# Modeling of Historical Bridges Using Photogrammetry and Virtual Realty

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**Key words:** virtual reality, 3d modeling, terrestrial photogrammetry, historical monuments

## SUMMARY

Anatolian civilizations left their marks on the development of science, culture and art and as a result, many scientists, engineers, artists and architects were born. No doubt the most important of these was Architect Sinan. He was an architect of high capability who has left his impact on the Golden Age of Architecture during the Ottoman Empire. After he was promoted to the position of Head Imperial Architect in 1558, he retained his position for 50 years and built more than 350. Among these small or large monuments or structures, water arches, bridges and mosques have the majorities.

In this study Kapuağası Bridge, which is one of the built of the Architect Sinan, has been selected as study object. This Bridge was built on Harami Stream in the 16th Century which is the closest bridge built by Architect Sinan to Istanbul city centre. It is approximately 75 meters in length and 6 meters in width with three arches. After the construction of a new bridge on the Edirne-Istanbul Highway, Kapuağası Bridge has become out of usage.

The aim of the study is to digitally photograph the historical bridge by means of the terrestrial photogrametric techniques. 2D and 3D coordinates of each single stones of the bridge were obtained from digital images. These coordinates were used to prepare sketches of the bridge in different scales. Those data also used to forming virtual model of the bridge. Using this model a short video that is in "avi" format was prepared. This model and video indicates the capability of these techniques in the preserving and documentation of cultural heritage, which is very difficult and time consuming with the conventional methods.

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## 1. INTRODUCTION

Throughout the history, lots of civilizations have come to the stage of history and many of them has wear off from this stage, since they could not hand on their cultural heritage to the new generations. Cultural heritages of civilizations, which are guidance to people to create a mutual culture, are significant gifts to not only their own generations, but also to the rest of the World. Some of them have been built for peace, some of them for wars and some of them just for to make people's life easy. However, all they have a mutual feature. All of them are masterpieces which show how people found solutions and how they lived together. When we look at the thousand years of the history of the civilization, a common problem for all mankind and which is accepted as a very important point at our time, is saving the valuable monuments and documents created by mankind or in partnership with the nature, is "Saving the Cultural Heritage". As the speedy increase of the the communication devices bring the nations closer to each other, mankind is faced with the problem of strengthening the feeling of "saving" this common heritage and this feeling is increasing their responsibilities. The necessity of having a common language and a common criterion for saving this heritage is a very strong point of having responsibility. The responsibility of the present generation is to carry these heritages to the coming generations with the least damage. It is very important that new technologies and knowledge is developed to protect, to strengthen and to restore these buildings and most important of all to understand these buildings within the scope of archaeology, structure and architecture as a total. Giving the priority to the documentation of the buildings is very important to save the heritage. To save the cultural heritage in its original form will enable us to see the damages which can occur later. If documentation is kept precisely, the restoration process will be much more correct. (Duran, Z., 2003)

Anatolia has been the cradle of many civilizations for thousands of years. Therefore there are many important monuments architecturally and culturally. Therefore the responsibility of saving the Cultural Heritage lies heavier on the shoulders of the Anatolian people with a history going back to ten thousand years. Many of these monuments both from the pre-historical times, from the Seljuqi or Byzantine and Ottoman periods have been preserved. Anatolian civilizations left their marks on the development of science, culture and art and as a result, many scientists, engineers, artists and architects were born. No doubt the most important of these was Architect Sinan. He was an architect of high capability who has left his impact on the Golden Age of Architecture during the Ottoman Empire. After he was promoted to the position of Head Imperial Architect in 1558, he retained his position for 50 years and built more than 350. Among these small or large monuments or structures, water arches, bridges and mosques have the majorities.

Although a big part of this national treasury has been preserved and documented very well, detailed documentation and preservation studies are still being carried on in every part of the country with the association of government and non-government organizations. Many applications of terrestrial photogrammetry are focused on architectural photogrammetry. Common usage of photogrammetry is sketch preparing for the restoration projects of architectural monuments. Photogrammetry is used either for recording of inside and outside facade of valuable historical monuments, or just for commercial aims on ordinary buildings.

In this study Kapuağası Bridge which is one of the built of the Architect Sinan has been selected as study object. This Bridge was built on Harami Stream in the 16th Century which is the closest bridge built by Architect Sinan to Istanbul city center. It is approximately 75 meters in length and 6 meters in width with three arches. After the construction of a new bridge on the Edirne-Istanbul high-way, Kapuağası Bridge has become out of usage.

