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Three-Dimensional Reconstruction of the Early Christian Temples of the Roman Fortress of Pitiunt

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Abstract: Since 2018, the authors have been working on reconstructing the exterior of the Great Pitiunt Roman fortress in 3D. This article presents the results of the visualization of the exterior and interior of the temple complex. During the study, the dimensions and plans of the site were analyzed, revealing discrepancies in various sources. To clarify the complex's dimensions, aerial photography using UAV was conducted, and photogrammetric models, orthophoto, and digital surface models were created. The research also uncovered previously unrecorded architectural features. During the reconstruction of the temples, much attention was paid to the structural design of the buildings, connections and load distribution. Engineering calculations have been carried out for the clarification of the structural solutions. The article presents the results of a detailed reconstruction of the exterior, interior and structural features of Temple Nos. 1–4, based on preserved archaeological evidence, excavation results, contemporaneous Early Christian sites, and an analysis of the materials and technologies used at the time. The reconstruction of the mosaic floor of Temple No. 2 allowed a realistic visualization of the interior.

Keywords: late antique and early medieval temples; early Christian architecture; eastern Black Sea region; Great Pitiunt; 3D reconstruction and visualization; photogrammetry; UAV

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1. Introduction

Pitiunt (modern Pitsunda, Abkhazia) (Figure 1) is one of the oldest cities and religious centres of north-western Colchis, both historically and spiritually.

The first mention of this city comes from Artemidorus of Ephesus, a famous geographer of the second–first century BCE, mentioned by Strabo in his "Geography" (Strabonis Geographica, XI, II, 14). The text refers to Pitiuntus as "great", indicating its importance in the eastern Black Sea region during the heyday of the Pontic kingdom under Mithridates VI Eupator. It later came under Roman interest and is mentioned in the works of Roman and Byzantine authors such as Gaius Plinius Secundus (Historia naturalis, V.16), Flavius Arrianus (PPE, 27), Zosimus (Zos NH, I, 32–33) and Theodoret of Cyrus (Ecclesiastical Historia, V, 34). Despite the destruction caused by the Geniochs in the first century CE, the status of the site remained high.

In the second half of the second century, a Roman fortress was built at Pitiunt, making it an important strategic outpost of the Empire on the northeastern frontier. It served to link Asia Minor, the eastern Black Sea, the Bosphorus and Chersonesos. Its remoteness from the centre of the Empire determined its status as the most distant and problematic area to live in. Therefore, when the persecution of Christians intensified under the emperors Diocletian and Maximian, Pitiunt became a place of exile for them. In the late third and early fourth centuries, the first Christian communities began to form here, followed by a bishopric being established. Bishop Stratophilus of Pitiunt is mentioned in the lists of participants of the First Council of Nicaea in 325, representing the diocese of Pontus of Polemon along with the bishops of Trebizond and Neocessaria.

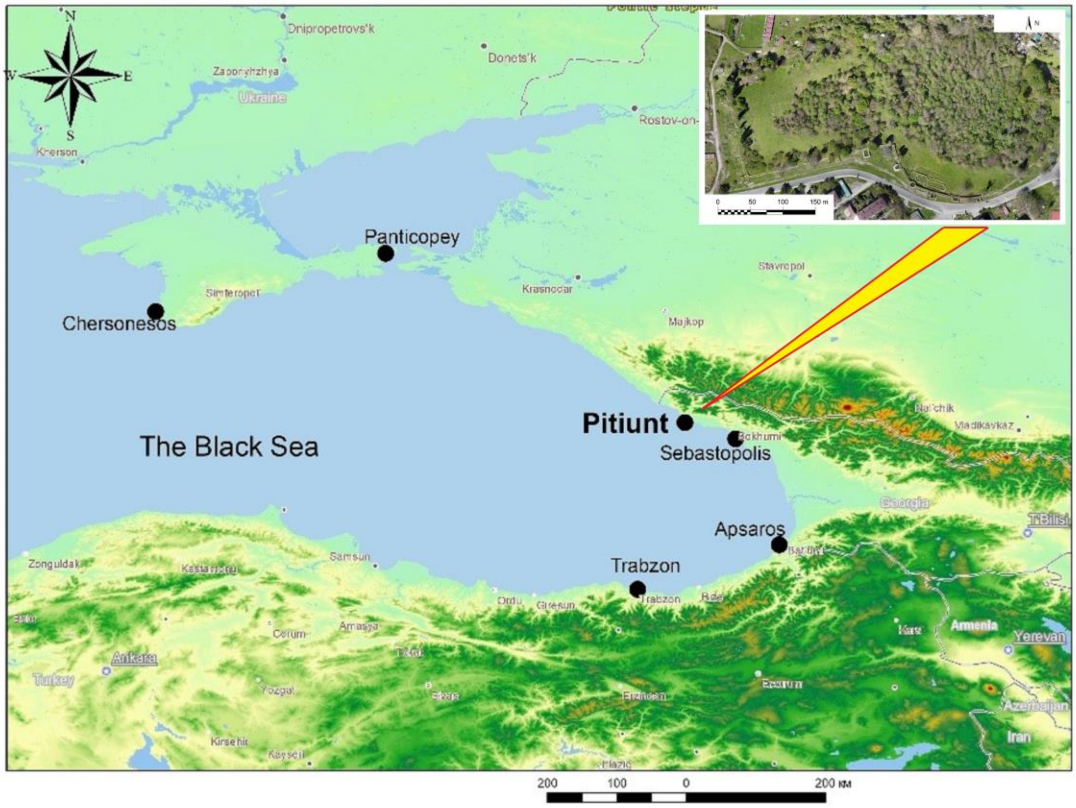

Figure 1. Pitiunt fortress on the map.

The first Christian centres in the eastern region of the Black Sea were established within the military fortifications of the Empire. The fortress of Pitiunt served as a centre for the spread of Christianity in northwestern Colchis for a considerable period of time. The study and reconstruction of the appearance of the first Christian temples in the region are of great importance for researching the spread of Christianity and the formation of early Christian architecture on the Black Sea coast of the Caucasus.

The Roman fortress of Pitiunt and its temples are among the best studied sites of Late Antiquity and the Early Middle Ages in the northwestern region of Colchis.

