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Monitoring and certification of buildings and structures

Preparation for the restoration of building structures of Palmyra's architectural monuments in Syria affected by the war

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Abstract: *Introduction.* The historical architectural monuments of world significance of the city of Palmyra in Syria, which are included in the UNESCO World Heritage List, such as the Monumental (Triumphal) Arch, the Temple of Bel, and the Temple of Baalshamin are described. The history of their creation in the city of Palmyra, their significance for the inhabitants of Palmyra of that period and destruction from past earthquakes and during hostilities since 2015 are given. The importance of these monuments for the country and the world community is indicated, which was the reason for their choice as objects for research.

Aim. The research is intended to contribute to the restoration of these masterpieces of world architecture, which have existed for a little less than two millennia.

Materials and methods. A kind of certification of architectural monuments on the territory of Palmyra was carried out using the visual method of studying the state of objects. A detailed description and characteristics of the above-mentioned objects built as a synthesis of Greco-Roman and ancient Near Eastern architecture are given. The distinctive features and dimensions of building structures are described, plans, sections and photographs of objects before and after destruction are given for their subsequent reconstruction virtually in 3D. To improve the accuracy of three-dimensional models, various projects of 3D models of Palmyra's architectural monuments, created by various scientists and organizations, were collected.

Results. The states of the architectural monuments of Palmyra before and after the destruction were recorded, followed by their reconstruction in 3D for future restoration.

Conclusions. Conclusions are drawn about the expediency of restoring the architectural monuments of Palmyra, since they are of great importance for the entire world community, and many of them are included in the UNESCO World Heritage List.

Keywords: architectural monuments, Palmyra, temple of Baalshamin, temple of Bel, Monumental (Triumphal) arch, Great colonnade street, theater, tetrapylon, 3D reconstruction

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Мониторинг и паспортизация зданий и сооружений

Подготовка к восстановлению строительных конструкций памятников архитектуры Пальмиры в Сирии, пострадавших в результате войны

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Аннотация: *Введение.* Описываются исторические памятники архитектуры мирового значения в Пальмире в Сирии, которые входят в список Всемирного наследия ЮНЕСКО, такие как Монументальная (Триумфальная) арка, храм Баала (Бела), храм Баальшамина. Приводится история их создания в городе Пальмира, их значение для жителей Пальмиры того периода и разрушения от прошлых землетрясений и во время боевых действий, начиная с 2015 года. Указывается важное значение этих памятников для страны и мирового сообщества, что явилось причиной их выбора в качестве объектов исследования.

Цель. Исследование предназначено для того, чтобы внести вклад в восстановление этих шедевров мировой архитектуры, которые существовали на протяжении почти двух тысячелетий.

Материалы и методы. Выполнена своего рода паспортизация памятников архитектуры на территории Пальмиры с использованием визуального метода исследования состояния объектов. Даны характеристики и подробное описание вышеназванных объектов, построенных как синтез греко-римской и древней ближневосточной архитектуры. Описаны отличительные черты и размеры строительных конструкций, приведены планы, разрезы и фотографии объектов до и после разрушений для последующей их реконструкции виртуально в 3D. Для повышения точности трехмерных моделей были собраны различные проекты 3D-моделей архитектурных памятников Пальмиры, созданные различными учеными и организациями.

Результаты. Зафиксировано состояние памятников архитектуры Пальмиры до и после разрушений с последующей их реконструкцией в 3D для будущего восстановления.

Выводы. Сделаны выводы о целесообразности восстановления памятников архитектуры Пальмиры, так как они имеют огромное значение для всего мирового сообщества, к тому же многие из них входят в список Всемирного наследия ЮНЕСКО.

Ключевые слова: памятники архитектуры, Пальмира, храм Баальшамина, храм Баала (Бела), Монументальная (Триумфальная) арка, улица Большая колоннада, театр, тетрапилон, 3D-реконструкция

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Introduction

Palmyra is an ancient city originally founded in 1500 BC, and located in the Syrian Desert on the territory of the modern province of Homs in Syria, 240 km northeast of the capital Damascus. Palmyra originated as a transit or staging post for caravans that crossed the Syrian Desert, a kind of oasis in this desert, as it was known for its fertile soil and water wells. Palmyra was known as the bride of the desert and the Venice of the sands.

The city gained fame a little over 1700 years ago during the reign of Queen (Fig. 1) Zenobia (240–275), who was called the queen of warriors and in many ways resembled the Egyptian Cleopatra. She ruled like Cleopatra and was defeated by the Romans around 273–274. Her reign coincided with an era when the Romans began to take an interest in Palmyra, first for economic and later for political reasons. The sharp increase in the interest of the Romans in oriental goods led to a sudden increase in the importance of Palmyra to the size of one of the largest cities in the East [18–20]. The city connected the Roman world with Mesopotamia, caravans transited through Palmyra, crossing the Syrian Desert, and their transit brought wealth to the city [3]. Its sudden and enormous prosperity was brought to an end by the Romans. From the day when the Roman emperor Aurelian (Fig. 2) ended Zenobia's rule over the desert, trade routes parted, and the importance of Palmyra began to decline [1, 4, 5, 8, 21].

The rich cultural heritage, which constitutes a significant part of the intellectual wealth of society, is constantly under the threat of destruction. Threats of destruction come primarily from disagreements and conflicts and from natural disasters such as earthquakes. Wars have always harmed cultural heritage as well as human life. For example, the damage to the UNESCO World Heritage Sites of the Bamiyan Buddha Statues in Afghanistan in 2001, which are more than 1,700 years old, was followed by serious damage to the ancient city of Palmyra in Syria in 2015, which is also a UNESCO World Heritage Site [6, 9].

In Palmyra, before the destruction in 2015 during the hostilities, there were well-preserved temples dedicated to the ancient Mesopotamian gods, the Great Colonnade Street with Corinthian columns, the Monumental (Triumphal) Arch, the theater [7], the castle and the valley of tombs (Fig. 3–5). The city was considered one of the most majestic cities of the ancient world partially destroyed by time and cataclysms [17]. As one of the outstanding cultural centers of the world, it has been included in the UNESCO World Heritage List.

