

## A REVIEW OF ANCIENT ROMAN WATER SUPPLY EXPLORING TECHNIQUES OF PRESSURE REDUCTION

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### ABSTRACT

The Ancient Roman Water Supply System still leaves us astonished when admiring the solidity of the ruins of aqueducts surviving around Europe. Some parts of these systems are still in use at present and prove the practical efficiency of Roman hydraulics in the principles acquired from the populations living in the different regions of the Empire.

In Pompeii the urban water supply system stands as a clear example of the Roman planning of urban complex networks by using small water towers to serve a limited numbers of users. This allowed to control the derivations and their maintenance and operated a disconnection from the high pressure mains and the low pressure pipes, maintaining a fixed maximum height of water over the final points of discharge.

Considering the techniques for pressure reduction as a method to control leakages, this paper examines the ancient Roman water supply system to deduce some applications to modern urban networks built in new establishments.

### KEYWORDS

Roman water supply, low pressure water supply systems, pressure control.

### INTRODUCTION

The description of the ancient Roman water supply system is contained in some details in the technical recommendations of the Latin writers Vitruvius (*De Architectura*, VIII, 1997 translation), Plinio the Elder (*Naturalis Historia*, XXXVI, 1988 translation) and Frontinus (*De Aquaeductu Urbis Romae*, 2004 commentary), *Curator Aquarum* in Rome from 97 A.D. to 106 A.D.



The water consumption of Rome couldn't be satisfied by the extraction from the private and public wells or rainwater harvesting, so Roman kings and emperors resorted to tap fresh springs in the outskirts of the city, in the Roman Campagna, to bring their freshness to the urban centre.

The first aqueduct to be built was Aqua Appia, in 312 B.C. and ten more followed in 540 years, so that by the time of Frontinus appointment to the office of *Curator Aquarum*, water in Rome was so abundant that he wrote in his report on Rome water supply assessment : "With such a quantity of structures dedicated to water, pyramids in comparison seem idle and Greek works, though famous, appear inert" (Op. Cit, Par. 16).

Remains are still in place and Roman suburban areas as well as the centre can offer astonishing views to the traveller (Figure 1, Aqua Claudia, *Romavecchia*).

**Figure 1. Aqua Claudia at Romavecchia, Rome South East outskirts**

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Taking baths became an important habit in Roman life, regardless of the social extraction, so an increased water supply was needed: ruins of channels or other structures part of the aqueducts exist in all regions of ancient Roman empire (Figure2, Pont du Gard, Nimes, France; Figure 3, Segovia, Spain; Figure 4, Merida, Spain).



