Sustainability of Constructions. Suleyman's Mosque, Istanbul.

Y.K. Aktuglu
Assoc.Prof.Dr.arhitect, Dokuz Eylul University,Izmir, Turkey

M. Altin
Assis.Prof.Dr.architect, Dokuz Eylul University, Izmir, Turkey

M. Tanac Kiray
Instructor, Dr.architect, Dokuz Eylul University, Izmir, Turkey

O. Yilmaz Karaman,
Research assistant, MSc,architect, Dokuz Eylul University,Izmir, Turkey

M.Secer,
Research assistant, MSc, civil engineer, Dokuz Eylul University, Izmir, Turkey

O.Bozdag,
Research assistant,MSc, civil engineer, Dokuz Eylul University, Izmir,Turkey

I. Kahraman,
PhD student, MSc, architect, Dokuz Eylul University, Izmir, Turkey

ABSTRACT: In the Turkish Architectural History, Mimar Sinan has the most important place to define the landmarks. The Mosques, the bridges, the kulliyes(with a mosque in the heart of the kulliye as an extensive assembly of religious schools and buildings housing social functions), etc. of Mimar Sinan are coming today along a more than 400years period. The compositon of the full dome and semi domes is very important for the rich space value under. The additional structural elements for controlling the praying sound to God prepare a fully solved situation in the meaning of acoustical control. In the paper, after the definition of the complex in the meaning of history and in the meaning of space compositions, its structural system in the context of building materials and constructional details, the reasons of its acoustical performance and the degree of the efficiency of the daylight use will be explained.

1 GENERAL INSTRUCTIONS

Not only the construction systems, materials and details, and also the importance of acoustical property of the buildings and the outside areas and the use of daylight inside and outside of the building made the products have more statual manner. The use of masonary, brick and stone together with iron bars are the construction materials for the envelope.

The amounts and the size of the windows for daylight are the main elements for a more sacred athmosphere while using the space for meeting with God. The LCA and the LCC situation of a such building complex as Suleyman's Mosque and education complex in the meaning of sustainability has a great importance in today's construction world.

For these reasons we are aimed to make investigations about Mimar Sinan's Suleymaniye Cami in Istanbul, Turkey.

1.1 *Mimar Sinan(Great Architect Sinan)*

The date of birth of Mimar Sinan remains uncertain, but is generally accepted to be 1490(Egli, 1992). He is coming from the village of Agırnas near Kayseri in Turkey. He says that he saw the monuments, the great ancient remains, from every ruin he learned, from every building he observed something. The maturation of Sinan can be followed in the miraculous deployment of Suleyman's great mosque and kulliye(can be accepted as university city). Most of Sinan's legacy survives(some250 out of 450 buildings). This gives us a great chance to follow the great architect's development and artistic ascertion. The works, he did in his life, give him the title "The Great Architect Sinan (Koca Mimar Sinan)".

1.2 *Suleyman the Lawgiver, 1520-1566*

Suleyman(Kanuni) who was the tenth Sultan of the Ottoman Empire, succeeds eminent rulers who, by their political savvy and strategic brilliance, secured a vast empire. When he was the Sultan, the Ottoman realm reaches great extension.

1.3 *Suleyman's Mosque, Kulliye, Istanbul,*

Suleyman's Mosque, Kulliye, Istanbul has an overwhelming impression. It is not only the calculated setting of the mosque on the precious site, but also the very well planned kulliye, created a splendid stage that assures its magnificences.

Photo 1. The view of Suleymaniye Camii from Galata Köprüsü over Haliç/Golden Dolphin, (photo is taken by Yesim Kamile Aktuglu, on 28th of April 2007)

2 SULEYMAN'S MOSQUE, 1550-1557

2.1 *The history and the description of its plan*

During the classical period mosque plans changed to include inner and outer courtyards. The inner courtyard and the mosque were inseparable. The master architect of the classical period was Architect Sinan, and he started a new era in world architecture, creating 334 buildings in various cities. Mimar Sinan's first important work was the Sehzade Mosque completed in 1548. His second significant work was the Suleymaniye Mosque and the surrounding complex, built for Suleyman the Magnificent. (The Selimiye Mosque in Edirne was built during the years 1568-74, when Sinan was in his prime as an architect.)