To restore the architectural monuments of Palmyra in Syria, the first step is to create their 3D models. The generally accepted algorithm for creating 3D models [11, 12, 13, 16] is as follows: Measurements of historical objects should mainly be carried out using laser-scanning technology for their subsequent 3D modeling. It is worth noting that merging scans into a single cloud of laser scanning points is a laborious process, and building an accurate dimensional 3D model of objects takes a lot of time, since software for designing buildings and structures gives few opportunities for accurate modeling non-ideal or imperfect walls of old buildings and structures.

Labor and financial costs for the production of measurement works and the construction of 3D models of buildings and structures can differ significantly depending on the required final detail and accuracy of the final model and on the complexity of the object itself. The duration and complexity of the shooting process depends on the distance to nearby buildings and the height of the building being shot, as well as on the possibility of shooting from the roofs of neighboring buildings.



Figure 1 – Zenobia in chains of the Roman emperor Aurelian
(Sculpture by Harriet Hosmer, 1859)

Figure 1 – Зенобия в цепях римского императора Аврелиана
(Скульптура Хэрриет Хосмер, 1859)



Figure 2 – The image of the Roman emperor Aurelian on a gold coin

Figure 2 – Изображение римского императора Аврелиана на золотой монете

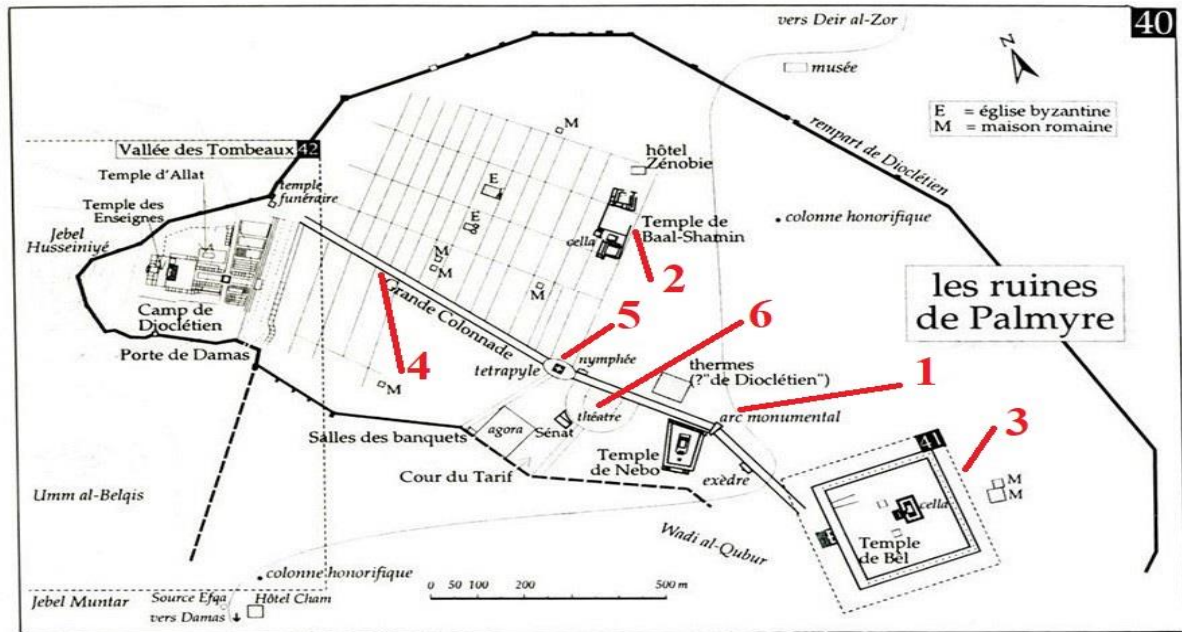


Figure 3 – Map of Palmyra, Syria:
1– Monumental Arch; 2– Temple of Baalshamin; 3– Temple of Bel; 4– Great Colonnade street; 5– Tetrapylon; 6– Theatre

Figure 3 – Карта г. Пальмиры, Сирия:
1– монументальная арка; 2– храм Баальшамина; 3– храм Баала (Бела); 4– улица Большая колоннада; 5– тетрапилон; 6– театр



Figure 4 – Palmyra before destruction (top view)

Рисунок 4 – Пальмира до разрушений (вид сверху)



Figure 5 – Great Colonnade Street (top view)

Рисунок 5 – Улица Большая колоннада (вид сверху)

Ancient water supply system

A system of pipelines (Fig. 6,a) and aqueducts to supply Palmyra with water from wells (Fig. 6,b) and grottoes existed before and during the reign of Queen Zenobia. They supplied the city and the caravans passing through it with precious water in the desert conditions.

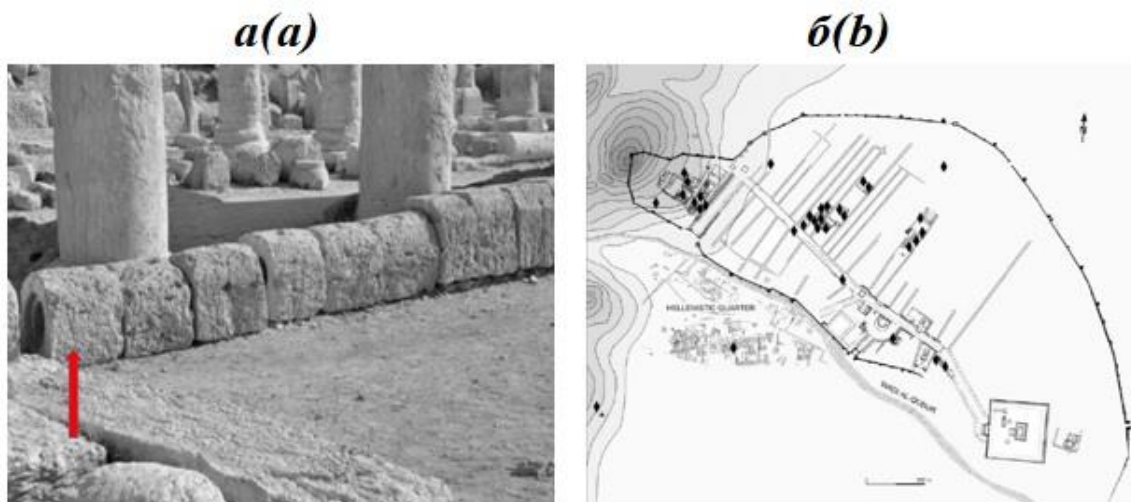


Figure 6 – The ancient water supply system of Palmyra:
a – Stone pipeline near the amphitheater (shown by arrow); *b* – Ancient wells on the territory of Palmyra (indicated by black diamonds)

