Acta Acustica united with Acustica
Vol. 99 (2013) 91 – 97

DOI 10.3813/AAA.918592

Francesco Milizia (1725-1798) and the Acoustics of his *Teatro Ideale* (1773)

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Summary
During the 18th Century several French scientists prior to Pierre Patte proposed a new concept of theatre architecture based on a democratic vision of the theatre, which was founded on Neoclassical architecture. The French vision of theatre architecture recalled the *Teatro Olimpico* in Vicenza, designed by Andrea Palladio, and reintroduced many neoclassical (i.e. Greek/Roman) elements such as columns, semi-circular shapes and a large balcony in place of box stalls. The new French ideas of theatre architecture did not find many followers in Italy. The only scientists that accepted this new concept of a "democratic theatre" were the architects Earl Enea Arnaldi (Vicenza, 1716–1794) who wrote *Idea di un teatro nelle principali sue parti simile a' teatri antichi all'uso moderno accomodato del conte Enea Arnald* (Vicenza, 1762), and Francesco Milizia (Oria, 1725- 1798), author of *Del Teatro* (Rome, 1773 and Venice, 1794) [1]. Milizia wrote his book after having read the Arnaldi's work and followed the idea of a semi-circular plan for the theatre with columns and other antiquarian elements. He was therefore influenced by the *Teatro Olimpico* architecture in Vicenza and introduced many Neoclassical elements into his conception of theatre architecture. He proposed the *Teatro Ideale* would solve several problems that existed in contemporary theatre architecture, including acoustic difficulties. In this paper, the *Teatro Ideale* proposed by Francesco Milizia has been acoustically analysed. Using his sketches as a starting point, a numerical model was created in order to simulate the acoustic behavior of the theatre, as is done today when a modern theatre is acoustically analysed. The results from the simulation are presented and commented on, with comparisons of the acoustic data measured in the *Teatro Olimpico*, and afterwards rendered by means of 3D auralisation.

PACS no. 43.55.Fw, 43.55.Gx, 43.55.Ka

1. Introduction

The new democratic ideas that emerged in France during the 18th Century derived from the philosophical and political principles of the Age of Enlightenment, such as Individualism, the social contract as theorised by the French philosopher Rousseau and the separation of powers espoused by Baron de Montesquieu. These principles of human rights were written in the United States Declaration of Independence where it is stated: "Men are born and remain free and equal in rights. Social distinctions may be founded only upon the general good".

These new ideas influenced several French scientists prior to Pierre Patte [2], who proposed a new concept of theatre architecture based on a democratic vision of the theatre, founded on Neoclassic architecture.

The French vision of theatre architecture immediately recalled the *Teatro Olimpico* in Vicenza, designed by Andrea Palladio, the renowned Neoclassical architect. Many Neoclassical elements were introduced such as columns, semi-circular shapes and a large balcony rather than box stalls. This new vision of theatre architecture greatly contrasted with the typical Italian-styled opera house.

Received 25 April 2012,
accepted 7 December 2012.

2. Historical background of Milizia's concepts for theatre architecture

The international debate over the renovation of theatre architecture began in 1749 when Voltaire inserted the *Préface-pamphlet* into the *Semiramis* [3]. Afterwards, the *Académie d'architecture* sent two architects to Italy in order to analyse the features of Italian theatres. One of these architects was Charles-Nicolas Cochin, who wrote a report in 1758 [4] that approved the Palladian theatre in Vicenza, and criticised the architectural distribution of the box stall in Italian theatres. In 1765 Cochin published *Projet d'une salle de spectacles* with an elliptical plan. The writings of Cochin can be considered the first publications that specifically criticised Italian-styled opera houses. His concept influenced Italian Neoclassicism, in particular Earl Enea Arnaldi's (Vicenza 1716–1794) publication in 1762 of the idea that a theatre should be Śas much as possible similar to the ancient theatres' [5]. However, the Arnaldi theatre maintained the box stall and converted the stalls into a semi-circular terrace (Figure 1).

Table I. Some important theatres designed in the 18th–19th Centuries.

