Earthen Architecture: Past, Present and Future – Mileto, Vegas, García Soriano & Cristini (Eds)
© 2015 Taylor & Francis Group, London, ISBN 978-1-138-02711-4

Ceramic connectors & culture connection

V. Cristini & J.R. Ruiz-Checa
Universitat Politécnica de Valéncia, Valencia, Spain

ABSTRACT: The Mediterranean is upheld with millenary constructive synergies, one of them is that of ceramic technology, held as a common base of the many civilizations which have made this sea a cradle of culture throughout the centuries. In this case, we aim to define the precise role of brick, in this geographic environment, as an auxiliary building element implemented in the construction method. In many cases bricks are found hidden, embedded in the stonework or within the cupolas, accomplishing constructive functions, otherwise unbeheld by the naked eye. They are just as important for the Late Roman Empire, as they are for the Byzantine Empire and the High-Medieval Age. Employment of brick, with alternative constructive solutions for local building dilemmas, not only cut down building expenses but also allowed a faster realization. All these interesting applications, which we could name "non-orthodox", emerge among Mediterranean constructive culture.

1 INTRODUCTION

1.1 *Approach*

Bricks count on considerable energy consumption related to their production. However they are really long-lasting and easy maintainable constructive materials. The burning of clay into constructive bricks requires obviously large amounts of fuels and energy, but the results are tangible, as shown by their strength and robustness. Brickwork can last for centuries, considering that finished bricks are "clean" recyclable building unit (Cristini et al. 2013). Bricks are an interesting example of a long lasting material, as History of Architecture can prove.

In this frame the research points out some versatile examples, related with bricks, that the authors have studied along different countries of Mediterranean Basin (Cristini-Ruiz-Checa, 2012), in the frame of the project "Characterization of Valencian Rammed Earth Walls: Documentation, Study and Improved Efficiency". The aim is to define the precise role of the brick, as an auxiliary building element implemented in the construction method.

Particularly, through simplicity and small scale, bricks possess a high generality, which eases integration in historically analyzed constructive cultures, especially the Romans and Byzantines. Brick use in these cultures is not a new topic; but its role, as recyclable historical material, is a fertile research field.

2 VERSATILE USE OF ROMAN BRICKS

Roman bricks undoubtedly record a long saga of foresight and organization trough the Mediterranean Basin. Sun-dried bricks, Vitruvius underlined, should be made only in spring or autumn and, to guarantee complete and uniform drying, they should be made at least two years in advance. The best bricks, like those at Carthage, had been left to dry for five years (Olesone, 2005). Under the Empire, when bricks were visible on the skins of buildings, they were no longer the structural material, in spite of their firing process. They were simply a protective layer covering a strong structure of concrete. Like marble, used in Roman buildings and mainly in slabs for facing, bricks are more "cosmetic" materials than really structural resources (Boorstin, 1992). They cover a solid core of concrete. At the same time this ceramic skin could be separated from the core and reused, as it occurs in medieval architecture (Figs. 1–2).

Roman bricks were made in several shapes and sizes. Often the bricks were cut into triangles which had their hypotenuse laid out and their apex inserted in the core of concrete, as mentioned before, as a facing layer (Fig. 3). As the decades passed, bricks became smaller and took new shapes, while the thickness of the mortar and its strength increased (Boorstin, 1992).

These changes are due to the fact that in the Roman Empire concrete is the main character of the constructions. Romans discover that *pozzolana*

Figures 1–2. Details about *opus testaceum* and fake stones treatment, Pompei, Italy (Cristini-Ruiz).

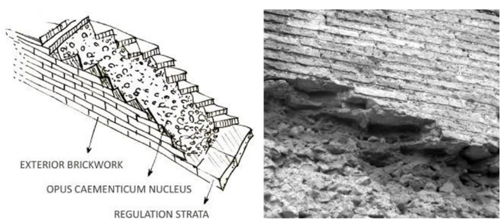
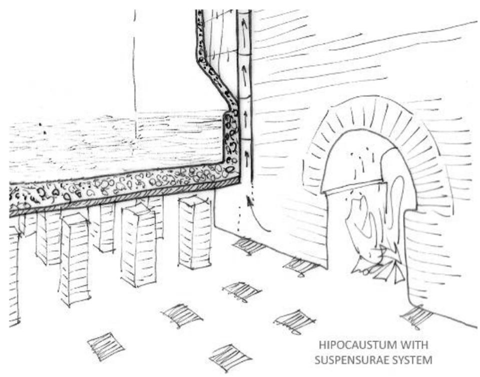


Figure 3. Bricks with apex inserted in the core (Adam/ Cristini).