Рисунок 6 – Древняя система водоснабжения Пальмиры:
a – каменный трубопровод недалеко от амфитеатра (показан стрелкой); *b* – древние колодцы на территории Пальмиры (обозначены черными ромбами)

Palmyra in the conditions of hostilities in Syria after 2011

Radical militants in a barbaric way, which is undoubtedly an act of vandalism, were destroyed in the following chronology, the Temple of Baalshamin was destroyed on August 24, 2015, then the Temple of Baal (Bel) was destroyed on August 31, 2015, then on October 4, 2015, the Monumental (Triumphal) Arch, and the main street of Palmyra, the so-called Great Colonnade Street, was partially destroyed. These architectural monuments were unique and combined mixed architectural styles, in which Greco-Roman architecture and ancient Near Eastern architecture were present. Currently, many masterpieces of world architecture in Palmyra are on the verge of extinction or have almost disappeared. This is an irreparable loss of UNESCO World Heritage Sites for us and for posterity.

The task of scientists and researchers is to reconstruct virtually with the help of modern science the above monuments of architecture so that they are preserved at least in such a virtual form for future generations and, of course, for their possible restoration. Three-dimensional computer graphics or 3D modeling allow you to virtually reconstruct, fix, preserve their previous state before destruction, and restore their authenticity and original appearance for the subsequent possible restoration of these beautiful architectural monuments, the building structures of which are an example of the high skill of ancient builders and a standard for their modern colleagues.

Since 2015, several steps have been taken around the world to preserve and revive the memory of the lost splendor of Palmyra, reconstructing the city's objects in 3D, thereby striving to resurrect them virtually in order to further restore the lost masterpieces of world architecture in Palmyra.

For example, a project called "Virtual Palmyra" was launched by a Turkish researcher, PhD Denker Ahmet with his students from Istanbul Bilgi University, or in the Russian Federation, by the Center for Rescue Archeology of the Institute of the History of Material Culture of the Russian Academy of Sciences, together with the Russian Geographical Society and Syrian specialists, was created a 3D model project Monumental (Triumphal) arch of Palmyra for its further restoration. Founded in France in 2013, Iconem is an innovative start-up that specializes in digitizing endangered cultural heritage objects, in 3D, together with the General Directorate of Antiquities and Museums of Syria (DGAM), 3D models of many of Palmyra's historical sites have been created. The California-based Arc/k project, created by an organization founded in 2014 in Los Angeles, has been working to create an online database of endangered historic sites. In particular, 3D models of the Monumental (Triumphal) Arch, the Temple of Bel, the Amphitheater and the Castle, which are located in Palmyra, were created.

The 3D models of the Temple of Bel and the Palmyra Triumphal Arch were created by Wissam Wahbeh, who is a PhD in architecture, lecturer in information modeling of buildings and structures, computational design, reconstruction of cultural heritage at the University of Applied Sciences and Arts of Northwestern Switzerland. The results of some of the above-mentioned 3D models have been presented in several figures in this article.

It is worth noting that the creation of 3D models of the same architectural objects by various specialists and organizations increases the accuracy and truthfulness of such models and brings them as close as possible to the original.

Temple of Baal (Bel)

In Palmyra, the main sanctuary is the Temple [10] of Baal (Bel) (Fig. 7). It was located on a stepped base in the middle of an almost square open courtyard measuring 175 x 180 m. The main building of the temple at the level of the stylobate rises above a rectangular

area measuring 29.52 m x 54.6 m. The building was surrounded by a portico about 30 m deep, therefore, the external dimensions of the temenos (the sacred area of the temple) were increased to 205 x 210 m, its central room was rectangular in shape and was surrounded on four sides by columns, and on the ends of the building there were in two rows. The Great Colonnade Street leads to its entrance. The central entrance to the temple was located on the longitudinal side, and not on the front side, as in other ancient temples. The entrance was distinguished by powerful pylons with stone reliefs. The inner space of the temple of Baal was a large hall not separated by either colonnades or walls. The temple was a magnificent synthesis of Greco-Roman and ancient Middle Eastern architecture.

The ancient builders erected the Temple of Baal in honor of the local supreme Mesopotamian god Baal (Bel), who was revered in the city and considered the main god of Palmyra and was equal to the Roman god Jupiter and the Greek god Zeus. The building structures of the temple before the destruction was in good condition.

Corinthian columns existed on the outer wall. The porticos of the temple had double rows of Corinthian columns. The exception was the western side, where only one row of columns existed. The ends of the Temple stood in a north-south direction. The main axis of the Temple was deviated by 5 degrees from the north-south axis and divided its open courtyard into two asymmetrical parts, namely in a ratio of 3:2. The western part had a depth of about 105 m, and the eastern part had a depth of 70 m. The inner part or main building, the so-called Cella, was a rectangular building measuring 15.8 x 39 m. (Fig. 8). This building was surrounded by one row of Corinthian columns, 8 columns from the north side and from the south side, 12 columns each on the west side and 13 columns each on the east side. The height of these columns was about 15.81 m, and their base diameter was about 1.33 m, the height of the building was 33.14 m (Fig. 9).

Until its destruction on August 31, 2015 (Fig. 10), this temple impressed visitors and tourists as it was one of the most impressive and famous structures in the Syrian Palmyra. This ancient city was associated with this magnificent temple.

Figures 11–14 show 3D models of the Temple of Baal (Bel) made by different organizations and scientists.



