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# From Byzantine to Ottoman period: technical aspects in construction

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## Abstract

In this paper two of the most important ancient structures of the city of Thessaloniki in Greece are discussed. One is the well known church of Byzantine period the Hagia Sofia of the 7th century AD and the other is the Bezesten, the ottoman market of jewelry and cotton of the 15th century. Both buildings form an integral part of the city's history and are concrete expressions of its multicultural heritage.

The discussion is focused on aspects of continuity by examining critically the traditional techniques and technology as well as by assessing the defects and good behavior of these architectural structures.

The morphology, the bearing structural system and the characteristics of old building materials of the two structures are presented. Similarities and differences are pointed out in relation to their pathology and degradation. Subsequent impact in their consolidation and restoration is also commented. By surveying the structure and materials of them, the technology and hidden pieces of knowledge concerning economy, social life and culture of that period are revealed.

## Historical Background

Thessaloniki had grown in one of the most important cities of the Byzantine Empire, the second city after Constantinople. Later on, during the "classical" period of the Ottoman Empire when Thessaloniki passed into the hands of the Ottomans in 1430, the city

did not stop playing an important economic role in the region of the Balkans. It had been a multi cultural city with an important Jewish community. It was on Thessaloniki that Jewish refugees from Spain and Portugal (Sepharad) were settled down on 15th Century.
The two monuments that are here presented are the Hagia Sofia, the byzantine church of the 7th century of the Early Byzantine period and the Bezesten, the Ottoman market of jewelry and cotton of 15th century. They form an integral part of Thessaloniki's history and are concrete expressions of its multi cultural heritage. The study of their building materials, bricks and mortars was made in the frame of the NATO Science for Stability Programme GR-Restoration, which is carried out at Aristotle University of Thessaloniki.

## Architectural and Technical aspects

Both buildings are built under difficult economic years for the city of Thessaloniki.

### The Hagia Sophia

The destructive earthquake of 618 AD seriously damaged the 5 aisled timber basilica of 120m length which stood in Hagia Sophia's place. The present Hagia Sophia was rebuilt in the same place of the ruined basilica and was smaller in dimensions. As pointed out by Mango [1] the 7th century accumulated chaos and disorder for the Byzantine Empire. Five times Thessaloniki was attacked by the Slavs and the Aravs. The chaos was spread over the Balkan region and Thessaloniki was miraculously saved from successive attacks.
The rebuilding was probably motivated by political concern namely to restore the lost symbols of the city. The new church, occupied only a part of the older church. Its foundations were interrupted from the stylobate of the older early Christian basilica on the N-S axis, while on the E-W axis the foundations were using the older stylobates as a retaining wall. Hagia Sophia is a cross-clomed church with a nartex, aisles and galleries. It's core is cross-shaped in plan. Over the center, which is marked by four strong piers, rises the dome with a span of about 11m. The piers carry the barrel-vaults of four cross-arms. The last arm of the cross terminates by an apse. The

dome on pendentives rises from the apices of the barrel vaults. A drum pierced by windows encloses the dome, made of brick and good quality mortar. The dome is covered by the famous mosaic of the 9th century of Ascension.

Until the 7th century AD all Thessaloniki's public and worship buildings were built of a rough green flysch stone, coming from the surrounding hills of the region of Thessaloniki, in mortared rubble construction. In Hagia Sophia, the outer face of the 7th century masonry (which has been analyzed by the NATO Research Programme) was built with rectangular blocks whitish limestone in strips of approximately one meter alternating with zones of bricks. A zone of five layers of bricks which covers all the thickness of the wall (2,20m) functions as a chainage. The four barrel vaults, the deep arms of the cross-domed church of Hagia Sophia have a span of almost 10m and a height of 1,10m. They are constructed with two brick arches, one resting on the other, the first made of a brick of 30-35cm length and the second of one and a half brick.

## The Bezesten

The other monument that is presented here is the Ottoman market, the bedesten of Thessaloniki.

Such structures, as the bedestens with a rectangular plan (with 4, 6, 8, 16 vaults), can be found only in the big commercial cities of the Ottoman period. The building of Thessaloniki's bedesten dates from 1455, some decades after the capture of the city by the Ottomans. Seven double brick arches carried the weight of the vaults to the surrounding walls and to the two central piers. The bonding of the central piers and the surrounding walls was achieved by the wooden tie beans of 0.30x0.30cm, a common structural aspect of all the bedestens. Research has shown that all the structure was tied with wooden beams forming a belting system. This belting system was found embedded in the drums of the vaults, in the roof, in the surrounding masonry walls and the central piers. The masonry of the external walls was made of the cloisonné system. The stone was the greyish and green stone that we can find in almost all the monuments of Thessaloniki.

