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INVESTIGATING THE IMPACT OF MUQARNAS ON THE DAYLIGHTING PERFORMANCE OF HISTORICAL TURKISH BATHS

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INTRODUCTION

Following UNESCO's adoption of the Safeguarding of Intangible Heritage, the documentation and digitalization of intangible cultural heritage as a field gained importance (Hou et al., 2022). This development brought attention to the intangible features of historical buildings. Against this background, preserving the daylighting features of historical buildings through measurements, digitalization and documentation is essential. How historical buildings control daylight greatly influences the design and feel of their interior spaces (Al-Maiyah and Elkadi, 2007). Historical hammams, established as public bathhouses (Taşçıoğlu, 1998; Yegül, 2012), not only serve their primary purpose but also host various ceremonies, speeches, and entertainment activities (Yanar et al., 2021). Unlike other historical buildings, hammams are designed to receive daylight from above. The placement of openings in hammams is related to privacy, creating a distinctive way in which daylight enters these spaces.

The subject of light in hammams has attracted significant interest from researchers due to hammams' reliance on natural daylight as the primary source of illumination (Önge, 1978; Tsikaloudaki et al., 2013). Light substantially impacts the interior atmosphere of the hammams (Šabanović and Numan, 2019). Hammams typically comprise several distinct sections, including hot, tepid, and cold rooms, each with varying levels of daylight intensity (Tsikaloudaki et al., 2013). In their study regarding the daylighting of seven Ottoman hammams in Thessaloniki, specifically detailing one hammam, the Bey Hammam, they found that daylight levels vary across bath spaces, influenced by specific activities. For instance, tepid rooms are moderately but uniformly illuminated. The tepid room is located between the hot and cold rooms to help users adjust to the interior climate (Karadayı Yenice and Ararat, 2022).

In the tepid and hot sections, light is typically provided by oculi, vernacular glass bulbs, installed in the dome and vaults (Ertuğrul, 2009).

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The use of oculi for light distribution is often preferred over larger openings in traditional Turkish baths (Ozel, 2013). Furthermore, Sibley (2018) analyzed the daylighting performance of 13 Moroccan heritage hammams, concluding that illuminance levels varied, with none exceeding 60 lx. The quality of light is also affected by the placement, shape, and color of the glass covering the oculi (Tsikaloudaki et al., 2013). These oculi can be round, octagonal (or polygonal), or stellar in shape (Orehounig and Mahdavi, 2011), allowing light to penetrate the interiors and create varying atmospheres, especially in the presence of steam (Sibley, 2018; Sibley and Sibley, 2013; Belakehal et al., 2004). Al-Maiyah and Elkadi (2015) investigated the changing daylight patterns through oculi across various wall surfaces in Demirçi Hammam, assessing their suitability for different purposes. In contrast to these studies, the present study on Tavuk Pazarı Hammam discusses the influence of hammam ornamentations on daylight intake.

Baker and Steembers (2014) emphasize that window size, building form, orientation, roof lighting, courtyards, and shading devices influence the quality of daylight in buildings. Similarly, Cammarano et al. (2015) examined the effect of architectural features, such as window size, visible glazing transmittance, external obstruction angles, site orientation, and room depth, on daylight intake. Studies on optimizing daylighting intake have mostly focused on shading devices (De Almeida Rocha et al., 2020; Grobman et al., 2017) and building form optimization (Dino and Üçoluk, 2017; Agirbas, 2018, 2022). In addition, studies by Hosseini et al. (2019, 2020a, 2020b) also explore daylighting control through façade design. However, the effect of ornamentation on daylighting remains unexplored; hence, further research should be conducted on this topic.

Muqarnas is an ornamental element in Islamic architecture, found in various parts of buildings (Agirbas and Yildiz, 2021). The projection plans of the muqarnas distinctly show its two-dimensional (2D) geometric forms (Necipoğlu, 1995; Agirbas et al., 2022), which, when extended into the third dimension, form three-dimensional (3D) cells. These cells can vary in form, with some being volumetric and others having thinner structures. Muqarnas are formed by arranging different types of these 3D cells side by side and stacked on one another. Given their composition of volumetric 3D cells (Dold-Samplonius and Harmsen, 2005; Gherardini and Leali, 2016; Ranjazmay Azari et al., 2023), muqarnas can impact various aspects of building physics, including daylighting.

Muqarnas manipulates light and shadow in buildings to alter visual effects. Outdoor muqarnas produce distinctive shadow patterns, while interior muqarnas directly affect the reception and dispersal of light within a space. Dold-Samplonius (1992) likens the geometrically cut surface created by the muqarnas to a crystal, breaking light into contrasts of light and shade. Burckhardt (2009) also notes that muqarnas trap and diffuse light through gradations across the room. Similarly, Özdural (1990) states that the interplay of light and shade in muqarnas ceilings creates a sense of infinity. These insights demonstrate the potential impact of muqarnas-styled ceilings on daylighting.

This study focuses on a historical building with muqarnas features, situated within the UNESCO World Heritage Site of the Khans Area (Vural Arslan, 2015; Gedik and Yıldız, 2016; Tlemsani Bozdağ et al., 2022). Originally a Turkish bath (*hammam*), the structure contains openings in its dome ceiling. Previous research by the authors, using simulation tools, demonstrated that muqarnas impacts acoustic quality (Agirbas and Yildiz, 2023). This study aims to measure the effect of muqarnas on the daylighting performance of interior space through simulations.

METHODOLOGY

The comparison of annual daylight intake between the selected bath section with and without muqarnas was carried out. Daylight Autonomy (DA) and Continuous Daylight Autonomy (cDA) simulations were performed for this comparison. DA measures the annual indoor daylight performance based on the building's location (Reinhart and Walkenhorst, 2001; Bian and Ma, 2017) and is defined as the percentage of time that a specific daylight level surpasses a given illuminance threshold. cDA is similar to DA but includes partial credit when illumination in the interior space is below the required level (Rogers and Goldman, 2006). These parameters measure light levels in relation to specific thresholds rather than directly assessing the visual comfort of occupants. In contrast to sDA (Lee et al., 2019) and UDI (Nabil and Mardaljevic, 2006), which are more concerned with visual comfort, this study utilized DA and cDA.