In this study; it is aimed to digitally photographed the historical bridge by the means of the terrestrial photogrammetric techniques. 2D and 3D coordinates of each single stones of the bridge were obtained from digital images. These coordinates were used to prepare sketches of the bridge in different scales. Those data also used to forming virtual model of the bridge. Using this model a short video which is in “avi” format was prepared. This model and video indicates the capability of these techniques in the preserving and documentation of cultural heritage, which is very difficult and time consuming with the conventional methods.

## 2. GREAT ARCHITECT SINAN AND HIS MONUMENTS

Mimar Koca Sinan, the "Great Architect Sinan", was born of Greek Christian parents in Anatolia, Turkey in 1489. He was drafted as a soldier into the Ottoman royal house in 1512; he quickly advanced from cavalry officer to construction officer. As construction officer he built bridges and fortifications. In 1538 he was appointed Architect of the Abode of Felicity. During his career Sinan built hundreds of buildings including mosques, palaces, harems, chapels, tombs, schools, almshouses, madrassahs, caravan serais, granaries, fountains, aqueducts and hospitals. Of this diverse group of works, his mosques have been most influential. (Bozkurt, O., 1992)

Various sources state that Sinan was the architect of around 360 structures which included 84 mosques, 51 small mosques ("mescit"), 57 schools of theology ("medrese"), 7 schools for Koran reciters ("darülkurra"), 22 mausoleums ("türbe"), 17 Alm Houses ("imaret"), 3 hospitals ("darüssifa"), 12 bridges, 8 aqueducts and arches, 48 inns ("Caravansarai"), 35 palaces and mansions and 46 baths. Sinan, who held the position of chief architect of the palace, which meant being the top manager of construction works of the Ottoman Empire, for nearly 50 years, worked with a large team of assistants consisting of architects and master builders.

Sinan, in the bridges he built, has masterfully combined art with functionalism. The largest of his work in this group is the nearly 635 m. long Büyükçekmece Bridge in Istanbul. Other significant examples are Silivri Bridge outside of Istanbul; Lüleburgaz (Sokullu Mehmet Pasha) Bridge on Lüleburgaz River, Sinanli Bridge over Ergene River and Drina Bridge which has became the title of the famous novel of Yugoslav author Ivo Andriç. The bridges done by Sinan are given Table 1 and Drina Bridge is given in Figure 1. (Çeçen, K., 1988a)

**Table 1**. Bridges of Architect Sinan

| Bridge | Construction Year | River | Location | Length (m) |
|---|---|---|---|---|
| Mustafa Paşa | 1528-1529 | Meriç | Sivilingrad (Bulgaria) | 295.00 |
| Odabaşı | 1529-1530 | Sazlıdere | Halkalıpınar (İstanbul) | |
| Sultan Süleyman | 16.th century | Dil Deresi | Gebze (Kocaeli) | |
| Esenköprü (Sokullu Mehmet Paşa) | 1565 | | Lüleburgaz (Kırklareli) | 92.60 |
| Kapuağası | 16.th century | Haramidere | Haramidere (İstanbul) | 74.40 |
| Alpullu (Sinanlı) | 16.th century | Ergene | Sinanlı-Babaeski (Edirne) | 129.40 |
| UzunKöprü (Sokullu Mehmet Paşa) | 1568 | Silivri Stream | Silivri (İstanbul) | 48.50 (332.88) |
| Drina | 1577-1578 | Drina | Vişegrad (Bosna-Herzigova) | 179.00 |
| Kanuni Sultan Süleyman | 1553-1554 | Tunca River | Edirne | 60.00 |
| Yalnızgöz | 1567 | Tunca River | Edirne | |
| Bolvadin (Kırkgöz) | 1550 | Akarçay | Bolvadin (Afyon) | 175.00 |
| Büyükçekmece1 | 1567 | Between | B. Çekmece (İstanbul) | 157.23 |

| | | | | |
|---|---|---|---|---|
| Büyükçekmece2 | 1567 | Büyükçekmece Lake and Marmara Sea | B. Çekmece (İstanbul) | 135.10 |
| Büyükçekmece3 | 1567 | | B. Çekmece (İstanbul) | 101.10 |
| Büyükçekmece4 | 1567 | | B. Çekmece (İstanbul) | 183.72 |

