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Full Length Research Paper

Documentation of an Ottoman replica tile via photogrammetric modeling

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Reproduction of the tiles often utilized as finishing material in Ottoman architecture is on the agenda during the restoration of the buildings. The documentation should be prepared before passing it on to the reproduction of the tiles. In this study, photogrammetric modeling has been used for the documentation of an Ottoman replica tile. The primary goal of the photogrammetric measurement system was to solve the problem of the issues concerning the time and the accuracy of modeling of small objects. Photogrammetric modeling is the best model that enables the minimum margin of error and documentation of the original model. There are conventional drawing methods for tile conservation and documentation. Photogrammetric modeling technique is faster and more precise than the conventional documentation. This modeling technique has the main advantage of measuring and modeling CAD documentation without touching the tile surface.

Key words: Ottoman tile, finishing material, close range photogrammetry, CAD modeling, building documentation.

INTRODUCTION

Problem description and research aims

Several factors account for the ‘universalisation’ of photogrammetry as a documentation technique. The use of simple, cheap, and fast methods that are accessible to a great number of people would definitely be among these. Some terms, such as the democratisation of photogrammetry or ‘photogrammetry for everybody’ have been coined for the purpose of defining this phenomenon. This new trend has prompted attempts to document traditional tile for conservation in Dereny (1993). The aim of this study is to use photogrammetric modeling for documenttation of traditional Ottoman tile motifs. To minimize the margin of error and to prepare the documentation of colors accurately are the main goals of the modeling that are applied on motifs of an Ottoman Replica Tile. Close range photogrammetry has been frequently used in architectural and archeological studies, especially when the measurement or modeling object was unique. The main advantage of this modeling method is fast modeling without touching the antique tile with real scale factor.

In the 1990s, a research project titled as “Documentation of Traditional İznik Tiles and Their Reproduction with Today’s Technology” was conducted by the Turkish Republic State Planning Organization. The scope of the project was the documentation of the Ottoman tiles in the Rüstempaşa Mosque. The patterns of the tiles were drawn by hand, putting the rough copies on them during the documentation. The hand drawing patterns were scanned through a scanner, and they were colored using the Adobe Photoshop software with 0.02 mm margin of error being observed at the documentation. Colors similar to the original colors of the tiles were chosen from Adobe Photoshop software. Photogrammetric modeling appeared to give better results during the documentation of the

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Figure 1. Replica tile (148.5*248.2 mm).

tile patterns for this type and in similar research. This research includes the modeling of the Ottoman Replica Tile. The chosen replica tile is an e×ample of an architectural ornament component with dimensions of 148.5*248.2 mm in Figure 1.

Anatolian ceramic tiles

Examples of the tiles were seen in the first quarter of the 13th century as an architectural ornament in Anatolia. The first examples, called Seljuk tiles, were used until the Ottoman classical period of the 15th century. They were categorized into two groups. The first was called glazed brick, which was baked in kilns, glazed, and utilized to cover the buildings until the 15th century. The other one was called glazed tablet. The glazed tablet is used for the oblong, square, hexagon, or octagon tiles. The brick surface to be glazed is dipped into molten enamel and baked in a kiln. If the tile is to be utilized in a mosaic, it is cut into smaller dimensions. A tile or tile mosaic is obtained in this way (Kuban, 2008).

Glazed brick, tile and mosaic tile are significant components of Middle Age architectural ornamentation. However, the tile ornamentation that was observed on the external surfaces of buildings in Iran during the Seljuk and subsequent sovereignty periods did not come into fashion at Anatolia. Stone ornamentation had been the preference for buildings during the Seljuk era, and glazed materials had been used mostly indoors (Kuban, 2008).

In the early Ottoman period, manufacturing of tiles using progressive colored-glazing techniques were further developed in addition to rare mosaic tile making in Edirne, Istanbul, and especially in Bursa. Following these developments, especially during the 16th century, under glaze-painted wall tiles are being manufactured using motifs that were created by imperial craftsmen in the Nakkaşhane (imperial painting workshop). Floral compositions and inscription bands were dominant elements. During the middle of the 16th century, the integration of red-colored under glaze reliefs, fritted rigid clay texture, and smooth glazing technique made Ottoman ceramics gain world-wide superiority. Very early at the end of the 17th century, the city of İznik started losing its prominence in tile production and consequently was replaced by Kütahya. Another important production center has been Çanakkale. None of the secondary production centers that tried to imitate Iznik style were able to achieve the perfection of Iznik ceramics and the quality of its paste (Sağlamer et al., 1999).

