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Architectural Acoustics in Vineyard Configuration Concert Hall

Jablonska J*

Faculty of Architecture, Wroclaw University of Science and Technology, Wroclaw, Poland

Abstract

Article was devoted for a study of vineyard configuration concert halls, considered as a concept allowing most innovative approach to the architectural and acoustical design, contemporary now and outgoing to the feature. Concept is based on two simple architectural manipulations that change overall spatial and sound perception of the room. Thus, there were two main aims set and proven: first-the most favourable acoustic conditions among today's concert halls with capacity over 1800 listeners can be provided by vineyard configuration, second-terrace solutions, alternative to rooms with boxed configurations and balconies, delivers architects the new possibilities for spatial shaping of concert interiors. Moreover, elaboration presents the authors' definition of vineyard configuration, which targets at capturing all features of arrangement. Showing the favourable aspects of hall comes together with revealing limitations, in order to keep the study as fair as possible. Research were based on thorough and years-long study for of both acoustical and architectural domains in pursuit of prove for novelty and usability of vineyard configuration over others existing concert hall layouts. The method of research was: analysis, cooperative analysis, and mostly graphical analysis of photographs and illustrations gathered in situ and with the use of literature review. In the formulation of conclusions synthesis and critical review were used, for acoustical issues like: reverberation time, lateral acoustical wave reflection, volume, clarity, Initial Time Delay Gap (ITDG), Intermural Cross Correlation (IACC), acoustical field spaciousness and blend and architectural issues like: layout size, volume, visual perception of the interiors, overall room geometry, evacuation, capacity and human interactions.

Keywords: Architectural acoustics; Vineyard concert halls; Shoe-box shaped concert halls; Concert halls design; Concert halls

Introduction

Before Baroque era, music was considered a background for other forms of art, i.e. theatre, religious and secular ceremonies or choir recitals. Therefore, the spaces for performance, had geometry, reverberation time and architectural layout adjusted to various forms of creative activity. Hence, the establishment of music as a separate field of arts resulted in the need to create a new group of buildings that could provide optimal sound field parameters for instrumental performances. Initially, they were opera theatres, which later development during the end of XIX century, led to the separation of concert halls, fully adapted to the needs of large symphonic orchestras [1]. For such buildings various spatial configurations of interiors were used and tested, inspired by the past, like: shoe-box shape rooms, fan shaped plans or horseshoe layouts. The real break-through in concert halls' design, allowing for architectural and acoustical sound field and space forming experiments, was initiated by the creation of so called vineyard configuration. This process started in the 2nd half of XX century with the works of acoustician Lothar Cremer - in 1956 first use in the auditorium of terrace instead of balcony in Mozartsaal in Liederhalle (in Stuttgart) - and architect Hans Sharoun - 50 of the XX century the conceptual design of Berlin Philharmonic Hall and 1960-1963 implementation [2]. From then, until now, there have been a number of music venues created, based on this spatial arrangement, proving that vineyard configuration can offer various architectural and acoustical advantages, with countless number of types and varieties as far as architectural and acoustical design is considered. Just to name a few: Boettcher Concert Hall, Denver, USA (1978), Nezahualcoyotl in Mexico City, Mexico (1978), Suntory Hall, Tokyo, Japan (1986), Kammermusiksaal in Berlin, Germany (1987), Sapporo Concert Hall Kitara, Japan (1997), Niigata City Performing Arts Center Ryutopia, Japan (1998), Walt Disney Hall, Los Angeles, USA (2003), Muza Kawasaki, Japan (2004), Shanghai Oriental Art Center (2005), DR Koncerthuset in Copenhagen, Denmark (2009), Musiikkitalo, Helsinki, Finland (2011) and Elbphilharmonie Concert Hall, Hamburg, Germany (2017).