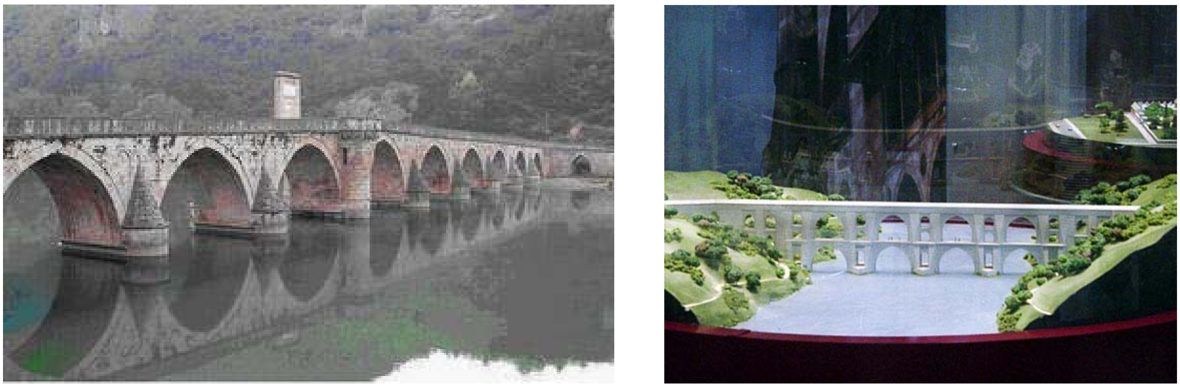

**Figure 1.** Drina Bridge and 1/100 Scaled model of the Mağlova Arch in Architect Sinan Briefing Room in the Ministry of Public works and Settlement of Turkish Republic

## 3. STUDY AREA

The Kapuagasi Bridge, which built in 16.th century on the Haramidere (Bandit Stream) on the Istanbul-Edirne highway as selected as monument. The bridge is 74.40 m. length. There are two spaces (1.50*0.56) on both sides of the bridge, but they are not for the inscriptions. The bridge consists of three arches, two disburdening cases and two discharging cases. The central arc is bigger than the others. All of the arches are sharp arches. The stones used for the arches are all carved stone. Current situation and location of the bridge is given in Figure 2.

**Figure 2**. Current position of the bridge

When the bridge constructed it was the main way between the most important cities of the Ottoman Empire: Istanbul; the Capital and Edirne; the old Capital and the main gateway to the Europe. Parallel to the rapid increase in the population of Istanbul after 50s, new roads and highways were constructed, in the area and the bridge has become out of usage. Half of the bride was destroyed by unknown reasons in the past years, and restored recently. Today the bridge is standing in the middle of highway junction. Unfortunately, such other monuments built up by Sinan, no more information have been collected about this bridge also. (Çeçen, K., 1988b)

## 4. METHODS USED

For documentation of the cultural heritage, terrestrial digital photogrammetry plays very important role. Terrestrial digital photogrammetry is the most economical and effective technique to obtain true 3D coordinates, which is required for documentation of historical monuments. Close range Photogrammetry, is the most convenient technique for documentation among the others. Many of the applications of terrestrial photogrammetry are focused on architectural photogrammetry. (Avşar, E. Ö., Aydar U., Şeker D. Z., 2006)

In this study; more than 30 pairs of photographs of the bridge were taken by a Samsung Digimax 430 digital camera which is 4.3 mega pixels was used. The calibrated focal length of the camera is 6.26591mm. All taken photos' dimensions are 2272*1704 pixels.

40 control points (20 for each side) were mounted on the bridge and measured by Pentax PTS total station and their coordinates were calculated according the equations of intersection method. A local coordinate system was defined and coordinate were calculated.

Photogrammetric evaluation was carried out using Pictran-D digital photogrammetric software. After the evaluation of the two sides; the model was combined using AutoCAD Software. This combined model of the bridge geo-referenced by putting together with the Haramidere Crossroads section of the 1:1000 scale cadastral map (Figure 3).

