Acoustic vases in the Portuguese synagogue of Tomar

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ABSTRACT: Since ancient times that the European construction history is confronted with the existence of ceramic pots inlaid in walls, often related to acoustic purposes. This paper focuses on the ceramic pots embedded in the masonry walls of the synagogue of Tomar, built in the 15t^{h} century. Although acoustic vases in Christian and Muslim worship buildings are relatively well known and documented, no similar studies published in English were found reporting similar devices in synagogues. This paper attempts to shed light on the presence of embedded ceramic vases in the walls of the synagogue building of Tomar. The study considers the research on ceramic vases in ancient worship buildings, as well as current acoustic research on the context of cavity resonators as an ancient building technique. The origins of Tomar synagogue were also investigated, in order to argue that this practice can be regarded as an expression of a coexistent tradition.

1 INTRODUCTION

The synagogue of Tomar is one of the oldest Jewish worship buildings in Portugal. It was built in the 15th century and converted into a museum in the 20th century. One of its features is a set of inlaid ceramic vases, located at the top corners of the walls.

The use of ceramic pots embedded in the walls became a common practice in churches during Romanesque and Gothic periods. Ceramic vases (the 'sebu' technique) were also applied in some Ottoman mosques in Turkey in the 16th century. Since restoration works revealed the presence of these cavities in the walls, increasing attention has been paid to their significance and influence on the perception of sound inside these spaces. Recent studies investigated the relation between that practice and acoustic purposes (Desarnaulds et al. 2001, Kayili 2005, Gül & Caliskan 2014, Valière & Palazzo-Bertholon 2017).

Although acoustic vases in Christian and Muslim worship buildings are relatively well known and documented in literature (Arns & Crawford 1995, Desarnaulds et al. 2001, Kayili 2005, Valière & Palazzo-Bertholon 2017) there were no found similar studies published in English reporting the use of acoustic cavities in Jewish temples.

This study attempts to provide a better understanding of the presence of embedded ceramic vases in the walls of Tomar synagogue, observing the importance of acoustics in Jewish ancient worship buildings. The main goal of the work is to place the ceramic vases of synagogue of Tomar in the general context of the historic relation between acoustics and construction, emphasising the importance of acoustics in the History of Construction.

The genesis of the construction of the synagogue building of Tomar is hereby investigated. A literature review on the use of ceramic pots in Churches and Mosques is presented, highlighting the results of experimental tests conducted to evaluate their efficiency. The paper also explores the main features of each type of worship building, with special regard to the specificity of the liturgy, and the acoustic challenges that architects and builders had to overcome in those days. Finally, the main findings on their function, position and efficiency are summarized and discussed to understand the similarities with those of the Portuguese Jewish House.

2 THE SYNAGOGUE OF TOMAR

Tomar is a small Portuguese town in the centre of the country about 150 km north east of the capital, Lisbon. The town is famous for the UNESCO World Heritage listed 'Convento de Cristo', an impressive Templar monastery and the remnants of its previous fortress. Less well known is the synagogue of Tomar, one of the oldest Portuguese Jewish worship houses, built in the second half of the 15th century (Afonso 2016).

Iberian Jewish communities, Sephardic Jewish, were established in the peninsula by the 8th century

as a minority people among the existing (majority of) Christians and Muslim invaders (Adams et al. 2008). The depose of Muslim domination in Portugal was followed by a period of religious acceptance for the Jewish people. In the 15th century, the Jewish presence in the village of Tomar was significant enough to permit the establishment of the synagogue.

Nevertheless, in 1496, religious intolerance resulted in the expulsion of Jewish from Portugal, or in their conversion to Christianity, where they continued to reside as 'novos cristãos' (new Christians). Thereby, the synagogue of Tomar served as a place of worship for the local community only until 1496. After its decommissioning as synagogue, the building had different uses: Christian chapel, wine cellar and warehouse (Teixeira 1925). In 1923, the building was rediscovered as ancient synagogue and purchased by Samuel Schwarz who donated it to the Portuguese State, in 1939. Nowadays, the building houses a Hebraic museum, the 'Museu Luso-Hebraico Abraão Zacuto', which is valued as a cultural tourism asset (Fig. 1).

