Water and sanitation management in medieval Portugal
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ABSTRACT

Water and sanitation played a crucial role in the evolution of Portugal and its empire, which in the sixteenth century dominated large portions of the world. Two relevant civilizations, the Roman Empire and the Arab invasion, had great influence on Portugal’s water and sanitation knowledge. Following the creation of Portugal in AD 1143, the Cistercian order was called for removing Arab influence and received large domains, where it built large monasteries, all provided with remarkable examples of water supply, sanitation and waste management, merging the Roman background in sanitary engineering with the local Arab experience. One of them, the Monastery of Christ in Tomar, is provided with a brilliant water and waste self-sustainable system, based on rainwater collection and storage, wastewater treatment and application in agriculture of treated waste and effluent. It testifies to the experience and innovative expertise of the Cistercian Order in sanitary/hydraulic engineering. It shows also one of the world’s first examples of a wastewater treatment plant. Their knowledge influenced also the lifestyle and water management of Portuguese medieval cities, ruled by municipalism, and protected the population from pestilence until the first half of the fourteenth century, making Portugal a powerful country, in contrast with the rest of Europe.

Key words | hydraulic works, pestilence, sanitation, sustainability, wastewater treatment plant, water supply

HISTORICAL CONTEXT

Portugal is a country that discovered and dominated many territories of the world using the same approach and strategy to the one used for consolidating its nationality and independence. These achievements are due to the favourable and synergetic cooperation of the King of Portugal with the Church in military, cultural, religious and, also, in water and waste technologies, a vital element for guaranteeing population health, agriculture, industry and the economic growth of the imperium.

The culture of the Iberian Peninsula was influenced by invasions of ancient civilizations. The Roman Empire subjugated almost all of the territory for 700 years, imposed its governance and culture and played a major role in the civilization of the Iberians. This empire had a profound and lasting influence on language, religion, architecture, philosophy, law and administration of the territory under their control. It bequeathed a considerable engineering patrimony: bridges, roads, buildings, water storage and supply, etc., many of them still operating under the original design, witnessing their high expertise.

With the fall of the Western Roman Empire, from AD 476, the barbarian invasions that succeeded the Romans did not leave engineering heritage works of historical interest or value, suppressing much of scientific knowledge in Europe. It was supplanted by a culture of superstition, called the Dark Ages or the medieval period (AD 500–1500), which lasted for nearly a millennium and merged into the Renaissance and the Age of discovery.
period the centre of culture was displaced to the Arabic world, especially Persia, resulting in a fusion of classical culture and Christianity centralized in Constantinople (Richard 2001).

In AD 711 medieval Islam was a prosperous and dynamic civilization and occupied the majority of the Iberian Peninsula, excluding the north, staying for about 800 years and transferring know-how in irrigation, water extraction and water mills (Hill & Al-Hassan 2013). Arab hydraulic and civil engineers implemented dams to impound and divert water for irrigation, built bridges to cross canals, employed surveying techniques to align and level canals and established hydraulic schemes for transporting water to cities. Arab mechanical engineering developed water-raising and mill grinding machineries moved by water flows. Civil engineering transmitted to future generations the use of brick, plastering and tiling, leaving sophisticated architectural masterpieces.

After a major victory against the Arabs the kingdom of Portugal was officially recognized in AD 1143 by the King of León and is the most ancient kingdom of Europe. Independence started from the northern County of Portugal and expanded to the south, by conquering territories under Arab control. The Church revelled in the opportunity of eradicating the Arab Muslims from Europe and offered Templar Knight military forces to support the Portuguese liberation movement, becoming the crucial instrument to consolidate the expansion and legitimate the new kingdom.

Following these achievements, military activity slowed down and the time came to change strategy. It was urgent to organize and manage the conquered territory, ensure its governance, retain the population in the new territories, create stability and promote prosperity. It was absolutely necessary to remove Islamic religion, normalize the Christian rite and educate the people. The Cistercian Order represented the most appropriate organization for achieving these goals, and received large domains from the King to remain in the Iberian Peninsula. The monks of the Cistercian Order are recognized as the world’s first sanitary engineers (Frangipane 2012) and their monasteries are an excellent example of prestigious works of sanitary/hydraulic self-sustainable systems, until the fifteenth century. Consequently, this Order also contributed decisively to the water and sanitation of the new country.

In AD 1170 King D. Sancho I, who devoted the most part of his reign to the administration of his kingdom, distributed the new territories to governors and promoted municipalism, a suitable political and administrative option capable of having the country under control, by promulgating juridical, administrative, technical and social laws for regulating the territory. The erection of municipalities surrounded by city walls and administered by definite rules allowed the establishment of a social structure integrated with a policy of spatial planning of territory, involving also water supply and waste management issues, and transformed Portugal into an advanced nation.