As the findings of Iznik excavations indicate that the graffito technique, commonly used in medieval east Mediterranean civilizations, was replaced later by the slipware technique. Because motifs were applied as raised coats of lining material (that is, slips) onto red clay, single color glazing resulted in a double color appearance. A further example for the red clay practice is the pottery that ac-commodated under glaze cobalt-blue application on white slipware. In addition to open forms like dishes, bowls, and cups, closed forms were produced. At the beginning of the 15th century, above mentioned techniques were adopted to manufacture pottery for every day use. Blue-white, and later turquoise adornments were the dominant colors used in white clay ceramics that competed with Chinese porcelain. The high quality white frit ware with under glaze red relief and dilatation-proof infrastructure made almost any form possible and stands out as the most significant ceramic production of 16th century. In the 17th century, there was a major drop in the production quality of ceramics that constituted a harmonious entity through the consistent usage of stylistic floral patterns. Following this, Kütahya ceramics that initiated the use of a soft yellow cast on lower quality clay spread more rapidly in the 18th century (Sağlamer et al., 1999).

In the Ottoman architecture, tiles are utilized in either religious buildings, such as mosques, masjids (prayer hall without a minber), and tombs or in civic structures like palaces, kiosks, fountains, imarets (soup kitchen for students, the poor, etc.), and libraries. Colonnade, Latecomers area, minaret, mihrap (portal that indicates the direction of Mecca), mihrap niche, interior walls, gallery, minber (the hooded dais reached by long stairs from which the weekly sermon is declaimed), minber cone, piers, tympana (windows and doors), spandrels, archivolts, fireplace hoods, and transitional elements (pendentives, muqarnas) are the utilization regions of tiles. Tiles in Ottoman architecture are usually put to use as decorative features in interior spaces to supplement the architectural agenda. The use of borders (Figure 2) at the end of tiled surfaces creates wholeness in the tile schedule (Sağlamer et al., 1999).

In the first half of the 16th century, when tile production

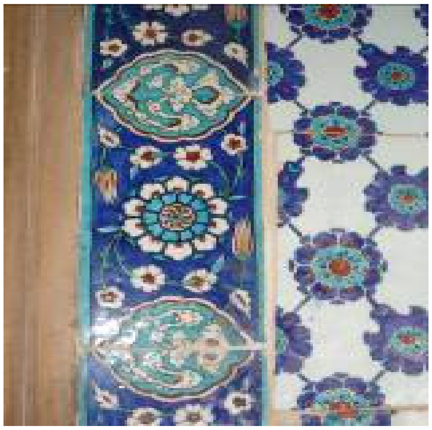

Figure 2. Border tile.

Figure 3. Stylized floral compositions.

and usage started spreading rapidly, standardization was adopted in the design of the patterns. During the second half, the usage of stylized floral compositions began (Figure 3). These compositions showing leaves, trees, flowers in vases/cups constitute the most important motifs of the generic tile glossary. Others that can be seen frequently carry geometrical or natural motifs, inscriptions in various styles, and architectural depictions like the Kaaba complex in Mecca (Sağlamer et al., 1999).

The most commonly used floral motif is tulip. Carnation, hyacinth, rose, rosebud, lily, chrysanthemum, pomegranate, and pomegranate flower follow the tulip in frequency of appearance. Leaves, weaving leaves, trees (cypress trees , plum trees with blossomed branches, trees with apple and peach blossoms, trees with vine blossoms), roses, tulips, hyacinths or chrysanthemums placed in vases or carafes, cloud patterns, geometrical motifs, rumi's, çintamanis (tiger strips), and inscriptions are used also (Sağlamer et al., 1999). Contrast to be achieved between the motifs and the background was a major factor in selection of colors. This eases the distinction of different shapes. Yellow and green were dominant colors in the first half of the 16th century, while white and blue are being govern in the second half. Coral red began to be used in the second half of 16th century (Sağlamer et al., 1999).