Figure 1. General view on the left corner of the worship hall of the synagogue of Tomar (in reference to the current main entrance).

Inconspicuously located in downtown Tomar and surrounded by other buildings, the synagogue has the ground floor approximately one-half metre below the level of the street. The lowering of the floor level was also carried out in other coeval synagogues, in order to provide a higher ceiling without conflict to the legal constraints on the height of the Jewish building, which could not exceed the height of neighbouring constructions (Stiefel 2011, Afonso 2016).

The building presents a rectangular floor plan with a length of 9.5 m, a width of 8.3 m and a height of 8.0 m. Afonso (2016) mentions other ancient Iberian Jewish worship buildings with similar floor plan dimensions, namely Arón del Rubio (10.0 m × 7.5 m), Bembribe (10.5 m × 7.5 m) and Tarazona (10.0 × 8.0 m).

The current white-painted façade, with the main entrance surrounded by two iron grate windows, faces to the North. On the opposite wall there are two narrow windows (Fig. 2). The roof structure comprises a set of ribbed vaults, supported on the walls by limestone corbels and by four central limestone columns (Figs 1 and 2). In each corner of the building, nearby the corbels, are visible two side by side cavities (Figs 1 and 2), which tally with the openings of the clay vases inlaid in the wall. The cavities do not have the same alignment in all corners, e.g. the two cavities located in the left corner are below the corbel (Fig. 1), while the cavities on the right side are above the corbel (Fig. 2). The local oral tradition associates the eight cavities with acoustic purposes.

Figure 2. The visible cavities on the right corner (in reference to the current main entrance) above the corbel.

While some authors (Teixeira 1925), (Krinsky 1985, Dodds 1992 and Simões 1992 cited in Afonso 2016) attribute the construction of the synagogue of Tomar to Muslim workers from North Africa, Afonso (2016) puts forward the hypothesis that the building, as well as another Christian church in the neighbouring village of Ourém, was built by an Italian master builder in the 15th century. This Christian church, namely its worship space, was destroyed by the 1755 Lisbon's earthquake, and afterwards rebuilt in a new architectural style. However, the crypt of the church remained intact, displaying similar characteristics to those of the ribbed vaults of the synagogue building of Tomar (Afonso 2016). As the church was destroyed, there is no way to know if its walls included ceramic pots.

Although acoustic vases have been a common practice in church architecture throughout Europe between the 10th and 17th centuries, there are no

findings on this tradition in other worship buildings in Portugal (Valière et al. 2013), (Valière & Palazzo-Bertholon 2017).

3 CERAMIC POTS IN ANCIENT WORSHIP BUILDINGS – A LITERATURE REVIEW

A ceramic pot inlaid in the masonry with its free aperture directed to the room acts as a cavity resonator. A cavity resonator or Helmholtz resonator, named after the German physicist and scholar Hermann von Helmholtz (1821-1894), is a hollow sphere (containing a volume of air) with an open hole through a small-diameter neck. A cavity resonator performs at once as sound absorber for an array of frequencies, and as amplifier for the resonance frequency.

Although air resonance phenomenon in a cavity was scientifically demonstrated in the 19th century, the Roman architect Marcus Vitruvius Pollio (c. 90 - c. 20 BCE) mentioned, in his treatise *De Architectura Libre Decem* (Vitruvius 1st century BCE), the use of resonant cavities as a coetaneous solution to improve acoustics in Greek theatres. The treatise comprises ten books detailing his knowledge based on ancient Greek scripts and some Roman building practices of the time. Book V, devoted to acoustics, specifies bronze pots, named 'echea', currently known as cavity or Helmholtz resonators. Before Vitruvius' treatise, also Aristotle (c. 380-c. 320 BCE) highlighted the relation between the quality of sound and the presence of a cistern or a well or buried empty pots in a building (Aristotle 4th century BCE, Book XI).

According to Vitruvius, and apart from other practices to enhance sound distribution to the audience, bronze pots were laid out on the ground or under the steps of Greek theatres built of stone. In fact, the Greek theatres of Dionysius and Syracuse (5th century BCE) reveal, even nowadays, an impressive knowledge of acoustics. Vitruvius' text also contains recommendations to improve acoustics in the Roman Senate House, an important public building where senators exposed their ideas, trough the speech and for which the long reverberation time was undesirable. Those recommendations included the dimensions of the building and the materials that should cover the cornice (stucco or woodwork).