The first comprehensive description of the territory of the town-fortress Pitiunt was made by the famous traveller, Dubois de Montperreux, in 1837 [1]. However, it was not until 1952 that the Bichvinta archaeological expedition of the I.A. Javakhishvili Institute of History, Archaeology and Ethnography of the Academy of Sciences of the Georgian SSR, led by Doctor of Historical Sciences, A.M. Apakidze, began the first systematic excavations of the territory of "Great Pitiunt". The team defined the outlines of the fortress and identified 27 towers, residential and administrative buildings. They also discovered and studied a garrison bath house and a multi-level temple complex in the eastern part of the fortress. The results of this study are presented in the three-volume monograph «*Great Pitiunt*» [2–4]. Subsequently, the site was further studied by O.D. Lordkipanidze, Z.V. Agrba and others until the mid-1980s.

In the south-western part of the eastern fortification, the expedition uncovered the remains of four early Christian temples, which were built successively on the same site over a period of two centuries [5]. The research made it possible to study the architecture of each temple and the mechanisms of successive transformation of one building into another. An important result of this work was the discovery of rich mosaic floors made in the Opus Tesselatum technique in Temple No. 2 [6–8]. Mosaics created using this technique have not been discovered on the eastern Black Sea coast. The temple complex excavation materials and mosaic floor themes have subsequently been analyzed by various authors [9–12].

The collected material served as the basis for a detailed 3D reconstruction of the exterior and interior of the temples of this significant early Christian centre in northwestern Colchis.

2. Materials and Methods

In recent decades, the development of new technologies and software has led to the widespread use of photogrammetry, 3D reconstruction and engineering modelling in archaeological research and work on the protection of historical and cultural heritage sites [13–18].

In this regard, the reconstruction and visualization of the original appearance of the Roman fortress of Pitiunt, an important economic, military and Christian centre of the eastern Black Sea region during Late Antiquity and the Early Middle Ages, is of great interest. This work, aimed at creating a virtual exhibition for the "Great Pitiunt" Museum in Pitsunda, has been carried out by the Markula Archaeological Expedition since 2018. The complex and varied task was divided into several stages.

In the first stage, from 2018 to 2019, a 3D reconstruction of the fortress of Pitiunt in its heyday (the second half of the 4th century to the beginning of the 5th century) was carried out [19]. The work resulted in models of defensive structures and infrastructure elements for the fortification. Initially, a probable appearance of Temple Nos. 1 and 3 was proposed as model-filling elements without significant details. In the second stage, there was a detailed elaboration of the appearance of the floor mosaics which decorated Temple No. 2 and which are partially preserved on the floor of Temple No. 3. A detailed description of the process and justification of each element of the composition is given in this work [20]. After the reconstruction of the historical environment and the interior elements, it was possible to proceed directly to the 3D reconstruction of the original appearance of the site of ecclesiastical architecture of the 4th–6th centuries.

A major advantage of the temple complex of the Roman fortress of Pitiunt is that the site has been the subject of very detailed research. This lasting expedition produced a wealth of documentation, including detailed drawings and descriptions of the site, photographs and analytical papers. All this is complemented by a large archaeological collection of artefacts held at the local Great Pitiunt Museum Reserve.

The good state of conservation of the site makes it possible to study in situ the materials used, the quality of the masonry, the thickness of the lime mortar and the presence of opus mixtum brick bands separating the layers of marine conglomerate masonry. The richness of the tile remains allows one to determine the geometric dimensions and their application in the model. This constitutes the fundamental quantitative material on which the work presented is based.

During the research, a comprehensive methodology for the 3D reconstruction of historical sites was developed. The methodology includes the following stages:

1. Clarification of the ground plan, preserved fragments of the structure, building materials, details, etc. This work is based on the use of photogrammetry involving taking pictures of the objects using a digital camera from the ground and/or using a UAV. The photogrammetric 3D model was used to create the primary plans, projections and sections of the reconstructed temple.
2. Study of the excavated materials, building materials to clarify missing dimensions and features of the building, and variations in the construction of some elements.

3. Studying literature to find architectural analogues of the modelled temple and to determine the influence of various architectural schools on the proportions and assumed vertical dimensions.
4. Producing drawings, projections and sections, as well as design variants for unpreserved elements based on architectural analogues.
5. A 3D model of the temple must be constructed according to the received drawings, with verification and correction of the power scheme of the building, taking into account the variations of proportions. Detailed modelling of door and light openings, as well as decorative elements, must also be done, taking into account analogues and building traditions accepted at that time.
6. Verification of the chosen technical solutions for strength and stability by carrying out the necessary engineering calculations.
7. Working out the appearance of the building, taking into account the archaeological data on the materials used, such as the presence or absence of plaster, brick, stone or combined masonry Opus Mixtum and the modelling of the roofing, depending on the presence or absence of tiles in the archaeological material.
8. Selection of background, lighting and final visualization of the site.

The study adopted a complex approach to the 3D reconstruction of architectural objects, allowing a deeper understanding of the technical solutions adopted by the architects of the period under study, leading to important historical and architectural assumptions about the peculiarities of the object under study.

With regard to the reconstruction of the described temple complex, let us examine some points of this methodology in more detail. The photogrammetric model of the site was used to analyze the primary geometry. This model was obtained using a well-established algorithm for sites of a similar class [21]. The algorithm involves capturing aerial photographs of the object using a quadrocopter Mavic Air 2S equipped with an 18 MP camera. Calibration markers are positioned on the excavation site, with fixed distances between them determined using a Bosch GLM 40 laser rangefinder. They are used to scale the resulting 3D model and to obtain accurate measurements.

The UAV flight altitude was set to avoid obstacles, and in our case, it was 10 m. The camera was set at a 90-degree angle to the horizon. Photos were taken automatically every 2 s, with the flight speed adjusted to ensure 60–80% overlap between the adjacent images. The manual mode was used to fly the UAV along a given trajectory. During the survey, several passes were made in a serpentine pattern from east to west and back, with the flight path being shifted northwards by 2–3 m in each cycle. The UAV survey data were processed using the Agisoft Metashape Professional program to create a photogrammetric model, orthophoto and digital surface model (DSM). Autodesk AutoCAD was used to produce drawings, plans, projections and sections of the structure.