Definition

The literature name of the configuration-vineyard-is directly recalling the spatial arrangement of concert hall interior, which reminds the landscape of terraces used for grapes cultivation [3-5] and can be defined as: Vineyard concert hall configuration is the interior of the concert hall with the stage located in the middle (center: geometric, sometimes asymmetrical), surrounded on all sides by the auditorium. Audience seats in this type of arrangement are grouped and placed on terraces that rise towards the crown of the auditorium. The walls set between the terraces - so called 'fronts of the terraces' - are additional planes for: diversifying the directions of reflection of acoustic waves, ensuring even blending of the sound field (direct acoustical wave with the waves from the first lateral reflections) and providing the formation of intense bounce of the higher order reflections of sound waves. In the cross-section, the seats located on the terrace rise according to the visibility diagram, towards the crown of the audience. In the vineyard configuration are used canopy or tent ceilings. In this type of rooms it is possible to gather more listeners closer to the sound source (orchestra) than in other types of concert halls configuration (Figure 1). There are several interesting issues connected to discuss arrangement of the concert halls and they are strictly connected to the aforementioned definition. Proving of these theories is the main focus of this article.

***Corresponding author:** Jablonska J, Faculty of Architecture, Wroclaw University of Science and Technology, Wroclaw, Poland, Tel: +48 602 46 37 10; E-mail: joanna.jablonska@pwr.edu.pl

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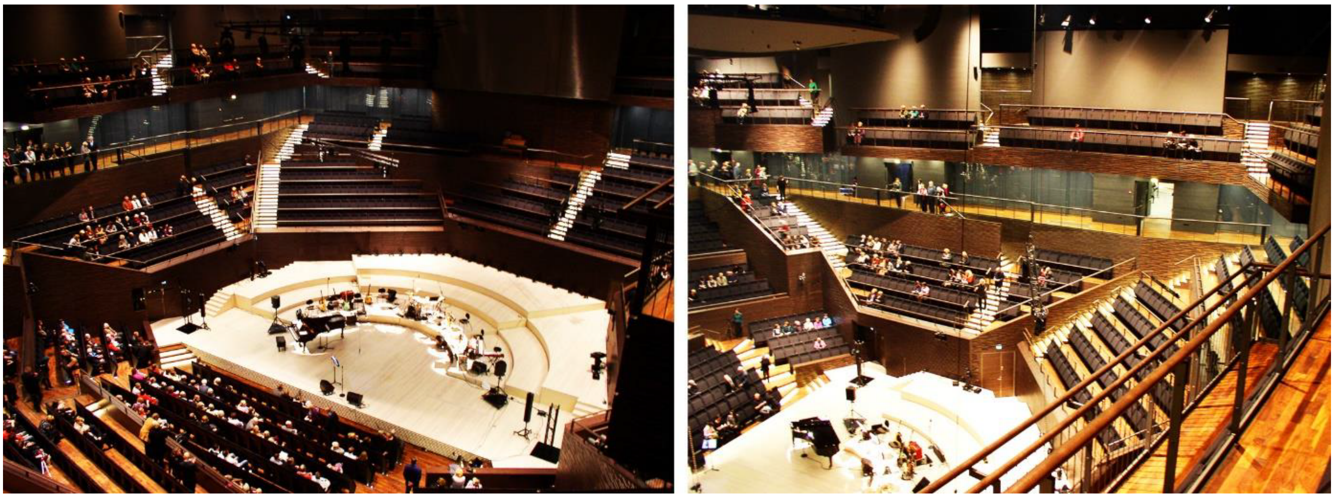

Figure 1: A concert hall in vineyard configuration.

Aim and Method

Aims of elaboration where divided for two groups acoustical and architectural. First claim states that the most favourable acoustic conditions among today's concert halls with capacity over 1800 listeners can be provided by vineyard configuration. Comparative analyses and synthesis for this study were carried out with the shoe-box shape arrangement, due to the fact that this room type was considered to offer the best acoustic parameters for concert halls, among the other contemporary spatial configurations (including fan, elliptical or round shape).

