CONNECTION BETWEEN ICONOGRAPHY AND REVERBERATION PERFORMANCE OF BYZANTINE TEMPLES: EXPERIMENTAL INVESTIGATION.

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ABSTRACT

Following the period of iconoclasm, in 787 AC the 7th ecumenical council restored the concept of "icons", creating so the well-known tradition of iconography on internal walls of temples. That tradition was expanded thanks to its historical and theological roots and dominated Byzantine temples "philosophically" as well as spatially. Nevertheless, that situation soon resulted in limited surfaces spare to accommodate any sound absorbing materials; therefore, reverberation according to today's view (classical theory) would not help from being excessive. Current acoustic measurements in historical cruciform temples, however, do not confirm the above. The aim of the present study is to investigate this enigma; reverberation time measurements are involved employing virtual space simulation. It is demonstrated that, (a) The concept of room 'complexity' such as it occurs for instance in cruciform temples, becomes pivotal; 'complexity' by definition was connected to geometry of space, namely the ratio of "volume -to- total room surface" i.e. the mean free path. (b) For a temple of given volume, reverberation was found to improve (decrease) by increasing the room 'complexity', since the latter has a great effect on the total absorption.

This finding presents a solution to improve the acoustic field in the case of large temples, without introducing absorptive materials, but rather using the potential of "complexity" as an acoustic design tool.

1 INTRODUCTION

Historical Context:

The seventh Ecumenical Council (or Second Council of Nicaea) of the Christian Church was convened on September 24, 787 A.D. in Nicaea, Bithynia[1]. During this session, the foundations were laid for the lifting of the ban on the worship of religious icons.

Indeed on September 24, 787 A.D in Nicaea, Bithynia, the 350 bishops under the presidency of the Patriarch of Constantinople Tarasios, repudiated the decisions of the iconoclastic synod of the Ieria (Iria), which had been convened n 754 A.D by the emperor Constantine the 5th, condemned the iconoclastic patriarchs and bishops and restored the honor of icons based on the "theology" of Ioannis Damaskinos.

The synod determined that there should be Iconography of saints in the churches, with the difference that Christians should not worship them, but simply honor them, because they depict holy persons who shed their blood for the faith of Christ or lived a life worthy of imitation.

The synod strongly contested the charge and the identification of Iconolatry with Idolatry. Then n 813 and 843 A.D. , after "political processes" the minutes of the 7th ecumenical council were ratified and/or renewed[2]

The detailed analysis of the beginning and the historical continuity of Byzantine iconography is not the subject of this study. In summary it is stated that Byzantine art is a continuation of ancient painting and the technique of Fayum portraits.

The iconography of the temples (in Greek called “Historisis”) was permanent, fast, practical and less costly than mosaics which could be afforded affluent “high society” members only. Accordingly, iconography addressing all social classes as a means of catechism would spread throughout the geographical range of the Byzantine Empire, as well as other countries under its religious and cultural influence. As a result, it profoundly influenced the aesthetics and philosophy of Byzantine church architecture.

2 QUESTIONS

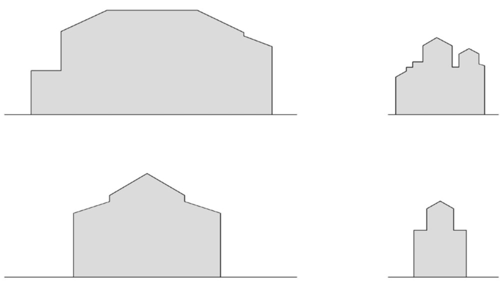
This study takes place and concerning at Thessaloniki, Greece, the second biggest city of the Byzantine Empire after Constantinople. Thessaloniki, now, has too many ritual buildings dated from the Byzantine era, in excellent preservation conditions and good shape.

In Byzantine era, during the development of the form of both, the free as well as the inscribed cruciform, and mainly from the 10th century onwards, the iconography of the interior of this type of temple was almost absolute, forming the final surface of the plaster-covered structural elements..