During the mid-16th century, the Turkish sultan known as Suleyman the Magnificent added much territory to the Ottoman Empire through conquest. Due to the wealth he gained, he ordered a mosque appropriate to his title. The Suleymaniye Mosque was built on the order of sultan Suleyman and was constructed by the great Ottoman architect, "Architect Sinan". The construction work began in 1550 and the mosque was finished in 1557.

Suleymaniye Mosque is considered to be a kind of architectural answer to the Byzantine Hagia Sophia, commissioned by the Emperor Justinian. Sinan's Suleymaniye is a more symmetrical, rationalized and light-filled interpretation of earlier Ottoman precedents, and assimilates so many aspects of Renaissance architecture (Goodwin, 1971).

The mosque itself was situated in the middle of a kulliye which was constituted of a a caravanserai, a public kitchen (imaret) which served food to the poor, a hospital (darüşşifa), four Qur'an schools (medrese), a specialized school for the learning of hadith, a bath-house (hamam), Mosque Precint, Latirns, and coffee houses, apart from the main mosque with the praying hall, and the arched courtyard. It was situated at the top of the third hill of the city above the Horn, and dominated this area with its significant dome, and added a terrific silhouette among the city.

The mosque complex had two main parts, firstly the courtyard area, and secondly the main praying hall. The courtyard is the preparation area for the religious rituals (Namaz). The courtyard was surrounded by porticos, and the porticos were supported by minor domes and arches. An Ablution fountain was placed in the center of the courtyard. One can enter to the courtyard from the outside with three defined gates- portals. After entering to the praying hall, one can feel an approximately square space surmounted by a central dome. To the north and south the dome is supported by two semi domes, to the east and west it was supported by arches with tympana filled with windows. The dome-arches rise from four great irregularly shaped pillars. Up to this point the plan scheme follows that of Hagia Sophia, but beyond this all is different. To the east and west directions, there are 10 minor domes supporting the main domes and arches. Two galley spaces reached from the inside of the mosque is situated under these minor domes, adding a third dimension to the interior. Inside there are also the mihrab (prayer niche showing the direction to Mecca-kıble) and the mimber (pulpit) made of finely carved white marble.

In his work of establishing the four Minarets defining the four corners of the Courtyard, he had achieved a classical symmetry, the minaret elements were beautifully proportioned with the two taller at the junction of the arched courtyard and the other shorter two on the front façade of the courtyard rising with ten balconies, representing Suleyman's being the 10^{th} Emperor of the Ottoman Empire. This contrast manner emphasize the axial movement of the monument from south to north direction, formed a grandly strong silhouette on the hill above the Horn.

2.2 *The Structure*

Suleymaniye is constructed on the third hill of the seven hill city, Istanbul. The construction for mosque had started in 1549 and completed by 1557. The main dome has constructed on four arcs over huge four columns. The white marbles was brought from Marmara Island and the green ones were taken from Saudi Arabia. The mosque has 138 windows which have marvelous handwork.

The plan dimensions of the Suleymaniye Camii is 58 meters in width and 59 meters in length. The main dome, which has diameter of 27.25 meters and 53 meters hight, is supported

with four columns. These columns are symbolized in the name of four Muslim Caliphs. The two of the columns are taken from Byzantium Palace, the third one is from Kıztaşı and the last one is from Jupiter Temple in Baalbek. The heights of the columns are 9.02 m with the diameter of the 1.4 m. The approximate weight of the each column is 30 t and carrying about 8000 t total loads.

The weight of the main dome is about 1000 t. The mosque was built at the glorious time of the Ottoman Empire. However, the diameter of the dome was not greater than the diameter of Hagia Sophia dome. The complex has four minarets. Two of the minarets has 3 balconies with 76 m. height and other two minarets have 2 balconies with 56 m. height.