Photogrammetric modeling

Photogrammetric modeling of objects is used for various purposes today. Digital photogrammetric systems have been used to solve various measurement problems in industrial applications for many years, ever since high-resolution CCD cameras and powerful computer technologies were available. In close range photogrammetric applications, working conditions of the industrial platforms are usually challenging. In such conditions, especially in the experimental area, a surveying engineer has to find the best solution of the problem. Industrial line-scan video cameras have been widely adapted for close range photogrammetry and in the applications of machine vision. Although the advantages of on-board storage of digital images, such as quick data storage and portability, industrial cameras are replacing small format sensor on cameras with the possibility of huge image scales and by satisfying PCI card requirements. The primary goal of the photogrammetric measurement system which was setup in the photogrammetry laboratory of GIT was to solve the problem of the issues concerning the time and the accuracy of modeling of small objects. This section involves photogrammetric modeling of a part of Ottoman Replica Tile.

Geometric camera calibration

The radial distortion causes straight lines in the space of the object which is rendered as curved lines on the film or on the camera sensor. It originates from the data of the transverse magnification. In other words, the lens has various focal lengths and magnifications in different areas. The radial distortion deforms the whole image, even though every point is in focus. This radial distortion causes the geometrical errors on the surface of the tile, which are detailed in CAD representation. Due to the design and manufacturing processes, the lens produces some geometric errors in images. The six major types of errors are spherical aberration, come astigmatism, field curvature, lens radial distortion, and chromatic distortion. Among these errors, lens radial distortion is the most severe one, especially in wide-angle lenses (Atkinson, 1996; Brumana et al., 2005; Ergun, 2006). The distortion intervals of different focal distances are shown in Figure 4.

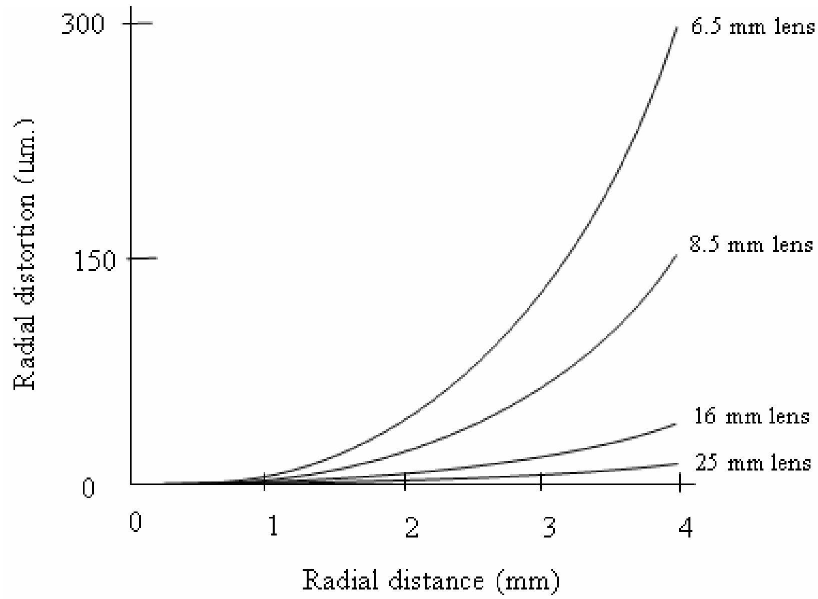

Figure 4. Distortion Intervals of different focal distances.

To reduce manufacturing cost, the majority of digital cameras are equipped with lenses having spherical surfaces. These spherical lenses have inherent radial distortion and must be corrected by manipulating the system variables (indices, shapes, spacing, stops, etc). The degree and order of compensation are varied from one manufacturer to another or even in different camera models by the same manufacturer. Therefore, lenses used by separate camera models may have different degrees of radial distortion (Atkinson, 1996). Variations in angular magnification with angle of incidence are usually interpreted as radial lens distortion. Design and construction of metric cameras ensure that such distortion is minimized, but calibration is usually necessary. Radial lens distortion is usually expressed as a polynomial function of the radial distance from the point of symmetry, which usually coincides with the principal point (Atkinson, 1996):

$$\delta r=K_1r^3+K_2r^5+K_3r^7 \quad (1)$$

where δr is the radial displacement of an image point, $r^2=(x-x_0)^2+(y-y_0)^2$, (x,y) are fiducially the co-ordinates of the image point, (x_0, y_0) are fiducially the co-ordinates of the point of symmetry, commonly the principal point, and K_1, K_2 and K_3 are coefficients whose values depend upon the camera focal setting. The distortion δr is usually resolved into two components (Atkinson, 1996):