Second aim was to prove that terrace solutions - alternative to rooms with boxed configurations and balconies - provides architects with the new possibilities for spatial shaping of concert interiors. Here, terrace was understood as the whole of the acoustic system, with the walls above it, its seating layout and the ceiling belonging to it. The method for this section of research was mostly graphical analysis of photographs and illustrations gathered *in situ* and with the use of literature review. The objects studied *in situ*, were among others: Berlin Philharmonic Hall with Kammermusiksaal (Gremany), Jelenia Gora Philharmonic Hall (Poland), Opole Philharmonic Hall (Poland), Lodz Philharmonic Hall (Poland), La Scala, Milano (Italy), Theatre of Caesars Palace in Las Vegas (USA), Glasgow Royal Concert Hall (England), Musiikkitalo in Helsinki (Finland), Casa da Musica in Porto (Portugal), National Music Forum in Wroclaw (Poland). In the formulation of conclusions synthesis and critical review were used.

Acoustics

The method for the acoustic wave propagation within the central terrace systems was carried out using two architectural manipulations in relation to the shoe-box configuration. The first manipulation was placement of a stage in central location of a room, which reduced significantly the distance between potential listener and sound source. Thus, the way of travel for direct sound has been shortened, assuming comparable number of seats at the audience. Bringing viewers closer to the stage, so the sound source has a beneficial effect on one of the basic acoustical parameters - on volume - for the intensity of the sound is inversely proportional to the square of the distance [6]. Of course, this issue is substantial for large-scale interiors (over 1800 listeners), where intensity of direct sound should be strong. The second operation was the use of terraces in order to enable precise design of arrangement of first lateral reflections of acoustic waves and at the same time to shorten the distance between audience member and primal bounce of sound. Bringing lateral reflection surfaces closer to the listeners allows dividing the interior of the room into smaller, acoustic segments acting individually. Thus, the propagation of both direct acoustical wave and its' side bounce is less screened by the members of audience themselves (human body is highly absorbent [3]). Both manipulations can be illustrated with the use of diagram (Figure 2).

The next benefit obtained in the large scale vineyard configuration concert halls, was substantial reduction of volume, towards analogical shoe-box shaped rooms. For Sabine's formula describing reverberation time [4]:

$RT=0.16*V/(A+4mV)$

Where:

V-it is a room volume,

$A=\Sigma S_i\alpha_i$,

S_i-the surface of each material in a room,

A_i-the absorption coefficient in each room,

m-the air absorption,

Depends this parameter directly to capacity of the room, volume becomes one of the control factors for final acoustical performance of the hall. In order to analyse this issue, a simple theoretical model was built, for both shoe-box shaped interior and central-stage room. In both types, theoretical place of a viewer was marked with a square of 1x1 units and a stage with a square of 4 × 4 units. In both examples, the number of 1x1 unit rectangles with was 48. In the case of the central hall, the stage was surrounded by places on all sides, in the box room all the seats were arranged in a rectangle in front of the stage. For each of the objects was prepared a volume simulation, limited by elevated in cross-section spaces. The increase of the theoretical rows elevation was set to 1 unit (simplification). For the vineyard room a full elevation was used, with a basic tent roof, and for the box room partial elevation-with additional cutting of the obtained figure above the stage-as it was presented on a diagram (Figure 3). On the basis of three-dimensional models, cubic volumes were calculated, amounting

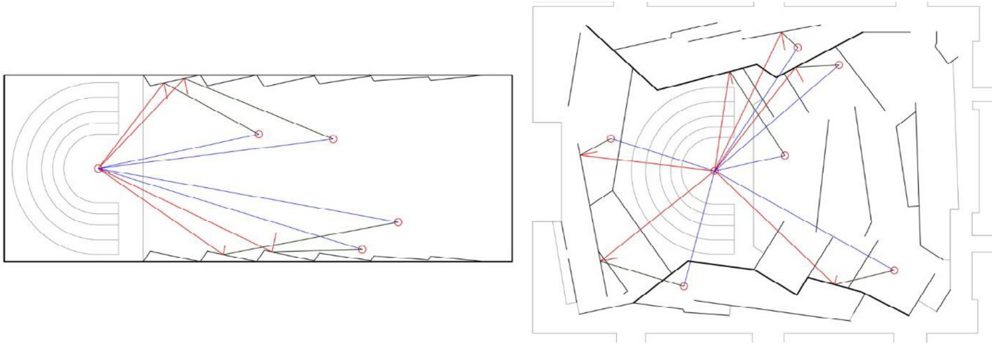

Figure 2: The scheme for acoustical wave propagation in, on left: shoe-box shape, on right: vineyard configurations, where rays: blue-means direct sound from source to listener, red-direct sound, which reflects before reaching listener, green-bounced sound reaching listener.