**Figure 3. Aqueduct of Segovia, Spain**



**Figure 2. Pont du Gard, Nimes, France**



**Figure 4. Aqueduct of Merida, Spain  
(from Perkins, 1994)**

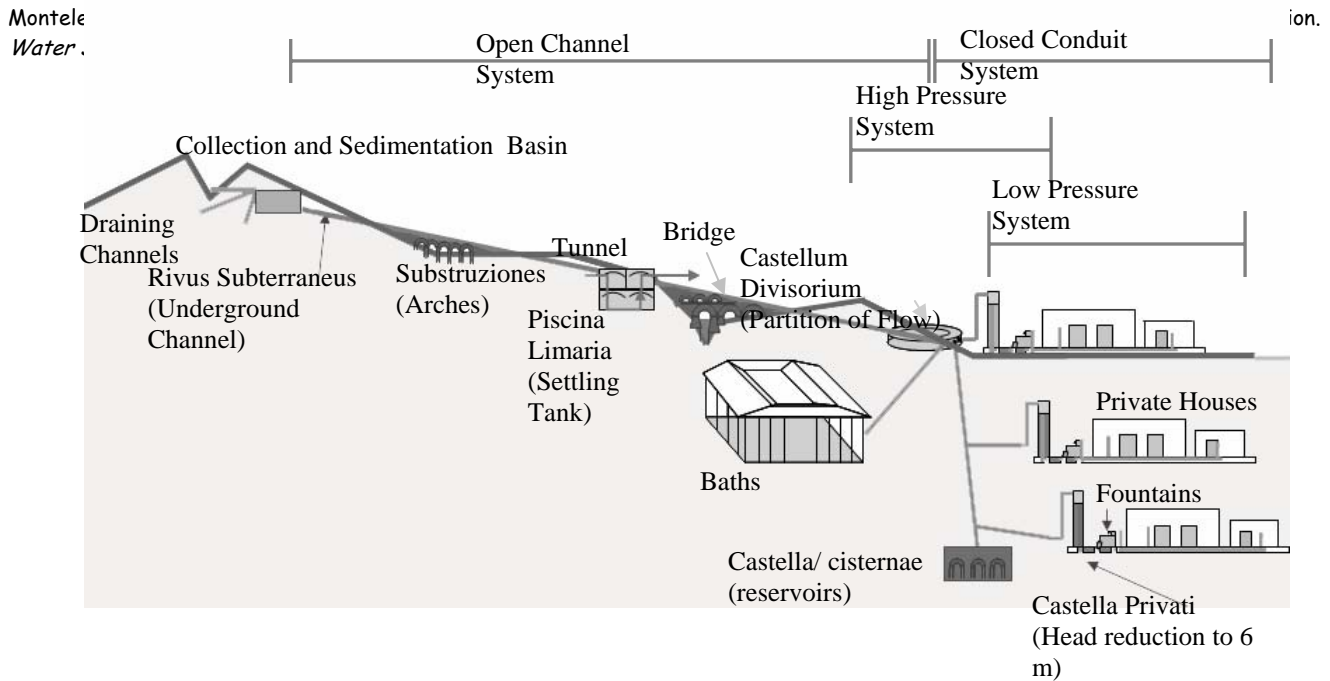
The construction of the ancient Roman aqueduct system is in some ways not different from the modern practice, since often modern technologies descend directly from Roman uses.

More over we can learn some useful lessons from those techniques. Let us consider the urban water supply system, whose well known example is the one of Pompeii, as will be described later (Richardson, 1989). It is based on low pressure areas, where the head of water (pressure in the mains) maintained after being conducted from the upstream springs is reduced by means of small local tanks elevated on pillars and serving a limited number of users.

In the view of the modern techniques for water leakage reduction, comprehensive of pressure containment methods as outlined in IWA perspective (Brothers, 2005, Thornton, 2003 and Thornton et al., 2005), and considering the direct relationship between quantity of leaking flow and pressure in the mains (Smith, 1999), the small local reservoir system can be assessed as a possible method of serving limited number of customers by means of clean/ reclaimed water tanks connected to single buildings by gravity mains or pumps.

## THE ROMAN WATER SUPPLY SYSTEM

The idea to which the Romans referred when transporting water down to the city was similar to river flow, in fact they called the channel “Rivus”. The general scheme as it was used in many cities of the Roman Empire is described in figure 5.



**Figure 5. The Ancient Roman Water Supply System.**

The search for new springs started as described by Vitruvius (Op.Cit, Book VIII, Chapter 4), to discover how much wholesome was the water; then water was collected in a basin, to allow sedimentation as well (Mucci, 1995)

When water run in soil stratifications, it was made to permeate trough walls with holes and to flow inside a channel until reaching the basins. Those arrangements are shown in figure 6.

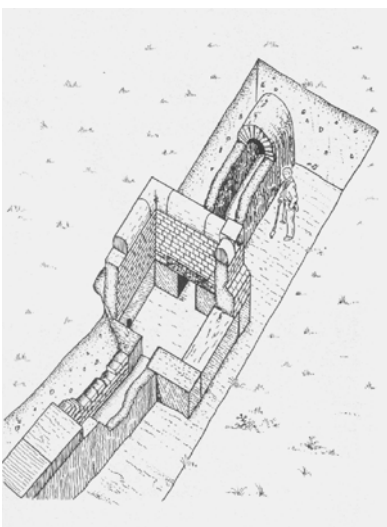
From the collection basin water was flowed into the channels, whose had a rectangular cross section shape, covered with a masonry vault or slabs of stone positioned in horizontal or roof shape (Corsetti, 1937, Ashby, 1991, Aicher, 1995, Hodge, 2002).

The interior of the channel was lined with hydraulic cement to make it smooth and waterproof.

From the spring down to the city the channel crossed the suburban areas in an open channel flow, therefore allowing air to be present at all times over the water surface.