Vitruvius also denoted the use of earthen vases in small Greek theatres as a similar and more affordable solution than bronze pots (Vitruvius 1st century BCE, Book V). Nevertheless, acoustic science demonstrated that the material of the vessel, the way it is mounted (loose or fixed to the base) and its geometry influence the behaviour of the sound field inside the cavity, and thereby the perception of the sound inside the room. Moreover, the number and the location of cavity resonators, besides the position of the sound source, affect the distribution of sound into an enclosed space.

Despite Vitruvius' descriptions, such acoustic pots have never been found in ancient theatres. As Vitruvius claims to be unaware of any example in Rome, it is plausible that he only became aware about sounding vessels through oral transmission or reading, and thus never had used or seen any of them. In this regard, Crunelle (2009) noticed an historic curiosity: almost everything what is known about ancient Greek resonators resulted from Vitruvius' text, even as with no findings; on the other hand, although the existence of several examples in medieval churches, no written records on the function of embedded ceramic pots have ever been found.

The potteries installed in Romanesque and Gothic churches, and in Ottoman mosques, are generally vases, vessels, jars, urns or pots with or without handles. They are manufactured of red or grey clay whose primary function appears to be, in most of the cases, typical of utilitarian use (Arns & Crawford 1995, Desarnaulds et al. 2001, Kayili 2005, Ergin, 2008). The employed vases are of small but variable size and shape, even within the same building (Crunelle 2009, Desarnaulds et al. 2001, Kanev 2020). The vases are generally embedded in the masonry with the visible openings placed on the plan of the wall, which sometimes are visible, while others stand integrated with the surrounding pictorial decoration (Desarnaulds et al. 2001, Kayili 2005). However, in some worship buildings, the openings of the ceramic vases are not visible, since they were covered with mortar and decorated with fresco paintings (Mijic & Sumarac-Pavlovic 2002) or filled with bricks and plastered over, during later restoration works (Kayili 2005, Ergin 2008).

The number of embedded ceramic pots in churches and mosques ranges from a few units to some hundreds in the same building. The Chartreuse du Val de Bénédiction in Villeneuve-lès-Avignon (France) includes 3 ceramic pots (Arns & Crawford 1995). The Süleymaniye Mosque in Istanbul has about 255 embedded ceramic pots open towards the worship space (Kayili 2005), (Ergin 2008). The Russian Orthodox church of St. Nicholas in Pskov has about 300 pots inserted into its walls (Kanev 2020).

As the inlaid ceramic pots are widespread to different building construction traditions and architectural cultures, their functions are approached in different ways. Arns & Crawford (1995) argue that besides acoustic purposes, ceramic pots found in churches may been burial urns unearthed during construction, or their openings used for suspension of ornamental hangings, or even to reduce the weight of the walls. In Byzantine construction, empty ceramic amphoras and pipes were incorporated in the church buildings with a view to lightweight the structure and to avoid moisture problems resulting from improper drying of the massive masonry of the

walls. Hence, no acoustic purposes were behind their use. However, when the vessels were embedded in the masonry with their openings facing the inner space, certainly architects and builders perceived their benefit on acoustics (Kanev 2020), as Aristotle also highlighted centuries before.

Arns & Crawford (1995) mention 17th century scripts that relate church vases to those described by Vitruvius for Greek theatres. These authors also noted that ancient Greek and Roman theatres were linked to pagan practices, thus it would be surprising if a prescription for that (heathen) auditoriums was approved for worship buildings. Furthermore, Vitruvius described a solution to improve the acoustics of theatres, i.e. open-air space buildings, which suggests that the vases installed in medieval churches could be a different practice for enclosed spaces (Arns & Crawford 1995).

Different studies provide detailed information about the location and characteristics of ceramic pots in Romanesque and Gothic worship buildings, in several countries. The most common positions of the embedded vessels, in the walls, are in their upper portions, in the vaults/ogives, in the corners/angles and around the windows (Arns & Crawford 1995, Desarnaulds et al. 2001, Zakinthinos & Skarlatos 2007, Đorđević et al. 2017).