$$\delta r_x=\delta r(x-x_0)/r \quad (2)$$

And

$$\delta r_y=\delta r(y-y_0)/r \quad (3)$$

For a large format metric camera (up to 150 mm say) the maximum magnitude of radial lens distortion is about 10 - 20 µm. Typical radial lens distortion curves for soma ine×pensive CCD camera lenses are illustrated in Figure 4. Geometric calibrations of the four U eye-2230 cameras with Pentax 16 mm fix focused lenses (CCTV) were done in 2D calibration zone, in GIT – Department of Photogrammetric Engineering, by PI 3000 software. Table 1 shows the calculated parameters.

Orientation and restitution

The online close range photogrammetric measurement system has been oriented with the calibration field, which was built up with 77 control points. The three-dimensional coordinates of these control points were mapped with CNC machinery with an accuracy of 0.001 mm. The photogrammetric resections of four cameras and exterior orientation parameters were calculated with bundle block adjustment technique. Then, the replica tile was settled to the measurement system, and images were captured simultaneously from the four different oriented cameras. Figure 5 illustrates the application setup with calibration and application process.

The rectified 3D model to the texture map model of the tile was produced by using four-different images from four various views. This process covered photogrammetry and 3D texture map, which was obtained with a high resolution representation of the image (Brumana et al.,

Table 1. Photogrammetric calibration parameters.

Camera focal ID	c (mm)	x_0 (mm)	y_0 (mm)	K_1	K_2	P_1	P_2
4002704847 463490	16.126380	2.922502	2.241684	1.343546×10^{-3}	-3.770213×10^{-5}	-2.03327×10^{-4}	-5.36897×10^{-4}
4002704846 463459	15.984727	2.957662	2.059350	1.130501×10^{-3}	-2.244936×10^{-5}	-4.44978×10^{-4}	-5.749067×10^{-4}
4002704844 460535	15.950093	3.154344	2.186467	4.435404×10^{-4}	1.756921×10^{-6}	-6.65668×10^{-4}	-2.603092×10^{-4}
4002679106 463644	15,886334	1,924322	1,588383	$1,702855 \times 10^{-3}$	$-8,417302 \times 10^{-5}$	$1,22405 \times 10^{-3}$	$-6,726401 \times 10^{-4}$

Figure 5. Setup system with orientation field and tile.

2005) (Ergun, 2006). The image had a real scale resolution of the pixels in 0.015 mm, with the support of standard enlargements on a 1:1 scale, without losing any details. TIN (Triangulation of Irregular Network) model of the surface geometry appears in Figure 6.

The information contained in the photographs will be materialized in a document irrespective of whether such photographs are plans and digital files (3D and/or 2D), coordinates lists with information on the mistakes observed, etc (Ergun, 2006). It can be seen that all the necessary and high quality information had a limited error in a planimetric and detailed scale of 0.01 mm. Setting the need for a 1:1 scale of representation, after photogrammetric orientation with hardware and software on a test field with 77 control points, and by verifying the ability to achieve the objectives, the entire tile was blanketed by nearly five pixels at a scale of 1:50. The result of the rectification process has been shown in Figure 7.

In the photogrammetric modeling of architectural items, the most important part was to produce rectified images of figures and patterns of the tiles. The accuracy of the patterns demonstrated the accuracy of the rectification. The ability to associate a 3D model of the tile surface with the wealth of information provided by photogrammetric rectification formed a representation of the details on several parts of the tile. The 3D digital model of the tile surface is as shown in Figure 8.

CAD application and precision

The use of direct measurement and CAD techniques hindered the capturing of a high number of details of the monument and took too much time. Besides, it was difficult to create a detailed 3D model from real tile surface with conventional methods (Atkinson, 1996) (Ergun, 2006). Because it created a complexity in the accessibility of the conditions concerning the interior part of life span of Ottoman Tiles, the photogrammetric method was used for quantitative metric data. Then, these data were associated with color and surface pattern. Details of the tile were modified in high quality, converted into the actual scale, and were drawn by using the usual CAD techniques. The resulting models containing metric information and the 3D models are ready to be exported in conventional formats (dxf, dxb, vrml, etc.) into other programs in order to be visualized, edited, or processed. Another feature of the system is its capability to generate 3D models, of surface sand, the subsequent projection of real textures, captured from the object's photographs, onto these models (Ergun, 2006; Arias et al., 2007).