The channel was built with almost constant slope of its bottom, varying in its length only in a restricted range (Lanciani, 1967, Lugli, 1970, Reina, 1917); Vitruvius gives a theoretical value inside the interval 0.0025 and 0.005 m/m.

To maintain the constant slope the “rivus” curved around hills and valleys, more than crossing them in a straight line, just as a river; however, when this was not possible, tunnels were excavated and the bottom of the valleys was crossed with siphons (Hodge, 2002) made with pressure lead or stone pipes.



The characteristics of the siphons are described in figure 7.

The bottom part was horizontal to avoid more acceleration and abrupt changes in direction, while stone blocks secured the pressure pipes along the sides of the valley.

Two tanks at the inlet and at the outlet of the pressure pipes were built to keep the disconnection with the open channel aqueduct.

This was necessary to allow water to go back at almost the same eight after passing the valley, that wouldn't be possible with the open channel arrangements.

**Figure 6. Draining channel and collection basin, Eiffel Aqueduct, Cologne, Germany (Habery, 1972)**

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Whenever the constant slope requirement imposed the channel to run higher than the ground level, it was built over structures. When the height became considerable, thick walls were substituted with the use of a succession of arches which could lay in different orders, such as for bridges.

Many sizes and material can be appreciated when visiting the ruin of those arches around the world, depending on the local materials available and customs. Some examples are shown in figure 8.

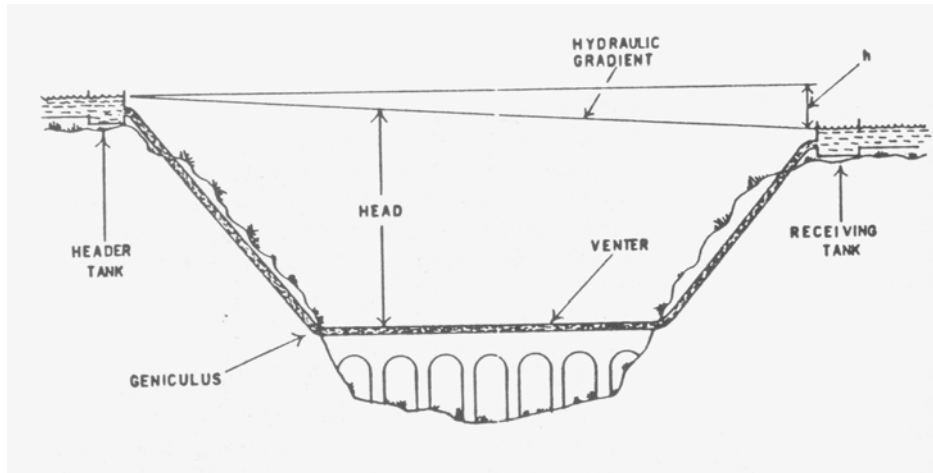


Figure 7. Channel crossing a valley: scheme of a siphon arrangement (Hodge, 2002)



Brick faced concrete, Nero's branch, Rome



Stone blocks without mortar, Pont du Gard, Nimes



Stone masonry, Aquil Terme, Italy

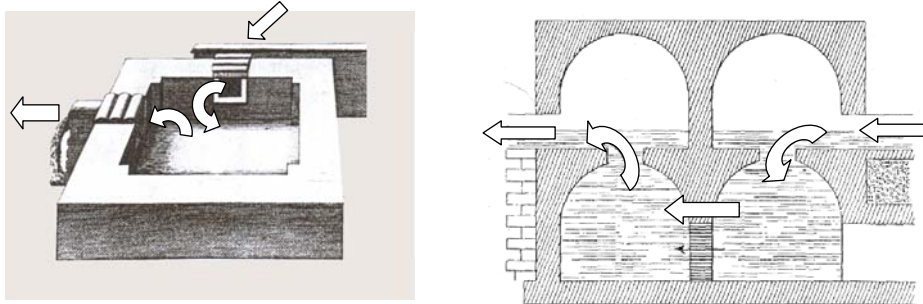


Brick and stone layers masonry, Taormina, Italy

Figure 8. Arches: different shapes and materials of construction.