Figure 7 – Temple of Bel in Palmyra, Syria

Рисунок 7 – Храм Баала (Бела) в Пальмире, Сирия

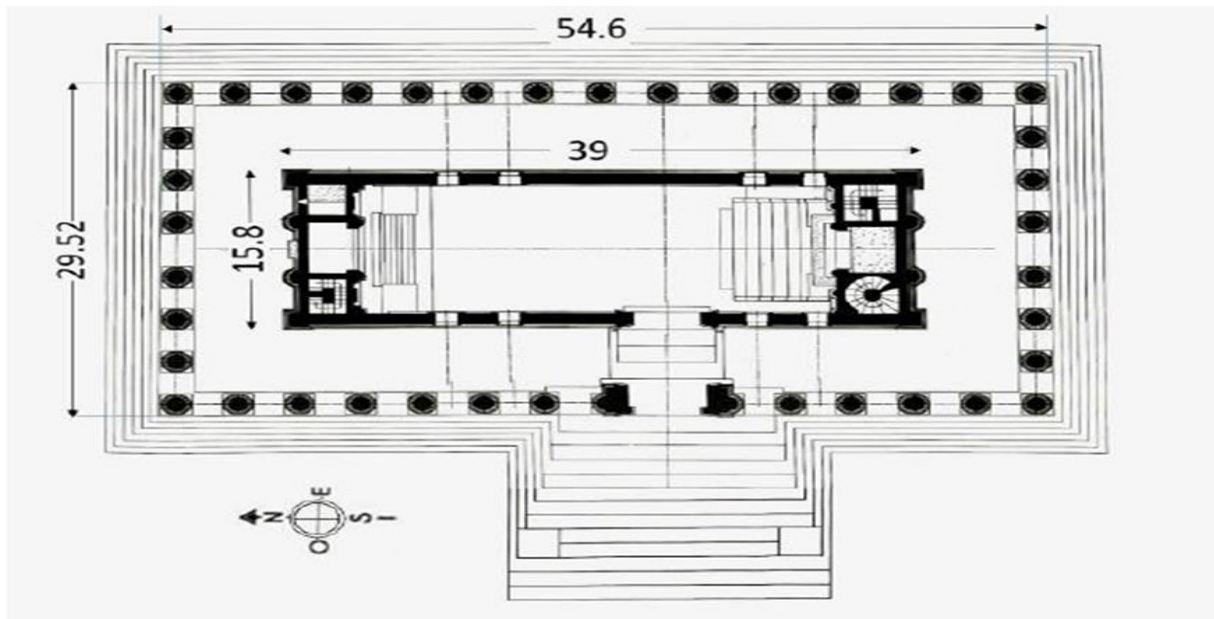


Figure 8– Plan of the Temple of Bel, (dimensions in m)

Рисунок 8 – План храма Баала (Бела), (размеры в м)

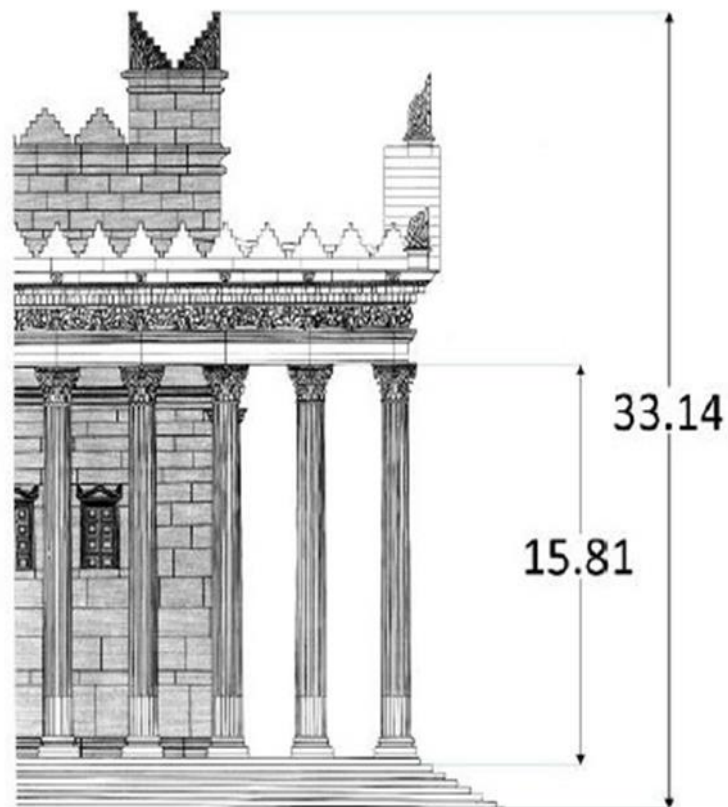


Figure 9 – Side view of the main building of the Temple of Bel, (dimensions in m)

Рисунок 9 – Вид сбоку главного здания храма Баала (Бела), (размеры в м)



Figure 10 – The ruined Temple of Bel

Рисунок 10 – Разрушенный храм Баала (Бела)



Figure 11 – 3D of the destroyed Temple of Bel in Palmyra (Source: Iconem and DGAM)

Рисунок 11 – 3D разрушенного храма Баала (Бела) в Пальмире
(Источник: Iconem and DGAM)



Figure 12 – 3D reconstruction of the Temple of Bel and its temenos in Palmyra (state before destruction) (Source: Arc/k project)

Рисунок 12 – 3D-реконструкция храма Баала (Бела) и его теменоса в Пальмире (состояние до разрушения) (Источник: Arc/k project)

A notable aspect of the architecture of the Temple of Bel is the asymmetry of the columns on the sides. This was due to the fact that access to the cella was not through the front door. The door was placed asymmetrically on the side wall, requiring the visitor to turn 90° to view the cult site (Fig. 13).