To retain the bath's original state in the analysis, the researchers selected the closest available data, where specific data detailing a few parameters were missing. As the study investigates the impact of muqarnas on interior daylighting performance, the data used do not affect the findings. Since the bath is located in Bursa, but the EPW weather data for the city was unavailable, Istanbul's weather data was used in the simulation due to its geographical proximity. The simulation software offers limited program type options, nonspecific to hammams or baths, therefore; the default 'office' setting was used. The purpose of determining a program type is to evaluate whether occupants receive sufficient daylight through various relevant metrics and identify when measures, such as artificial lighting or shading devices, are needed to ensure the visual comfort of occupants. Since this study aims to measure the effect of muqarnas on daylight intake, the program choice does not change the results. Additionally, surrounding buildings were excluded from the simulations, as their impact on daylight intake was beyond the focus of this study (**Table 1**).

For daylighting simulation, this study employed the Honeybee and Ladybug add-ons (2023) within the scope of Grasshopper (2023) program. The Galapagos add-on (2021) was utilized to conduct optimization. Galapagos is an optimization tool based on Genetic Algorithm (GA), a method rooted in the principles of biological evolution (Holland, 1992; Forrest, 1996). In this type of optimization, the algorithm generates an initial population and optimal solutions evolve through successive generations. To carry out the optimization, the desired Fitness Value and relevant variables, including their value ranges, must be defined. In this study, the Fitness Value was defined as adjusting the annual average

Location (weather data)	**Istanbul (170600) EPW data**
Programme (function of building)	**Office**
Operational hours of the building	**9 a.m-12 a.m, 1 p.m-5 p.m, Monday-Sunday**
Surrounding site	**Not included**
Size of grid cells	**50 cm**
Number of virtual sensor points	**100**
Height of sensor points	**18 cm**

Table 1. Setup for the daylighting performance simulations

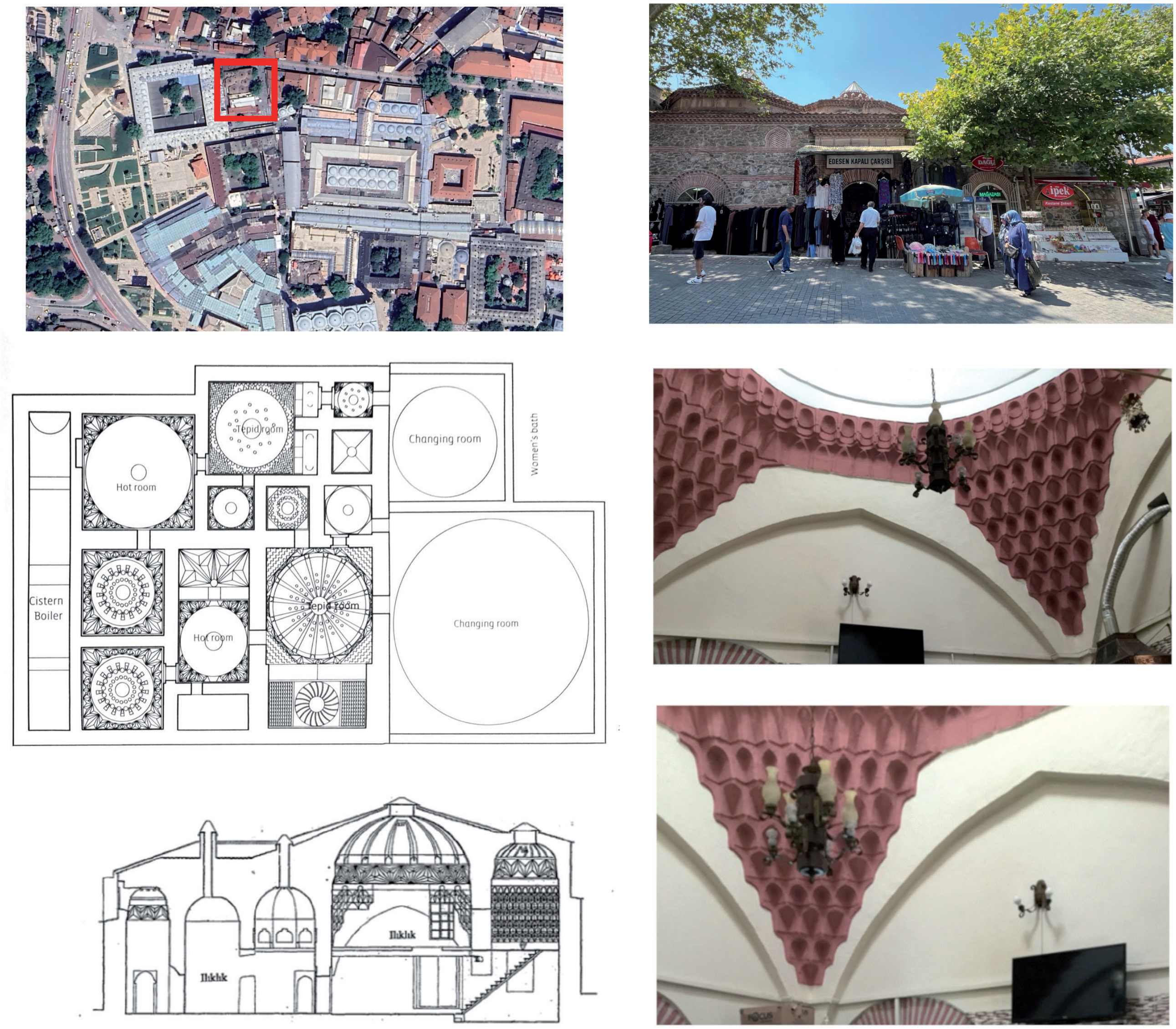


Figure 1. Tavuk Pazarı Hammam. The plan and section were sourced from Şehitoğlu's (2000, 2008) work, where she credited T.A.Ç. Foundation archive and E.H. Ayverdi's studies for their development.