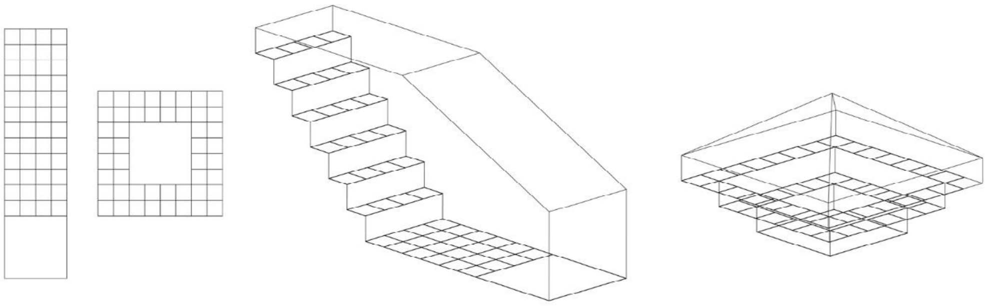

Figure 3: Theoretical scheme of the layout: shoe-box shaped and central-projections of rooms with the same number of places (for the same module and number of places) with schematic axonometric.

to: 168 cubic units-for a vineyard room and 308 cubic units-for a box room. Therefore, it was found that for the same number of people in the shoe-box shaped room almost twice the volume of the room should be used, than the vineyard configuration interior. In addition it was proofed, with comparison made on the theoretical model, that a distance of a last viewer from a stage in the box room is 12 theoretical units, while in the central room with terraces, with the same number of listeners, this parameter measures only - 2, 83 theoretical units which are four times smaller. This may benefit few more parameter measured in concert halls, which are important to create overall favourable sound field and are connected to room geometry and need for short time of propagation in case of initial reflections of sound. First of them is clarity defined as a balance between energy of arrival of a direct sound and it's reverberation, described with formula [not direct after: 3, s. 24, 42]:

10 log=energy reaching in 80 ms with the direct sound/energy reaching after 80 ms after the direct sound, where energy arriving within 80 ms takes both energy from direct sound and first order reflections. Practically, it means that reflected sounds should reach the listener in a sufficiently short time, about 80 ms, to maintain the sound clarity. Similarly so called intimacy of room (subjective parameter), correlated with Initial Time Delay Gap (ITDG, which is objective parameter), requires arrival to the listener of earliest and most significant reflection towards the direct sound, at the optimal time-without masking it or being visibly late [7].

Another advantage of central terraced configuration seems to be lack of large surfaces of parallel walls, on which fluttering echo may occur. This phenomenon is defined as multiplication of the singular acoustic wave which repeatedly traverses the room, so the same sound over lapses itself. Subjectively it may be perceived by the audience as a sort of distortion of speech and music [3]. In order to avoid this unfavourable phenomenon in shoe-box shaped configuration, additional subdivisions of walls are introduced into the interior, on horizontal, vertical or irregular fields. Such surfaces are set at different angles and diversified depths against each other. In vineyards walls of terraces provide this geometry, without the need of additional actions. The geometrical agreement aspect is also connected to the sound spaciousness occurrence, which was first described by Marshal in 1967, and can take place, when the acoustical waves of reflections can reach the listener from almost each possible direction [3, 8, 9]. It is strictly connected to the notion of Intermural Cross Correlation (IACC) and is defined as the difference between signals received by one person in both ears. The identical signals will measure +1, and this could be obtained if sound source emitting mono signal will be placed directly in front of the listener and time of sound arriving to both ears is exactly the same. So a room will offer ideally parallel walls on sides of the room. Moving the sound source to the side will cause diversification of the signal for both ears and the parameter to drop towards 0. However 0 measurements can be obtained, when signals for each ear will be totally different from each other. For concert halls it is important to remember that ICC is recommended to range between 0,14-0,5 [8]. Thus, asymmetrical geometry of room would be indicated. Such situation would likely occur in the vineyard configuration, which was already shown on the previous diagram (Figure 2). Due to IACC, it is assumed that some central-terraced concert halls are purposely designed as asymmetrical, just to mention examples like: Berlin Philharmonic Hall, Boettcher Concert Hall, Muza Kawasaki, DR Koncerthuset, Musiikkitalo and Elbphilharmonie Concert Hall.