It is noted that it was inconceivable at that time from both theological and philosophical point of view, to cover any of the depicted figures with absorbent materials. Therefore the question arises: how spaces with a volume of 800m³ to 4000 or 5000m³ constructed mainly of Opus Mixtum, stone, plaster, etc., without the use of sound-absorbers, shaped their Reverberation time at levels acceptable even by modern guidelines such as DIN18041 (case of music), where as other forms (e.g. Basilica etc.) are far from the expected levels even with the use of more absorbent elements”.[3]

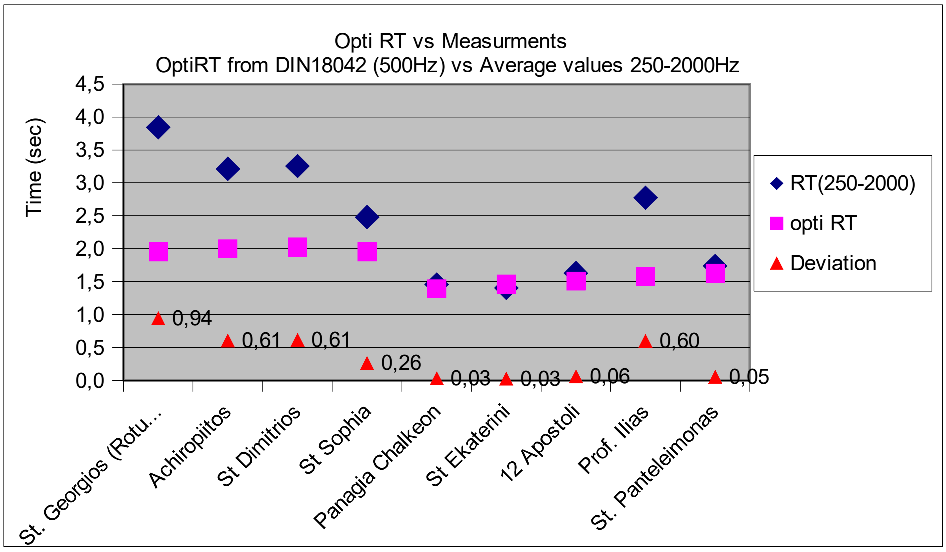
Previous research[4] reached to conclusions on how the reverberation times have large or small variations from the ideal reverberation time specified in DIN18041. The latter specifies the optimal reverberation time of spaces, depending on their usage and volume.

In the case of “Panagia Achiropoiitos” Church of Thessaloniki Greece (Temple with large volume) the differences are very large, whereas in the case of “Panagia Chalkeon” Church of Thessaloniki (Temple with small volume) they are very smaller.



Picture 2.2 The relation of the sizes of “Panagia Achiropoiitos” and “Panagia Chalkeon”

In order to further analyze the properties of spaces and their acoustic effects, virtual models were designed with the same volume but with very different complexity; the simple space and the complex one.



Picture 2.2 Comparison of OptiRT (DIN18041), Measurements 2008 (average 200-2000Hz) and deviation [3] in Paleochristian and Byzantine ritual halls, at Thessaloniki Greece.

2.1 Technical Approach.

Initially in the simple case, the reverberation time is calculated through Sabin's expression. According to this calculation, the reverberation time of a space with volume V_{tot}, absorption of materials α1, α2... and surfaces S1, S2... is calculated by the formula (1.1)

$$Rt = k \cdot 0{,}163 \cdot \frac{Vtot}{[\,(\alpha 1\ S1 + \alpha 2\ S2....) + A\ air]} \text{ in sec} \qquad (1.1)$$

The coefficient k[5] is derived from the shape of the room and improves the prediction of the calculated reverberation time depending on the shape of the room[6].
In general, when Sabin's law (1.1) applies:

$$MFP \approx 4(V_{tot}/S_{tot}) \qquad (1.2)$$ [7]

MFP: Mean Free Path.

In the case under study below, we consider that the space is created by a material[7], hence the Sabin expression can be written as:

$$Rt = k \cdot 0{,}163 \cdot \frac{V_{tot}}{(\alpha \cdot S_{tot} + A\ air)} \qquad (1.3)$$

A air: the air absorption in Sabine.