One of the most significant advantages of the temple complex of the Roman fortress of Pitiunt is its extensive knowledge base. The Bichvinta expedition has made a substantial contribution to the study of the site, with the result that a considerable amount of material is now available, including detailed drawings, descriptions, photographic material and analytical articles. This is further enhanced by the presence of an extensive archaeological collection of artefacts stored in the local museum-reserve, known as "Great Pitiunt".

The good preservation of the site allows for the study of building materials, the quality of masonry and the thickness of lime mortar, as well as the presence of Opus Mixtum brick belts separating layers of masonry from marine conglomerate. The abundance of tile remnants permits the geometric dimensions of these tiles to be determined and applied to the construction model.

Furthermore, the justification of certain vertical dimensions in the structures of temples constitutes an important factor in this work. The principal distinction between the methodologies employed in the architectural designs of ancient and modern times is that ancient architects did not rely on engineering calculations, but instead adhered to the established proportions codified by Pythagoras, Plato and Vitruvius [22]. As they were primarily philosophers, their knowledge influenced the practical implementation of the proportions in architecture. They employed the concept of mathematical ratios in the design of exterior architectural features, selecting the optimal width-to-height and width-to-length proportions. The motivation for these rules was not so much to provide a constructive plan, but rather to achieve a sense of harmony. As a result, they were actively applied in Roman architecture and, subsequently, in Christian temple construction.

The proportions of early Christian temple plans have been the subject of extensive research [23,24]. However, due to the destruction of many sites, the determination of vertical proportions is less straightforward. Nevertheless, an analysis of the proportions of the preserved temples allowed us to hypothesize certain ratios and rules, which could then be used to calculate the height of specific elements with a certain degree of probability. The results of the sketch modelling were displayed on the primary drawings in the Autodesk AutoCAD 2019.1.2 engineering software. The missing vertical dimensions could be obtained using the construction method on the side projections and cross-sections [24].

The finished drawings were then imported into the Autodesk 3DsMax environment, where the object was finally modelled in 3D.

The realism of the resulting visualization is an important aspect of the work. Adobe Photoshop was used to create realistic material textures.

In this type of reconstruction, it is important to ensure the validity of the technical decisions taken. If there were any doubts, the necessary strength and stability calculations were carried out using CAD LIRA, a common tool for structural engineering.

3. Results and Discussion

The work presented here is based on the assumptions of the archaeological expedition to the Bichvinta site. Architect I.N. Tsitsishvili, who led the study of this complex, proposed the following chronology of temple construction [5].

The oldest single-nave basilica with a semicircular apse was built in the first third of the fourth century. Apparently built during the reign of Emperor Constantine the Great, it is the earliest monument in the complex, Temple No. 1. It is believed to be the earliest known Christian temple in the eastern Black Sea region. It is generally believed that this temple was the residence of Bishop Stratophilus of Pitiunt. The temple was destroyed by fire in the middle of the fourth century.

In the second half of the same century, a large basilica was built on the site of the destroyed church. It had a rich mosaic floor and marble columns. But even this temple did not last long and was soon destroyed.

By the end of the fourth century, the temple was rebuilt once again. The new basilica was characterized by a modified apse and a reduced narthex. Marble columns were replaced with brick pillars. The surviving parts of the mosaic floor were left in place, while the missing parts were replaced with ceramic tiles. This temple was also destroyed, probably at the end of the fifth century. The basilica was never rebuilt and, judging from the burials in the central and northern aisles, became a tomb.

The last small temple was built at the beginning of the sixth century, and its apse cuts deeply into the narthex of Temple No. 3. It is smaller in size and has a more modest decoration. It may have been destroyed in 542 by the Romans during the invasion of Chosroes, when the Romans, according to Procopius of Caesarea, "prior to the enemies burnt houses and demolished walls to their foundations" (Procopius of Caesarea. IV (VIII), 4, 4, 6).

Subsequent research [9,10] has slightly adjusted the dating of Temple Nos. 2 and 3: Temple No. 2 is now attributed to the end of the fourth century, with its mosaic to the beginning of the fifth century and Temple No. 3 to the end of the fifth or beginning of the sixth century.

The Pitiunt temple complex is therefore made up of the remains of four temples. They were built in succession on the same site between the fourth and sixth centuries.

Simultaneously, the first three temples overlap, while the fourth temple is moved to the west.

Part of the wall of the third temple was dismantled during the excavation of Temple Nos. 1 and 2. As a result, all that remains of the complex are the outlines of the foundations, with some sections of the walls poorly identified (see Figure 2).

Figure 2. Exterior view of the Pitiunt temple complex, current state.

The question arises as to the basic contours of the temple foundations, which can be used in 3D reconstruction. In the materials of the Bichvinta expedition [3,4], the plans of the temple were given in different variants. Subsequently, several authors, including Lekvinadze [9] and Khrushkova [10], have researched this issue and offered drawings and dimensions based on the same primary source. However, our analysis of these researchers' plans and descriptions revealed several errors and discrepancies that we have carefully reviewed and corrected to ensure accuracy. The scaling and orientation of the drawings showed inconsistent geometric dimensions that did not match the available descriptions. To refine the complex's geometry, an orthophoto obtained through aerial photography was used. This allowed for the identification of several structural features and the clarification of their dimensions. Photogrammetry revealed that the foundations of Temple Nos. 1–3 have a prominent parallelogram in 3–4° (see Figure 3), which was not reflected in any of the primary plans obtained by the Bichvinta expedition. The temples were all inscribed within a rectangular outline formed by the north, west and south walls.

The use of parallelogram plans is a characteristic of Byzantine architecture, as seen in the temples at Chersonesos, Greece and Asia Minor [23,25].The analysis shows that in the early Byzantine period, the rule of diagonal equality was often neglected in the planning of buildings. This resulted in geometric distortions and deviations from perpendicularity. Consequently, there is a deviation from the ancient rules of architecture, which respected diagonal equality.

The reasons for not respecting the right angles can vary. There is an interesting peculiarity: the parallelogram of Temple Nos. 2 and 3 is not the original one. An analysis of the resulting orthophoto (Figure 3) shows that the foundations of Temple Nos. 1, 2 and 3 are aligned along the southern and western walls. Temple No. 1, considered the cathedral temple under Bishop Stratophilus of Pitiunt, established the geometry for Temple Nos. 2 and 3. Temple No. 4 was moved to the west and its eastern wall is attached to the western wall of Temple Nos. 1–3, but does not quite coincide with them. Therefore, most of its angles are almost right angles, and it was not bound by the original geometry of the walls of its predecessors.

