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Geometry of a Medieval Town in the Context of Political Religious Governance of the Territory

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***Abstract* – Recent studies proved that, at least since the Medieval epoch, the sound of bells played a broader role than the liturgic one. In the Norman period, for example, it played an immaterial social role as a tool for territorial management and coordination, as verified in Southern Italy, reflecting also the evolution of the relationship between old and new rulers and the Church. The positioning of bell towers and towers was part of the integration between the defensive and liturgical buildings network, manifesting itself with the propagation of the sound of the bells. In this context, adopting a geometric physics metrological approach, we show how this procedure of territorial positioning was integrated into the urban texture in the case of the city of Salerno (Campania Region, Italy), adopting spatial and acoustical solutions, that we prove to be coherent with our hypothesis. Consequently, this work confirms the potentiality of adopting this type of geometrical physics metrological approach to implement and verify new research hypothesis. Moreover, we confirm that, through a quantitative metrological modelling, it is possible to discover some immaterial aspects of heritage assets, that often remain undocumented, being characteristic of ancient practices totally based on repeated experiences and experiential knowledge of natural phenomena. This is also the case of this study, where we observed the immaterial acoustic links, connecting the relevant points of religious and political control of the city of Salerno in the Norman period.**

I. INTRODUCTION

The modern vision of cultural heritage has largely evolved through an integrated and synergic multidimensional representation, a synthesis of its material and immaterial dimensions, in the context of a historical-evolutionary interpretation [1,2]. However, the adoption of quantitative metrological approaches often remains confined to their use as ways to provide an ancillary expertise to support decision-makers and heritage managers. This option, however, contrasts with the evolution of research and heritage management practices, that require a multidisciplinary harmonized vision, evolving synergically to include the preservation, the valorization and an evolving comprehension of any heritage asset in its space and time, as well as in its evolution.

This is why we decided to overcome an obsolete ultra-specialist approach, looking, from one side to a multi-disciplinary contamination, and, on the other side, preserving a quantitative metrological approach. Thus, we chose to include multiple disciplinary interpretative perspectives from the beginning, while avoiding their parallelization. We worked, then, to define innovative inverse analysis methods, based on quantitative metrology, to formulate new interpretative hypotheses, whose validation can be later entrusted by archaeological, documentary and metrological evidence.

In this context, vibro-acoustic metrology, seen as an independent element of proposition and quantitative validation of interpretative hypotheses, is taking on a new role, fully consistent with the archaeological and documentary approach, also aimed directly at formulating functional hypotheses for understanding any historical asset [3,4]. Removing the fictious separation in the study of mechanical vibrations, that derived from the different disciplines, which faced the study of the same phenomenon and its different applications, we tried to recover historical unity of disciplinary vision. Then, overcoming a further fragmentation of research and culture, we work to find more general theoretical and experimental visions that can be interconnected with archaeological and historical research.

II. ACOUSTIC CONTROL OF TERRITORY

The use of bells for signaling is well assessed. Since the late antiquity, in fact, they were also called *signa ecclesiae*, even when used only in liturgical functions [5]. Starting from the 4th century, the coupling between bells and bell towers was more frequent, as attested by some passages of

Gregory of Tours [6], thanks to gradual improvements in the design of more stable structures, attesting an evolution of construction practices.

This is also the case of the city of Salerno (Campania Region, Italy), for which, looking to the Longobard-Norman transition, occurred in the 11th century, a bell would be larger and heavier than the one supported by the original bell tower of Guaimario, one of the Longobard rulers of the city. In fact, the most frequently adopted solution of the epoch would have been a wooden *turriculum*, placed on the roof of the main urban church and collapsed during the 11th century.

However, between the end of the 11th century and the 12th century, the investments of the Normans, as new rulers of Southern Italy, in liturgical buildings was notable, also considering the political-religious situation that occurred in Salerno. In fact, the final and most relevant act of political and religious unification of Southern Italy occurred in Salerno, culminating with the presence of a pope, Gregory VII, who sealed a period of great cultural, political, economic, religious and military ferment centered on Salerno.