### MIDDLE AGES SANITATION IN PORTUGAL AND IN EUROPE

Many historical reports described the European Middle Ages as a time of poor water, sanitation and hygiene control, generating epidemic diseases and causing substantial decrease of population. The medieval city was labelled as a hell toilet providing conditions favourable to disease propagation: unpaved and dirty roads, chaotic urbanization, low illumination and air ventilation in houses, garbage accumulation and contamination of water supply sources, etc.

In that period, due to economic crisis and loss of hydraulic/sanitary knowledge, the European population had poor access to water. People were still living on the basis of the spirit and precepts of St Benedict’s Rule, practicing a basic agricultural economy. The water capitation was just 1 litre for an inhabitant, daily, and the water supply was taken directly from river courses, which is the poorest practice, compared with the Romans’ long-distance withdrawal and transportation of good quality water. The Roman technology reported by Frontinus’ book De aquis urbis Romae, containing teachings on hydraulics, sanitation and its management, was shelved in religious monasteries and was ignored throughout the Middle Ages. Scarce water availability and quality carried serious consequences for public health in Europe.

In the Portugal peninsula, from the beginning of the Middle Ages (AD 500–1500), water was recognized as a vital element for economic growth. Arabs transferred its technology into Portugal where many water wheels and water
mills were designed to provide energy for feudal industrial activity (food milling, textiles, painting and tanning).

Since the beginning of Portuguese nationality, until the fifteenth century, several prestigious public works represented a way to consolidate the reign and to show the capability of the government. Civil and sanitary/hydraulic structures such as bridges, monasteries, lazarettos, fonts, aqueducts, water cisterns, spas, sewage pipes etc., were inaugurated all over the occupied territory, providing examples of brilliant technological capacity (Correia 1954) contributing to its stabilization. The best national and foreign technicians were engaged in undertaking the design and construction of these works, creating remarkable examples of the powerful new kingdom.

The Cistercian religious order contributed in many ways to the evolution of the country. They promoted agriculture to stimulate economic growth, introducing intensive farming examples in vast areas of the occupied land and disseminating innovative hydraulic techniques for irrigation. They employed great discipline and methodologies for consolidating the territory: land forestation, river bank and stream regularization, water supply planning, sanitation works, underground conduit construction, diversion of flows, and hydraulic wheels for energy production. Their monasteries are an excellent example of prestigious works of sanitary/hydraulic self-sustainable systems, until the fifteenth century.

Pereira (2005) reports that the Portuguese medieval cities were healthily planned and protected against propagation of epidemic diseases, for a long time. Their iconography, influenced by Cistercian and Templar culture, shows well-planned arrangements: the city centre was compact and provided with paved roads. Around the centre were situated spacious and distinct surrounding areas, endowed with plentiful green spaces, and not crowded with people. High quality and abundant water supply was provided and stored in large cisterns. Wastewater was fluxed out of the wall and disposed in the fields or rivers.

The city centres of the Portuguese municipalities served for demarcating social class. This living area was exclusively restricted to the nobility, dictating the local economy and governing the rural population. These medieval cities, even when accommodating more people inside the walls, were protected from disease propagation by the large surrounding intramura land reserve and adjacent rural areas. Water supply systems derived from the Romans and applied by the Cistercian Order kept out contagion from the Iberian Peninsula history until the fifteenth century. It started in a later time, in the transition period from the end of the Middle Ages (AD 1400) and lasted until the modern age (AD 1600). Curiously, it was not due to poor water supply as in Europe.

Contagion was caused by the migration and excessive concentration of the countryside population inside the city walls and inadequate waste management. From the late Middle Ages, the richest farmers were eager to transfer to living in the city, for prestige and appearance, triggering a great demand for renting houses and creating an opportunity to enhance profits for the nobility. The new compact group of houses with a common wall was seen as an additional protection, capable of fortifying ground defence value. So both medieval military practice and civil legislation were in favour of concentrating people inside the medieval towns, thus incurring uncontrolled population increase and urban crowding.

The countryside people now living in the town were accustomed to practicing an economy of self-sufficiency and food-processing daily activities. When residing in the fields, they used their own and livestock excrement as fertilizer, mixed with forest residues, composted or stabilized during storage, having an immediate and recognizable utility value. Their wastes did not contain contaminants harmful to health and, perhaps, were not smelly. Likewise, other forms of waste, if any, were produced and discarded with a speed that allowed regeneration by the action of the environment, without causing accumulation.

Until the fourteenth century a good portion of this productive waste management process stayed in the countryside, bringing benefits. When urbanization increased, an important number of peasants established living inside the city walls, keeping consumption habits proper to the dominant rural countryside economy, interrupting the natural cycle of waste reuse.