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During its course the channel reversed its waters to a so called “*piscina Limaria*”, a settling tank to avoid transport of particulate impurities downstream (Frontinus, *Op. Cit.*, 19). The shape of the tank varied (Cagnat, 1916, Pace, 1983) from the simple enlargement of the channel, to the more complex multi-storey arrangement of *piscina* of Aqua Virgo (figure 9).



**Figure 9. Piscinae Limariae of Aqua Alessandrina, left and Aqua Virgo, right (Adapted from Piranesi and Cagnat)**

Once approached the city the channel was flowing to a partitioning tank, the “*Castellum Divisorium*” (Perkins, 1994), where it was subdivided in different supply pipes going in separate parts of the city. This second part of the system, the urban distribution, was a pressure pipe distribution, into lead, terracotta or wood pipes, depending on the abundance of the materials in the different regions of the empire (Hodge, 2002).

The description of the principle governing the operation of the *castellum divisorium* is given by Vitruvius (*Op.Cit*, Book 8, chapter 6, par. 1–2.) The best preserved examples are Nimes and Pompei Castella (Richardson, 1989).

Figure 10 reports the plan, picture of the façade and picture of the inside of the building placed in the highest point of the city, near Porta del Vesuvio.



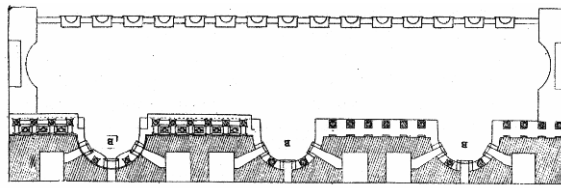
**Figure 10. Castellum Divisorium in Pompeii: Plan, S-E Facade, View of the interior catwalks and partitioning masonry walls.**

The pressure pipe served other reservoirs throughout the city, when the city was much extended in dimensions (Rome). These “*Castella*” had, on the contrary of the *castellum divisorium*, mainly a storage function, to overcome the fluctuations in the daily consumption.

Other examples of reservoir in the city with a exterior water display functions are the *Nimphai* and *Naumachie* (Cagnat, 1916).

They were huge reservoirs, with an ornamental facade decorated with niches, statues and columns, through which water was allowed to flow covering multiple cascades and collecting in a large basin at the bottom of them.

Plan of Side Ninpheum (Asia Minor) and the view of the ruins of a similar construction in Taormina, Italy, are given in figure 11.



**Figure 11. Side Ninpheum plan (Asia Minor) – from Lanckoronsky- and Taormina Naumachia (Sicily, Italy)**

From the castella the water run into high pressure pipes to secondary “*Castella Privati*”, small water towers, serving a limited number of users public and private (Hodge, 2002) (figure 5).