Accuracy of orientations and accuracy of the application

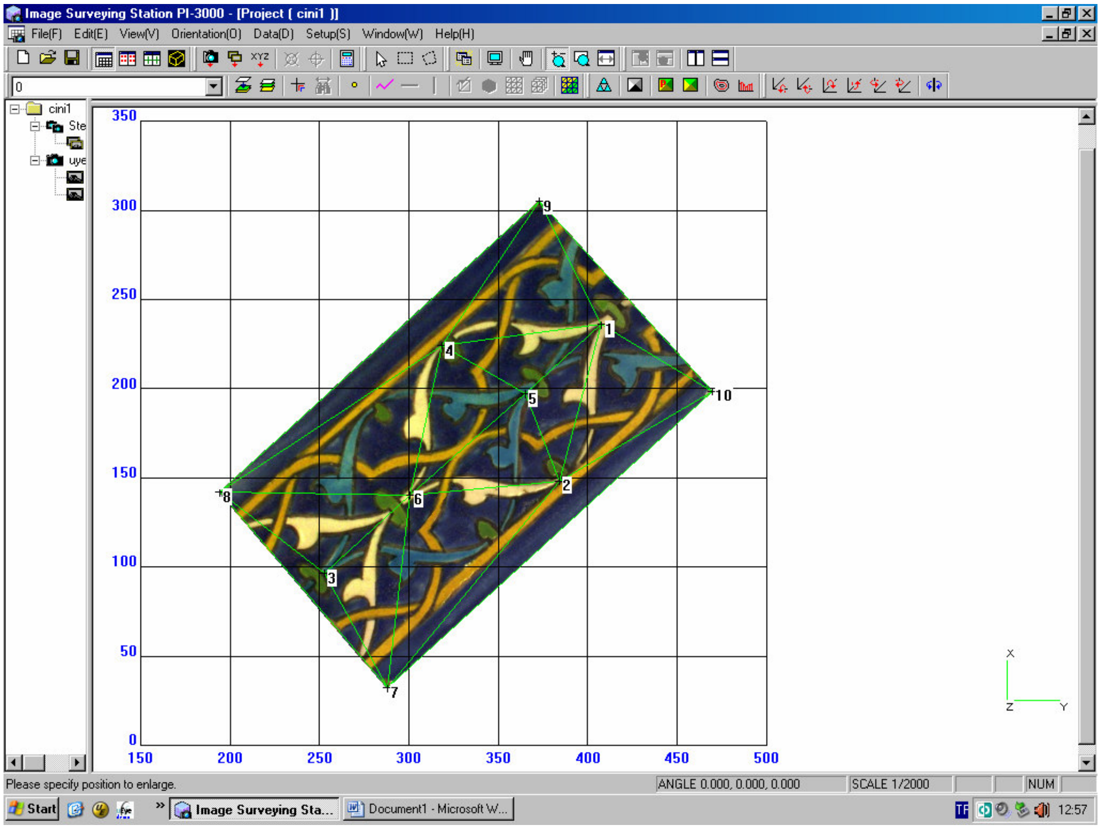

Figure 6. TIN model.

Figure 7. Rectified image.

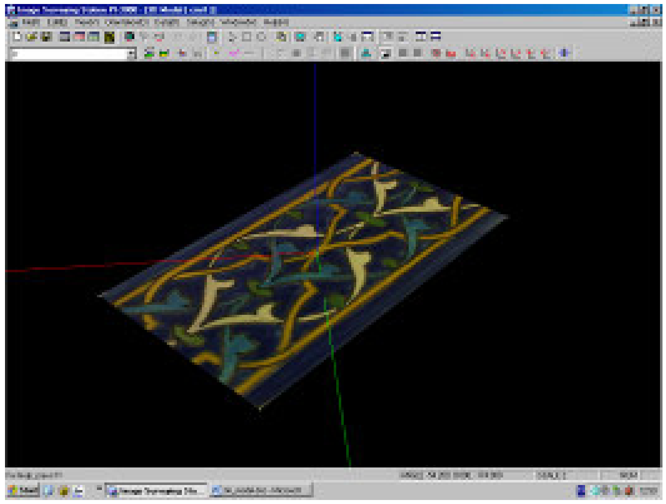

Figure 8. 3D model with texture map.