daylight level, either by decreasing or increasing it, while the variable values represented the geometric properties of muqarnas cells. Daylight tests were carried out for the tepid room of the women's section of the Tavuk Pazarı Hammam, also known as the Meyhaneli Hammam (**Figure 1**). Historical records show that the hammam was built in 1426 (Şehitoğlu, 2000; Şehitoğlu, 2008). The women's tepid room has a dome ceiling with many round-shaped vernacular glass bulbs on it. The hammam building is not currently used as a hammam. The 3D model of the hammam was created by the authors in their previous study (Agirbas and Yildiz, 2023), and this model was used for the daylighting analyzes conducted in this study (**Figure 2**). To handle the computational demands of optimization, hexagonal oculi were used for the simulations. The hammam's floor plan measures 544 cm by 544 cm. A grid at 50 cm intervals was laid across the floor, with each cell of this grid containing 100 sensors placed 18 cm above ground level, all required for the daylighting simulation. The operational hours were set from 9 a.m. to 12 a.m. and 1 p.m. to 5 p.m., running daily from Monday through Sunday.

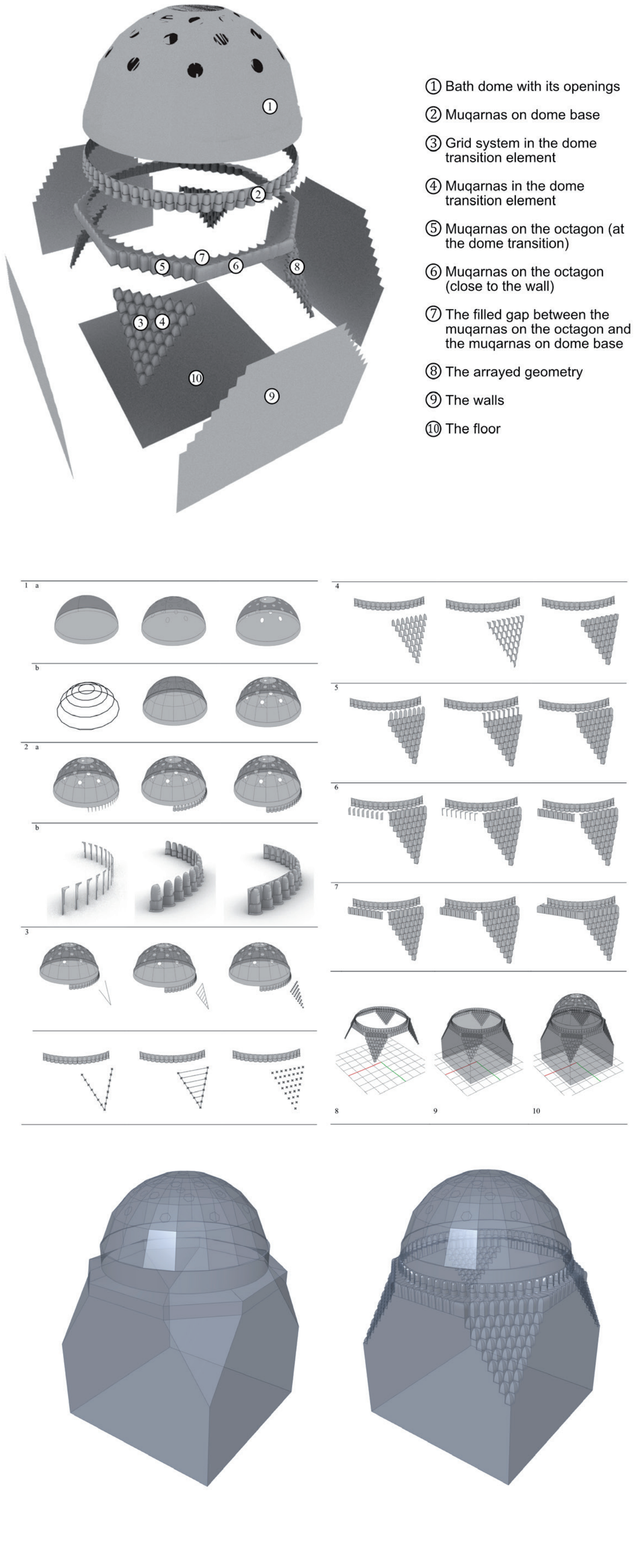


Figure 2. 3D model creation process (Agirbas and Yildiz, 2023)