The minarets have a total of 10 galleries which is also represents that Magnificient Suleyman was the 10^{th} Ottoman Sultan. The mosque complex not only consists of the praying hall(cami) and courtyard (avlu), but also includes a caravanserai or seraglio (sarayı; han), a public kitchen (imaret) where food is given to the poor people, a hospital(darüşşifa), four Qur'an schools (medrese), a specialized school for the learning of hadith, and a bath-house (hamam). The tombs of Magnificent Suleyman I, his wife Roxelana(Haseki Hürrem), his daughter Mihrimah, his mother Dilaşub Saliha and his sister Asiye are located behind the main mosque in the garden. The great architect Sinan's tomb is outside the northward of the mosque walls.

Outside of the mosque there is a courtyard with 24 columns. The six of the columns are granit, six of them are dark granite, and the other 6 of them are Marmara granit. Their approximate weights are 10.6, 4.1, 3.8 for per column respectively. The last six columns are short and have gained a pyramid form to the structure.

The mosque is designed so detailed that air circulation of the mosque is high enough to clean the candle smoke and have sufficient air flow. Even the candle smoke is collected and converted to be used in ink production.

2.3 *The stabilizing structural element, iron baring*

Nearly all of the arches, inside and outside of the mosque, above the columns to collect the loads coming from domes, and semi-domes, are having iron bars for tension loads to keep the whole structure in a steady situation, coming from the mid of the main dome to the bottom of the columns. These iron bars, can be double in main places of the inner and outer spaces.

In the capital of a column, there are many structural features. The bronze collar is used both at the base and in transition from shaft to capital, which is a serviceable instrument. The fixing of the capital to its place is done with an iron pin and no mortar is used. The insertion of an iron pin and a lead plate is a normal intersection point to provide a flexible connection, which is vital to prevent transmission of earthquake shock waves (Egli, 1992).

2.4 *Daylight*

The mosque is important in Islam religion and the use of light is very important in the mosques. Architect Sinan had used the light as a design element in his mosque designs. His mosques are lightened with the daylight with many windows on the walls. These windows are placed in different levels as lines from the bottom of the dome to the ground level and they have different sizes, shapes and light transmittances.

There are 249 windows in the mosque which are placed in 7 levels.(Kuran, 1986) The high number of windows also show the importance of the mosque and the power and wealth of both the Ottoman Empire and Kanuni Sultan Suleyman due to the fact that the production of such big window glasses at those times (around 1550) was very difficult and expensive. Glass technology was accepted as a prestige technology that palaces and governments supported. (Kucukerman, 1998) There are many windows in the mosque.

There are notebooks which were written during the construction of the mosque. The details of the construction were written in them. According to these notes, 1417 people worked in the construction of the windows and glasses. 540 of them took 12 kurus (money unit of that time), 70 of them took 10 kurus. The payments are grouped into 5. The highest paid group took 12 and 10 kurus, and these were the most talented workers group. They were 610 workers. This shows that these workers were the most talented craftsmen, and their number was more than their

helpers. (Kucukerman, 1998) The other groups and their payments are shown in the table below:

Table 1. The worker groups of Suleymaniye Mosque construction and their payments*

Number of workers	Amount of payment
540	12 kurus
70	10 kurus
15	9 kurus
25	8 kurus
124	7 kurus
153	6 kurus
387	4 kurus
97	3 kurus
6	2 kurus

* (Kucukerman, 1998)

This shows that many talented workers were used to finish the construction in a very short time and that the architect wanted the mosque to be of high quality. Therefore this made the mosque live and sustain for hundreds of years with the same quality.

The windows on the bottom of the dome lighten and emphasize the dome. These are arched windows.

The 3 levels of windows on the rear tympana walls that are under the great arches provide intensive daylight to the interior. It is seen that Architect Sinan tried to open as many windows as possible due to the different shapes which help to open more windows. There are 4 circular small windows in the rear parts of the wall where he could not open the regular arched windows. And there are 19 regular arched windows on each of these two walls together with these 4 circular small windows.

The semi-dome supporting the main dome on the chancel (Mihrap) side also has a line of arched windows. There are also arched windows on this semi-dome. The two little supporting semi-domes also have arched windows.