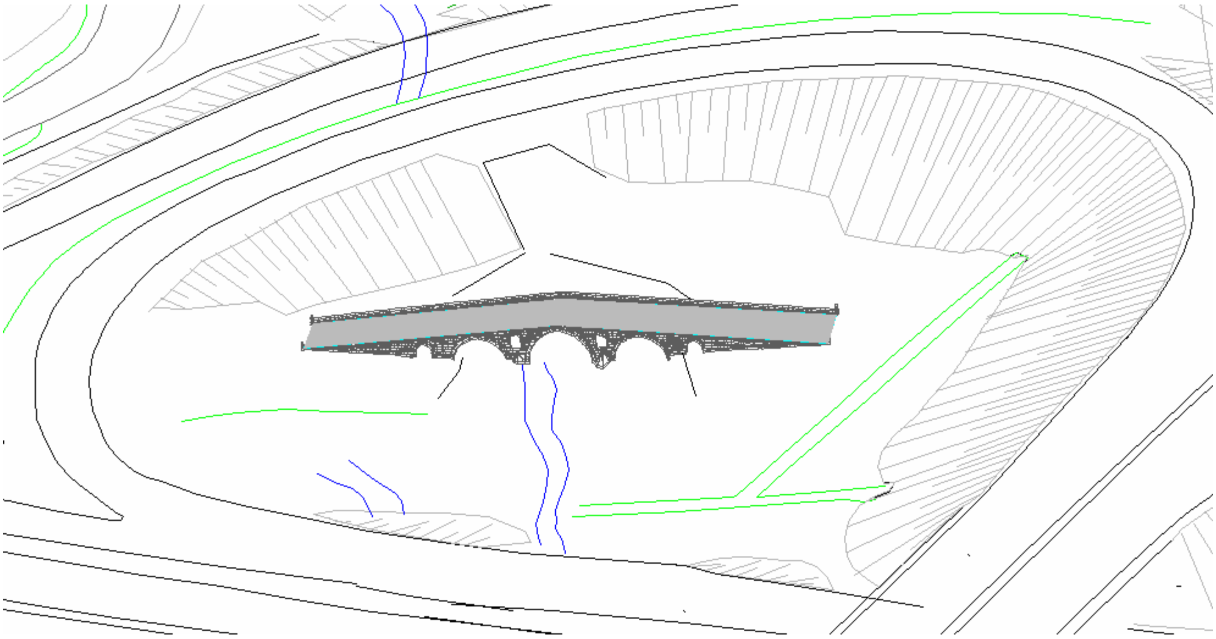

**Figure 3**. Ground surface model with the evaluated bridge.

The model of the bridge was imported into the 3D Studio Max for lightning up to enrich the details. The texture samples of the stones were captured from the original photos to assign by generalizing to all the stones in the same layers of moulding, arch, and scarecrow of the bridge for visualization. This model was fitted up to the ground and the position and the way of the camera was determined. By rendering the videos was produced in different resolutions (800*600, 1024*768 and 1600*1200). Some frame samples from the videos are given in Figure 4.