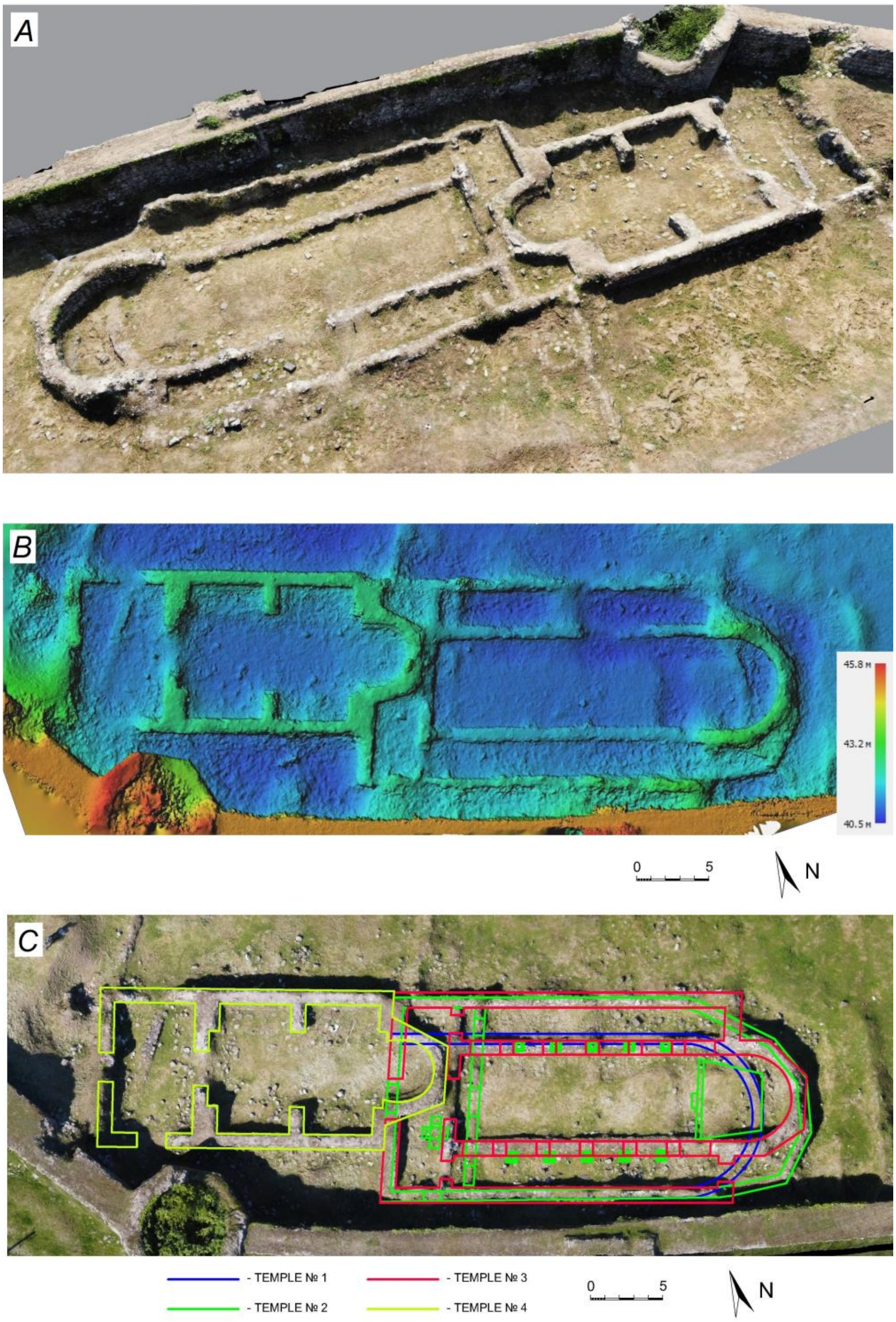

Figure 3. The Pitiunt temple complex: (**A**)—photogrammetric model, (**B**)—DSM of the temple complex, (**C**)—orthophoto and contours of the foundations of Temple Nos. 1–4.

The use of photogrammetry with calibrated markers allowed precise measurements to be obtained, which were used in the subsequent 3D reconstruction. Furthermore, parallelogrammatism was discovered in the plans of Temple Nos. 1–3.

The reconstruction of the interiors and exteriors of each temple in the complex is important, but it is also crucial to have an understanding of the historical context in which the object is to be depicted, for which a 3D model of the fortress is necessary. To achieve this, it is necessary to determine when the wall of the eastern fortification of the fortress, known as the "canaba", was built, along which the foundations of Temple Nos. 1–4 are now located. It is unclear which structure was constructed first: the wall or the temples. The initial question was posed by I.N. Tsitsishvili, who, in his description of Basilica No. 2, noted that the distance between the fortress wall and the southern wall of the basilica was too insignificant, with a discrepancy of 1.08–1.70–2.23 m. In his opinion, this fact indicates that it is implausible that a fortress wall existed during the construction and operation of Basilica No. 2. However, he goes on to note that at the time of Temple No. 3, the wall was already in place, as evidenced by the presence of a room attached to its apse on the south side, which joined the fortress wall.

However, the same wall is evident in all three temples. This is demonstrated on the combined plan of the entire complex, as presented in the monograph "The Great Pitiunt" [4], and the same result was demonstrated by our photogrammetry (Figure 3). If the wall was in existence at the time of Temple No. 3, it is also reasonable to conclude that it was present at the same time as Temple Nos. 1 and 2. Moreover, in the case of Temple No. 4, at the time at which the wall already undoubtedly existed, the minimum distance between the wall and Temple No. 4 was only 0.8 m. Therefore, I.N. Tsitsishvili's arguments based on the small distance between the temple and the fortress wall are not tenable. Meanwhile, this perspective has gained considerable traction and is frequently referenced (see, for instance, [10,26]).

It is noteworthy that a report by A.M. Apakidze [27] indicates that excavations of Tower No. 1, situated in the northeasternmost part of the eastern fortress, unearthed a considerable quantity of fragments of red-lacquered pottery and Roman amphorae dating to the third–fourth centuries.