The chancel (Mihrap) wall is divided by windows on 3 levels but these windows' glasses are decorated and colored (called as vitray) to prevent the daylight entering the building and disturbing the praying peoples' eyes. These windows are also in different shapes and different sizes in order to open as many windows as possible and to break the monotony of the plain wall.

The level of the sitting people who are praying is lightened with the use of big rectangular windows. All the windows except these are protected with honeycomb shaped curtains which help to diffuse the daylight entering the building through the windows. This helps to reduce the excess illumination and the discomfort of the eyes. And also help to provide a mystique atmosphere inside.

There are less windows on the entrance side. There are two reasons of this. One of the reasons is that this is the northern side and it is the coldest side. Therefore Sinan had designed less windows on this side in order to keep the interior warmer in the winter, because this is a very huge building with many cubicmeters of space and it is very difficult to heat up the interior. The other reason is spiritual: people are facing south when they are praying, that is due to the fact that Mecce is in this direction. Therefore there mustn't be much prevention between the praying people and the Mecce. Because of this, there is not much need to open many windows on the northern side, and Sinan opened just enough windows.

Windows are used generally to lighten the mosque interior. But there is the fact that many people use this building. Not only the people's breathing, but also the soot of the burning candles and lamps at nights and dark winter days would have polluted the interior air. So this brings the ventilation and air-cleaning problem. But Architect Sinan had solved this problem with a very good and efficient solution. He had made a room at the top of the entrance door which takes and gives the polluted inside air out. The soot is collected at the ceiling of this room and it is used to produce ink. It is said to be the best quality ink. (Kuban, 1997)

2.5 *Acoustical Performance*

One of the most important design criteria for such a huge volume is acoustics in terms of obtaining both silence for praying and indoor acoustic quality. In Mosques, music practice is usually not used while praying. It is more important to be concentrated as much as possible during the pray. But, on religious days, a special session named as 'mevlid' is held and in this session musical function is more emphasized. Another activity is speech, which is made by muezzin (religious officer) in the mosque. These different types of activities need different acoustical properties.

If we think of the interior noise level, it was probably not a big problem to obtain the low levels of noise in 16th century, since there was not a noise problem that we have today. So, it could be ignored at those times. But even today, the thick stonewalls and limited openings prevent unwanted sound coming to inside.

On the other hand, if we think about the indoor acoustical quality, having approximately 88000 m3 volume, and having a dome shaped roof above, Suleymaniye Mosque is expected to have some acoustical problems. But, it can be said that Sinan was obviously aware of the importance of the acoustics, while designing Suleymaniye Mosque. He realizes such a complex's problems and tries to solve them.

He tries to prevent echoes, which are caused by dome, by using some ceramic containers (Helmholtz/ Cavity Resonators) in the forms of pots (Topaktas 2003, Kayili 2005). The dome form is one of the most difficult forms in acoustics. Because of the concave forms of the domes, the incident sound energy does not go out without reflecting several times in the dome. Because of this, the reflected sound energy from the dome reaches back to the room with a time delay. So the result is echoes or noise in the room and reduction on the percentage of intelligibility. Cavity resonators, placed in a dome, prevent the reflection of sound energy and reradiate it throughout the room (Kayili, 2005). Today's measurements show that Suleymaniye Mosque has approximately 6-7 seconds Reverberation Time at middle frequencies (Topaktas 2003, Fausti et.al. 2003). This value can be long for rooms for speech, but it is considered quite reasonable for Suleymaniye. But, this value could be measured lower than today when the time Mosque built. During the restoration studies over the years, sealing the openings of ceramic containers and changing the original material have resulted different acoustical conditions from the original one.

Besides this, selection of surface materials has also a very important effect on acoustics of the room. And it is believed that Sinan also made his decisions with this knowledge. Suleymaniye Mosque has mainly plaster and stone interior surfaces. And floor is completely covered with highly sound absorbent material, thick carpet.