Theatre	Designer	Town	Type
Olimpico	Palladio	Vicenza	Semicircular
-	Cochin	-	Elliptical
-	Arnaldi	-	Semicircular
-	Dumont	-	Semicircular
La Scala	Piermarini	Milan	Italian-style
La Fenice	Selva	Venice	Italian-style
San Carlo	Medrano	Naples	Italian-style
Patriottico	Canonica	Milan	Semicircular
Grand Théâtre	Louis	Bordeaux	Without boxes
Théâtre	Ledoux	Besançon	Semicircular

Francesco Milizia considered Arnaldi's publication of great importance, identifying him as an '*eruditissimo accademico olimpico*' (very erudite Olympic academician) and believing the concept was a good idea. Milizia was also optimistic that the *Teatro Olimpico* 'designed by *Palladio, the Vitruvian*' could be considered as a good theatre' [1].

However, Milizia did not consider the Arnaldi theory exhaustive enough and a decade later published a more radical project, which also mentioned the need of acoustic enhancements of the room. 'Due to the circular plan and of the box stalls often in the Italian theatres only whispers could be heard from those strange people [the singers], and never could the words be heard' [1]. Since Milizia also worked in Rome, he probably knew the work of Gabriel-Pierre-Martin Dumont [6] and his concept of theatre architecture, which would be fully realised in French Neoclassicism (Figure 2).

Milizia also introduced French revolutionary themes into the theatre, writing: 'Everybody must sit comfortably and see the scene. Therefore, it is necessary to recall the semi-circular shape and avoid the box stall' [1]. Substituting the box stall with a gallery would have avoided separating aristocracy from the common people, therefore mixing all the people together democratically without attention to social station.

The new ideas of Arnaldi and Milizia were not to be realised in Italy. All the new theatres, such as Milan (La Scala, 1778), Venice (La Fenice, 1790), Rome (Tordinona, 1794; Costanzi, 1880) and Naples (San Carlo, 1817) were instead realised in the Italian style. Only the *Teatro Patriottico* (now called *Filodrammatici*), built in Milan under Napoleonic rule for the Young Republicans (1800), was provided with a balcony rather than box stalls.

In France instead, many theatres were designed according to this new concept, including the Grand Théâtre of Bordeaux (1777-1780) and the Théâtre of Besançon (1778–1784, designed by Claude-Nicolas Ledoux).

3. The *Teatro Ideale* of Francesco Milizia

In this context, Francesco Milizia published in 1773 his book proposing a new *Teatro Ideale* in order to solve many of the problems of contemporary theatres. The most important new elements introduced in his *Teatro Ideale*, with an audience capacity of 5000, included the semi-circular plan, lateral walls and ceilings, cavities and resonators, galleries and new door locations (Figures 3, 4).

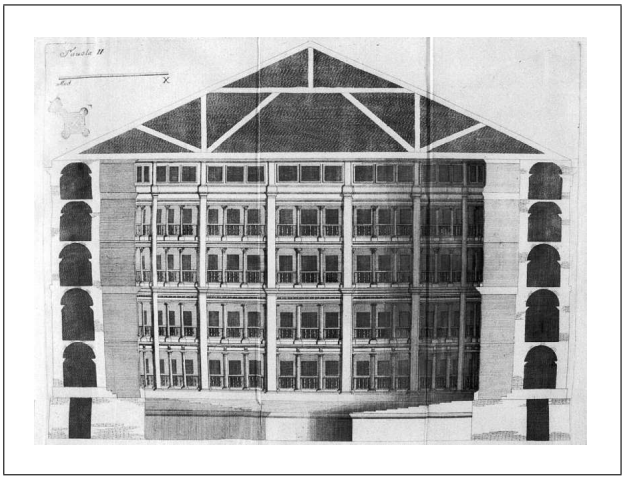

Figure 1. The Arnaldi theatre – section – Tav II (1762).