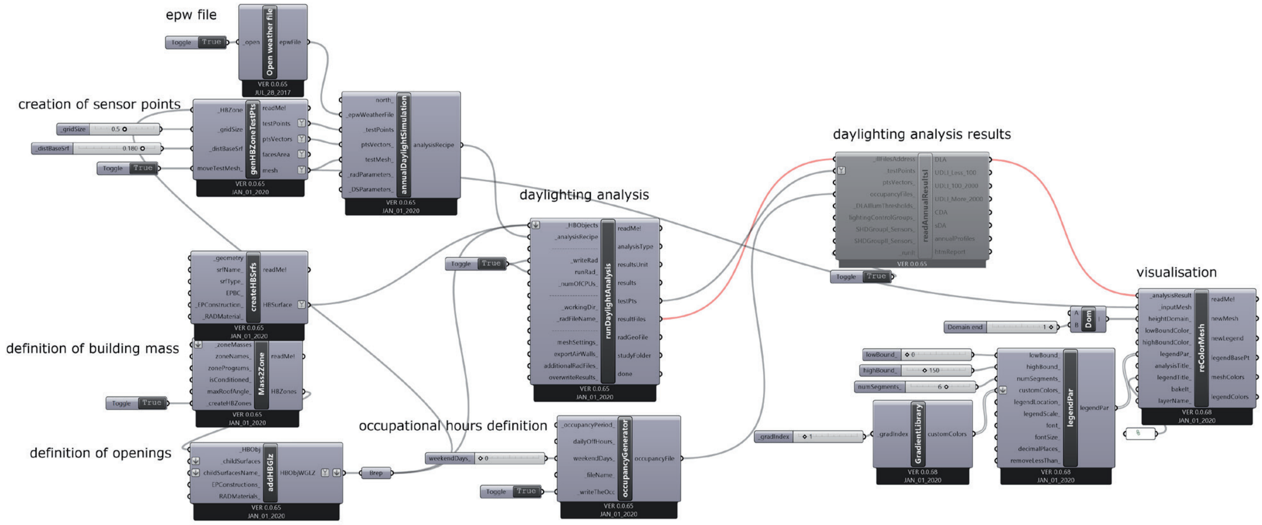


Figure 3. Daylighting analysis script

In the original setting, steam in the tepid room may have affected daylighting levels. However, in this current simulation setup, this impact remains unaddressed. Future studies may analyze this effect using various methods, such as in-situ analysis.

For the daylight analysis, the building mass and openings were defined within the "run daylight analysis" component. Sensors were arranged in the space, and EPW data was fed into the "annual daylighting simulation" component. The "read annual results" component was connected to the "run daylighting analysis" and "occupancy generator" components, which aided in defining occupational hours and days. DA and cDA results were derived from the simulation, with visual outputs generated through visualization components (**Figure 3**). This analysis built on Roudsari and Pak's (2013) scripts. For the optimization, the average DA value from each sensor was linked to the Galapagos as the Fitness Value, with the muqarnas geometric parameters as variables. The Galapagos evolutionary solver was set with the following initialization settings: Max Stagnant = 50, Population = 50, Initial Boost= 2, Maintain = 5%, Inbreeding = 75%.

RESULTS AND DISCUSSION

Daylight simulations were performed on models with and without muqarnas to test their effect. Findings revealed that DA and cDA values were higher in the model without muqarnas (**Table 2**, **Figure 4**). The model with muqarnas had an annual average DA value of 21.81%, while the model without it recorded 22.84%. Similarly, the annual average cDA value followed the same trend, increasing from 61.96 % in the model with muqarnas to 62.48% without muqarnas. When sunlight strikes the building, some is reflected off the exterior, some is absorbed, and the rest passes through transparent materials. Once inside, the light may be absorbed, refracted by the interior surfaces, or penetrate through other transparent materials, such as oculi. **Figure 4** illustrates a graphical representation of the annual distribution of refracted daylight within the interior space. These results suggest that muqarnas influence the amount of light entering the space, likely increasing light refraction due to their complex geometry.

Table 2. Daylighting analysis simulation results for the models with and without muqarnas

Parameter	Type	Value (%)
DA	With muqarnas	21.81
	Without muqarnas	22.84
cDA	With muqarnas	61.96
	Without muqarnas	62.48

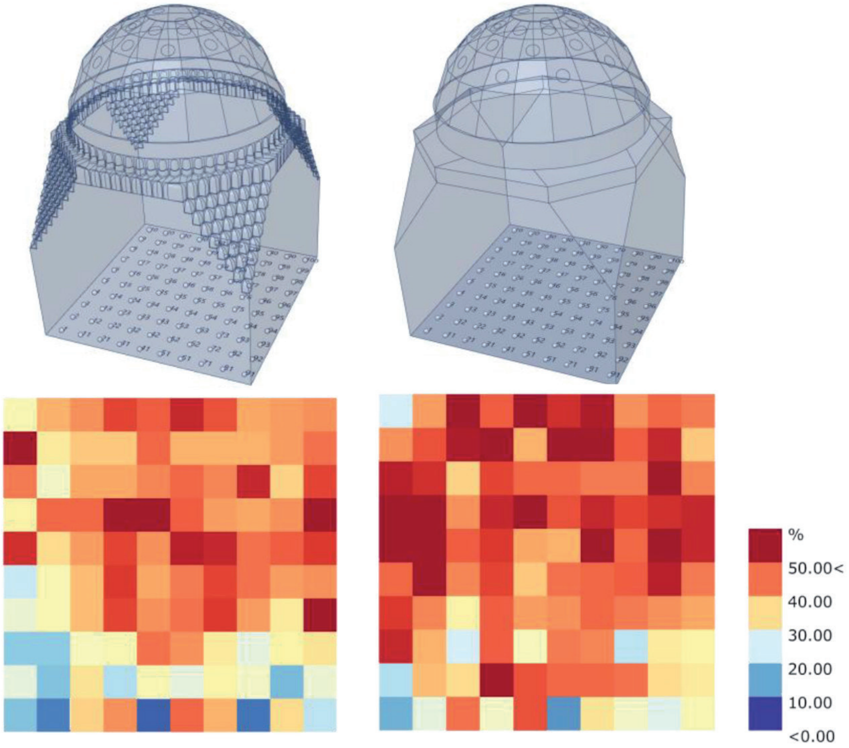


Figure 4. Graphical representation of the daylighting test results for DA simulations in the models with and without muqarnas decoration (Scale: 50% value is shown in red)