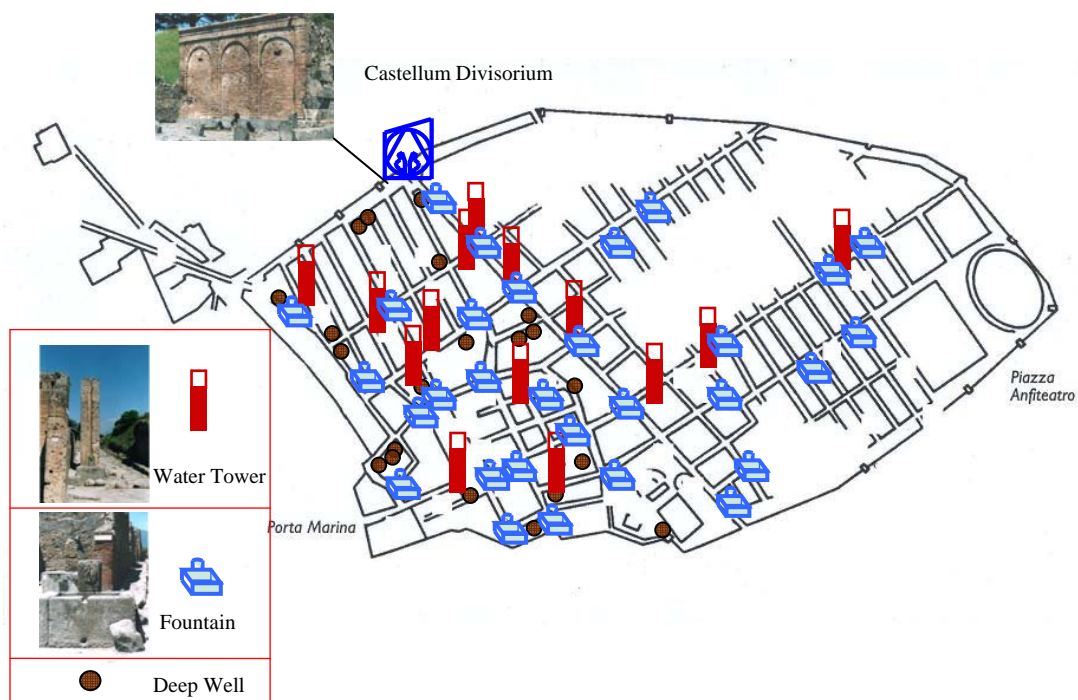
### POMPEII URBAN WATER SUPPLY SYSTEM

A clear vision of the urban water supply system by means of water towers is given by Pompeii ruins. The castellum divisorium was connected with three mains to the water towers standing along sides of roads throughout the city.

The outline of the distribution of public fountains, water towers and deep wells is given in figure 13. The water towers were made of brick masonry 6 metres tall pillars, sustaining a lead tank on their top. The single users paid to derive some amount of water for their own uses (*domus, taberna*), but even public fountains were fed by these towers and were often placed beside them.

The means of metering the water in concession to the users were the calices, bronze orifices (Pace, 1983) connecting the tanks to the single pipes serving each customer. In Pompeii case study they were placed at the bottom of the lead tanks, with pipes running into cavities left in the brick pillars. Minimum size of pipe connected was the *quinaria* pipe, about 2.31 cm in diameter.

Therefore the lead small tank of the water towers acted ad a disconnection between the system at higher pressure, the mains in the road, and the local low pressure system of the final users.



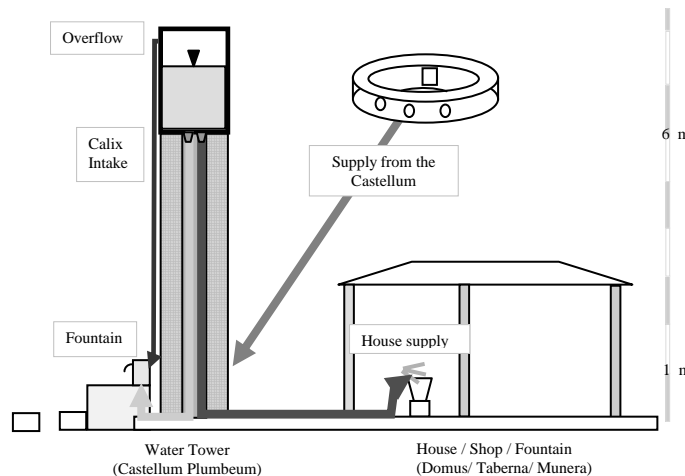
**Figure 12. Pompeii Urban Water Distribution System (Adapted from Richardson, 1989)**

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For no reasons other than prosecutable behaviour of officers or users water had to be extracted directly from the major diameter pipes.

The only connection available was through these purpose built water towers or castella private, after contacting and arranging the consumption quantities with the water office personnel (Frontinus, Op.Cit., par. 105 -106).

Looking at this system of water supply to the final point of use it is clear that the pressure built up in the mains descending from the castellum at the top point of the city was dramatically broken down and regularised in the water towers tanks ,so that a level of water of about 7 meters, without accounting for all the pressure losses in the delivering customer pipes, was maintained over the final point of discharge (figure 14).



**Figure 13. Scheme of Pompei private water supply from water towers**

This method was reckoned to reduce the pressure in the mains, because, although it has recently been demonstrated that Roman lead pipes could bear more hydraulic pressure than they were used for, Romans were preventing failures of pipes especially due to leakages in the pipes longitudinal joint and in the various fittings.

#### A ROMAN WAY TO REDUCE PRESSURE IN WATER SUPPLY MAINS

This Roman urban water supply system gives some hints on a possible method to reduce internal pressure in water supply mains in newly built housing arrangements.