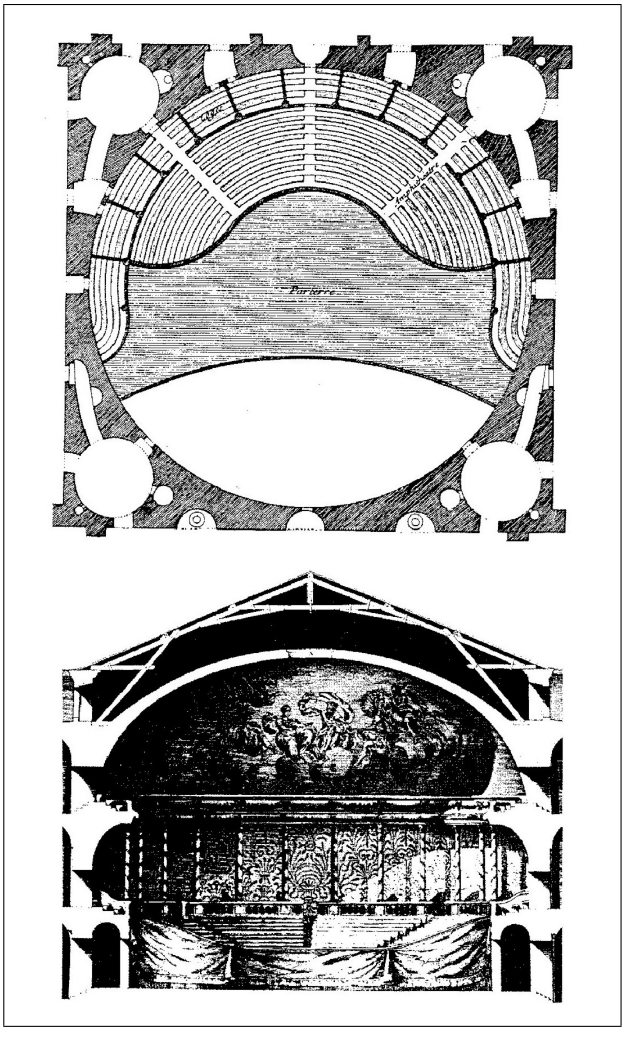

Figure 2. The Theatre by Gabriel-Pierre-Martin Dumont – 1764–1766.

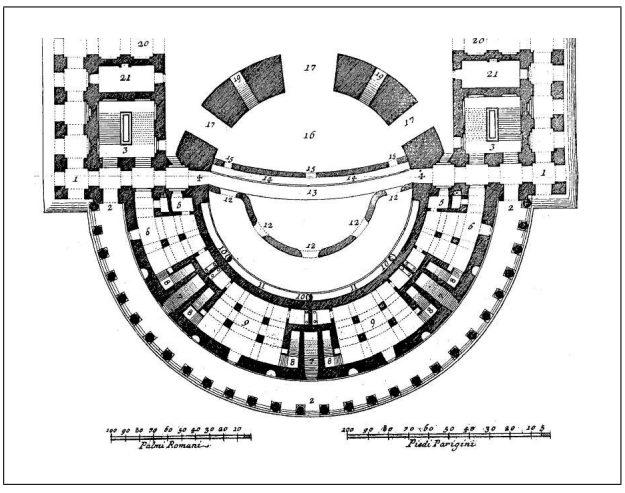

Figure 3. Milizia's *Teatro Ideale* (plan).

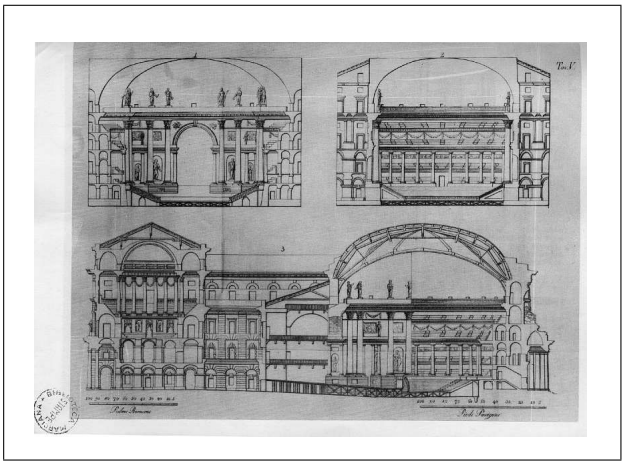

Figure 4. Milizia's *Teatro Ideale* (section drawing).