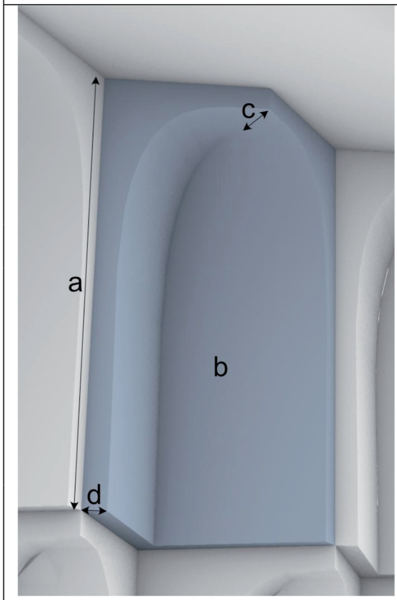
The variable value ranges for the muqarnas in the *hammam* model are presented in **Table 3** and **Figure 5**. These ranges, used to parameterize the muqarnas geometries are based on the previous work of the authors (Agirbas and Yildiz, 2023). As shown in **Figure 5**, the minimum and maximum values are defined according to the geometrical constraints of the muqarnas. For example, the maximum height is limited by the building's height, with potential unit configurations, such as the number of units, revised to fit accordingly. Similarly, the minimum and maximum values for unit protrusion and thickness are defined to maintain the geometric characteristics of the muqarnas. Using these values, optimization tests were conducted to measure the effect of various muqarnas dimensions on daylight intake. It is pertinent to note that sustaining the authenticity of the heritage hammam is crucial, however, the optimization results offer insights into how muqarnas affect interior daylight levels.

The optimization tests were conducted based on daylight intake levels. As a result of the test aimed at increasing daylight intake in the interior space, the muqarnas were found to be shortened. This process consisted of 17 generations and lasted approximately 14 days. The Fitness Value was connected to the average DA value in the Grasshopper script, leading to an annual average DA value of 29.34% and cDA value of 63.97 %. Variable

No	Variables	Min Value	Max Value	Values in the original model (approximately)
a	**Unit height**	**10 cm**	**50 cm**	**25 cm**
b	**Number of units**	**7**	**9**	**8**
c	**Unit protrusion**	**5 cm**	**8 cm**	**7 cm**
d	**Unit thickness**	**1 cm**	**3 cm**	**2 cm**

Table 3. Variables of optimization tests (Agirbas and Yildiz, 2023)

Variable information

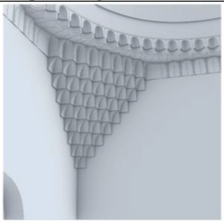


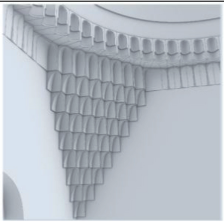
No	Variables	Min Value	Max Value
a	Unit height	10 cm	50 cm
b	Number of units	7	9
c	Unit protrusion	5 cm	8 cm
d	Unit thickness	1 cm	3 cm

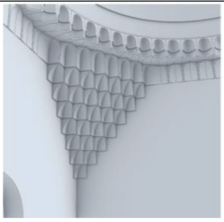
Values in the original model (approximately)

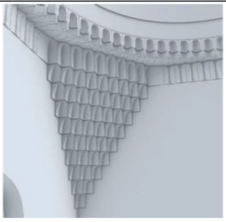
a: 25 cm
b:8
c:7 cm
d: 2 cm

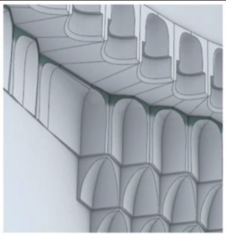
Sample configurations

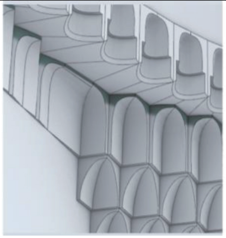

a: 21 cm, b:8, c:7 cm, d:2 cm


a: 29 cm, b:8, c:7 cm, d:2 cm


a: 25 cm, **b:7**, c:7 cm, d:2 cm


a: 25 cm, **b:9**, c:7 cm, d:2 cm


a: 25 cm, b:8, **c:5 cm,** d:2 cm


a: 25 cm, b:8, **c:8 cm,** d:2 cm


a: 25 cm, b:8, c:7 cm, **d:1 cm**

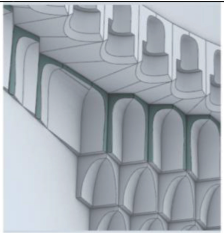

a: 25 cm, b:8, c:7 cm, **d:3 cm**

Figure 5. Muqarnas configurations according to the different variables (Agirbas and Yildiz, 2023)

were set as follows: a = 14 cm, b = 7 cm, c = 8 cm, and d = 2 cm (**Table 4**). For the reduced daylight intake, muqarnas maintained an average height. Five generations were conducted in 4 days, resulting in an average DA value of 20.05% and a cDA value of 60.3 %. The variables were set as follows: a = 22 cm, b = 8, c = 6 cm, and d = 2 cm were obtained (**Table 4**). These tests were sufficient for understanding how muqarnas affect daylight levels.

The openings at the top of the space in the daylighting enhancement-oriented optimization indicate that shortening the muqarnas will logically enhance light diffusion. Therefore, the optimization results can be deemed

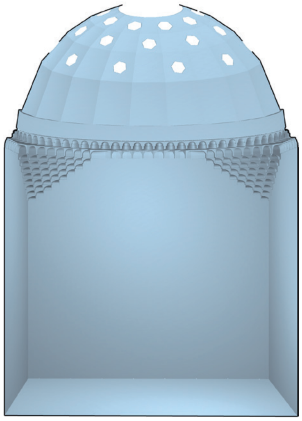
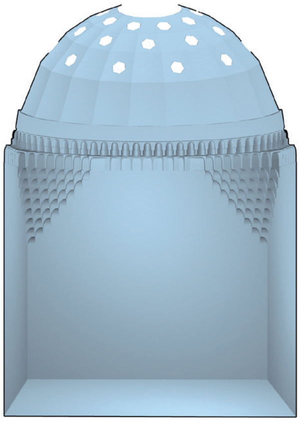
Test no	Resulted form	Results
Test no: 1 (Increase daylight intake)		DA: 29.34 % CDA: 63.97 % Variable a: 14 cm Variable b: 7 Variable c: 8 cm Variable d: 2 cm Duration: approx. 14 days Generation generated: 17
Test no: 2 (Decrease daylight intake)		DA: 20.05 % CDA: 60.3 % Variable a: 22 cm Variable b: 8 Variable c: 6 cm Variable d: 2 cm Duration: approx. 4 days Generation generated: 5

Table 4. Results of the optimization tests

logical. However, in the optimization study focused on decreasing daylight intake, the size of the muqarnas increases, which may lead to reduced light emission into the space. This suggests a correlation between daylight intake and the volumetric size increase of muqarnas.