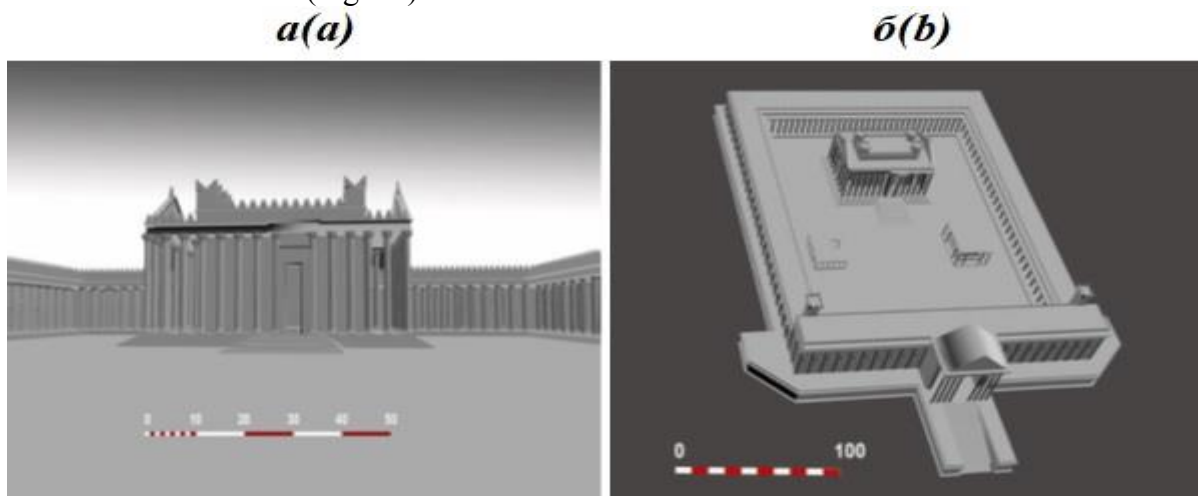


Figure 13 – 3D reconstruction of the Temple of Bel:
a – Full 3D reconstruction of the western side of the Temple of Bel in accordance with historical records, (scale in m); *b* – Full 3D Reconstruction of the Temple of Bel and its temenos in Palmyra in accordance with historical records. Bird's-eye view (scale in m) (Source: Denker Ahmet)

Рисунок 13 – 3D-реконструкция храма Баала (Бела):
a – Полная 3D-реконструкция западной стороны храма Баала (Бела) в соответствии с историческими записями, (шкала в м); *b* – Полная 3D-реконструкция храма Баала (Бела) и его теменоса в Пальмире в соответствии с историческими записями. Вид с высоты птичьего полета (шкала в м) (Источник: Denker Ahmet)

The temple of Bel in its appearance was built according to the canons of Hellenistic architecture (Fig. 13). The entrance to the courtyard was carried out from the western side through the monumental propylaea (that is, the front passage formed by porticos and columns) 35 m wide. This entrance occupied almost one sixth of the front wall. Visitors were led to the gate by a majestic staircase. The facade was decorated with a projecting portico with 8 columns (Fig. 14).

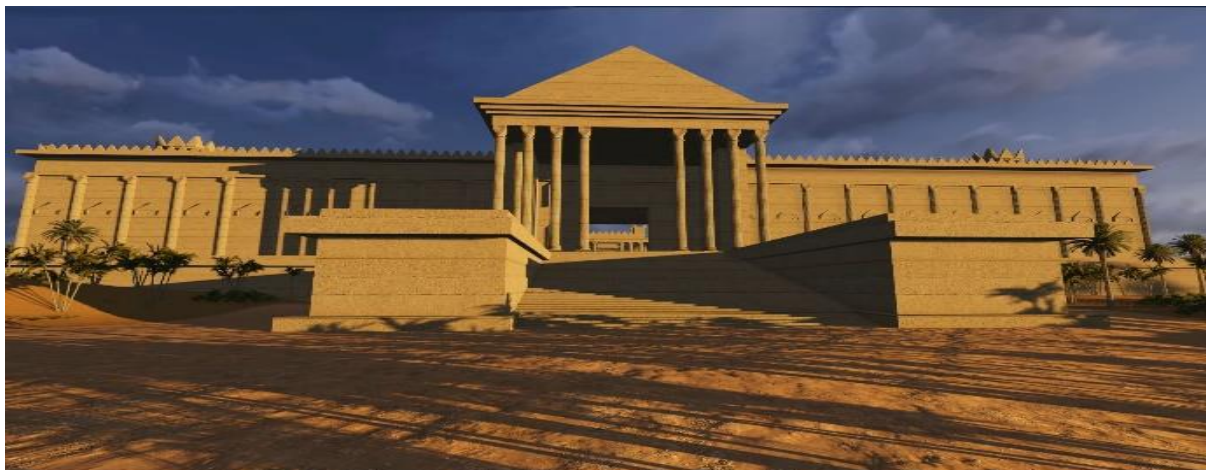


Figure 14 – Complete 3D reconstruction of the monumental propylaea of the Temple of Baal (Bel) in accordance with historical records (Source: Denker Ahmet)

Рисунок 14 – Полная 3D-реконструкция монументальных пропилеев храма Баала (Бела) в соответствии с историческими записями (Источник: Denker Ahmet)

Temple of Baalshamin

The Temple of Baalshamin (Fig. 15) was located 200 m north of the Great Colonnade Street. It was facing east. The main temple building was located in a semi-rectangular temenos with a maximum length of 163 m and a maximum width of 58 m (Fig. 16).