Crunelle (2009) argues that the vases inserted in the masonry represent a conscious attempt that could give a specific acoustical character to a space. Ars & Crawford (1995) state that ceramic vases had been installed, in medieval European churches, in a systematic and purposeful way and probably with acoustic purposes. Đorđević et al. (2017) analysed the position and physical characteristics of embedded ceramic vases located inside of fifteen medieval Serbian churches; this study pointed out that the use of acoustic vessels can be considered as an expression of the musical tradition of medieval worship Serbian architecture.

In order to demonstrate the influence of ceramic pots in the sound absorption of Christian churches, experimental tests were carried out according two different approaches: in situ measurements, i.e. inside the buildings, and in laboratory facilities. Carvalho et al. (2002) performed experimental laboratory measurements of ceramic pots similar to those used in some medieval churches; the results demonstrated that sound absorption increases. Therefore, regarding the same authors (Carvalho et al. 2002), this conclusion confirms the relevance of the tradition that often involves the use of acoustic pots inside the churches, especially near the corners. Zakinthinos & Skarlatos (2007) studied the effect of several cavity resonators with the same resonance frequency, placed inside an orthodox church, by measuring and analysing the impulse response of the building. The authors concluded that the vases located in the corners were more efficient, which shows a kind of knowledge on acoustic performance of enclosed spaces. Mijic & Sumarac-Pavlovic (2002) carried out laboratory experiments with several ceramic vessels found and removed from some medieval Serbian churches, in order to measure the reverberation time under simulated real conditions; these authors concluded that the ceramic vases inlaid into the walls and domes of the buildings resulted of an orally transmitted tradition without any real knowledge of their function.

Ceramic vases were also embedded in the walls of some Muslim worship buildings, which is believed to have become a tradition in Ottoman mosques to overcome acoustic problems resulting from their geometric configuration (Kayili 2005, Sü & Yilmazer 2008). Ottoman mosques are generally domed structures. The concave shape of these structures imposes specific challenges, because within these forms incident sound energy reflects back and forth several times, making speech unintelligible. Cavity resonators placed in a dome prevent the multiple reflection of sound energy. Hence, the incident energy is reradiated in all directions, the sound field becomes diffused and the inconvenient echoes, due to delayed reflections from the dome, are eliminated. In addition, the sound coming from the dome shortly after the direct sound, creates an appropriate effect for this worship environment (Kayili 2005).

Kayili (2002) measured and compared the reverberation times of six Ottoman mosques with cavity resonators with free (in four mosques) and plastered openings (in two large-size mosques); the experimental results indicate that the mosques with cavity resonators with free openings present lower reverberation times at low frequencies. Thus, the cavity resonators control excessive low frequency content, and contribute to lessen the weight of the dome (Gül & Caliskan 2014), this latter especially important in large-size structures.

4 LITURGY IN ANCIENT WORSHIP BUILDINGS

Judaism, Christianity, and Islam claim descent from Abraham. These monotheistic religions are based on literature considered, by their believers, of divine origin (sacred). Each one of them has different rituals and consequently specific building's features and requirements, to provide the accurate worship environment for their believers. In this context, a proper acoustic ambience is essential for a good communication and understanding of the liturgy, but also for the praying of the worshipers.

The next sections summarize the main features of each worship building, with special regard to their ritual activity and sound environment.

4.1 *Synagogues*

The spiritual Jewish heritage, embodied in the Hebrew Bible, was integrated into the liturgy, first in the Temple of Jerusalem and later, after the destruction of the Temple (70 CE), in houses of prayer, study and community assemblies known as synagogues. As much as synagogues provided this main three functions, they also reflected the conditions and the way of thinking of those who built and used them (Simha 1995, Weissbach 2011) in the different countries where the Jewish people settled.

According to Burton (1896), the main elements of the ancient Jewish service were worship and instruction. The spoken liturgy was the dominant sound source and the Torah its basis. In Sephardic synagogue buildings, the Torah was read from a centred raised platform. During the service, the worshipers were arrayed around this central raised platform, which apart from the symbolic meaning also suggests acoustic purposes (Carvalho & Amado 2011, Weissbach 2011). Therefore, a clear perception of sound was certainly of high relevance in the synagogue worship hall.