It is challenging to imagine that Tower No. 1, situated 250 metres from the eastern wall of the original castellum, was constructed a century and a half earlier than the section of the wall directly adjacent to the castellum. This indicates that the construction of the eastern fortification, known as the "canaba", can be attributed to the era of Emperor Diocletian (late third century), when the fortress was rebuilt following a destructive raid on Pitiunt by the Goths and Borans in the middle of the third century.

Consequently, it is plausible that the wall was already in existence at the time of Temple No. 1, particularly given the improbability of constructing a bishop's cathedral outside the fortress walls in the pagan land of Abazgia at that time. Khrushkova acknowledged this, yet failed to provide an explanation, maintaining Tsitsishvili's opinion regarding the date of the construction of the wall [10].

Our analysis leads us to conclude that the representation of all the temples of the complex against the background of the canaba wall between fortress towers No. 3 and No. 20 is both legitimate and reasonable.

Temple No. 1

Temple No. 1 is considered the oldest, with different authors dating it either between 313 and 325 CE [10] or immediately after 325 CE [11]. It is believed to have been the cathedral of the bishop of Pitiunta Stratophilus, indicating that by 325 CE, Pitiunt had already formed a church organization headed by the city bishop [20]. The temple was discovered in 1973 during further investigations of the complex. All that remained of the church was the foundation, made of worked blocks of marine conglomerate. The temple is a simple form of Christian religious building, consisting of a hall with a single nave and a semi-circular apse on the eastern side. The apse, a semicircle without shouldering, continues into the long walls. There was no narthex or other parts.

It is worth noting that in Hellenistic or Late Antique times, wide apses were not typical for buildings of this size, being more common in small funerary or memorial buildings.

According to L.G. Khrushkova [10], the oldest church in Archaeopolis (Nokalakevi) had a very similar ground plan and dimensions. The architectural form of the apse-exedra in the church of Kolakert in Armenia is of ancient origin. It was attached to an ancient pagan building. This is also evident in the apse of Pitsunda Church No. 1, suggesting its antiquity [10,28].

The temple was short-lived and was destroyed by fire.

The temple's dimensions, obtained through photogrammetry, are as follows: the site's length along the east–west axis is 26.1 m, the width across the axis is 11.4 m, the western facade's width is 11.6 m, the southern wall's length is 21.6 m, and the northern wall's length is 20.9 m. A noticeable parallelogram of approximately 4 degrees is defined between the south and west walls.

The inner hall measures 24.7 m in length and 10.0 m in width. The depth of the apse is about 4.2 m. From the foundation plan and the width of the hall it can be deduced that the dimensions of the temple were chosen from a 100 ft module divided into thirds. The proportion of the naos, excluding the apse, is nearly 1:2.

Temple No. 1 has relatively thin walls of 0.7 m. Due to the single nave construction and the building width of 11.4 m, a stone vault is unlikely. The ceiling is thought to have been wooden trusses covered by a tiled roof. Some authors have questioned the lack of intermediate supports due to the large span between the long walls. For example, P.P. Zakaraya [12], in his analysis of the similarity between the Nokalakevi church and Temple No. 1 at Pitiunt, suggested that both structures had two rows of wooden supports, because the width of 11.0 m in the light was too large for a continuous covering. However, the foundations of such supports, which were preserved at Kolakert, were not found at Pitiunt. It is worth noting that the archaeological reports of the Bichvint expedition with regard to Temple No. 1 do not contain all the necessary information. There is no information on the discovery of the remains of the floor. This suggests that the temple was not fully explored. This may be the reason for the absence of the bases of additional pillars. The walls of the temple were for the most part covered in ancient times by the walls and the stylobates of the columns of Basilica Nos. 2 and 3. From the small sections of wall preserved in the apse, it is clear that the wall lacked pilasters at the transition from the hall to the apse. Therefore, it is illogical to assume that the arch between the naos and the apse was supported by the pillars in the wall, considering the strong tensile loads on the walls. Consequently, the existence of the vault between the naos and apse in the construction of Temple No. 1 is excluded.

Digital modelling in CAD LIRA confirmed our assumption that the structure of the temple with thin, long and high walls would be unstable without rigid horizontal connections in the upper part of the building, such as roof trusses. It is unclear what provided the strength and stability of the building, as archaeological research has not revealed any pilasters or other structural elements that could have strengthened the structure. It must be acknowledged that the archaeological material found at Pitiunt Temple No. 1 is insufficient to find a solution that would guarantee the stability and strength of the longitudinal walls, which are 20 m long, 10 m high and 0.7 m thick. In addition, it is worth noting that the temple was constructed using marine conglomerate, a less durable material than stone blocks. Thus, we conclude that we do not have sufficient data to reconstruct the interior of Temple No. 1. However, we propose the following appearance of the temple, which corresponds to the architectural ideas of the period, on the basis of the established foundation contours and the inferred vertical dimensions (see Figure 4).

An analysis of the vertical dimensions suggests that the width of the hall was most often related to its height in a ratio of 1:1 or 3:4, based on the surviving fourth-century hall constructions. The wall thickness (0.7 m) makes it impossible to use the second option.

The Basilica of Constantine in Trier (310 AD) is a remarkable example of a synchronous monument with a hall cross-section ratio close to 1:1. The stability and strength of the building's construction is ensured by the presence of pilasters on the outside of the longitudinal walls and a strong arch separating the hall from the apse, which connects the longitudinal walls transversely. The hall is 27 m wide, and the walls have a total thickness of 2.7 m.

Based on these observations, it is concluded that the temple's short existence was due to the fact that the stability of the structure depended solely on the horizontal connections of the roof trusses.