Figure 15 – The Temple of Baalshamin in Palmyra, Syria, before the destruction

Рисунок 15 – Храм Баальшамина в Пальмире, Сирия, до разрушения

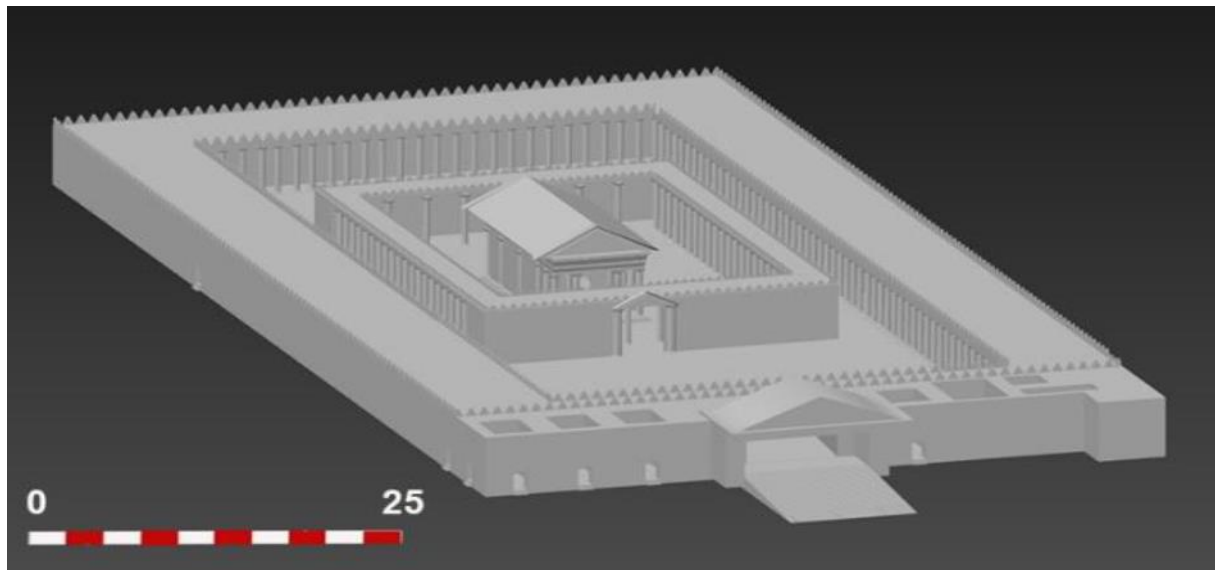


Figure 16 – Full 3D reconstruction of the Temple of Baalshamin and its temenos in Palmyra in accordance with historical records. Bird's-eye view (scale in m) (Source: Denker Ahmet)

Рисунок 16 – Полная 3D-реконструкция храма Баальшамина и его теменоса в Пальмире в соответствии с историческими записями. Вид с высоты птичьего полета (шкала в м) (Источник: Denker Ahmet)

As in the case of the Temple of Bel, the Temple of Baalshamin [15] also demonstrated hybridity in design. Greco-Roman features were demonstrated by its colonnade, prostyle, facade and tetrastyle structure i.e. with four columns in front.

The main building of the temple stood on a stylobate measuring 10.6 x 16.9 m (Fig. 17). The four free-standing columns of the portico are made in the Corinthian order. They were 7.8 m high and stood on Attic bases; the total height of the building was 12.9 m (Fig. 18). The walls of the cella were decorated with flat plaster in the Corinthian style.

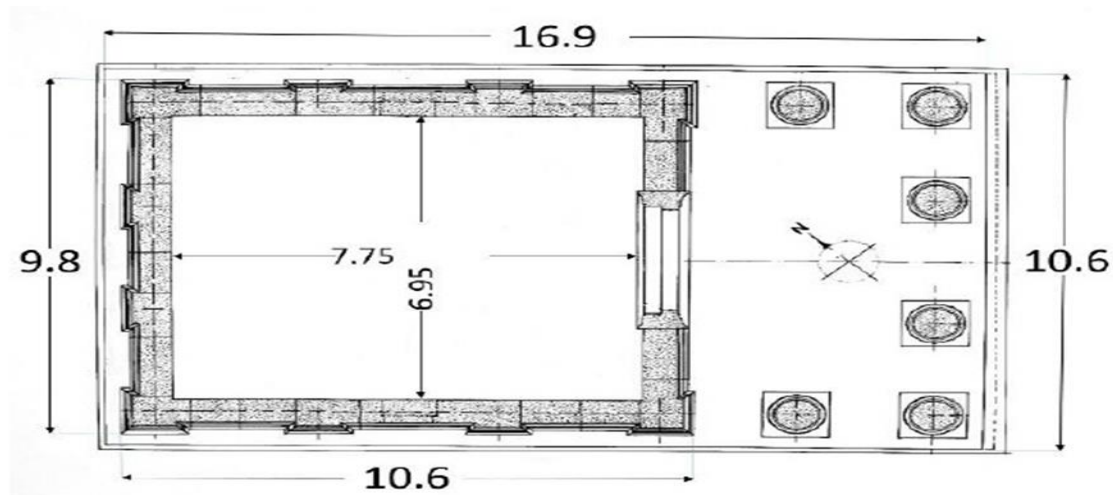


Figure 17 – Plan of the main building of the Temple of Baalshamin (dimensions in m)

Рисунок 17 – План главного здания храма Баальшамина (размеры в м)

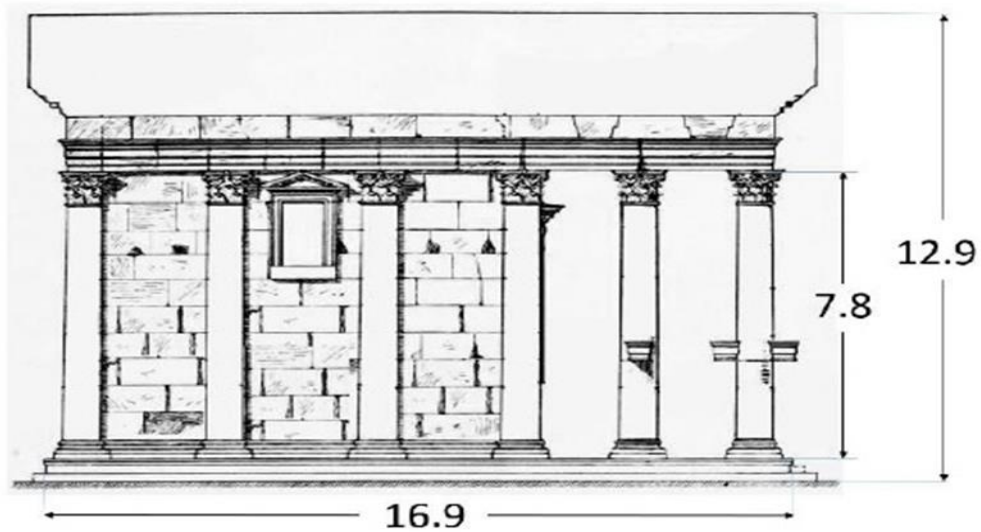


Figure 18 – Side view of the Temple of Baalshamin (dimensions in m)

Рисунок 18 – Вид сбоку храма Баальшамина (размеры в м)

The Association for the Protection of Syrian Archaeology reported that the temple of Baalshamin was destroyed by radical militants in August 2015 (Fig.19).