## Comparisons among structural elements

Hagia Sophia : The masonry foundation as deep as 4.50m rested on a stratum of compact clay, deeper than the foundation of the early Christian basilica. It is a rubble masonry with mortar only without any layers of brick. The earthquake of 618 AD and the destruction of the older basilica probably led the builders to make a choice for deeper foundations.

Bedesten : The masonry foundation is as deep as 5.00m from today's surface rested on a strata of mixed of debris sand and clay. The density of debris is variable while the thickness of its layer goes further till the 11m. It is a rubble masonry with mortar only without any layers of brick. The foundation is underlied by a 6m layer of debris. The bad quality of the soil was the main cause of the differential settlement of the monument.

## Masonry

Hagia Sophia : The 7th century masonry of the monument was an ashlar masonry of rectangular limestone with horizontal layers of brick. The bricks covered all the thickness of the wall (2,20m). In contrast, the outer of the walls was built with rectangular stones while the inside was filled with small stones and mortar.

Bedesten : The 15th century masonry is almost a cloisonné masonry. "Greek builders from the late 10th century use a cloisonné Facing" [2]. Two layers of brick were inserted both vertically and horizontally between the green stones. A complicated system of intra mural timber tie beams (roof, piers, surrounding walls) tied the whole structure. The system of tie beams like this was used broadly in the region of Macedonia, Thessaly and Eperus from the late Byzantine period. These tie beams were jointed together in the interior of the masonry. The differential settlement of the two central piers in relation to the surrounding walls caused the destruction of the timber tie beams, so the vault's thrust deformed the masonry. "A complete system of tie beams like this has the effect of producing a rigid construction, enabling it to move as a homogenous unit during earthquake [3]. The destruction of the system due to differential

settlement created the voids, and "they are worse than use less constituting dangerously weak spots in the structure".
Comments : Regarding structural elements it seems that the way of building the foundations, remains the same from 7th to 15th century although the substrate of it differs in the case of the two monuments. The bearing system and the type of masonry of the two monuments are different. It is obvious that more care was taken for the construction of Hagia Sophia.

## The characteristics of the old materials

By analyzing an adequate number of brick and mortar samples, taken from the two monuments, [4] [5] comparisons among them were easily made.

## Characteristics of old bricks taken from Hagia Sophia

| | | |
|---|---|---|
| Dimensions | : | length: 40cm width: 30cm thickness: 4-5cm |
| Roughness | : | The upper surface is less rough than the under one |
| Colour | : | red-brounish |
| Apparent specific gravity | : | 1.82 - 1.90 |
| Absorption | : | 12.5% - 13.5% |
| Compressive strength (crushing value) | : | 100 -140 kg/cm$^2$ |

Microscopical observations (by stereoscope) : The content of clay in argillaceous minerals is low. The pores are smaller than 1mm and. Its percentage is below 5%. They are well distributed in the mass. There are no cracks in the interior of the brick as well as zones of different colour. There are some crystals of salts mainly in the pores but their presence is not intense. The materials enclosed in the mass are coarse aggregates up to 10mm, chips of wood and grains of calcite. The very good bonding of the bricks with mortar is the outstanding characteristic of those bricks.
Comments : The old bricks of Hagia Sophia (7th century) could be characterized as bricks of very good quality. It seems that special care had been taken for their manufacture since they do not present setting cracks. It is suggested, that the soil was purposely enriched with coarse aggregate contributed to avoiding cracking. The low content in phyllosilicate minerals made them not susceptible to

## Characteristics of old bricks taken from Hagia Sophia (continued)

pulverization. There are not significant differences in the properties studied experimentally among the samples of the bricks taken from various places of masonry. This means that all the numbers of bricks required for the construction of the monument had been prepared by the same manufacturer and from the same raw material.

## Characteristics of old bricks taken from Bezesten

| | | |
|---|---|---|
| Dimensions : | length: 40cm width: 30cm thickness: 3-4cm | |
| Roughness : | The upper surface is less rough than the surface below which presents bulges, scrapes or hollows | |
| Colour : | Group I : Different hues of red-brown from deep to light yellowish<br>Group II : red-brown | |
| Apparent specific gravity : | | 1.60-1.72 One group (I) of brick specimens around 1.60 (from 1.60 to 1.63) and another (II) is around 1.70 (from 1.69 to 1.72) |
| Absorption : | Group I 18%-19% Group II 19%-20% | |
| Compressive strength (crushing value) : | Group I 155 -180 kg/cm$^2$<br>Group II 115-125 kg/cm$^2$ | |

Microscopical observations (by stereoscope) : All brick specimens have deep circular grooves. The size of pores ranges from 2mm to 4mm and their content is from 4% to 6%. In some of the samples there are many cracks and colour change in the interior of the mass. The presence of salt crystals could be characterized as medium. The materials enclosed are coarse aggregates, chips of wood, grains of calcite and carbon. The brick-mortar bond is good.