Table 2. Exterior orientation parameters and accuracy for only one image.

Exterior parameters	X_0(mm)	Y_0(mm)	Z_0(mm)	ω (gon)	φ (gon)	γ (gon)
Image No:4	708.7569	260.7872	739.0634	-3.42	39.02	-198.02
R. M. S. (mm/gon)	±0.023	±0.022	±0.028	±0.001	±0.001	±0.001

Table 3. Comparison between conventional method and photogrammetry.

Methods	Producing time	Precision (mm)	Color	Saving life	Transportation
Conventional	18 h	0.02	Not Original	5 years	Hard copy
Photogrammetry	30 min	0.01	Original	Unlimited	Digital copy

of the operator may be evaluated to calculate the accuracy of generated three dimensional digital terrain model. In fact, in terrestrial photogrammetry, there is a direct relationship between accuracy and calibration, and calibration accuracy means model accuracy. Of course, operator based vector errors due to 3-D view and photogrammetric measurement are under the 25% threshold mentioned above. Actually, these errors may be eliminated by filtration and softening operations during generating digital CAD model. Table 2 shows that exterior orientation parameters and root mean squares for one image of a stereo model. Figure 7 shows the result measurement data by means of photogrammetric restitution.

During conventional drawing method, the pattern of the tiles is prepared step by step. At the first step, the pattern of the tiles is drawn by hand using transparent paper and a pencil. The transparent paper is placed on the tile at the field study area, and the patterns are drawn by hand by using pencil. At the second step the hand drawn pattern is scanned by a scanner under 600 DPI resolutions. In this way, a preparation was made for the digital copy of the pattern to be colored. At the third step, the digital copy of the pattern is colored using the Adobe Photoshop software. Colors similar to the original colors of the tiles are chosen from Adobe Photoshop software. After all these steps, the colored digital copy of the pattern is prepared.

The preparation of the colored digital copy of each tile, which has the dimensions approximately 150,0*250,0 mm, takes nearly a day by conventional method. Consequently, it is a long time, when compared with photogrammetric modeling (Table 3). The margin of error is 0.02 mm in the documentation that was drawn by hand. Also, the colors do not reflect the original colors because they were chosen from the Adobe Photoshop Software. The saving life of the rough copies is approximately 5 years because transparent paper loses the original drawings on it over time. It is impossible to reproduce a digital copy of the pattern from the rough copy after 5 years. Precision and the colors do not reflect the real pattern. As a result, the reality is not perfect. Trans-portation of the rough copies is provided by hand or by vehicle. The comparison between conventional method and photogrammetry has been displayed at Table 3. The differences between the two methods in terms of producing time, precision, color, saving life, and transportation could be followed in the Table 3.

Conclusion

The margin of error of the Ottoman tile is 0.01 mm in the documentation that was obtained through photogrammetric modeling. The margin error is 0.02 mm in the documentation that was drawn by hand. The minimum margin of error is preferred when it comes to accurate remanufacturing for the purpose of restoration. As can be seen, the result with the minimum margin of error is obtained through photogrammetric modeling. In addition, the colors are the original colors of the tile in the documentation prepared with photogrammetric modeling. The colors of the sample documentation direct the remanufacturing practices for the purpose of restoration. Hence, the accuracy of the colors in the documentation becomes an issue in the reproduction of the original colors of the tiles to be remanufactured.

Remanufacture of the tiles often utilized as covering material in Ottoman architecture, is on the agenda during the restoration of the buildings. The documentation should be prepared before passing them on to the remanufacture of the tiles. Photogrammetric modeling is the best model that enables the minimum margin of error and documentation of the original color. The only downside of the model is that it is not appropriate for field surveys. The required remanufacture of architectural tile is performed after having been ripped from the building and the documentation is prepared in the laboratory. It is unlikely that the newly developed model will be utilized outside the laboratory.

Ottoman tiles also have considerable merit for the cultural heritage of old Turkish history. Most of landmarks of Ottoman architectural arts have used these tiles for traditional and purity purposes, particularly in indoor areas. Therefore, traditional tile conservation is a very important topic in the name of cultural heritage documentation for civilizations alliance with the east and west. These types of studies have been supported by international society foundations for conservation of cultural heritage in the entire world.

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