The new citizens continued to pursue in their small townhouses activities like food preparation for immediate consumption or for preservation (drying, salting or smoking), using for this purpose urban backyards, balconies or terraces, spaces indispensable for carrying out everyday healthy life in the medieval urban environment. These various factors made the urban area inadequate for their
needs, the appropriation of the streets with waste taking place. The urban condition was not enough to accommodate the total recycling process practiced in the peasant economy and was not capable of managing the digestion of such remnants into fertilizers, the solution applied in the countryside environment. The wastes and residues built up in the cities and established the kingdom of putridity (Pereira 2005). The city was the great inventor of nauseating smells.

Plagues appeared in many medieval cities around the country simultaneously with the settlement of rotting, leading residents to establish a causal relationship between them. Putrid organic urban waste was identified as the main cause of the illness of the inhabitants. Portuguese cities were faced with relevant sanitary problems (Pereira 2005). The monasteries and other isolated structures maintained a high sanitation level and were saved from the disease. Unfortunately, the sanitary knowledge of the Cistercian Order was not spread enough to attenuate pestilence.

In Portugal epidemic disease struck all the cities, even the ones who adopted the measures prescribed by the authorities to eradicate pests and improve health. In the second half of the fourteenth century, outbreaks of bubonic plague led to severe depopulation. The economy was highly localized in a few cities and migration from the fields led to the abandonment of agriculture and a rise in unemployment in the villages.

The sea offered alternatives, a way to escape from pestilent cities, and most of the population settled on the coast for fishing and trade. The diseases that occurred in this century stimulated Portuguese people to go out into the ocean, to navigate far away, thus contributing to the discovery of new territories and to the evolution of the world. Therefore, the disease was a good navigator spreading across the Portuguese empire, a phenomenon of globalization.

The important periods in the evolution of the history of sanitation are shown in Figure 1.

**EXAMPLE OF SUSTAINABLE SANITATION IN PORTUGAL: THE CONVENT OF CHRIST**

**Introduction**

There was a time in Portugal when this concept of sustainable use of sewage, water and waste, was applied by the Cistercian monks, anticipating the future. They left some remarkable examples from the twelfth century until the seventeenth century, witness to sustainability concepts and practices.

The convent of Christ in Tomar occupies major monumental complexes in the space and time of the peninsular and European architecture. It shows also an excellent water supply and sanitation technology and a model of sustainable water and waste management. In the thirteen century the convent was surrounded by forestry and agricultural territories, providing food and wood, making it self-sufficient, as well as allowing recycling of all the generated wastes: an example of full sustainability, covering all the duties and needs of the religious community.

A medieval monastery, to operate under appropriate hygienic and sanitary conditions, needs water for cooking, drinking, and hygiene, but also for irrigation of gardens, orchards and agricultural activities. The infrastructures for water and wastewater management adopted in the Monastery of Tomar shows the important know-how of the Cistercians in sanitary engineering.

**Rainwater supply storage and distribution**

The monastery, due to its position of high elevation for military occupation did not have wells or other natural sources of water. The rainwater from roofs and the other open paved spaces was the main water supply source.

Rainwater for drinking and food preparation was conducted to reservoirs and to a supply system, distributing it to the faucet of the kitchen, lavatories and any other potable water fountains. Storage in separate cisterns and the hydraulic systems was completely independent according to water end-use: garden irrigation, fountain feeding, washing, sewage draining and latrine flushing. All the potable water system was isolated from sewage and the other waters, preventing any possible contamination.
Practically almost all the cloisters were provided with a large cistern placed in the centre or under one of the lateral buildings. Of these it is possible to emphasize the cistern of the ‘Micha’ cloister (900 m³ volume) and the ‘Corvos’ cloister (605 m³ volume). The plan of the main core of the convent is shown in Figure 2. The cloisters provided with cisterns are in green colour (Di Berardino 2014).

Water supply of the monastery by an aqueduct

The old rainwater supply system was reinforced in the sixteen century by a monumental aqueduct commissioned by Felipe II of Spain from the architect Filipe Terzi. It drains high quality ground water from natural springs in the mountains and was intended to make the convent and its land totally autonomous in water supply. The channelling of the aqueduct by gravity over a distance of more than 5.8 km consists entirely of hewn stone troughs, provided with beautiful arcades.

The aqueduct reaches the convent building by an arch structure built into the south wall (Figure 3), and ends in a water reservoir constructed in AD 1617 in the southern part of the dormitory. At the end of the aqueduct there exists a small strainer, before the water flows into a storage tank, accumulating the excess water from the basin of the aqueduct in low consumption periods, and capable of reinforcing the water flow at peak demand. A sophisticate system of locks enables the control of water flow in the basin and regulation of the amount of water in the channel.