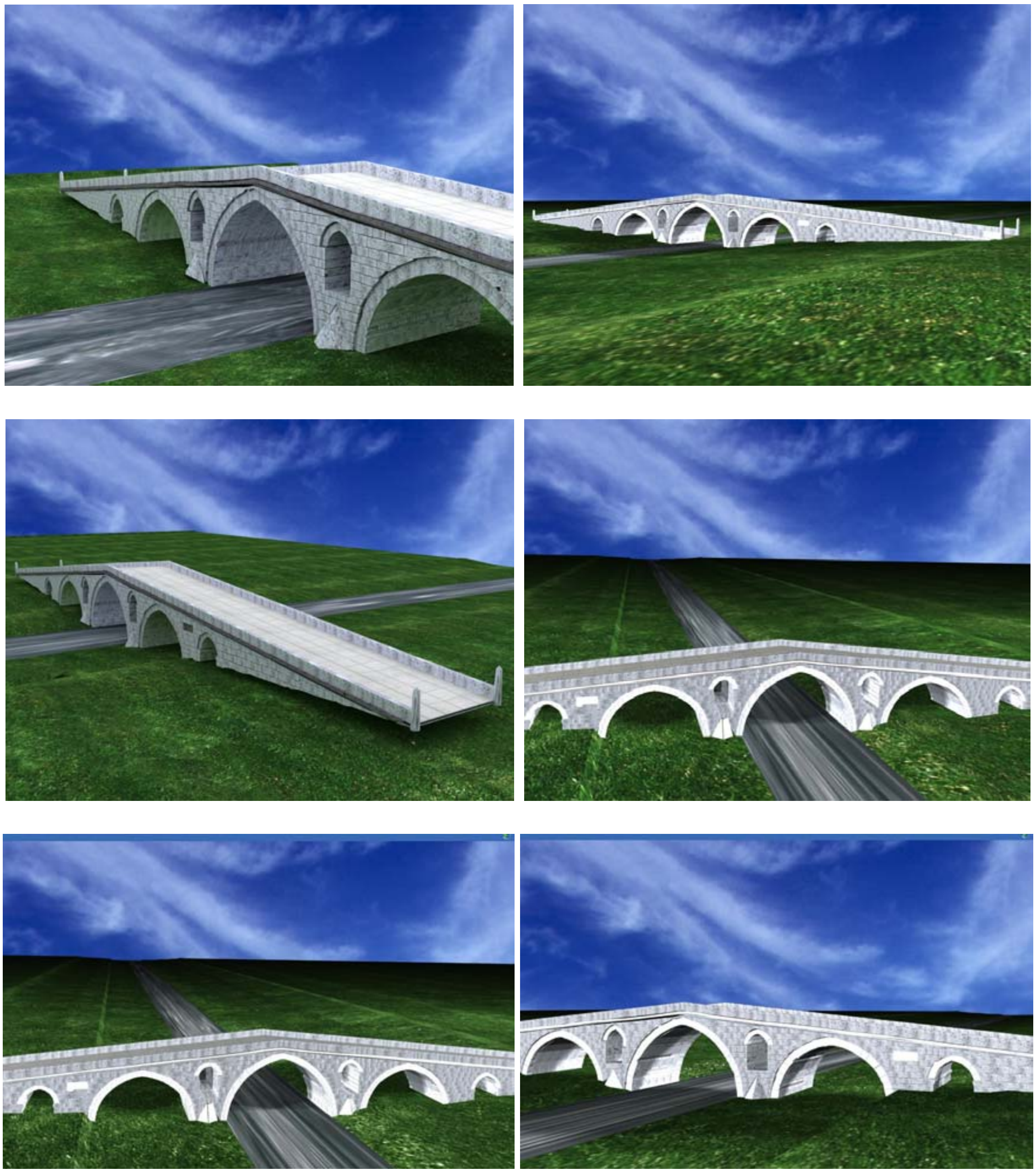

**Figure 4.** Frame samples from produced video.

**Table 2.** Coordinates of control points

| Control Point | Coordinates calculated according the equations of intersection method | | | Coordinates evaluated after adjustment | | |
|---|---|---|---|---|---|---|
| | X (m) | Y (m) | H (m) | X (m) | Y (m) | H (m) |
| 1 | 1012.709 | 939.692 | 102.189 | 1012.703 | 939.689 | 102.178 |
| 2 | 1008.175 | 945.194 | 102.401 | 1008.172 | 945.199 | 102.391 |
| 3 | 1006.449 | 947.181 | 100.853 | 1006.453 | 947.178 | 100.864 |
| 4 | 1004.560 | 949.717 | 102.313 | 1004.557 | 949.723 | 102.324 |
| 5 | 1001.507 | 953.164 | 100.981 | 1001.508 | 953.168 | 100.967 |
| 6 | 1000.996 | 953.847 | 103.389 | 1001.006 | 953.845 | 103.405 |
| 7 | 1000.439 | 954.362 | 102.116 | 1000.443 | 954.365 | 102.102 |
| 8 | 997.748 | 957.502 | 100.307 | 997.753 | 957.500 | 100.317 |
| 9 | 992.518 | 963.958 | 100.787 | 992.525 | 963.962 | 100.769 |
| 10 | 990.583 | 966.401 | 105.004 | 990.589 | 966.405 | 104.987 |
| 11 | 984.858 | 973.455 | 104.230 | 984.863 | 973.461 | 104.239 |
| 12 | 979.265 | 980.070 | 104.069 | 979.262 | 980.064 | 104.077 |
| 13 | 970.339 | 991.046 | 103.445 | 970.346 | 991.049 | 103.435 |
| 14 | 966.026 | 996.167 | 102.096 | 966.027 | 996.160 | 102.085 |
| 15 | 972.245 | 988.525 | 100.700 | 972.251 | 988.523 | 100.713 |
| 16 | 976.488 | 983.266 | 102.209 | 976.493 | 983.268 | 102.218 |
| 17 | 984.166 | 974.078 | 100.872 | 984.173 | 974.076 | 100.884 |
| 18 | 985.668 | 972.304 | 101.945 | 985.661 | 972.310 | 101.933 |
| 19 | 980.654 | 978.224 | 102.745 | 980.649 | 978.225 | 102.732 |
| 20 | 960.752 | 992.187 | 101.749 | 960.758 | 992.191 | 101.738 |
| 21 | 965.722 | 986.052 | 102.072 | 965.716 | 986.054 | 102.087 |
| 22 | 966.800 | 984.758 | 100.605 | 966.807 | 984.755 | 100.616 |
| 23 | 970.407 | 980.310 | 100.647 | 970.410 | 980.305 | 100.635 |
| 24 | 991.780 | 953.901 | 103.421 | 991.787 | 953.904 | 103.429 |
| 25 | 971.389 | 979.232 | 101.625 | 971.394 | 979.233 | 101.613 |
| 26 | 970.638 | 979.992 | 102.761 | 970.631 | 979.997 | 102.770 |
| 27 | 973.726 | 976.309 | 100.023 | 973.734 | 976.306 | 100.036 |
| 28 | 976.995 | 972.362 | 102.191 | 977.003 | 972.366 | 102.199 |
| 29 | 994.289 | 961.704 | 102.276 | 994.295 | 961.707 | 102.263 |
| 30 | 979.029 | 969.877 | 102.482 | 979.036 | 969.875 | 102.473 |
| 31 | 980.366 | 968.100 | 100.696 | 980.362 | 968.097 | 100.710 |
| 32 | 972.985 | 976.966 | 102.621 | 972.991 | 976.972 | 102.638 |
| 33 | 983.269 | 964.277 | 104.225 | 983.275 | 964.283 | 104.239 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 34 | 987.587 | 959.248 | 100.377 | 987.590 | 959.249 | 100.389 |
| 35 | 993.445 | 952.008 | 101.262 | 993.438 | 952.011 | 101.248 |