The effect of sound field blend has not yet been described in a mathematical way. Currently, it is determined with use of graphical methods. It was observed that in the halls with a central terrace configuration, in which there are a large number of irregular surfaces (especially shaped with the use of convex arches or modelled on Bézier curves), the 'mixing' of the acoustic field is visible. This phenomenon was shown of the diagram (Figure 4).

Architecture and Result

Aforementioned boundary of 1800 seats in the audience to ensure favorable acoustic parameters of the shoe-box shaped room is the average value resulting from the comparative analyzes of existing concert halls and statements contained in the literature and during scientific discussions. According to Toyota is the size of 1600 people [10] and according to Barron-2000 people [3]. The Tables 1 and 2

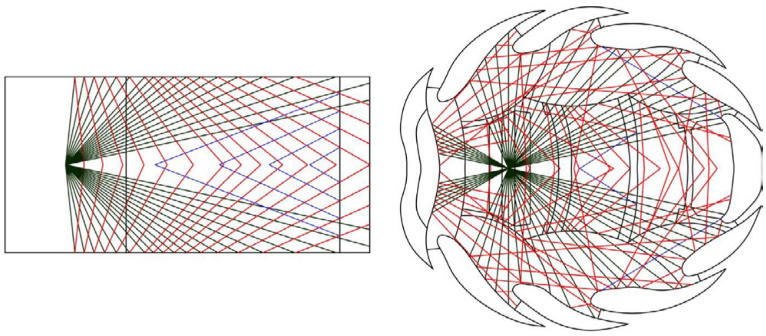

Figure 4: Blend of the acoustical field diagrams-schemes of halls, on left: shoe-box shape configuration, on right: vineyard configuration. The scheme for vineyard configuration was based on Shanghai Oriental Art Center main room plan.

No.	Name of the room, city	Year of erection	No. of seating
1	Stadt-Casino, Basel	1779	1448
2	Konzerthaus, Berlin	1821	1507/1677
3	Grosser Tonhallesaal, Zurich	1856 (1930 refurbished)	1546
4	Grosser Musikvereinssaal, Vienna	1870	1680
5	Royal Liverpool Philharmonic, Liverpool	1939	1767
6	Herkulessaal, Monachium	1953	1287
7	Town Hall, Watford	1940	1586
8	Royal Festival Hall, Londyn	1951	2645
9	Minnesota Orchestra Association Orchestra Hall, Minneapolis	1974 (1993 refurbished)	2450
10	Seiji Ozawa Hall, Massachusetts	1994	1180
11	Concert Hall, Kyoto	1995	1839
12	National Music Forum in Wroclaw	2015	1804

Table 1: Number of seats in selected shoe-box shape configuration rooms.

No.	Name of the room, city	Year of erection	Liczba miejsc
1	Philharmonic Hall, Berlin	1963	2440
2	Opera House, Sydney	1973	2700
3	Roy Tompson Hall, Toronto	1972	2812
4	Christchurch Town Hall, Christchurch	1972	2338
5	Hall Nezahualcoyotl, New Mexico	1978	2436
6	Boettcher Concert Hall, Denver	1978	2750
7	Music Centre Vredenburg, Utrecht	1979	1700
8	Leipzig Gewandhaus, Lipsk	1981	1900
9	St. David's Hall, Cardiff	1982	1682
10	Michael Fowler Centre, Wellington	1983	2566
11	Suntory Hall, Tokyo	1986	2006
12	Royal Concert Hall, Glasgow	1990	2475
13	Kitara Concert Hall, Sapporo	1997	2008
14	City Performing Arts Center, Niigata	1998	2000
15	Walt Disney Hall, Los Angeles	2003	2265
16	Muza, Kawasaki	2004	1997
17	Oriental Art Center, Shanghai	2005	1979
18	Symphony Center, Atlanta	2012	2200
19	DR Koncerthuset, Copenhagen	2009	1800
20	Musiikkitalo, Helsinki	2011	1704
21	Elbphilharmonie, Hamburg	2017	2011

Table 2: Number of seats in selected vineyard configuration rooms.

below presents the analysis of the number of seats in boxed concert halls recognized by acoustics and musicians as the best concert halls in the world (Table 1 for box halls, Table 2 for vineyard halls) [3, 4, 8].