(a volcanic earth first used at Pozzuoli, close to Naples) enriches concrete and it makes possible for better performances of mortar in contact with water (Adam, 1999). The result is a concrete so called *opus caementicium*. This substance, as Vitruvius explained, when mixed with lime and rubble, not only lends strength to buildings of other kinds, but even when piers of it are constructed in the sea, they set solidly under water. Concrete made of *pozzolana* resisted fire as well as water, and would preserve Roman masonries through centuries (Wright, 1924).

The remarkable qualities of perfected concrete with bricks skin would be possible by further trial and error phases, improving the proportions of lime and *pozzolana* and arrange bricks in the best positions. Some detached results are visible, for example, in many *thermae* buildings, where the use of bricks is exploited in walls, in vaults and in hydraulic structures. Bricks, when added in the concrete, gave character, novelty, and grandeur to their works, thanks to coarse-laid brickwork used to face a core of concrete (*opus testaceum,* Adam 1999). Walls of brick required less labor than stonework of the same quality, and could be made of local clay where there was no stone. They perfectly resist humidity and they can shape interior spaces flawlessly. Romans also considered that fired bricks have a good heat and moisture capacity that can help maintain good indoor air quality, above all of the *thermae*. Interesting systems of underfloor heating, used to heat spaces with hot air, called *hypocaustum*, also counts with bricks (figs. 4–5). In this case the suspended floor is raised above the ground by thin bricks pillars, called *pilae* or *suspensurae*, and covers the *hypocaustum* cavity (Adam, 1999).

Another interesting Roman goal is about vaults experimentations. These constructive elements are extended arches and the Romans used them to create large open rooms and high, covered passageways, above all thanks to barrel or groin vaults.



Figures 4–5. Underfloor heating system, Villa La Tejada, Palencia, Spain (Cristini-Ruiz).

The barrel-vault is generally semi-cylindrical in section, and it is used to cover corridors and oblong halls, like the temple *cellas*, or it is bent around a curve, as seen in amphitheater passages. On the other hand the groined vault is formed by the intersection of two barrel vaults, where thrusts are concentrated at all four corners and when several compartments of groined vaulting are placed together over an oblong plan, a double advantage is secured. A lot of apparels of bricks in vaults have been studied and recognized for experts (Humphrey et al., 2008).

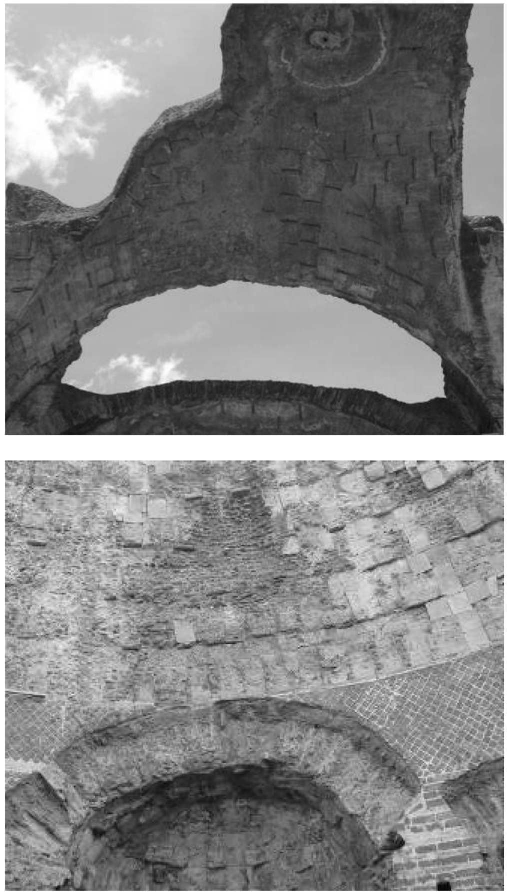
Roman brick vaults are constructed in the same manner as common brick arches. The bricks are bonded lengthwise of the vault, with a header course every five or seven courses. Vaults are sometimes built of a combination of brickwork and concrete, using light brick arches and backing up with concrete. They are also built entirely of concrete, the concrete being rammed on the centers in the same way that concrete footing courses are laid (Fig. 6).