| 36 | 995.198 | 949.837 | 101.698 | 995.192 | 949.839 | 101.713 |
| 37 | 998.940 | 945.107 | 100.516 | 998.944 | 945.113 | 100.507 |
| 38 | 1001.812 | 941.359 | 101.285 | 1001.814 | 941.362 | 101.275 |
| 39 | 1007.057 | 935.130 | 101.653 | 1007.061 | 935.123 | 101.641 |
| 40 | 997.118 | 947.301 | 102.384 | 997.113 | 947.305 | 102.393 |

## 4. RESULTS AND CONCLUSION

Developments techniques in computer technologies caused to use new tools, which can be used for saving the cultural heritage and nature easily. Photogrammetry is the most convenient tool for documentation of historical heritage. Accurate coordinate values are produced by this method faster than any other technique. Due to limitless information contained by the photograph, they might be used to understand the current status of the historical monuments. 3D models are becoming the most popular visualization techniques for the cultural heritage.

In this study; documentation of the Kapuağası Bridge has been done by the means of digital terrestrial photogrammetry. Different scaled sketches and 3D model of the bridge were evaluated by photogrammetric evaluation. Virtual reality and visualization techniques were used to produce short videos in different resolution.

The coordinates of the control points were evaluated after the adjustment to determine the accuracy of the modelling. The Coordinates calculated according the equations of intersection method and coordinates evaluated after adjustment were compared to set the $m_x$, $m_y$ ve $m_z$ and the point positioning error $m_{xyz}$ for the control points;
$m_x$ = 5.7 mm;
$m_y$ = 4.2 mm;
$m_z$ = 12.3 mm;
$m_{xyz}$ = 14.2 mm.

This point positioning error can be accepted as the accuracy of the model by not taking into consideration of the evaluation of the control points after the adjustment. (Avşar, E. Ö., 2006). Obtained results are given in Table 2.

Representing the model of the cultural heritage with the digital terrain model will enrich the visualization. It is important to use the real pattern captured from the monuments for covering the model will provide the most truthful modelling. Documentation studies of Cultural Heritages should be shared with public and be used to make public conscious of importance of Saving Cultural Heritages. (Avşar, E. Ö., 2006)

All monuments done by Architecture Sinan, must be documented. No evident about his calculation and drawn were inherited from his time. Relief of the monuments obtained from photogrammetric technique might be a guide for the architectures and hydrologist to understand his genius.

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## BIOGRAPHICAL NOTES

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