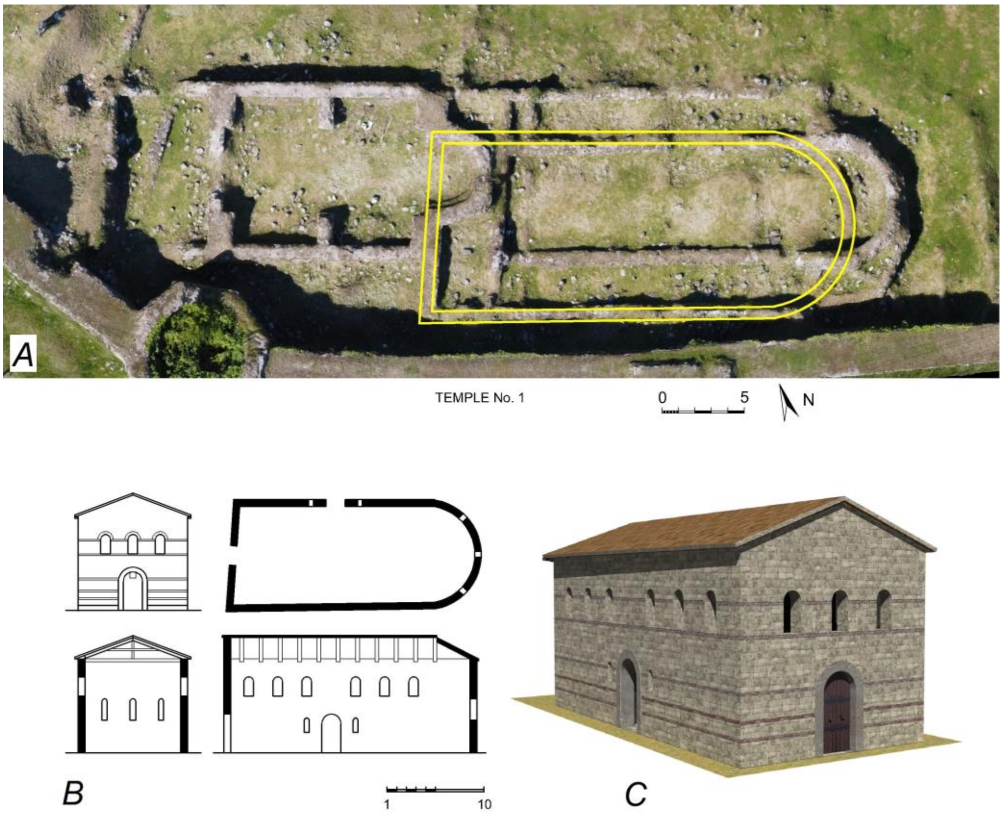

Figure 4. Pitiunt. Reconstruction of Temple No. 1: (**A**)—outlines of the foundation of Temple No. 1; (**B**)—plan, facades and section; (**C**)—proposed exterior view.

Temple No. 2

Temple No. 2 was built on the location of Temple No. 1 in the mid- to late fourth century. It is a three-nave basilica with a polyhedral apse of irregular shape covering all three naves. The apse has six facets, two of which are smooth on both the inside and the outside.

This is the most luxurious temple in the complex. The floor is decorated with mosaics, and the naves are separated by marble columns. The altar wall is decorated with marble columns connected at the bottom by marble slabs with carved ornaments and covered at the top by a three-part architrave [5].

In the centre of the apse, there is a trapezoidal platform with two steps in front of it, decorated with mosaics. The temple has a spacious narthex on its western side. Towards the southern end of the interior, there is a cross-shaped baptistery.

The temple's dimensions, as determined by photogrammetry, are as follows: the length along the central axis from east to west is 29.1 m, the total length (due to the asymmetry of the apse and parallelogram of the plan) is 29.4 m, the width across the central axis is 13.9 m, and the width of the temple along the western wall is 14.1 m. Similar to Temple No. 1, the temple also has a parallelogram plan with an angle of approximately 4 degrees.

The naos and apse have a combined length of 22.1 m along the central axis, with the apse measuring 9.0 m and the naos measuring 13.1 m. The boundary between them is not clearly defined, but based on the preserved fragments of mosaics in the north aisle, it appears to have been along the edge of the eastern columns (pillars). The naos has an almost square shape, measuring 13.1 × 12.6 m (more precisely rhomboidal, taking into account the parallelogram). We do not know any analogies of similar proportions among synchronous sites. The only readable proportion that we found in this temple is the ratio of the width of the temple to its total length, which is 1:2. Many early Christian Greek basilicas had a similar proportion, including one of the earliest, the fourth-century church of extra muros in Philippi [23]. The lack of other clear proportions in Pitiunt Basilica No. 2

is probably due to its early construction, dating from the second half or end of the fourth century, at a time when the architectural style of Christian temple architecture had not yet fully developed.

The basilica's naves were separated by five pairs of columns, the foundations of which were discovered by the Bichvinta Expedition. The artefacts were partially destroyed during the later reconstruction of the temple and finally lost during the archaeological excavations of 1952–1974. Therefore, we can only assume their location based on the distorted rectangular plan of the temple given in the monograph [3,4]. This means that we can only estimate the width of the individual naves. The central nave is 6.9 m wide, and the northern and southern naves are 2.3 m and 1.9 m wide, respectively. The distance between the columns of the orders is 2.6 m. The narthex of the basilica measures 12.6 m by 5.0 m. The walls of the basilica are estimated to be 0.7–0.8 m thick, indicating the absence of vaults in any part of the temple [10]. The roof is made up of wooden trusses and beams, covered with tiles.

The dimensions and references of the central platform and the baptistery are difficult to determine due to their loss during excavations. The published plans in the monograph are distorted and therefore unreliable.

The 3D reconstruction was conducted on the basis of the available data.

The remains of Temple No. 2 were not thoroughly documented during the archaeological work, leaving room for interpretation. According to various scholars, there are different opinions on the structure of Temple No. 2: G.A. Lordkipanidze and P.P. Zakaraya suggest that it was a hall church without central nave supports, while L.G. Khrushkova reconstructed it as a columned basilica with an architrave [12]. The presence of pillars is proved by the discovery of the walled-up remains of marble pillars of 44 cm and 22 cm in diameter in the stylobates of the pillars when the later Temple No. 3 was excavated. The assumption is that the former divided the aisles, and the latter formed the structure of the altar barrier.

The 3D reconstruction is based on the temple being a three-aisled columned basilica with a narthex, a high central nave and light openings in the upper part.

The principle of proportion was used to determine the total height of the temple and the position of the points where the roofs of the side aisles adjoin the central one. These values, although the site lacks the symmetry of the apse or nave on the central axis, allow for variations within certain limits.

The height proportions of Temple No. 2 were determined using the proportions of the Basilica of Sant'Apollinare in Classe in Ravenna, where the ratio of the width of the central nave to its height is 3:4, given the lack of direct analogues. We have also taken into account the proportions of ancient Greek basilicas as described in the work of V.M. Polevoy [24]. The height of the apse and side aisles was equal to the width of the central aisle, and the height of the central aisle was equal to the combined width of the central and side aisles.