As per the above representation, in order to influence the reverberation time of the space, the volume of the space must be changed and/or the surface must be changed and/or the sound absorption capacity of the materials must be changed. In fact, if the volume of the space increases, the reverberation time increases, while on the contrary, if the sound absorption coefficient of the space or the total absorption surface increases, the reverberation time decreases.

In the Paleochristian and Byzantine churches building, generally in most cases, the space is constructed using homogeneous materials.

Based on the above formula (1.1), it becomes clear that the only way to change the reverberation time of the space (while the values of both the volume of the space and the sound absorption of the materials remain constant), is by changing the total surface.

2.2 Experimental investigation

For the needs of the investigation, 2 virtual rectangular spaces were designed with dimensions of 22X12X12m and a volume of 3168m³.

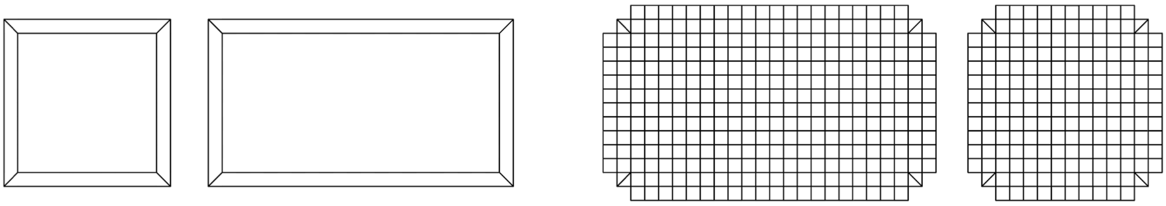


Figure 1.2.1 the two designed spaces, Left, 2 different views of the Simplex, right, 2 different views of the complex. The models enclose the same volume.

The space on the left is fairly simple ("*shoebox"*) with all 6 sides and the opposites parallel. The space on the right is much more complex with 1m³ cubes being added to and subtracted from the "shoebox" space, maintaining the volume identical.

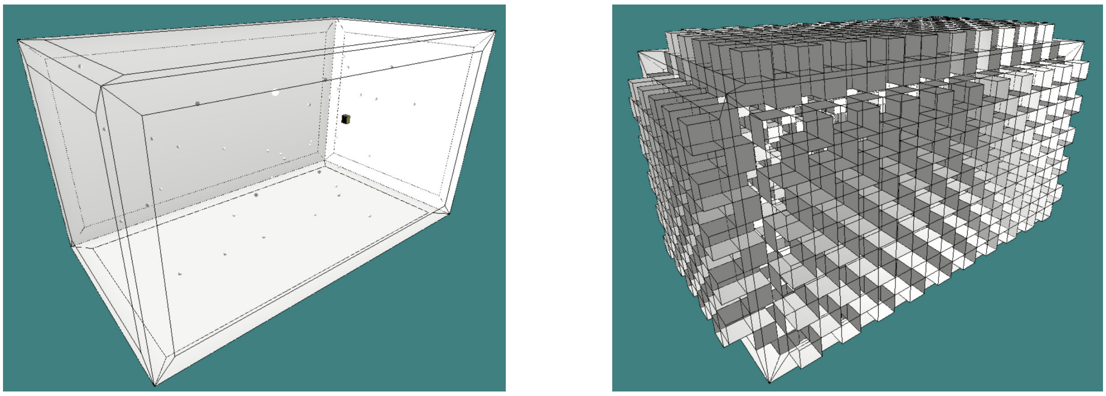


Figure 1.2.2 Simple space and Complex space

Both the above spaces have the same volume of V_{tot}=3168m³.

38 receivers have been "placed" at random positions,, within both models at distances of at least 1.5m from the external boundaries.

The absorption coefficients used included α parameters which derived by statistical analysis of the 2008 data, measured at the sites of "Achiropoiitos" and "Panagia Chalkeon" churches.[8]

	α in %					
Frequency in Hz	**125**	**250**	**500**	**1000**	**2000**	**4000**
Achiropoiitos	16	15	13	14	17	16
Panagia Chalkeon	10	9	9	11	10	11
Average	13	12	11	13	14	14

Table 2.2.1 Absorption coefficients obtained from measurements in temples of Thessaloniki.