The city of Salerno, far from being a marginal urban center, was chosen to integrate and strengthen the relations between the Normans and the Catholic Church, being favored by the Euro-mediterranean attraction pole represented by the Salerno Medical School, the first Medical School in Europe, already active at least one century before the foundation of University of Bologna around year 1088. A few decades after, the Treaty of Melfi was signed on August 23rd, 1059, between Pope Nicholas II and the Norman Lords Robert of Hauteville and Richard I of Capua. This integration was mediated and supported by the Benedictine order, thanks to the support of the abbot Desiderius of Montecassino [7], later Pope Victor III (the successor of Gregory VII). Consequently, this integration evolved with the pre-existing Longobard and Mediterranean cultural structure.

The Normans financed the construction of churches and monasteries throughout the territory, placing most of the buildings in strategic locations to gain a broader territorial integration, while preserving its security. Then, bells and their sounds became something more than a liturgic sign or an instrument of local territorial domination, as commonly done in the case of abbeys and similar religious structures [8,9]. Coherently, the repertoire of melodies had to include a succession of sounds capable of calling together and signaling to the surrounding population natural events, such as fires or floods, and imminent dangers, such as the arrival of enemies [5,8].

Coherently with this evidence, we hypothesized that bell sounds, so widespread in everyday life, could be normally used as elements of territorial information and cohesion. However, such information must be transmitted and shared, requiring an acoustic communication network, used to cover large distances and guarantee the speed and efficiency of the transmission of the information itself [10]. To use contemporary language, the structuring of an acoustic network is, somehow, very similar to that of an electromagnetic communication network, made up of repeaters and based on the use of coding languages, widely different for civil, religious or military purposes. Consequently, the sound of the bells also acquired an immaterial social role, broader than the religious one, being used as a tool for territorial management and coordination, indirectly reflecting the evolution of the relationship between old and new rulers and the Church. And the positioning of the bells and of the bell towers was part of such an integration,

In this context, specific studies based on an innovative vibroacoustic metrology vision are currently aimed at recovering the geometries of the bell communication network in the chronological period compressed between the Longobard and Norman domination in southern Italy, with the aim of identifying the elements of the network on the territory, such as liturgical buildings already recorded in the published sources and/or and to identify presumable positions of elements no longer present today, but cited in the documentation and in the original toponymy of the places.

III. THE BELL TOWER OF THE SALERNO CATHEDRAL

The monumental Norman bell tower of the Salerno Cathedral (Fig. 1), an important testimony to the Byzantine-Norman fusion of the period, was built more than half a century after the Cathedral of Salerno by Guglielmo da Ravenna, archbishop of Salerno from 1137 to 1152.

Fig.1. The Bell Tower of the Cathedral of Salerno

This bell tower, leaning against the southern side of the cathedral's quadriportico, rises almost 52 meters in height with a base of about 10 meters per side. Its structure is very simple, composed of four cubic stages, ending with a

cylindrical turret with a hemispherical dome. The appearance of the bell tower unquestionably highlights the difference in style between the first stages of the bell tower itself and the last stage, the turret, where the bells were presumably positioned in the 12th century.

A. The Turret as Geometric Acoustic Resonator

The structure of the turret (Fig. 2) is geometrically very simple, being made up of a hollow cylinder covered by a spherical dome. Starting from the lower half of the cylinder, twelve vaulted windows open, which functionally allow the sound emitted by the internal sources (bells) to propagate outwards. These windows are oriented isotropically in different directions (at multiple angles of 360/12°). Some of them were closed, following subsequent restorations, presumably for reasons linked to the statics of the turret itself. The orientation of the windows follows the orientation of the bell tower, whose North side is oriented at 10° NNE. The external part of the cylinder clearly presents several arches intertwined with each other, a light but effective structure to support the hemispherical dome.