The mains leading to single apartments could depart from a common local tank situated in an accessible location, so that pipes with larger diameters and higher pressure running into streets could be left untouched.

This could give easy life for repairs, and most of all could create a disconnection between the high pressure network and the users low pressure network. Therefore the number of junctions to the high pressure loops in the streets, instead of being one per user, could be reduced to one per group of users.

Provision could be made for a tank using reclaimed water for non potable uses, given that in the next future water can become precious even in countries with a “wet” climate, and that purifications systems such as membrane filtration allow nowadays a more economic use.

#### DISCUSSION AND CONCLUSIONS

Comparing the application of the low pressure distribution system to our urban realities, it can be noticed that modern buildings are in many cases higher than the ancient two stories houses, however pumps can be available for all sort of conditions allowing many combinations.

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Considered the attention paid to pressure reduction achieved by installing complex devices such as valves, in existing networks, whose monitoring, maintenance and control arises many different concerns, the idea of a different “point of use” layout can be assessed.

Issues such as energy consumption or savings, maintenance work, robustness of the system, reliability of the supply, health and safety concerns, have to be addressed.

Future work can involve the possibility to test local small pressure systems to understand how they can cope (driven from the past Roman experience) with the modern issues of the urban network realities.

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## REFERENCES

- Aicher, P.J. (1995) *Guide to the Aqueducts of Ancient Rome*. Bolchazy Carducci Publishers, Wauconda, Illinois.
- Ashby, T. (1991) *Gli Acquedotti dell'Antica Roma*. Quasar, Roma.
- Brothers, k.J. (2005). IWA approach to water loss management. *Proc. of the IWA Specialized Conference Leakage 2005*, Halifax, 12 -14 September 2005.
- Cagnat, R. Chapot, V. (1916–1920) Citernes, Aqueducs, Fontaines et Egouts. In: *Manuel d'Archéologie Romaine*. Picard, Paris.
- Corsetti, G. (1937). *Acquedotti di Roma*. Palombi, Roma..
- Frontino, G, Commentary by Rodgers, R.H. (2004). *De Aquaeductu Urbis Romae*. Cambridge University Press, Cambridge.
- Haberey, W. (1972) *Die römischen Wasserleitungen nach Köln*. Bonn.
- Hodge, A.T. (2002). *Roman Aqueducts and Water Supply*. Gerald Duckworth & Co. Ltd, London.
- Lanciani, R. ( 1967 edition). *The Ruins of Ancient Rome*. Benjamin Blom, New York.
- Lanckoronski, C. (1890). *Städte Pamphylens und Pisidiens*. Vienna.
- Lugli, G. (1970). *Itinerario di Roma Antica*. Periodici Scientifici, Milano.
- Mucci, A. (1995) *Il Sistema degli Antichi Acquedotti Romani*. F.lli Palombi, Roma.
- Pace, P. (1983). *Gli acquedotti di Roma e il De Aquaeductu di Frontino*. Art Studio S. Eligio, Roma.
- Perkins, W. (1994). *Roman Imperial Architecture*. Yale University Press, Hong Kong.
- Plinio the Elder. Translated by A.Corso. ( 1988). *Naturalis Historia*. G.Einaudi, Torino.
- Reina,V., Corbellini,G., Ducci,G. (1917). *Livellazione degli antichi acquedotti romani*. Tipografia della Reale Accademia dei Lincei, Roma.
- Richardson, L. (1989). *Pompeii*. The John Opkins University Press Ltd, London..
- Smith, E. (1999). The crack opening area for a multiple loading situation. *International Journal of Pressure Vessels and Piping*, N. 76, pp. 801 – 802.
- Thornton, J. (2003) Managing leakage by managing pressure. A practical approach. *Water 21, Magazine of the international Water Association*, October 2003, pp. 43 – 44.
- Thornton, J., Shaw, M., Aguiar, M., Liemberger, R. (2005) How low can you go? Practical approach to pressure control in low pressure systems. *Proc. of the IWA Specialized Conference Leakage 2005*, Halifax, 12 -14 September 2005.
- Vitruvio, M.P. Translated and discussed by Gros, P.Corso, A. Romano, E. (1997). *De Architectura*. G.Einaudi, Torino.