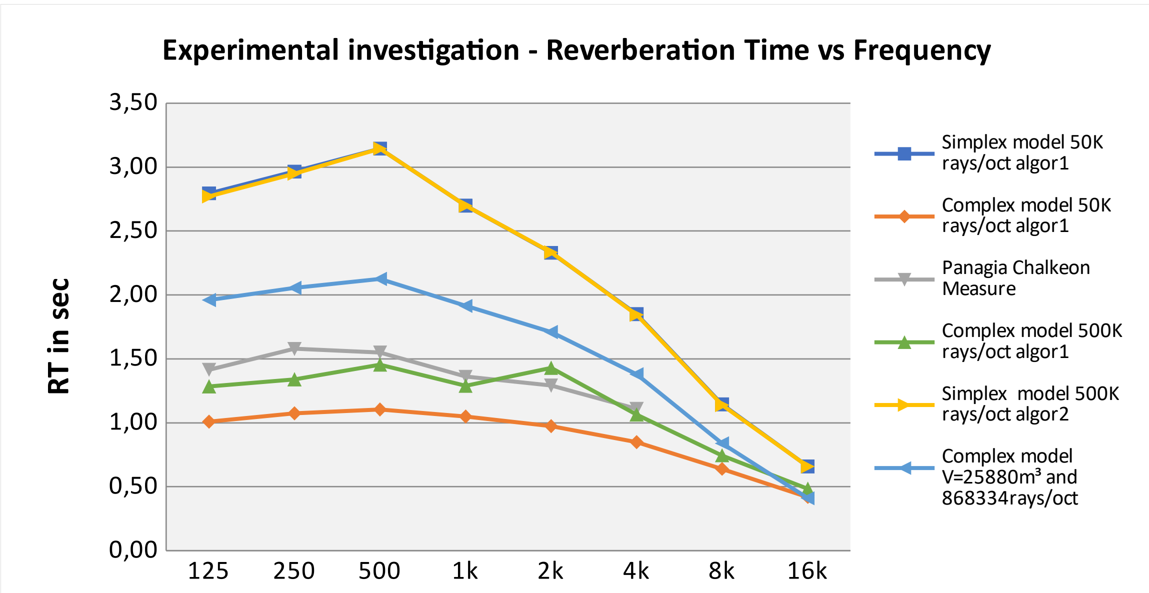
In general low absorption coefficients could be used, due to the "hard" absorbent building materials. Table 2.2.1 includes the average absorption per frequency applicable to the “opus mixtum” construction method.
It is noted that the “Achiropoiitos” coefficients are higher; this probably due to the presence of additional absorbents.

The above mentioned study for both models was carried out using CATT 9.0/TUCT V1.1 software. The simple space model consists of from 30 main surfaces in total, and the analysis was done using 50000rays/oct with algorithm 1.1.The complex model consists of 5024 surfaces and the analysis was done using 50000rays/oct1 with algorithm 1.1. Additional simulations made with 500000rays/oct with out differences in the simplex model and small differences in the complex one.

2.3 Results.

The following results derived from the above analysis:

Regarding reverberation time:
The reverberation time calculated for the two models is depicted in the graph below:



Graph 3.1 Reverberation times of the models

(NOTE: It is clear from the results, that in the simplex model, the low number of rays/octave gives the same results. On the contrary, in the complex model for the calculations with 50K compared to 500K observed small differences.)

is shown The reverberation time measured at “Panagia Chalkeon” church, 2008 is depicted with green with color triangles line, between the graphs representing the models for comparison purposes.

In the graph above it is noted that while all parameters (except the total S_{tot} area) remain constant, in the transition from the simple to the complex model, the reverberation time decreases dramatically.
Moreover, the following observations derive from the acoustic models:
The V_{tot}/S_{tot} ratio is greatly reduced from the simple model to the complex.