Fig. 2. Detail of the turret of the Bell Tower of the Salerno Cathedral

The turret of the bell tower is the key element for the geometric acoustic analysis of the sound emission of the bell tower of the Cathedral of Salerno. A simplified geometrical physics model was developed to provide insights on the functional implications of the adopted constructive solutions. This approach, based on quantitative metrology, is aimed at understanding the effects of an architectural design and realization, decoupling it from its aesthetic language. Furthermore, the adopted approach is chosen also to discover how the knowledge and understanding of natural phenomena and practical knowledge, coupled with skills and available technologies, allowed us to define certain solutions, like in the case of constructions, that could be adapted to specific needs and to the territory.

The bell tower turret, together with the bells housed inside, acts as an acoustic source. In fact, the bells, characterized by an acoustic emission spectrum, interact with the turret structure, so that the acoustic power emitted into the external environment can be maximized. In Fig. 3, the different typology of acoustic modes for a cylindric cavity are shown.

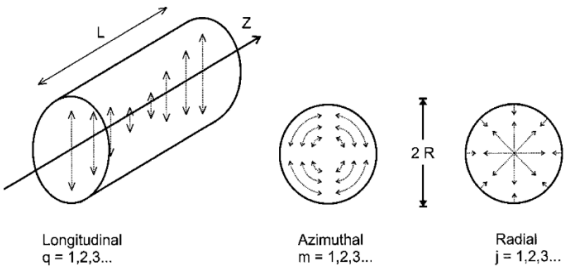

Fig.3. Acoustic longitudinal, azimuthal, and radial modes in a cylindrical resonator.

Only the radial modes are relevant for the coupling of the internal acoustic power with the external environment. For this reason, in Table 1 only the first twenty-one radial acoustic modes of resonance are shown compared to the modes of oscillation of the 13th century bell [11], the oldest one positioned inside the turret (Fig. 4).

Table 1. The first twenty radial acoustic resonance modes (and the ratios between the bell acoustic modes with respect to the second one) of the turret of the bell tower of Salerno Cathedral evaluated assuming R=2.70 m.

Mode	Turret Frequency [Hz]	Bell Frequency [Hz]
1	77.47	
2	141.84	
3	205.69	209.18
4	269.39	
5	333.01	
6	396.61	
7	460.18	460.39
8	523.74	548.00
9	587.28	
10	650.83	653.43
11	714.37	
12	777.90	
13	841.44	
14	904.97	915.29
15	968.50	
16	1032.0	
17	1095.6	1085.48
18	1159.1	1144.56
19	1222.6	
20	1286.1	
21	1349.7	1346.64

This purely functional and metrological design consideration was, then, extended. In fact, considering the objective of governing a territory the efforts and cost for

its construction would be fully justified for an important city like Salerno.

Fig. 4. The 13th century bell positioned inside the Salerno Cathedral bell tower turret.

B. The Turret Windows as Acoustic coupling element with environment

The elements connecting the internal sound source with the outside environment are the vaulted windows, positioned at the base of the turret itself and uniformly distributed on its surface (Fig.5). These windows occupy only a lower lateral portion of the turret itself, allowing the cylinder to be considered as an efficient resonator, with defined acoustic power losses (lateral windows). The quality of the emission is guaranteed by the fact that the windows are normal to the radial acoustic modes of oscillation, allowing perfect coupling with the outside.

Fig. 5. View of Salerno through the West (left) and South (right) windows of the turret of the Tower Bell. These views show the areas of the city of Salerno covered by the acoustic emission of the Tower Bell of the Cathedral.

The width of the windows, of the order of a meter, guarantees the quality of the emitted ray. In fact, the values of the acoustic emission modes of the XIII Century Bell suggest that the width of the windows was not only defined with purely structural or aesthetic purposes, but also on the basis of functional acoustic implications. In fact, the width of the windows is greater than the shortest wavelength of the resonant modes of the bell and their opening is divergent, narrower on the inside and wider towards the outside, with the two sides of the window tangent to the geometric rays departing from the central axis of the cylinder-turret.