3.1. The Semi-circular plan

In 1765–66, Joseph-Jérôme de La Lande wrote of the theatre Alibert in Rome [7]: 'the hemisphere in the ceiling is too flat, and the voice cannot reach the stalls'. The solution would have been to make the ceiling a circular shape, as mentioned in the Vitruvian writings. Milizia added that the circular shape could also enhance visibility. Milizia also wrote that the Farnese theatre in Parma (constructed in 1618 and having a U-shaped plan), despite having poor visibility, has good acoustics.

Milizia considered the *Teatro Olimpico* in Vicenza a good theatre, where, despite its semi-circular plan, contains many wooden panels and elements on the lateral walls - components that have been experimentally demonstrated to avoid strong focalisation [8].

3.2. Lateral walls and ceilings

In analysing the Arnaldi project, no evident focalisations would appear, since the *gradons* (permanent seating tiers as in ancient Greek theatres) are made of wood and the theatre has lateral box stalls (Figure 1). Milizia proposed a larger theatre, which would probably have had greater focalisation. To compensate for this, he proposed to cover all lateral walls with wooden panels, at a certain distance away from them and therefore acting as resonance panels as are found in musical instruments. Galli Bibiena had tried this innovation in the Teatro Filarmonico at Verona (1724–1729) [1].

The ceiling proposed by Milizia was circular. Considering the dimension of the theatre (60 m diameter) and the geometry of the hall, it is likely that it could have focalisation. However, the ceiling had an elastic mechanical structure that avoided strong reflection at low frequencies.

3.3. Cavities and resonators

Arnaldi and Milizia tried to enhance the "resonance" of the theatre by adding Vitruvian vases and wooden panels. Milizia proposed cylindrical wells that could act as Helmholtz resonators or bass-traps and, further, three cylindrical wells that 'are necessary to amplify the voices' (Figure 4). Indeed, many contemporary cylindrical cavities can be identified, for example, Nicodemus Tessin in Venice reported that 'a great well that amplifies the sound of the voices' was found underneath the *Teatro Vendramin* in 1688 [9]. Similar devices were installed in theatres at Naples (1742), Lisbon (1792) and Ravenna (1840). The importance of these cavities located underneath the orchestra pit was recently experimentally verified in the *Teatro Alighieri* in Ravenna, where it was discovered they could indeed increase reverberation and strength, especially noticeable in the farthest stall positions [10, 11].

3.4. Box-stall and galleries

An important aspect of the new design is related to the box stall. The French theatre architects abandoned them, as they were considered too un-democratic. Arnaldi maintained separate box stalls 'for tradition', but Milizia abandoned them for reasons of acoustics and visibility. One previous experiment was installed in *Teatro Marsigli*, Bologna - the walls that separate the box stalls were substituted with a light wooden structure [12]. In 1762 Francesco Algarotti [13] proposed to lower the fence in front of each stall for acoustic and visibility reasons, and because 'the spectators must be involved in the show'.

3.5. Doors

Another element of theatre design is the location of the inner doors. Milizia agreed to locate the doors laterally, not only because 'they were used in ancient times', but also because without them the voice would be weakened. In 1766 Chevalier de Chaumont [14] suggested not locating a door below the royal box, in order to avoid air blowing onto the scene. This could be useful especially for sound insulation, rather than the room's sound quality.

4. Acoustic simulation

Milizia provided a full-scale set of drawings of the *Teatro Ideale*, which have been utilised to verify the acoustics.

Table II. Characteristics of the 3D model in the *Teatro Ideale*.

Number of surface	6345
Number of receivers	134
Number of materials	21
Most relevant (extension) surfaces and area	Stage walls (2422 m^2)
	Walls (2362 m^2)
	Ceiling (2097 m^2)
	Stage floor (1566 m^2)
Gross volume	51000 m^3

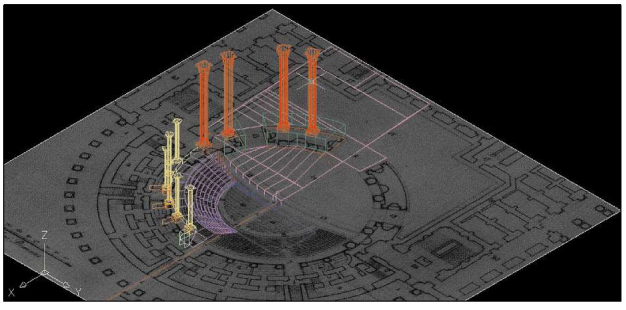

Figure 5. Realisation of the 3D model of the *Teatro Ideale* of Francesco Milizia.