Following the daylighting analysis of the tepid room in the selected bath, it became evident that muqarnas decorations affect the daylighting performance of the interior space. The annual daylighting intake in the bath model with muqarnas decorations is lower than in the model without. This disparity can be attributed to the excessive refraction of light caused by the complex geometry of the muqarnas decoration. Daylight preferences may vary for other spaces with different building functions and in various other locations. Furthermore, visual environment preferences can also change according to exterior conditions, outside views, personal preferences, etc. (Xiong et al., 2018).

The restoration and maintenance of hammam buildings should prioritize preserving the authentic level of refraction. This refractive quality in daylighting, combined with the presence of steam, is integral to the hammam's intangible heritage. Maintaining this aspect, particularly with regard to the steam, can be achieved by keeping the hammam's original function intact. Moreover, digitalizing and documenting the original state of these buildings would be helpful for preserving their heritage for the future.

LIMITATIONS

Limitations of the study:

- The daylighting analyses in this study were conducted through simulations. Results from various simulation tools may differ.
- The daylighting simulation focused on a specific part of the selected hammam. The simulation setups were prepared by approximating real-world conditions as closely as possible. To generate definitive data, *in situ* daylighting analyses of the *hammam* should be performed.
- In this study, the behavior of daylight in the presence of steam and its effect on refraction were not taken into account. *In situ* daylighting analysis of a hammam that maintains its original functionality would provide further understanding of the effect of steam.
- This paper focuses only on one muqarnas in a hammam, and the results should be assessed alongside new studies on muqarnas applications in other hammams.

CONCLUSIONS

The combination of light and steam in hammams creates the mystical atmosphere of the interior space, and this atmosphere has become a traditional feature of the hammam. Whether the geometry of muqarnas affects daylighting performance in this space or not is discussed within the scope of this study. Accordingly, the possible effect of muqarnas on daylighting was discussed in the context of the selected hammam building. The results from the simulation tests for the tepid room, with and without muqarnas, indicated that muqarnas may influence daylighting performance. Additionally, optimization tests were carried out to clarify the relationship between daylighting and muqarnas.

The main contributions of this study are as follows:

- It was demonstrated that the use of muqarnas affects the daylighting performance of interior space based on its size and location.
- Optimization tests provided a sufficient understanding of the contribution of muqarnas to daylight level.

There is a growing interest in the reinterpretation of traditional geometric elements and motifs in contemporary buildings in the Middle East. These designs offer great potential, and advancements in technology can improve their architectural features. The optimization method presented in this study can be used to facilitate the design of spaces that optimize daylight intake.

BIBLIOGRAPHY

AGIRBAS, A. (2018) Performance-Based Design Optimization for Minimal Surface Based Form, *Architectural Science Review* 61 (6) 384-99.

AGIRBAS, A. (2022) Multi-objective building design optimisation using acoustics and daylighting, *Indoor and Built Environment* 31 (3) 853-67.

AGIRBAS, A., YILDIZ, G. (2021) Origin of Irregular Star Polygons in Ground Projection Plans of Muqarnas, *Nexus Network Journal* (23) 507-48.

AGIRBAS, A., YILDIZ, G., SAHIN, M. (2022) Interrelation between grid systems and star polygons of muqarnas ground projection plans, *Heritage Science* 10 (12).

AGIRBAS, A., YILDIZ, E. (2023) The Effect of Muqarnas on Acoustic Quality of Traditional Turkish Bath Interior Space, *ACM Journal on Computing and Cultural Heritage* 16(3) 1 20.

AL-MAIYAH, S., ELKADI, H. (2015) Turkish D-light: accentuating heritage values with daylight, *Proceedings of the Institution of Civil Engineers - Engineering History and Heritage* 168(4) 139-49.

AL-MAIYAH, S., ELKADI, H. (2007) The role of daylight in preserving identities in heritage context, *Renewable and Sustainable Energy Reviews* 11(7) 1544–57.

BAKER, N., STEEMERS, K. (2014) *Daylight Design of Buildings: A Handbook for Architects and Engineers*. Abington, Oxon: Earthscan.

BELAKEHAL, A., TABET AOUL K., BENNADJI, A. (2004) Sunlighting and daylighting strategies in the traditional urban spaces and buildings of the hot arid regions, *Renewable Energy* 29(5) 687-702.

BIAN, Y., MA, Y. (2017) Analysis of Daylight Metrics of Side-Lit Room in Canton, South China: A Comparison between Daylight Autonomy and Daylight Factor, *Energy and Buildings* (138) 347–54.

BURCKHARDT, T. (2009) *Art of Islam, Language and Meaning* (Commemorative Edition). World Wisdom Inc, Indiana.

CAMMARANO, S., PELLEGRINO, A., LO VERSO, V.R.M., AGHEMO, C. (2015) Assessment of daylight in rooms with different architectural features, *Building Research & Information* 43 (2) 22237.

DE ALMEIDA R., PAULA, A., REYNOSO-MEZA, G., OLIVEIRA, R.C.L.F., MENDES, N. (2020) A pixel counting based method for designing shading devices in buildings considering energy efficiency, daylight use and fading protection, *Applied Energy* 262 114497.

DINO, I.G., ÜÇOLUK, G. (2017) Multiobjective Design Optimization of Building Space Layout, Energy, and Daylighting Performance, *Journal of Computing in Civil Engineering* 31(5).