This geometry is very important, since the radial modes of the cylinder guarantee that the acoustic rays exit the turret with a direction normal to the external surface of the turret, with a well-defined aperture angle, linearly propagating outwards, and, practically, without acoustic diffraction effects.

Making an optical analogy, this structure could be imagined as an acoustic lighthouse, which transmits sound signals in 12 specific directions, distributing them to the city of Salerno. Therefore, not only the number and orientation of the windows, but also the orientation of the bell tower itself, appear to be very important elements when defining the potential functions of the bell tower.

IV. ACOUSTIC GEOMETRY OF SALERNO

Hypothesizing the bell tower as an acoustic source of information, the above-described symmetrical distribution of acoustic rays emitted by the turret is likely to have had a more and unexpectedly important purpose in the Norman period. In fact, before the construction of the present Cathedral of Salerno, the main church in Salerno was Sant'Andrea de Lama, positioned toward the West walls, which has a turret structure very similar to that of the Cathedral bell tower.

Thus, the construction of a new bell tower could have been linked to the inclusion of new urban expansion elements towards the East side of Salerno. On the other hand, a simple geometric analysis of the city shows that the directional symmetrical emission structure of the acoustic component of the turret fits well with the structure of the historic center of the city of Salerno, whose present layout was finally defined in the Norman period (Fig. 6). Therefore, it would be very interesting to hypothesize that the directions of emission and the number of vaulted windows of the turret were not random, especially if we consider that the bell tower is not oriented in the East-West direction but has an offset of about 10° NNE.

Fig. 6 shows the main acoustic coverage of the bell tower with its emission directions and the intersection of the key points of the city: Porta Catena (church of S. Anna al Porto); Porta Marina; Church of S. Andrea de Lama; Church of San Giorgio; Church of San Benedetto; Castello di Arechi; Porta Elina. This figure shows also that there are directions, particularly towards the East, in which the acoustic direction does not seem to intersect points of historical relevance.

However, urban elements that existed at the time of the construction of the bell tower could be no longer present.

A striking example is given by the acoustic emission directivity in the direction of the medieval aqueduct (locally known as devil's arches) that supplies the elevated area with water, naturally defended towards the West and North-West by the Rafastia river and currently known as Piazzetta dei Mutilati in Salerno.

Fig. 6. View of Salerno. The yellow lines show the 12 acoustic emissions centered on the turret of the Tower Bell of the Salerno Cathedral. The red points are points of historical interest that may have had a role in the Norman acoustic bell network aimed at the religious and political governance of the city of Salerno. (source: Google Earth)

A global analysis, that uses the orographic typology of the place (elevated area), the fact that it was certainly served by water (medieval aqueduct) and that the eastern side was naturally defended by the Rafastia river could suggest a hypotheses on the possible position of the palace of Robert d'Hauteville, so far not yet located, right along this acoustic direction, near the Piazzetta dei Mutilati. A similar analysis could also be carried out to identify disappeared churches, monasteries and bell towers whose existence is only documented, but whose position is still unknown.

V. CONCLUSIONS

It has been recently demonstrated that the sound of bells had an immaterial social role in the Norman period, that was broader than the religious one and was used as a tool for territorial management and coordination. This particularly significant role reflected also the evolution of the relationship between old and new rulers and the Church.

Starting from the hypothesis that bell towers and towers were used as acoustic tools, connecting the defensive and the liturgical buildings in a coherent immaterial network, interacting through the propagation of the sound of the bells, we studied the area, covered acoustically by the bell tower of the Salerno Cathedral. We tried to recover the possible acoustic links, connecting the relevant point of religious and political governance of the city of Salerno.

The results show that the architecture of the bell tower of Salerno appears to be functional to serve as primary acoustic source for many relevant points of the city of Salerno, on the basis a pure geometric acoustic approach. Furthermore, using a reverse analysis approach, this method may become also very effective to determine the positions of relevant monuments (places, churches, etc.) that are presently not yet identified in term of position, but whose existence was certain according to the documentation.

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