According to recent studies (Lancaster, 2005) mortar improved significantly between the late first century B.C. and the second century A.D.

Lighter *caementa* in the upper sections of domes and vaults lessened their potential lateral thrust (fig. 6). Brick linings on the intrados of vaults prevented wooden frames from adhering to the concrete after it had cured (Figs. 7–8).

Dependent on brick industry, these linings were only in use for about a century (between the reigns of Trajan and Caracalla).

The brick industry declined precipitously when political problems ended large-scale building projects in Rome (in the later third century A.D).



Figures 7–8. Brick linings on the intrados of vaults prevented wooden frames from adhering to the concrete after it had cured Villa Adriana, Italy (Cristini).

Figure 6. Bricks on the intrados of vaults, *thermae* of Villa Adriana, Italy (Ruiz).

So due to this factor, a policy of bricks recycling progressively started (Adam, 1999).

3 VERSATILE USE OF BYZANTINE BRICKS

One of the detached legacies of Byzantine architecture is its masonry. At first glaze the Byzantine masonry is very similar to Romans, both used square stones and bricks, fundamentally based on the Roman measures. But in Roman architecture the masonry is used, as said before, "just" for sheet piling, while Byzantine architecture uses bricks for the entire wall. Byzantines probably didn't trust their concrete without *pozzolana* or that former eastern cultures were still influential. But the use of bricks for the entire wall has definitely a radical impact and consequences on the byzantine architecture (Boorstin, 1992).

Byzantine masonry consists above all of *opus mixtum* with alternating layers of bricks and stones (Fig. 10). Decorative masonry connections are also typical, which were possible because of the freedom created by the thick walls and thick mortar joints (Mango, 1978).

There are great varieties of patterns (radial, spiral, zigzag, alternating squares, fishbone and diagonal) as it is proved in a lot of example of this type of architecture, visible above all in Eastern Mediterranean Basin. All these patterns are usually made by recycled and broken bricks (Fig. 11).

Byzantine masonry has thick horizontal joints, almost as thick as the bricks and small vertical joints of just a few millimeters, which gives the wall a rich texture. Because of its popularity the effect is even intensified by the 'hidden layer' method, probably around the tenth century. The method consists of one layer of bricks that is set deepened in the wall and is entirely covered with mortar, so the horizontal joints seemed to be even thicker. This solution (Figs. 12–13) is mentioned as "recessed-brick technique", built with a row of bricks set back from the vertical line of the wall in alternate rows (Ousterhout, 1999).

Figure 9. Bricks connectors, Livia's House, Rome, Italy (Cristini).

Figure 10. *Opus mixtum* with alternating layers of bricks and stones, Istanbul, Turkey (Cristini).

The presence of masonries with well-marked layers exists all over the Mediterranean countries (Mango, 1978), related with the legacy of post-Roman constructive tradition, featured by masonries with joints the same thickness as the bricks or even thicker (70–90 cm). In fact, there are several techniques from the Orient made with this kind of brick. Some of them combine mixed techniques, using stone or timber, while others just use ceramic elements or applied into rammed earth walls (Ward Perkins, 1954). All these solutions guarantee a reduced quantity of bricks, as an interesting way to save a percentage of raw materials.

Brick grit was also often added to the mortar for its color, but it also worked as catalyst for mortars. This use, inherited by Romans (during the Empire the solution is known as *cocciopesto* technique fig. 14) is quite frequent in all Byzantine architecture.

In this case, the reused bricks act as a waterproof material and raw material to be used for making especially resistant mortars and coatings for pavements (Fig. 15), cisterns and ponds.

It is also interesting to consider that pendentive was made real by Byzantine architecture (Oleson, 2008).