Comments : There are distinct differences among the bricks. Those of Group I are of higher strength and most of them were taken from the arches of the structure. Differences in specific gravity and colour are indications that various argillaceous material had been used for their manufacture. The burning is not the same for all bricks which maybe means two or more ceramaria were used for the production of the required quantity.

## Similarities

The bricks of both monuments are of the same shape. They are burnt at low temperature. Coarse aggregates are used in clay raw material. They contain very small quantity of phyllomorphic minerals that means that there were some kind of criteria for the selection of clay. Their resistance to weathering was relatively good. Some of brick specimens were from places on which old interventions were made (19th century). They differ significantly and they suffer from pulverization since they contain in excess phyllosilicates.

## Characteristics of old mortars taken from Hagia Sophia

| | | |
|---|---|---|
| Colour : | White-pink characteristic of the presence ceramic | |
| Description : | Very compact material | |
| Compressive strength (crushing value) : | | 50 - 60 kg/cm$^2$ |
| Apparent specific gravity : | | 1.70 - 1.75 |
| Absorption : | | 15% - 16% |
| Enclosed materials : | coarse aggregate : gravel and crushed brick of size 0-16mm, concentration of calcite, grains of carbon | |
| Chemical analysis : | oxides | percentage % |
| | total ($S_1O_2$+$Al_2O_3$+$Fe_2O_3$) | 36-39 |
| | Soluble ($S_1O_2$+$Al_2O_3$+$Fe_2O_3$) | 2.7-2.8 |
| | Total CaO | 30-32 |
| | Soluble CaO | 22-31 |
| | Total MgO | 2-3 |
| | Soluble MgO | 1-1.5 |

Microscopical study : The pores are of diameter around 2mm and their content estimated around 5%. There are small crystals of salts inside the pores and cracking is intense. In cracks there is recrystallization phases. It is remarkable the good bond of paste with crushed brick aggregates.

Gradation : Even gradation curve

Comments : The mortars of Hagia Sophia are of the highest strength among the old mortars found in Byzantine monuments. Their best quality could be attributed to the right combination of binders, to

**Characteristics of old mortars taken from Hagia Sophia (continued)**

| |
|---|
| good gradation of aggregates used, and to very well compacted material during application. |

**Characteristics of old mortars taken from Bezesten**

| | | |
|---|---|---|
| Colour : | White-brownish with a pink hue | |
| Description : | The volume stability is medium Thickness 3-4 cm | |
| Compressive strength (crushing value) : | | 15 - 20 kg/cm$^2$ |
| Apparent specific gravity : | | 1.65 - 1.70 |
| Absorption : | | 16.5% - 18.5% |
| Enclosed materials : | crushed bricks of small size, concentration of calcite, grains of carbon | |
| Chemical analysis : | oxides | percentage % |
| | total ($S_1O_2$+$Al_2O_3$+$Fe_2O_3$) | 26 - 28 |
| | Soluble ($S_1O_2$+$Al_2O_3$+$Fe_2O_3$) | 2.0 - 2.5 |
| | Total CaO | 39.5 - 40.5 |
| | Soluble CaO | 39 - 40 |
| | Total MgO | 1.0 - 1.7 |
| | Soluble MgO | 0.25 - 1.0 |
| Microscopical study : The pores are small <4mm and there is intense cracking. In the cracks there is recrystallization phases. The enclosed calcite is of high porosity. The bond of paste-brick is very good. Gradation : Most of aggregates are fines of diameter 0-4mm. Their percentage is around 85%. The gradation curve is not continuous. Comments : The mortar is rich in lime of good quality. A great variety of aggregates grains is used including a small quantity of crushed bricks. | | |

**Comparisons**

The mortars of Bezesteni are lime mortar of lower strength compared with that of Hagia Sophia. The source of lime used in

Bezesteni is different from that of Hagia Sophia. The proportioning of Bezesteni mortars was not so successful as in case of Hagia Sophia. About six centuries later the expertise of high quality mortars had been lost. However some additives such as carbon grains seem to be continuously used for mortars' preparation.

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