Therefore, with a width of 7.6–7.7 m along the column axes, the central nave has a height of 10.1–10.2 m. The same height for the central aisle was obtained from the width of the middle and north aisles (along the column axes).

Determining the height of the side aisles, which vary in width, was a challenge. To address this, we considered that the height should be sufficient to accommodate the continuation of the outer walls of the temple into the apse. Additionally, the roof of the side aisles should leave space for the upper windows when it meets the central roof. The height of the apse and side aisles was made approximately equal to the width of the central nave between the bases of the columns.

The central nave was supported by marble columns finished with Ionic capitals. The remains of these capitals were found during excavations. The columns could reach a height of 3.9 m, based on their thickness of 0.44 m. The maximum ratio of column diameter to height rarely exceeded D:L = 1:9.

In our reconstruction, the upper part of the central nave is supported by arches on the columns. Tsitsishvili's mention of the discovered remains of a three-part architrave should be attributed to the construction of the altar barrier. The use of an architrave on the end of the columns would have weighed down the construction of the central nave and blocked the light from the windows of the lower tier into the central nave.

To ensure the stability of the central aisle structure with such small diameter columns, it was assumed that the eastern supports should have been made in the form of massive pillars rather than columns (Figure 5).

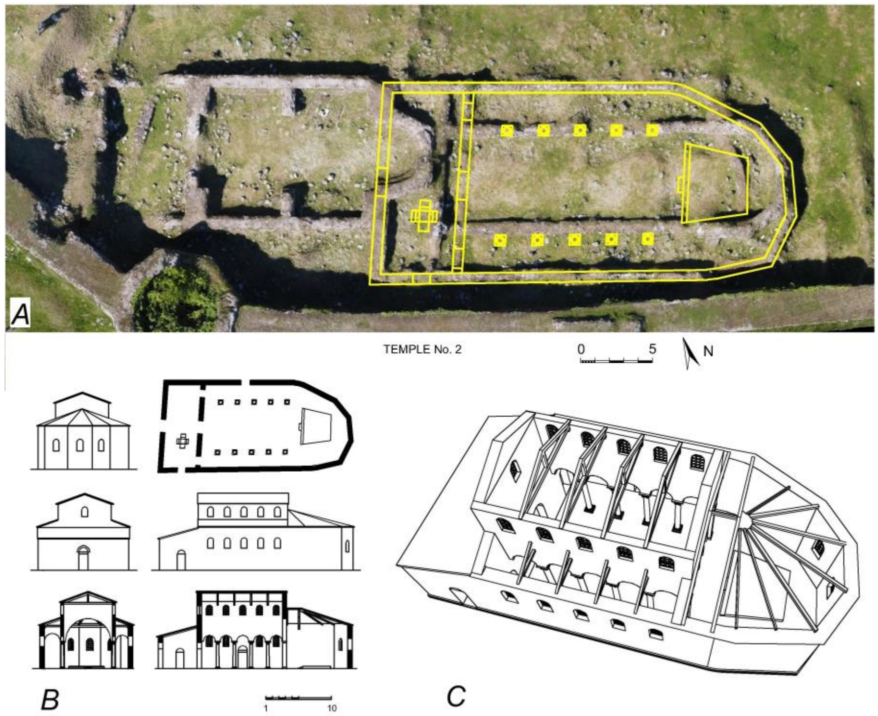

Figure 5. Pitiunt. Reconstruction of Temple No. 2: (**A**)—Outlines of the foundation of Temple No. 2; (**B**)—plan, facades, section; (**C**)—proposed force structure of walls and roof beams.

The force structure of the temple was worked out, and doubts were raised about the load-bearing capacity of the columns and the stability of the structure. In order to verify these assumptions for the design and calculation of the building structures, the CAD LIRA 2021 Build R4 software package was used. The software allows for both static and dynamic calculations, and the calculation scheme is modelled using rods (beams, columns, pillars), plates (walls, slabs), and volumetric elements. A calculation model was created for Temple No. 2 based on the proposed 3D reconstruction variant. The model was used to analyze the loads and determine the most heavily loaded elements. The strength of the temple's structures, including walls and columns, was checked using the finite element method.

The calculation model (Figure 6) was based on the following assumptions: the finite elements were sized as multiples of 0.30 m, and the structure was assumed to be symmetrical. The walls were modelled using plates with thicknesses of 0.70 m for the external walls and 0.45 m for the central nave. The columns and pillars were modelled using rods with a square cross-section of 0.45 × 0.45 m and a round cross-section of 0.44 m in diameter. The arches of the central nave were modelled with a cross-section of 0.50 × 0.40 m. The rigidity of these elements is expressed in terms of Young's modulus, Poisson's ratio and density. Their respective values for different structural elements are provided in Table 1.

In the calculation of the structure, we considered the weight of the building itself and the load from the tiled roof. The roof load, which takes into account the structure, was assumed to be 150 kg/m^2.

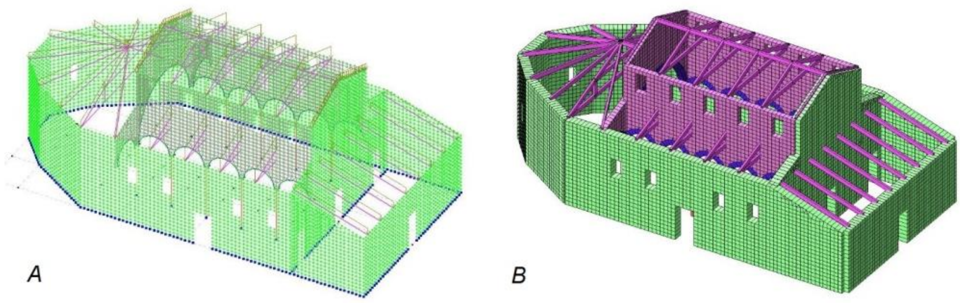

Figure 6. Calculation scheme (**A**) and spatial model (**B**).

Table 1. Mechanical characteristics of the building elements considered in the calculation.