A 3D model was realised and used to estimate the sound propagation in many positions inside the room (Figure 5, 6). Table II summarises the characteristics of the model.

The geometry and the materials of the model were defined by following Milizia's design while other previously studied theatres of similar geometry were referred to for considering the absorption coefficients of the materials. The simulations were performed using Ramsete, a pyramid tracer software [15]; the 134 receivers were homogeneously distributed in the theatre, covering all seating areas. From these receivers, also Binaural Impulse Responses (BIRs) were obtained in many representative positions of the room using a previously developed procedure that utilises the measured Kemar HRTFs [16].

5. Results

The overall acoustic parameters obtained from simulations are reported in Table III. The average was conducted among all the receivers, homogeneously located in the room, in the reverberant field and where the parameters are less position-dependent.

Considering the overall values of the acoustic parameters reported in Table III, the *Teatro Ideale* appears as a reverberant theatre. However, the numerical values here reported do not differ considerably from the values measured in the *Teatro Colon* in Buenos Aires, where the reverberation time is approximately 2.5 seconds at mid-frequencies [17, 18]. One other issue was the sound distribution in the theatre. The circular shape of the main hall could have caused focalisation in the centre of the room. Nevertheless, the distribution maps of the energy parameters (i.e. Centre Time or strength) reveal focalisation was limited, due to the acoustic treatment on the ceilings and lateral walls (Figure 7).

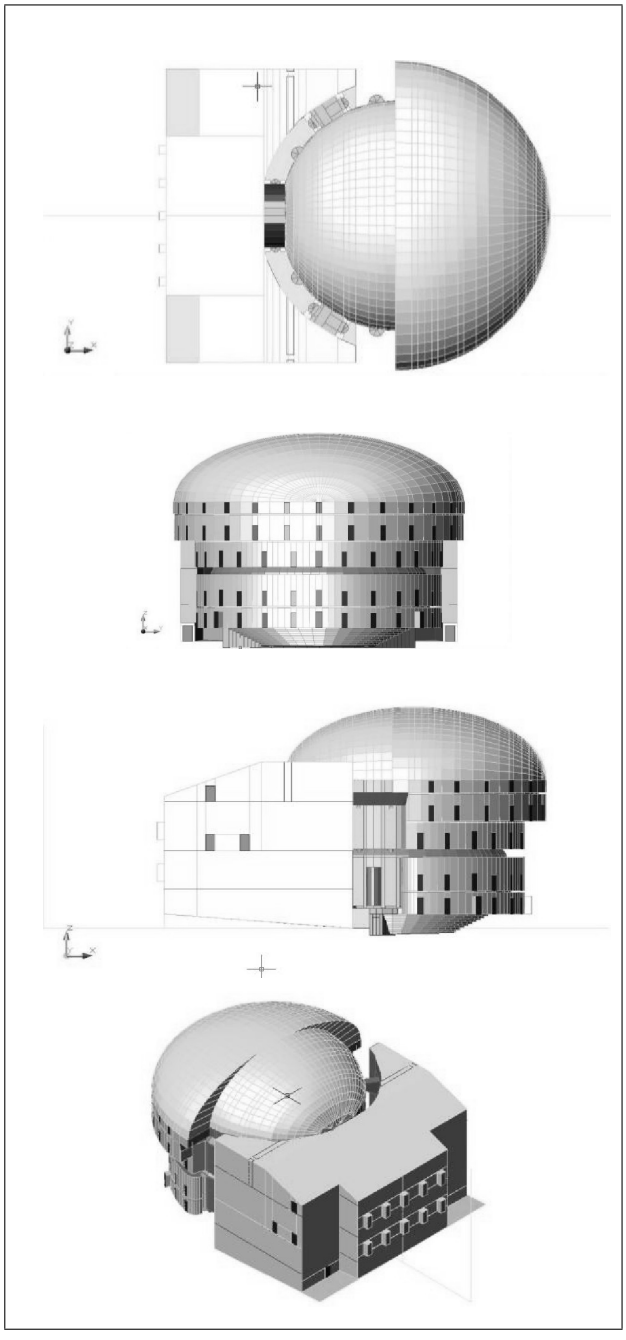

Figure 6. The 3D model of the *Teatro Ideale* of Francesco Milizia.