A comparison of concert halls with box arrangements indicates that their audiences are between 1180 and 2645 places, but the vast majority of interiors oscillate between 1500 and 1800 places, due to the good acoustic parameters. And for the vineyard configuration, most of the rooms obtain capacity over 1800 of listeners. That is not all, hence, the vineyard concert halls, along with the undoubted acoustic advantages, offer interesting visual spaces. Architects gain possibilities to design more spacious, vertical interiors, multiplying the planes, shaping them in varied directions. Overall effect can be strengthening by the strongly inclined slope of the audience, the suspension of acoustic systems and paneling or the curved and undulating ceilings. It cannot be forgotten that this arrangement origins form expressionist modeling of Berlin Philharmonic Hall and the idea of music in round [2]. Also for the mentioned pioneers of this design a sociological aspect of such interior was important. In the shoe-box shape interior it is more common to encounter the interactions between audience and the musicians-observation, listening, while in vineyard configuration audience has a chance to observe other viewers and their emotional reaction to the music. While players, surrounded by listeners from all the sides and may gain a feeling of being in the center of concert. This simple phenomenon has been illustrated on a diagram (Figure 5).

In vineyard halls, a convenient solution is to design escape routes for each of the terraces leading to staircases or evacuation routes located in the public area. The evacuation scheme for interior of this type has been presented graphically in combination with a shoe-box shaped concert hall (Figure 6).

Limitations

One of the most important limitations of the vineyard configuration is placement of the audience at the back of the stage and a risk of reduction of the cross-stage reflection in the stage area (this bounces allow musicians to hear each other and play in the assembly). These issues very simply solved with the use of fronts of terraces, placed opposite to the stage, parallel to its boundary. Also, side stage terraces are crucial in order to lateral cross-stage reflections to be formed. This was shown in the simplified diagram as in Figure 7.

Conclusions

In the acoustical and architectural part of this article it was confirmed that the most favorable acoustic conditions, among contemporary concert halls over 1800 listeners, provide rooms with a vineyard configuration. It was established that due to the economics

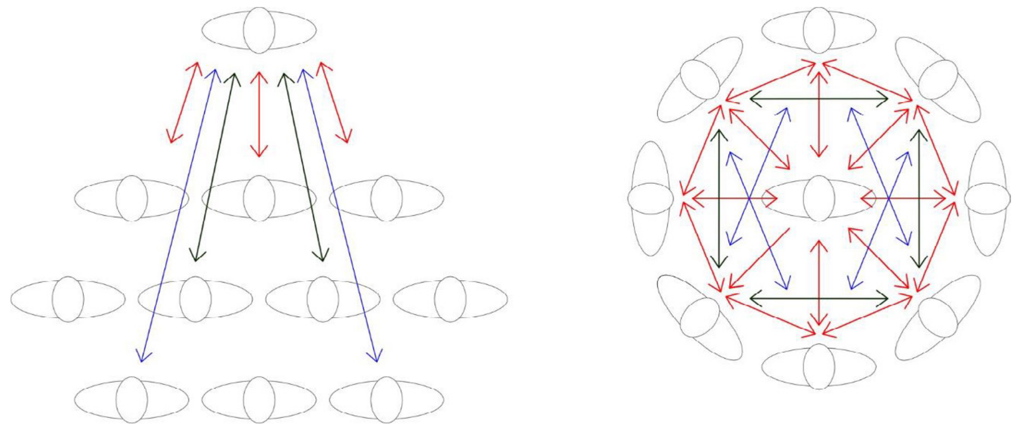

Figure 5: Diagram of interaction between musicians and the audience and between listeners in the shoe-box shape configuration and in the vineyard configuration.

