster, *Concrete Vaulted Construction in Imperial Rome: Innovations in Context* (Cambridge: Cambridge University Press 2005), 18-20.

[iv] For the Parthenon see Judith M.Barringer, *The Art and Archaeology of Ancient Greece* (Cambridge: Cambridge University Press, 2014), 225-240.

[v] For the temple of Apollo at Didyma, see Judith M. Barringer, *The Art and Archaeology of Ancient Greece* (Cambridge: Cambridge University Press, 2014), 292-96.

[vi] For the Pantheon see Nancy H. Ramage and Andrew Ramage, Roman Art: Romulus to Constantine (Upper Saddle River New Jersey: Pearson Education, Inc., 2009), 235-9.

[vii] Lynne C. Lancaster, *Concrete Vaulted Construction in Imperial Rome: Innovations in Context*, (Cambridge: Cambridge University Press 2005), 169.

[viii] Peter Green, trans., *The Sixteen Satires* (London: Penguin Books 1998)78.

[ix] For the Colosseum see Nancy H. Ramage and Andrew Ramage, Roman Art: Romulus to Constantine (Upper Saddle River New Jersey: Pearson Education, Inc., 2009)170-174.

[x] Jean-Pierre Adam*, Roman Building: Materials and Techniques*, trans. Anthony Matthews (Bloomington: University of Indiana Press, 1994), 241

[xi] Jo-Ann Shelton, *As the Romans Did: A Source Book in Roman Social History* (New York: Oxford University Press 1988), 308.

[xii] . Ingrid D. Rowland, trans., *Vitruvius: Ten Books on Architecture* (New York: Cambridge University Press, 1999), 37.

[xiii] For Roman ports see, C.J.Brandon, R.L Hohlfelder and M.D. Jackson, *Building for Eternity: the History and Technology of Roman Concrete Engineering in the Sea* (Oxford: Oxbow books, 2014)

[xiv] Mehta Kumar, "Reducing the Environmental Impact of Concrete," *Concrete International*, October 2001, 61.

[xv] Ingrid D. Rowland, trans., *Vitruvius: Ten Books on Architecture* (New York: Cambridge University Press, 1999), 37-38.

[xvi] Vince Beiser, "The Sand and the Fury," *Wired*, June 2015. http://contentviewer.adobe.com/s/Wired/5857345fd35d4d1f9a1f00273013f68a/WI0615_10_Folio/8030_2306FF_sandpolice.html

[xvii] Jean-Louis Cohen and G. Martin Moeller, "Introduction," in Jean-Louis Cohen and G. Martin Moeller, ed. *Liquid Stone: New Architecture in Concrete*, New York: Princeton Architectural Press 2006), 6.

[xviii] Franz-Josef Ulm, "What's the Matter with Concrete," in in Jean-Louis Cohen and G. Martin Moeller, ed., *Liquid Stone: New Architecture in Concrete,* New York: Princeton Architectural Press 2006), 218-242 describes these new techniques.

[xix] Robots and Concrete, Ulm, 243.

**Concrete Chapter Figure Citations**

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Figure 9. Map of Roman Empire. Wiki Media

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Figure 12. Garden of Loreius Tiburtinus. Wiki media.

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Figure 14. Roman port, Hersonisos, Crete. Wiki media.

Figure 15. Soldier Field, Chicago. Wiki media.

Figure 16. MuCEM.  Wiki media.