6. The acoustics of the Teatro Olimpico

The *Teatro Olimpico* in Vicenza [19] has been considered, since the 17th Century, a reference for Milizia's architecture and acoustics. It should be remembered that in the 17th and 18th Century the aesthetic evaluation of theatre acoustics was different from today. For example, one of the most important works of Athanasius Kircher emphasised theatre sound effects rather than sound quality [20].

Today the dominant opinion is that the *Teatro Olimpico* is an excellent, resonant theatre. However, this opinion may reflect the qualitative impression of the historic architecture of the room rather than purely of its acoustics.

Table III. Value of acoustic parameters obtained after simulation.

Freq (Hz)	125	250	500	1000	2000	4000	8000
EDT (s)	3.3	3.0	2.8	2.8	2.9	2.7	2.1
T15 (s)	3.1	2.8	2.6	2.6	2.7	2.6	2.2
T30 (s)	3.2	2.9	2.6	2.6	2.7	2.5	2.1
C50 (dB)	−6.6	−6.4	−5.9	−5.9	−6.0	−5.7	−4.5
C80 (dB)	−3.7	−3.3	−2.8	−2.8	−2.9	−2.6	−1.3
D (%)	17.9	18.7	20.3	20.5	20.2	21.4	26.0
CT (ms)	219	203	184	185	191	178	142
STI (%)	0.52	0.53	0.55	0.55	0.55	0.56	0.61

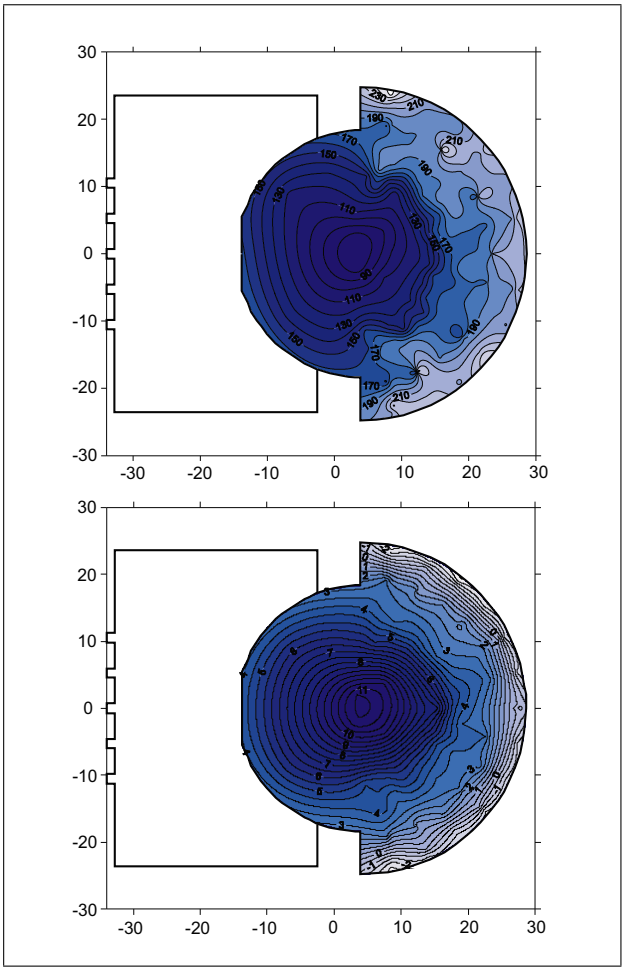

Figure 7. Spatial distribution of CT (top) and strength (bottom) in the *Teatro Ideale*.