DOLD-SAMPLONIUS, Y. (1992) Practical Arabic Mathematics: Measuring the Muqarnas by Al-Kashi, *Centaurus* (35) 193–242.

DOLD-SAMPLONIUS, Y., HARMSEN, S.L. (2005) The Muqarnas Plate Found at Takht-I Sulayman: A New Interpretation, *Muqarnas* (22) 85–94.

ERTUĞRUL, A. (2009) Hamam Yapıları ve Literatürü, *Türkiye Araştırmaları Literatür Dergisi* (13) 241-66.

FORREST, S. (1996) Genetic Algorithms, *ACM Computing Surveys* 28(1) 77–80.

Galapagos, https://grasshopperdocs.com/addons/galapagos.html (Accessed 11 November 2021)

GEDİK, G.S., YILDIZ, D. (2016) Assessing the role of users in sustainable revitalization of historic urban quarters: The case of Bursa-Khans District, *A/Z ITU Journal of the Faculty of Architecture* 13(1) 195-208.

GHERARDINI, F., LEALI, F. (2016) A Framework for 3D Pattern Analysis and Reconstruction of Persian Architectural Elements, *Nexus Network Journal* (18) 133–67.

Grasshopper, Algorithmic Modeling for Rhino. www.grasshopper3d.com/ (Accessed on 10 February 2023)

GROBMAN, Y.J., CAPELUTO, I.G., AUSTERN, G. (2017) External shading in buildings: Comparative analysis of daylighting performance in static and kinetic operation scenarios, *Architectural Science Review* 60(2) 126-36.

HOLLAND, J.H. (1992) Genetic Algorithms, *Scientific American* 267(1) 66-73.

HOSSEINI, S.N., HOSSEINI, S.M., HEIRANIPOUR, M. (2020a) The Role of Orosi's Islamic Geometric Patterns in the Building Façade Design for Improving Occupants' Daylight Performance, *Journal of Daylighting* (7) 201-21.

HOSSEINI, S.M., MOHAMMADI, M., GUERRA-SANTIN, O. (2019) Interactive kinetic façade: Improving visual comfort based on dynamic daylight and occupant's positions by 2D and 3D shape changes, *Building and Environment* (165) 106396.

HOSSEINI, S.M., MOHAMMADI, M., SCHRÖDER, T., GUERRA-SANTIN, O. (2020b) Integrating interactive kinetic façade design with colored glass to improve daylight performance based on occupants' position, *Journal of Building Engineering*, 31, 101404.

HOU, Y., KENDERDINE, S., PICCA, D., EGLOFF, M., ADAMOU, A. (2022) Digitizing Intangible Cultural Heritage Embodied: State of the Art, *Journal on Computing and Cultural Heritage* 15(3).

KARADAYI YENİCE, T., ARARAT, M. (2022) Turkish bath tradition: The example of Gaziantep, Turkey, *International Journal of Intangible Heritage* (17) 198-210.

Ladybug Tools, https://www.ladybug.tools/ (Accessed on 10 February 2023)

LEE, J., BOUBEKRI, M., LIANG, F. (2019) Impact of Building Design Parameters on Daylighting Metrics Using an Analysis, Prediction, and Optimization Approach Based on Statistical Learning Technique, Sustainability (11) 1474.

NABIL A., MARDALJEVIC J. (2006) Useful daylight illuminances: A replacement for daylight factors, *Energy and Buildings* 38 (7) 905-13.

NECİPOĞLU, G. (1995) *The Topkapi Scroll: Geometry and Ornament in Islamic Architecture*The Getty Center for the History of Art and the Humanities, Santa Monica, CA.

OREHOUNIG, K., MAHDAVI, A. (2011) Performance evaluation of traditional bath buildings via empirically tested simulation models, *Journal of Building Performance Simulation* 4(1) 63-74.

OZEL, F. (2013) SolarPierce: A Solar Path Based Generative System, *Proceedings of the eCAADe Conference,* Delft University of Technology, Delft, The Netherlands, 18-20 September; 127-34.

ÖNGE, Y. (1978) Eski Türk Hamamlarında Aydınlatma, *Vakıflar Dergisi* (12) 121-35.

ÖZDURAL, A. (1990) Giyaseddin Jemshid el-Kashi and stalactites, *METU Journal of Faculty of Architecture* 10(1-2) 31–49.

RANJAZMAY AZARI, M., BEMANIAN, M., MAHDAVINEJAD, M., KÖRNER, A., KNIPPERS, J. (2023) Application-based principles of islamic geometric patterns; state-of-the-art, and future trends in computer science/technologies: A review, *Heritage Science* (11) 22.

REINHART, C.F., WALKENHORST, O. (2001) Validation of Dynamic RADIANCE Based Daylight Simulations for a Test Office with External Blinds, *Energy and Buildings* 33(7) 683–97.

ROGERS, Z., GOLDMAN, D. (2006) *Daylighting Metric Development Using Daylight Autonomy Calculations in the Sensor Placement Optimization Tool –Development Report and Case Studies*. Boulder, Colorado.

ROUDSARI, M.S., PAK, M. (2013) Ladybug: A parametric environmental plugin for Grasshopper to help designers create an environmentally-conscious design, *Proceedings of the 13th international building performance simulation association conference*, Chambery, France, 26–28 August; 3128–35.

ŠABANOVIĆ, N., NUMAN İ. (2019) Cultural Heritage Related to the Water Case Study: Hammams in Bosnia and Herzegovina, *SAR Journal* 2(2) 68-76.

SIBLEY, M. (2018) Let There Be Light! Investigating Vernacular Daylighting in Moroccan Heritage Hammams for Rehabilitation, Benchmarking and Energy Saving, *Sustainability* 10(11) 3984.