Figure 19 – The ruined Temple of Baalshamin

Рисунок 19 – Разрушенный храм Баальшамина

Along with the general classical Greco-Roman appearance, it also reflects pronounced Near Eastern motives. The most notable of these were the cella windows. A three-

dimensional reconstruction [14] of the Temple of Baalshamin and its environs is shown in Figures 20–22.



Figure 20 – 3D reconstruction of the Temple of Baalshamin in Palmyra corresponding to the state before the destruction (Source: archeologie.culture.gouv.fr and Iconem)

Рисунок 20 – 3D-реконструкция храма Баальшамина в Пальмире, соответствующая состоянию до разрушения (Источник: archeologie.culture.gouv.fr and Iconem)

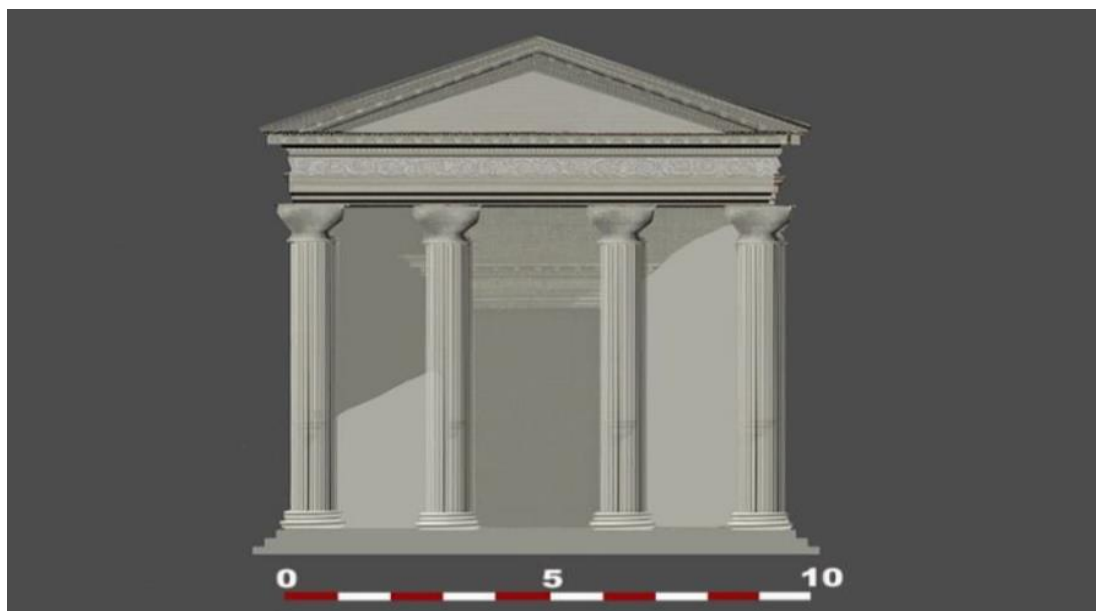


Figure 21 – 3D reconstruction of the portico of the Temple of Baalshamin (scale in m) (Source: Denker Ahmet)

Рисунок 21 – 3D-реконструкция портика храма Баальшамина (шкала в м) (Источник: Denker Ahmet)



Figure 22 – 3D reconstruction of the Temple of Baalshamin in Palmyra in accordance with historical records (Source: Denker Ahmet)

Рисунок 22 – 3D-реконструкция храма Баальшамина в Пальмире в соответствии с историческими записями (Источник: Denker Ahmet)

Monumental Arch (Triumphal Arch) of Palmyra

The monumental Arch of Palmyra or as it is otherwise called the Triumphal Arch (Fig. 23) was built at the end of the 2nd century during the reign of the Roman emperor Lucius Septimius Severus and belongs to Roman architecture [2]. It consists of three parts (entrances), to which the Great Colonnade Street adjoins. Structurally, it is located at an angle of 30° to the above-mentioned straight street (Fig. 24), which connects to the Temple of Bel. The middle part of the street is about 11 m wide, was not paved with flat stones and was used for driving animals and passing ancient vehicles. On the sides of the street, there were two covered porticos built of golden limestone and pink Aswan granite, the width of each portico is about 7 m. The diameter of the columns of the above-mentioned porticos was about 0.95 m, and their height was about 9.5 m. As of 2014, there are about 150 columns left. In 2015, the Monumental Arch was blown up by radical militants (Fig. 25). 3D reconstruction of the Monumental Arch is shown in Figures 26–28.



Figure 23– Monumental Arch (Triumphal Arch) of Palmyra, Syria, before destruction

Рисунок 23 – Монументальная арка (Триумфальная арка) Пальмиры, Сирия, до разрушения

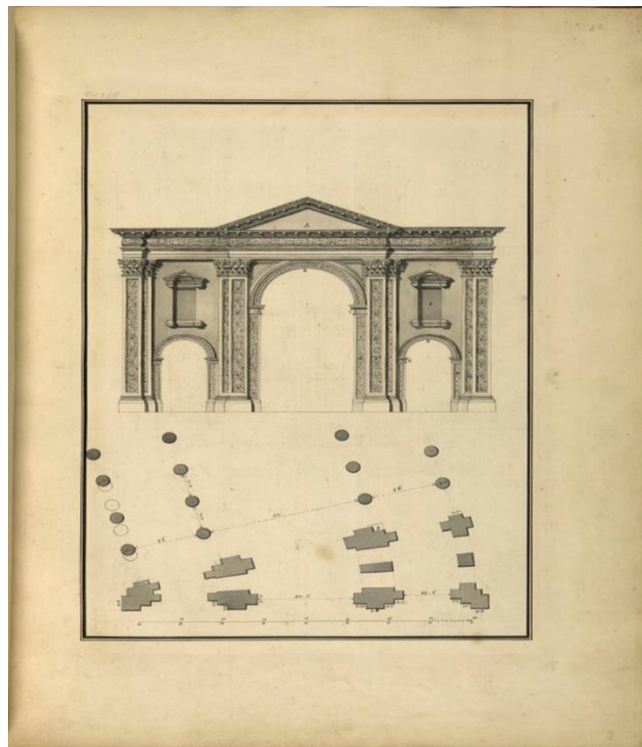


Figure 24 – Reconstruction of the plan and facade of the east side of the Monumental Arch of Palmyra, Syria (Author: Borra, Giovanni Battista, London, 1753)