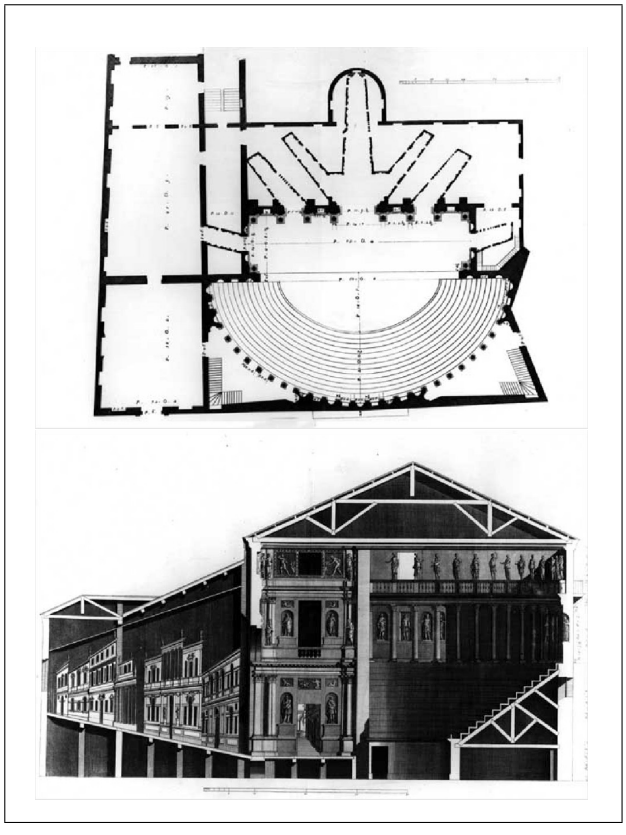

Figure 8. Plan and Section of the *Teatro Olimpico*, by Ottavio Bertotti Scamozzi (1776).

In 1994 Vicenza and its Palladian architecture was included on the UNESCO World Heritage List. Today the *Teatro Olimpico* is rarely utilised for musical performance; there is no conditioning system in the space and the capacity is limited to only 400 seats due to conservation constraints. As a result, it is difficult for a sufficient number of people (musicians or listeners) to express their opinion about its acoustics.

The *Teatro Olimpico* has a volume of about 12000 m^3. The main architectural characteristics include the floor and thirteen *gradons* (seating tiers), which are all made of wood. A wooden structure suspends from the ceiling. In the upper part of the *cavea* are thirty columns surmounted by statues. Likewise, statues are also situated in the ten niches in front of the stage. The wooden scene was originally designed and built by Vincenzo Scamozzi in 1584/5. All of these elements in combination contribute to scattering the sound distribution and creating a good sound distribution.

6.1. Measurements in the *Teatro Olimpico*

Since Charles-Nicolas Cochin, Enea Arlandi and Francesco Milizia himself cited the *Teatro Olimpico* in Vicenza as an example of good architecture and acoustics, an experimental campaign of acoustic measurements was carried out in the theatre to determine its acoustic quality.

Table IV. Overall value of acoustic parameters measured in Teatro Olimpico, Vicenza.

Freq (Hz)	125	250	500	1000	2000	4000	8000
EDT (s)	1.7	1.9	2.3	2.4	2.3	2.0	1.3
T15 (s)	1.5	2.1	2.4	2.6	2.4	1.7	1.2
T30 (s)	1.7	2.1	2.3	2.6	2.6	1.9	1.3
C50 (dB)	0.87	0.27	−2.13	−5.49	−2.18	0.22	0.93
C80 (dB)	1.96	1.53	−0.55	−3.68	−0.57	1.58	2.82
D (%)	55.0	51.6	38.0	22.0	37.7	51.2	55.4
CT (ms)	99.4	99.9	141.9	185.2	143.5	96.3	70.4
STI (%)	0.537	0.539	0.45	0.361	0.453	0.533	0.547

Table V. Acoustic differences between the Teatro Ideale and Teatro Olimpico.