Also, while enlarging the volume of Suleymeniye, Sinan tries to increase sound power by a number of sources. For this purpose, he placed the muezzin's mahfil (a gallery for the call to prayer) next to the southwest pillar and in addition, he added small mahfils (balconies) to the two north pillars (Kayili, 2005). Addition of mahfils also show that the awareness of the need for extra sound power during the design process.

2.6 *The effect of sustainability*

Sustainability is becoming a central concern. It is a concern that has grown out of wider recognition that rising populations and economic development are threatening a progressive degradation of the earth's resources.

As being architects and engineers we have to think about the construction industry. The industry operates globally, and on a much larger scale than other industrial sectors. It consumes more materials than any other industry, and is a large direct and indirect consumer of energy.

The industry is a very large consumer of materials, and it operates on a growing scale.

At the same time, concerns about the effects on the Earth's environment have been emerging.

Buildings are the greatest producers of harmful gases such as CO2.

For example concrete is one of the most widely used construction materials in the world. However, the production of portland cement, an essential constituent of concrete, leads to the release of significant amount of CO2, a greenhouse gas; one ton of portland cement clinker

production is said to creates approximately one ton of CO2 and other greenhouse gases (GHGs).

Was it always like this? We are living on this planet for million years. But we rarely mentioned about sustainablity. Why? Because up to now we have used different construction types which were much more natural than the materials we use today. Our masters were much more respectful to environment.

According to the World Commission on Environment and Development: sustainability means "Meeting the needs of the present without compromising the ability of the future generations to meet their own needs."

Which means being respectful for the future generation needs. Suleymaniye Mosque as a sustainable structure did minimum damage to environment. During its construction CO2 gas was not produced. And Architect Sinan achieved not giving any harm to the nature 400 years ago. After 400 years we are arguing how to resume the damage we make to the environment.

Designing for sustainability means accounting in the design the full short-term and long-term consequences of the societal impact. Therefore, durability is the key issue.

After 400 years we can say that the consequence of the societal impact of Suleymaniye Mosque is really impressive.

Durability is the ability to endure. And if we think about 400 years we can understand that this master piece still gives fresh ideas to us about sustainibility.

Sustainability requires that engineers and architect consider a building's "lifecycle" cost extended over the useful lifetime. For Suleymaniye Mosque how can we decide about the useful lifetime? We can only say that it deserves the biggest time period which a building can get.

Light colored concrete walls reduce interior lighting requirements. This helps us to use less energy for the interior areas. And Architect Sinan also got this idea years ago.

The windows for the natural lighting has a great role for sustainability because of reducing the energy. An we also find right answers to this problem at this mosque.

Sustainability is briefly being smart.

And for getting hints of smart thoughts we have to search about the great architect's and engineer's way of thinking. Architect Sinan is one the greatest architects world wide. We can learn lot about his way of using natural light, his way of using wall colors for greater interior effects and minimising energy, his respectful design policy and his way of using natural materials for getting a natural structure.

We are talking about sustainability just for 20 years (after Brutland Report in 1987) but Architect Sinan was building sustainable constructions 400 years ago. This shows that human kind acts in different ways. We give harm to ozene layer and we also give great respect to nature and built marvelous structures with marvelous effect on human soul.

This effect not only gives a great feeling that man kind can solve the problems which he causes and also teaches the techniques of designing natural structures.

3 CONCLUSION

Mimar Sinan's buildings and structures are the foundation of a sustainable future of Turkish Architecture. Here it is aimed to introduce a global view over the Suleyman's Mosque (Suleymaniye Mosque), of Sinan's second perfect product. Suleymaniye Mosque: one of the foundations of a sustainable future following a positive response to the research with this case study, we do share with you the Turkish Architecture's Progress toward sustainable development by providing an overview of the financial, environmental and social preferences of Sinan's second perfect product about mosques.

This paper provides a measurement of the Turkish Architecture of Mimar Sinan's economic, environmental and social preference. It also illustrates the importance of a perfectly constructed buildings and structures in providing sustainable solutions in the construction sector.

As an architecture, we recognize that strong financial performance must continue over the long term in order to maintain a sustainable industry delivering value added products to society.

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