In European countries, the synagogue building should be oriented toward Jerusalem, i.e. toward East, with no specific exterior shape or pattern. Throughout the Middle Ages and the Early Modern period, synagogue buildings were raised according to the norms of vernacular architecture that prevailed in the country in which they were built (Steifel 2011, Weissbach 2011).

4.2 *Churches*

Churches are the houses of worship for Roman Catholic Church, Eastern Orthodox and Greek Catholic congregations. In Western Europe, several Christian worship buildings erected between the 11th and the 17th centuries include earthen vases in their masonry walls (Crunelle 2009, Valière & Palazzo-Bertholon 2017). Orthodox churches, in the same period of construction, also reveal the presence of ceramic vases (Mijic & Sumarac-Pavlovic 2002, Zakinthinos & Skarlatos 2007, Kanev 2020).

In the 1st and 2nd centuries CE, the newly emerged Christian Church used catacombs, underground Roman galleries, with long reverberation times, for clandestine religious rituals. This circumstance besides the inherited Hebrew tradition, related with the ceremonies of intonation of the religious texts, would influence the latter development of the Church service, such as the presence of the choir in the liturgy (Girón et al. 2017). Hence, the dominant sound source in Romanesque and Gothic Christian worship buildings was mainly based on monophonic chant, traditionally performed by male vocalists. The human voice was similarly dominant in Orthodox services (Đorđević et al. 2017). In this sense, the use of cavity resonators can be understood as to modulate the acoustic environment, emphasising the mood and the ambience for worship. However, it is important to highlight that cavity resonators operate in a narrow frequency band in the vicinity of the resonant frequency, therefore it is quite unbearable to assume their influence in the wide range frequency of speech.

4.3 *Mosques*

Islam's most important text is the Qur'an. In Islam, the concept of scripture is closely linked to the acoustic ambiance created by the recitation of the Qur'anic text. The oral nature of the Qur'an imposes the ability not only to hear, but also to understand the sacred text. The high relevance on the experience of Qur'anic recitation must have been an essential requirement of Ottoman mosques, and a priority for their architects and builders (Ergin 2008). Therefore, mosque design and its construction were almost certainly influenced by worship considerations which required a high level of speech audibility and intelligibility.

Recent restoration works revealed the existence of inlaid ceramic vases in the walls, surrounding the domed structures of the complexes of the Shehzade Mhemet (completed in 1548), the Süleymaniye (completed in 1557), the Sultan Amhet or Blue mosque (completed in 1616), all located in Istanbul, and the Selimiye (completed in 1575) mosques, located in the city of Edirne. However, the openings of most vases have been sealed during some previous repair works, denoting the lack of knowledge about their original function.

5 DISCUSSION

Architectural acoustic concerns date back from antiquity, as reported in the Vitruvius' treatise. The text describes some coeval solutions to overcome acoustic problems, in the most important public spaces at that times. Acoustic vases were proposed for open-air spaces, while specific materials, ceiling shape and dimensions were recommended for enclosed spaces. Vitruvius' treatise lasted through the ages, with relevance in Medieval and Renaissance periods.

Several Christian Romanesque and Gothic churches present cavities in their masonry walls formed by inlaid ceramic vases. The vases, with different shapes and sizes, were installed, mainly during construction, in diverse positions of the buildings, including in the corners. Byzantine traditional construction included hollow spaces in masonry walls and vaults to lightweight the structure and to overcome moisture problems. This practice also hosted acoustic changes inside the buildings, per-

ceived by their architects and builders, which probably linked the effect to acoustic benefits. In fact, long reverberation times result in insufficient intelligibility and audibility of speech, especially in large-size enclosed spaces with stone walls.

Recent experimental tests carried out in churches with inlaid ceramic vases revealed a perceptible reduction of reverberation, for low frequency content, which was more evident for those placed at the corners of the building. These studies also highlighted that this practice probably derived from a kind of awareness on the perception of sound inside enclosed spaces. Moreover, despite monophonic chant was the prevailing sound source in Romanesque and Gothic churches, it would be necessary to select the number of suitable cavity resonators, i.e. size and shape, to act successfully in that wide range of frequency.