Runoff and drainage

In the Christ convent two separate distinguishable drainage and treatment systems have been identified (Virgolino 2012). One is the simple connection of the wastewater from the cuisine, the olive oil room and the oven room to the outside of the convent. This low contaminated wastewater ends in the
court yard and was used for irrigation of gardens and agricultural fields (Virgolino 2012). The size of the manholes and collectors has remarkable dimension.

The sanitary contaminated and polluted sewage from latrines was drained by the second system to a wastewater treatment and disposal system, displaying a more complex lay-out designated to meet precise functions with important derivations and connections between them. The system ends in a distinct, separate building, the ‘Bloco das Necessárias’, comprising the latrines, the drainage and convergence of the sewage and the treatment system (Virgolino 2012). The localization of the main pipes was indicated using precise stone signals and marks (Figure 4), facilitating repairs.

**Sewage treatment**

The sixteenth-century rectangular building called the ‘Bloco das Necessárias’ has three floors above ground and one floor in a basement, represented in Figure 5. The latrine and personal hygiene facilities were placed in the two upper floors of the building, where small corridors, one on each floor, allow direct access from the dormitories to the area of latrines. These corridors are ‘S’ shaped and provided with ventilation windows, placed strategically in the curves, capable of preventing and eliminating any possible odour propagation inside the living area of the monastery (odour control technique).

The wastewater treatment plant (WWTP) is placed in the underground of this block of latrines, with internal dimensions of 12.6 m × 9.0 m. The system is divided into two compartments, separated by a central wall, provided with two large venting channels, for aeration (Figure 6). Each latrine evacuates the excrement directly over the treatment tank.

The wastes were retained until the liquid level reached its maximum height (1 m approximately) and completely filled the two compartments, taking a period of about 12 months (Figure 6). The settled suspended solids in the treatment tank underwent a process of hydrolysis and degradation by biological processes. The upper water layer was in contact with air renewed by the excellent natural ventilation system of the building, preventing smell and improving stabilization.

Cleaning and sludge removal from the tank was performed by flushing abundant poor quality water drained by two channels and stored in the 240 m³ reservoir of the ‘Necessárias’ cloister, placed close to the WWTP. The treated, flushed sewage was transported by a disposal channel, (a stonemade tunnel measuring 0.51 m high and 0.48 m wide, surmounted by a gallery) to a nitrification system, not existing today, where vegetable residues were joined to the waste, forming a fertilizer to be used for agriculture and forest fertilization, contributing to the enrichment of the soil of its boundary.

Therefore, this example testifies to the high level of knowledge of the Cistercian community in terms of water management, security of supply, air ventilation, treatment technology and waste disposal.
Conclusions

The official history of Portugal dates back to the Middle Ages, to the year AD 1143, conquering territories controlled by the Arabs, thus creating common motivations with the Catholic Church at the time of crusades. The Church recognized the new kingdom, provided military and religious support through Templar Knights and the Cistercian Order, becoming a vital support in the expansion strategy.

The Cistercian religious order staying in Portugal received large domains to colonize, involving medieval monasteries displaying high levels of knowledge and domain in water supply, hygiene and sanitary procedures, hydraulic infrastructures, energy production, waste treatment and management irrigation and agriculture.

One of them, the convent of Christ in Tomar and its convent garden, is not just a very important historical remain with artistic architectural relevance; it is also a witness to an excellent water supply and sanitation technology, a model of waste and water management and sustainability. It is provided with one of the most ancient wastewater treatment systems, testifying to the experience and technical expertise of its builders in the field of hydraulic and sanitary engineering. This knowledge is a valuable testimony, in part, still intact and in use, unique in the history of the medieval and modern hydraulic monasteries in Portugal.

Cistercian Order culture influenced the planning and approach of Portuguese medieval age cities, provided with an adequate water supply and sanitation system and a well-defined city-centre surrounded by an abundant reserve area, which protected the population from pestilence until the end of the fourteenth century. Water supply systems were based on Roman and Arab backgrounds. Consequently the first part of Middle Ages in Portugal was not as dark as in the rest of Europe, where water scarcity and sanitation in urban areas provoked disease until the seventeenth century. This is one of the reasons which explain the powerful growth of Portugal, in that period.

Unfortunately, the sanitary sapience of the Cistercian Order did not spread enough to attenuate pestilence and, from the second half of the fourteenth century, pestilence also attacked Portuguese cities with outbreaks of bubonic plague, which led to severe depopulation. It was caused by excessive accumulation of people and putrescible waste in the cities. The sea offered alternatives, a way to escape from pestilent cities, and most of the population settled on the coast for fishing and trade. The diseases stimulated Portuguese people to go out in the ocean, to navigate far away, thus contributing to the discovery of new territories and to the evolution of the world.

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