SIBLEY, M., SIBLEY, M. (2013) Hybrid Green Technologies for Retrofitting Heritage Buildings in North African Medinas: Combining Vernacular and High-tech Solutions for an Innovative Solar Powered Lighting System for Hammam Buildings, *Energy Procedia* (42) 718-25.

ŞEHİTOĞLU, E. (2000) *Bursa Hamamları'nın Yapısal, Çevresel, İşlevsel Sorunları ve Çözüm Önerileri*. Master's thesis, Mimar Sinan University, Istanbul.

ŞEHİTOĞLU, E. (2008) *The Historic Hammams of Bursa*. Tarih Vakfı Yurt Publications, Istanbul

TAŞÇIOĞLU, T. (1998) *The Turkish Hamam*. Unilever & Duran Ofset, Istanbul.

TLEMSANI BOZDAĞ, H., BENABBOU, R., VURAL ARSLAN, T. (2022) A Framework proposal for resilience assessment in traditional commercial centres: Case of the historical bazaar of Bursa as a resilient world heritage site, *Heritage Science* (10) 154.

TSIKALOUDAKI, K., CÖCEN, Ö.N., TASOPOULOU, K., MILONAS, I. (2013) Daylighting in Historic Bathhouses: The Case of Ottoman Hamams, *METU Journal of Faculty of Architecture* 30(1) 45-55.

VURAL ARSLAN, T. (2015) Developing A Strategic Approach for Managing Sustainable Revitalisation in World Heritage Sites: Historical Bazaar and Khans District, Bursa – Turkey, *Archnet-IJAR: International Journal of Architectural Research* 9(1) 289-304.

XIONG, J., TZEMPELIKOS, A., BILIONIS, I., AWALGAONKAR, N.M., LEE, S., KONSTANTZOS, I., SADEGHİ, S.A., KARAVA, P. (2018) Inferring personalized visual satisfaction profiles in daylit offices from comparative preferences using a Bayesian approach, *Building and Environment* (138) 74-88.

YANAR, A., SÖYLEMEZOĞLU, F., ERDOĞAN, Z., ÖZGEN, Ö. (2021) Preservation of Tangible and Intangible Cultural Heritage: Sample of Turkish Bath, *Turkish Online Journal of Design Art and Communication* 11(1) 1-19.

YEGÜL, F.K. (2012) Anadolu Hamam Kültürü: Bin Işık Huzmesi, Bin Ilık Parmak. In *Anadolu Medeniyetlerinde Hamam Kültürü: Mimari, Tarih ve İmgelem,* eds. N. Ergin, Koç Üniversitesi Yayınları, Istanbul; 17-65.

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MUKARNASIN TARİHİ TÜRK HAMAMI'NIN GÜNIŞIĞI PERFORMANSINA ETKİSİ

Tarihi yapıların somut olmayan kültürel miras özellikleri, UNESCO'nun Somut Olmayan Mirasın Korunması kararının kabul edilmesinden sonra önemli bir konu haline geldi. Türk hamamlarının diğer tüm geleneksel özelliklerinin yanı sıra iç mekanlarının günışığını ve buharı da içeren atmosferi, onların somut olmayan kültürel miras özelliği olarak kabul edilebilir. Ayrıca günışığı ile hamamların geometrik özellikleri arasındaki ilişki de bu atmosferin yaratılmasında etkili bir parametre olarak sıralanabilir. Bu nedenle bu çalışmada geleneksel Türk hamamlarının günışığı alımı ile mukarnasları arasındaki etkileşime odaklanılmıştır. Bu çalışmanın amacı, tarihi Türk hamamı iç mekanındaki mukarnas süslemelerin günışığı alımına etkisini simülasyonlar yoluyla ölçmektir. Ayrıca bu çalışmada mekanda yıllık olarak istenilen günışığı miktarına göre mukarnas geometrisini optimize edebilecek bir model önerilmiştir. Hamamın kubbe geçiş elemanı mukarnaslı olan bir odası günışığı analizi için seçilmiştir. Simülasyon kurulumları yapıldıktan sonra mukarnaslı ve mukarnassız Türk hamamının 3 boyutlu modelleri üzerinde günışığı analiz simülasyonları yapılmıştır. Simülasyon sonuçlarına göre, mukarnasın günışığı alımına az da olsa etki ettiği görülmüştür. Önerilen optimizasyon modeli ile iç mekandaki günışığı miktarı ile mukarnaslar arasındaki ilişki vurgulanmıştır. Optimizasyon deneyleri, mukarnas süslemeleri yardımıyla doğal aydınlatma performansının artırılabileceğini göstermiştir.

INVESTIGATING THE IMPACT OF MUQARNAS ON THE DAYLIGHTING PERFORMANCE OF HISTORICAL TURKISH BATHS

The intangible cultural heritage features of historical buildings became an important issue after the adoption of UNESCO's Safeguarding of Intangible Heritage. In addition to all their other traditional features, the atmosphere of the interior of Turkish baths (*hammams*), which includes daylight and steam, can be regarded as their intangible cultural heritage feature. Furthermore, the interrelation between daylight and the geometric features of these baths is a crucial parameter in creating this atmosphere. Therefore, this study focused on the interaction between daylight intake and the muqarnas of traditional Turkish baths. The purpose of this study is to measure the effect of muqarnas decorations on daylight intake in the interior space of historical Turkish baths through simulations. Also, a model that can optimize the muqarnas geometry according to the desired amount of annual daylight intake in the space was proposed. A section of the bath with muqarnas in its dome transition element was selected for daylighting analysis. After the simulation setups were completed, daylighting analysis simulations were conducted on the three-dimensional models of the Turkish bath, both with and without muqarnas. According to the simulation results, muqarnas were observed to have a slight effect on daylight intake. The proposed optimization model emphasizes the relationship between the amount of daylighting in the interior and the muqarnas. The optimization experiments demonstrated that daylighting performance can be enhanced with the help of muqarnas decorations.

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