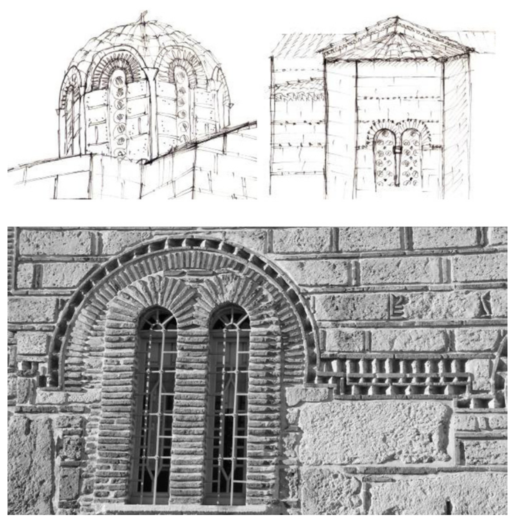
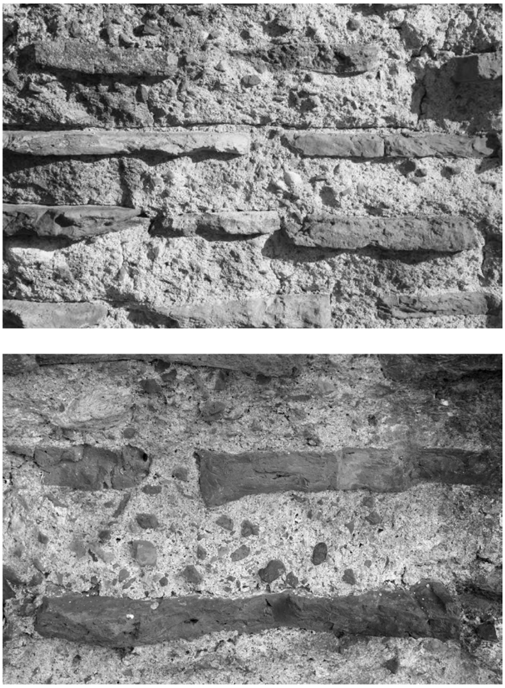


Figure 11. Bricks patterns in Byzantine Greek churches in Agii Apostoli, Agios Thomas, Agia Ekaterini, Athens (Cristini).



Figures 12–13. Recessed brick technique, Old Nicea, Cyprus (Cristini).

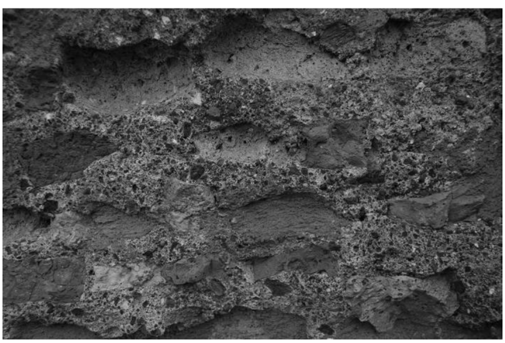


Figure 14. Brick grit as catalyst for mortars, Basilica of Maxentius, Rome, Italy (Ruiz).

A pendentive is fundamentally known as a spherical formed triangle that progressively realized the transition between a square plan and a dome (Fig. 16). Setting bricks in parts of circular layers created pendentives.

These parts of circular layers increased in length, but decreased in diameter from the square plan to the circular form of the dome. Undoubtedly the proper use of bricks plays a k-role in the trial and error phases of pendentive constructive experiments.

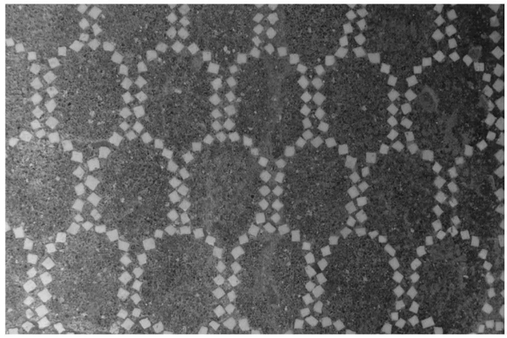


Figure 15. Pavement with brick grit, *opus signinum*, with marble *tesserae*, Ercolano, Italy (Ruiz).