Freq (Hz)	125	250	500	1000	2000	4000	8000
EDT (s)	1.6	1.1	0.5	0.4	0.6	0.7	0.8
T15 (s)	1.6	0.7	0.2	0	0.3	0.9	1
T30 (s)	1.5	0.8	0.3	0	0.1	0.6	0.8
C50 (dB)	−7.47	−6.67	−3.77	−0.41	−3.82	−5.92	−5.43
C80 (dB)	−5.66	−4.83	−2.25	0.88	−2.33	−4.18	−4.12
D (%)	−37.1	−32.9	−17.7	−1.5	−17.5	−29.8	−29.4
CT (ms)	119.6	103.1	42.1	−0.2	47.5	81.7	71.6
STI (%)	−0.017	−0.009	0.1	0.189	0.097	0.027	0.063

The measurements were conducted by positioning an omnidirectional sound source, pre-equalised in the frequency domain, fed by an exponential sine sweep from 40 Hz to 20 kHz [21, 22], a Dummy head (Neumann KU 100) and a Soundfield microphone (MKV). The sound source was located on the stage in front of the wooden scene, while the microphones were located in several positions in the stalls. The results are reported in Table IV.

It is evident that the *Teatro Olimpico* is much more reverberant than any other Italian-style opera house. For instance, the *Teatro la Fenice*, measured in 1997 [23], revealed a Reverberation Time at mid-frequencies of about half the value measured in the *Olimpico*.

7. Analysis of the results

Since the mean value of reverberation time and other parameters obtained from measurements is not comparable with the same value obtained from simulations, because of the difference at very low frequencies (31.5 and 63 Hz) that are due to the frequency response of the (real) loudspeaker, the comparison between the two theatres should be made from 125 Hz to 8 kHz, and especially between 250 Hz to 4 kHz.

Comparing the data of Table III and IV, the most surprising result is the similarity between Reverberation Times in the two theatres. Apart from 125 Hz, the differences between T15 and T30 simulated for the *Teatro Ideale* and measured in the *Teatro Olimpico* are consistently less than one second, and at mid-frequencies less than 0.3 seconds. At 1 kHz, T15 and T30 have the same values. At low frequencies the difference increases, and only for EDT the difference is slightly greater. Considering the differences between the values reported in Table V, it is evident that the value of STI is almost the same for both theatres, and only Clarity and Centre Time differ between them. The differences between the two theatres are due to the increased scale of the *Teatro Ideale* – having a capability of 5000 seats it is much larger that the *Teatro Olimpico*. Nowadays, due to conservation reasons, the *Teatro Olimpico* only accommodates an audience of 400, but in 18th Century it could host at least 800 people (or more).

The architecture of the *Teatro Olimpico* differs from Milizia's proposed theatre in volume and dimensions, but the shape does not considerably differ. The mean absorption coefficient in Milizia's theatre is about 0.35 (i.e. 35%), thanks to the acoustic treatment that he proposed for the ceiling. In the *Teatro Olimpico* the main value is about 0.3 (i.e. 30%). However, this value does not modify to any considerable extent the acoustic quality of the room.

The acoustics of the *Teatro Ideale* seem to be very similar to the *Teatro Olimpico*, confirming the intentions of Francesco Milizia, who considered that theatre as a reference.

8. Conclusions

Francesco Milizia proposed in 1773 a detailed project for his *Teatro Ideale*, which was hoped to have improved acoustics, visibility, comfort and spectator inclusion. Despite the large scale of the theatre, the simulation and 3D auralisation demonstrates, two centuries after its conception, that its acoustics would have been very similar to some of our contemporary theatres such as the *Teatro Olimpico* in Vicenza and *Teatro Colon* in Buenos Aires.

Francesco Milizia's concept of sound quality in theatres was closer to modern opinions of theatre acoustics than to his contemporaries. The sound characteristics of existing

Italian opera houses are much less reverberant than the theatre that Milizia proposed. His concept tried to solve most of the acoustic issues that persist to the present day in several modern theatres that still require attention. Whereas the theatres of the Italian style are acoustically too dry and not preferable for musical performance, the acoustic concept of Milizia's theatre is shown here to be far more advanced than his contemporary designers and conceptually closer to modern theatre acoustic architecture.

Acknowledgement

The author wishes to thank Giorgio Guidotti and Patrizio Barbieri for their help during the realisation of the model and the analysis of Milizia's work, and David J. Knight for proofreading this article. He also thanks Angelo Farina for his precious suggestions during the modeling of scattering and diffusion in the theatre.

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