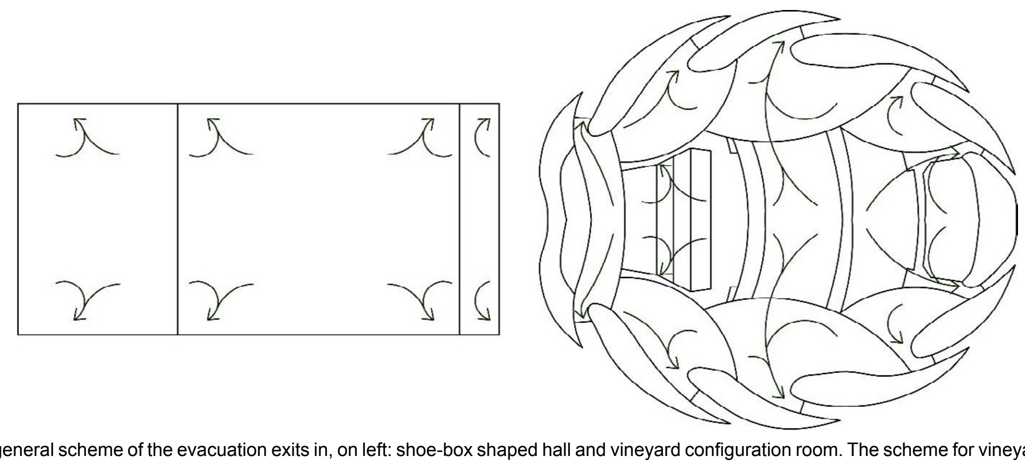

Figure 6: The general scheme of the evacuation exits in, on left: shoe-box shaped hall and vineyard configuration room. The scheme for vineyard configuration was based on Shanghai Oriental Art Center main room plan.

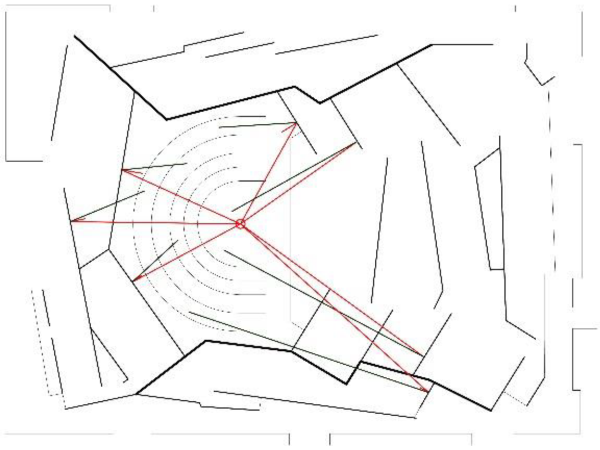

Figure 7: The diagram for around-stage acoustical wave reflection scheme. The vineyard scheme was based on Musiikkitalo plan.

of volume in vineyard configuration, configuration should be used for halls containing more than 1800 people, benefiting from significant reduction of the excessive reverberation time, in comparison with shoe-box shape rooms of the equivalent capacity. Also favoring in the room is the central stage location, which allows fitting more audience members near the sound source. It also enables obtaining a large surface of audience on which the direct sound is mixed with loud first lateral reflection, propagated through short transmittance way. Thus, parameters of acoustical field, like: loudness, clarity, ITDG can be optimized, even in large capacity rooms. The geometrical shape of the vineyard configuration rooms favours: reduction of risk in fluttering echo occurrence, optimization of IACC and overall feeling of spaciousness and intimacy in room and proper blend of the sound field. In the architectural considerations in this type of rooms, a sense of community and better fire safety can easily be provided. Summing aforementioned discuss, it seems that vineyard configuration might be the future for concert halls in the large cities, where there is a need for erecting symbolic, iconic public use buildings, providing the possibilities of gathering substantial number of music enthusiasts. For, the possibilities of forming unusual rooms with surprising geometry and unique architecture come together with methods of precise acoustics optimization.

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