Experimental tests conducted in Ottoman mosques with inlaid ceramic vases, also revealed a reduction of reverberation times at low frequencies. Despite large-scale Ottoman mosques were masterpieces of building techniques and fine arts, their architects also were aware of acoustic problems due to dome's shape, and thereby used ceramic containers, or Helmholtz resonators, to overcome those difficulties.

It seems plausible that beside Vitruvius' descriptions on the benefits of 'echea', the practice to embed ceramic vases in the walls also would arise from the constructive tradition to decrease the weight of masonry walls and avoid moisture problems, which together would have contributed to the belief of an effective technique to overcome acoustic issues in enclosed spaces. In this regard, given the importance of worship buildings back at those days, and as well the predictable existing problems due to undesirable reverberation inside worship spaces, it is also probable that the 'technology' became a practice for acoustic intents.

Throughout the Middle Ages and the Early Modern period, synagogue buildings were inconspicuous edifices, with no external specific signs and built according to local rules and following the prevailing vernacular construction styles. The synagogue of Tomar, built in the 15th century, was used as worship building only a few years by the local Jewish community, however the building and its main constructive features lasted well preserved. This circumstance seems to be an exception, given the historic context and the religious persecution of Jewish: most of these buildings were destroyed or radically altered to accommodate other functions, remaining few original specimens. The synagogue building of Tomar, rediscovered in the beginning of the 20th century, has been studied by historians which related its constructive origin and architectural features with the crypt of a coeval Christian church, located in the area. A recent study puts forward the hypothesis that the synagogue was built by an Italian master builder that also built the mentioned neighbouring Christian church. Moreover, there is no evidence of the practice of embedding ceramic vases in the walls in other Portuguese worship buildings.

Despite the specificities of liturgy and rituals of each religion, Judaism, Christianity and Islam, the dominant sound source in synagogues, churches and mosques would have been mainly based on the intonation of human male voice which should convey the divine message. Therefore, it is predictable that the demand on a high level of speech intelligibility and audibility had been shared by the three religions, which emphasised the importance of architectural acoustics in their buildings. The architects and builders of ancient worship buildings were certainly aware of this demand.

In light of the above, the construction of some synagogue houses would have been conducted by architects and builders who also would have designed and built other type of worship buildings. In this perspective, it seems probable that the synagogue building of Tomar followed the prevailing constructive practices which were adopted by other worship buildings. It is also plausible that the builders that incorporated the eight ceramic vases in the walls at the corners of the synagogue hall had the main intention to improve its acoustics. Although there are no findings on this tradition in other Portuguese worship buildings, this circumstance seems congruent with the hypothesis that the construction of the synagogue was conducted by a foreign master for whom the technique was familiar.

6 CONCLUSIONS

This paper reports the eight embedded ceramic vases in the corners, nearby the corbels, of the synagogue of Tomar, in Portugal. This building is one of the few preserved synagogues built in the 15th century. Nonetheless, these vases had been orally related by residents to acoustic purposes, there were no found studies written in English on the use of ceramic vases in other coeval synagogue buildings, neither in other Portuguese worship buildings. In fact, there are a small number of synagogue buildings that survived to the destruction throughout History.

The incorporation of ceramic vases in the walls was a common practice in Christian churches between the 11th and the 17th centuries and Ottoman Mosques in the 16th century. However, according to some experimental tests conducted in different churches, it is probable that the use of the ceramic vases rested more on a tradition than on effective knowledge of the laws of acoustics. Despite this finding, it should not be forgotten that ancient buildings and their technologies are not yet completely understood because, in most cases, there are no writ-

ten records on them, or those records have been lost over the centuries.

Specific research on ancient construction practices and even unsuccessful technologies, as it seems to be the case of the practice of acoustic vases, may offer the opportunity to fully understand ancient buildings, and thus draw its constructive history. Besides the benefits on increasing knowledge in the field of History of Construction, the research on ancient building techniques, namely in this specific topic of acoustics, also contributes to accomplish more accurate restoration works in these buildings. Additional advantages that may be associated for other domains: supporting the conservation of intangible heritage, increasing cultural understanding and consequently benefit cultural tourism.

A multidisciplinary approach, i.e. building techniques, acoustics, psychoacoustics and ancient religious studies, would be helpful in order to understand if the problems related to acoustics had the same importance in synagogues as they had in Christian and Muslim worship buildings.

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