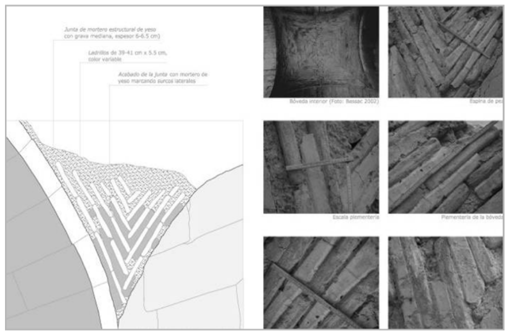


Figure 16. Pendentive in Byzantyne architecture, Pretorium at Zenobya City, Syria (Cristini).

4 CONCLUSIONS

Both Roman both Byzantine historic examples of versatile brick use show interesting concepts about flexibility and reusing capability. Both case-studies appoint that these ancient constructive cultures hold an overall high reusability of bricks, not only due to high scores for reversible connections but for all the criteria regarding the life-cycle analysis of the material. An interesting concept, recently introduced in sustainable architecture studies, called "salvageability" (Nordby et al., 2009), was under lined for centuries by Roman and Byzantine historical use of bricks. It‘s interesting to consider, in this frame, that historically is feasible to deconstruct an old brick walls, and reuse the material, especially thanks to flexible lime mortar commonly used as in Roman as in Byzantine architecture (Cristini-Ruiz-Checa, 2009). So, indirectly, historical good optimization of bricks and their long-lasting use are obtained due to a proper use of lime mortar, as a binder that is not aggressive for the ceramic connectors. Bricks for centuries, along the Mediterranean Basin, because of this building practice, are used like a recyclable product, and the masonries, cyclically, have been considered as potential "banks" of constructive sources and raw-materials.

ACKNOWLEDGEMENTS

This article would not have been possible without the funding of the research project "Characterization of rammed earth walls with bricks: documentation, study and improved efficiency" (*Caracterización de fábricas tradicionales de "tapia valenciana": documentación, estudio y mejora prestacional* UPV/PAID-06-12/SP20120466/main researcher V. Cristini).

REFERENCES

Adam J.P., 1999, *Roman Building: Materials and Techniques*, Routledge Ed., London, 1999.

Boorstin D.J., 1992, *The Creators*, Random House Ed.,NY, pp. 107–126.

Cristini V., Mileto C., Vegas F., Ruiz-Checa J.R., 2013 "Recycling of bricks in rammed earth walls" in *Vernacular Heritge and Earthen Architecture, Contribution For Sustainable Development,* Correia-Carlos-Rocha Eds. Taylor & Francis Ed., Balkema, pp. 383–388.

Cristini V., Ruiz-Checa JR., 2009, "A historical Spanish traditional masonry technique: some features about tapia valenciana as a reinforced rammed earth wall", in *Canadian Masonry Symposium Proceedings*, Toronto, Canada, CMS Ed., pp. 435–442.

Cristini V., Ruiz Checa JR., 2012, "Core, connectors and crust: Methodological restoration options for reinforced rammed earth wall with bricks" in *Rammed Earth Conservation*, Balkema Ed., London, pp. 297–302.

Humphrey J.W., et al., 2008, *Greek and Roman Technology: A Sourcebook*, Routledge Ed., London.

Lancaster L.C., 2005, *Concrete Vaulted Construction in Imperial Rome: Innovations in Context*; Cambridge Ed., NY.

Mango C., 1978, *Byzantine architecture*, Electa Ed., Milan, 1978, pp.233–56.

Oleson J.P., 2008, *The Oxford Handbook of Engineering and Technology in the Classical World*, Oxford University Press, NY, pp.256–279.

Ousterhout R., 1999, *Master builders of Bizantyum*, Princeton University Press, pp. 157–184.

Sigrid Nordby A., Berge B., Hakonsen F., and Hestnes A.G., 2009, "Salvageability of building materials", *Journal Building Research & Information* (Bri) Vol. 37:1, pp. 55–67.

Ward Perkins J.B., 1954, "Notes on the structure and buildings methods of early byzantine architecture" and "notes of structure" in *The great Palace of the byzantine emperors*, II° report, St. Andrew Ed., pp.56.

Wright G.R.H., 1924*, Ancient Building Technology, Volume 3*: Construction (2 Vols), Brill Ed., Denver, pp.374–383.