	Vtot in m^3	Stot in m^2	Vtot/Stot (in m?)	Mean RT (125-4K Hz) in sec
Simplex model	3168	1344	2.36	2.63
Complex model	3168	5344	0.59	1.01

Table 1.2.1 V_{tot}/S_{tot} ratio

As demonstrated in the above table, the reduction of the V_{tot}/S_{tot} ratio, results in a reduction of the reverberation time. Indeed, when comparing two spaces having the same volume and constructed of the same materials,, the one which consists of a larger number of surfaces, i.e. the one with a lower V_{tot}/S_{tot} ratio, has a lower reverberation time.
Accordingly, when it comes to spaces of the same volume and the same absorbing parameters, the one with the most complex geometry has a lower reverberation time.
In addition, it is worth noting that the values of the average MFP reflected distance are configured for the simple model (Simplex) at MFP_S=9.43m and for the complex (Complex) at MFP_C=2.37m. In other words, the smaller MFP value, results to lower Reverberation time value.

3 CONCLUSIONS

After the 8th century, the use of icons for religious purposes was restored and wall paintings (Iconography) were widely used for the "Historisi" of the temples, because their application favored the "Decoration" of the Temples, for "philosophical" and "economic-technical" reasons.
The covering of almost the entire interior surface of temples with mosaics or similar materials had already started even before the period of iconoclasm; however after the 8th century this technique spread widely..
In temples with extensive “Historisi”, any surfaces that could be potentially used for acoustic improvement have been lost irreversibly .This is usually the case with cruciform temples.
The acoustic issues that had arisen during the use of the Basilicas were partially addressed with the transition to smaller churches (exp. Agia Sophia of Thessaloniki) and the prevalence of cruciform churches.
Despite the improvement of the reverberation time, the spaces of the temples still occupied so much volume that "special treatment" was still needed to become acoustically "acceptable".
Based on the analysis and the results presented in the previous sections, it is evident that the only practical intervention to improve the reverberation time of a specific space, would be to increase the complexity of the space, i.e. reduce the V_{tot}/S_{tot} ratio i.e. increase the value of S_{tot} or the reduce the value of MFP.
Since the construction of “Hagia Sophia” Church in Thessaloniki as well as during its life span to this day, (considered a experimental type) the "Hıstorisis" dominates but at the same time a conscious increase of the cruciform temples complexity is observed.
With the process of "complexation" i.e. reduction of V_{tot}/S_{tot} i.e. increases of active absorbing surfaces, even when the space final exposed material of this surface is "poor" absorbent.
In the next table is very clear this chronically improvement
It could be stated that possibly the "obsession" of Byzantine Church building with the "HiIstorisi" of the churches and the strict observance of the rules, created acoustic issues. The solution of those was one-way and possibly consciously, led to the increase in the complexity of the form of the cruciform templesfrom10th century onwards.

Church	**Construction year**	**V_{tot}/S_{tot}**	**Reverberation time (RT) @500Hz**	**Deviation RT with DIN18041**
Achiropoiitos	~450 A.D.	2.51m	3.75 sec	61%
Hagia Sofia Thessaloniki	~650 A.D.	1.91m	2.69 sec	26%
Panagia Chalkeon	~1028 A.D.	0.94m	1.55 sec	3%

Table 3.1 chronically improvement of "complexation" i.e. to RT

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2 https://www.sansimera.gr/articles/1170

3 Panagiotis Karambatzakis, Observations on the evolution of the acoustics of the Christian religious buildings of Thessaloniki. From the Early Christians, to the temples of the 14th century. ELINA Conference Thessaloniki, Greece, 2014.

4 Julius O. Smith III, `Physical Audio Signal Processing, W3K Publishing, 2010,

5 Lothar Cremer, Helmut A Muller, Theodore J Schultz, Principles and Applications of Room Acoustics, Volume 2, Applied Science Publishers, Ltd., Barkiny, Essex, England, 1982

6 Similar to [5]

7 Π. Karampatzakis Panagiotis, Measurements in 11 Byzantine churches of Thessaloniki). ELINA Conference, Xanthi, Greece, 2008

8 As 7