Рисунок 24 – Реконструкция плана и фасада восточной стороны Монументальной арки в Пальмире, Сирия (Автор: Борра, Джованни Баттиста, Лондон, 1753)



Figure 25 – Destructions in the Monumental Arch of Palmyra

Рисунок 25 – Разрушения в Монументальной арке в Пальмире



Figure 26 – 3D of the destroyed Monumental Arch of Palmyra (Источник: Iconem)

Рисунок 26 – 3D разрушенной Монументальной арки в Пальмире (Source: Iconem)



Figure 27 – 3D Reconstruction of the Monumental Arch of Palmyra to the state before destruction in 2015 (Source: Arc/k project)

Рисунок 27 – 3D-реконструкция Монументальной арки в Пальмире до состояния перед разрушением в 2015 году (Источник: Arc/k project)



Figure 28 – Full 3D reconstruction of the Monumental Arch in Palmyra approximately in accordance with historical records (Source: SCADL & Co)

Рисунок 28 – Полная 3D-реконструкция Монументальной арки приблизительно в соответствии с историческими записями (Источник: SCADL & Co)

Monitoring, certification, and 3D modeling of other important facilities in Palmyra such as the Great Colonnade Street, the Tetrapylon, the Theater, and the Castle (Fig. 29–32) and others, which have been damaged since 2015, may be the subject of further research.

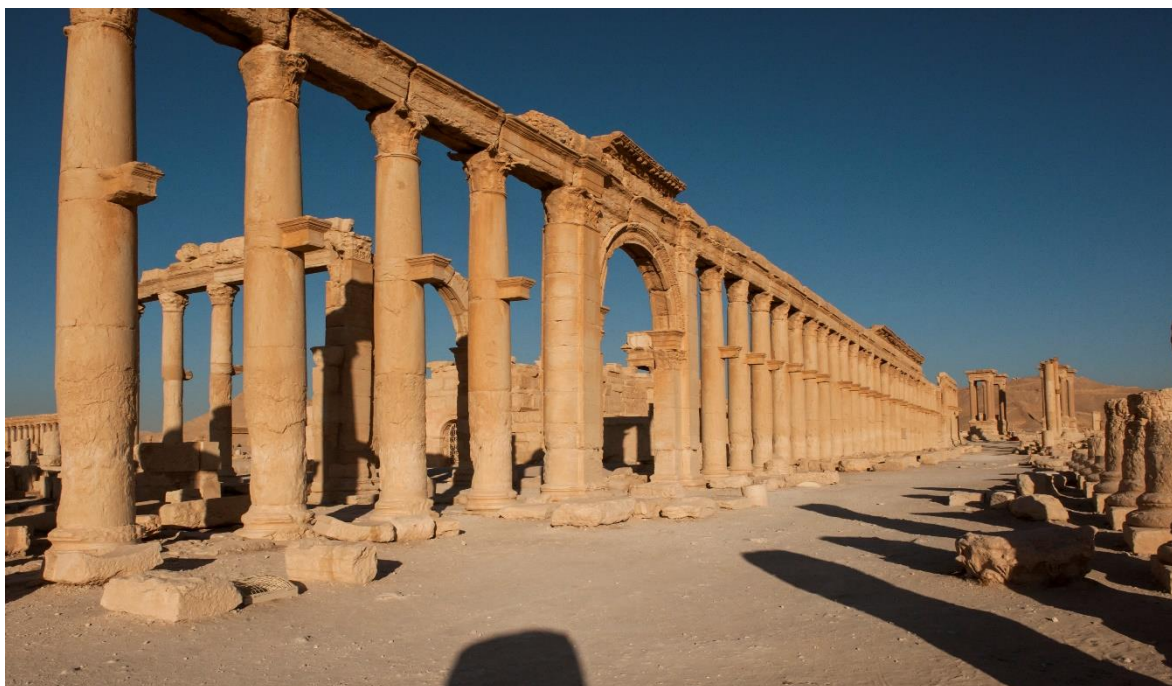


Figure 29 – The Great Colonnade Street in Palmyra in 2013

Рисунок 29 – Улица Большая колоннада в Пальмире в 2013 г.



Figure 30 – The Tetrapylon in Palmyra in 2009

Рисунок 30 – Тетрапилон в Пальмире в 2009 г.



Figure 31 – The Theater in Palmyra in 2015

Рисунок 31 – Театр в Пальмире в 2015 г.



Figure 32 – The Castle in Palmyra in 2015

Рисунок 32 – Замок в Пальмире в 2015 г.

Conclusions

- This study examined the most significant masterpieces of world architecture in Palmyra that existed for many centuries and were included in the UNESCO World Heritage List, disappeared, or partially disappeared overnight due to the inability of people to appreciate their past in order to have a better future;
- 3D models of the Temple of Baal (Bel), the Temple of Baalshamin and the Monumental (Triumphal) Arch were collected, which were practically destroyed as a result of the war;
- The presence of various projects of 3D models of Palmyra's architectural monuments created by various scientists and organizations will improve the accuracy of such models and bring them as close as possible to the original;
- The presence of many projects of 3D models created by various scientists and organizations will allow preserving the above-mentioned architectural monuments virtually and restoring them in the future;
- It is necessary to create 3D models of other significant objects of Palmyra such as Tetrapylon and Great Colonnade Street, etc., thereby continuing the research in this direction.

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