No.	Building Elements	Standard Values			Values Used in the Calculation		
		Range of Modulus of Elasticity, E, t/m^2	Range of Volumetric Weight, ρ, t/m^3	Compressive Strength, R, t/m^2	Poisson's Ratio, V	E Value, t/m^2	Value ρ, t/m^3
1.	Wall masonry	2.7–2.9 × 10^5	2.2–2.4	150–200	0.25	2.8 × 10^5	1.8
2.	Marble columns	5.7–7.3 × 10^6	2.3–2.6	3000–15,300	0.25	5.7 × 10^6	2.5
3.	Arches of order and openings	1.6–2.4 × 10^5	1.60–2.00	100–150	0.25	2.0 × 10^5	1.8
4.	Wooden elements (struts, trusses)	3.3–3.7 × 10^5	0.65	-	0.5	3.5 × 10^5	0.65

The load on the columns was calculated to be between 20.50 and 23.70 tonnes, resulting in a compressive stress of 1.89 MPa for a 40 cm diameter section. Although the compressive strength of marble ranges from 30 to 153 MPa, the marble column has a significant margin of compressive strength. Additionally, the calculation revealed significant forces in the capitals of columns and in the places where the arches are supported.

The compressive stresses in the walls (as shown in Figure 7) do not exceed 0.35 MPa (35 t/m^2), which is less than the calculated compressive strength of the material used for the walls and arches.

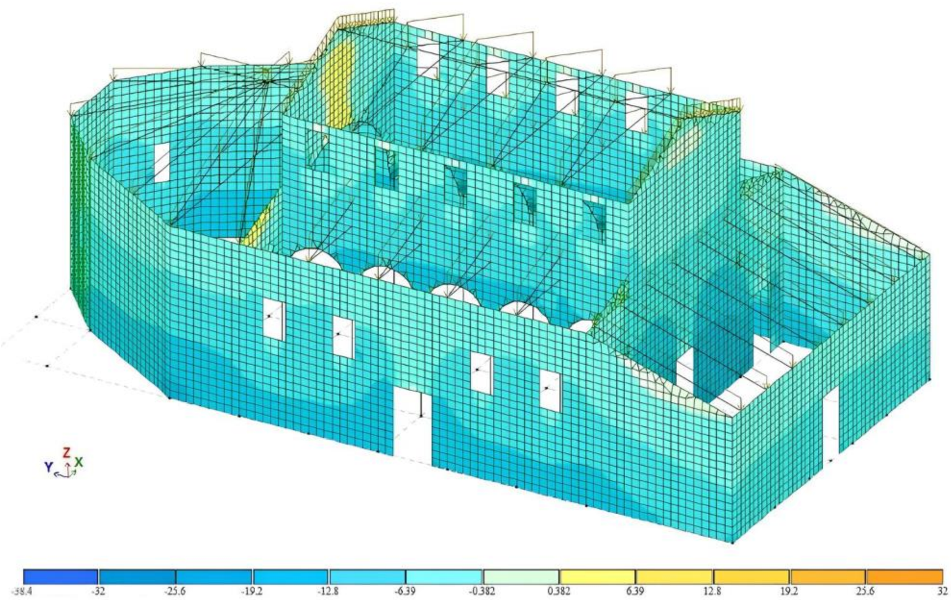

Figure 7. Stress distribution in the walls.

The estimated deformations of wall structures do not exceed 2 mm, and the deflections of truss structures do not exceed 6 mm. Our calculations have shown that the loads in our proposed reconstruction of Temple No. 2 do not exceed the compressive strength of the materials, and the resulting deformations are insignificant. These results validate the technical solutions that we have adopted.

Temple No. 2 is characterized by its asymmetrical apse, both internally and externally, which covers all three naves. Its length is almost a third of the basilica's total length. The reason for this asymmetry, which makes the construction of the roof very difficult, is not known. There are no known examples of such a solution on any contemporary monument.

Over the last fifty years, various explanations have been proposed for this geometry, most of them based on the assumption that the central platform was more important than the outline of the apse, and that the apse was moved to accommodate the older platform with the Martyrium [7,10]. However, analysis has shown that this assumption cannot be an explanation for the actual shape of the apse. A revised version of the observed geometry is proposed in Figure 8.

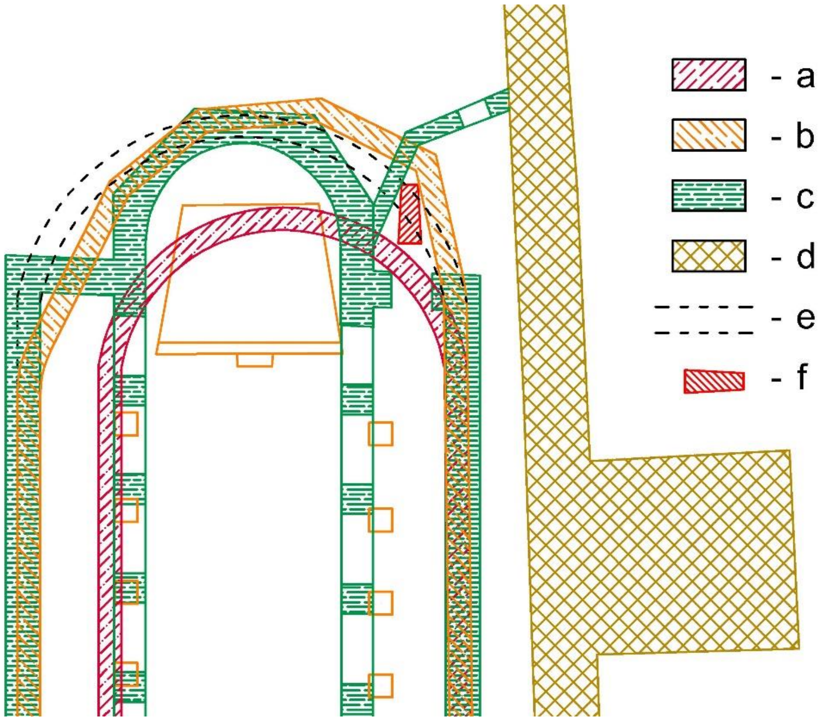

Figure 8. Location of the apsidal parts of Temple Nos. 1–3 in relation to the fortress wall. (a)—Temple No. 1; (b)—Temple No. 2; (c)—Temple No. 3; (d)—fortress wall with Tower No. 19; (e)—symmetrical variant of the apse of Temple No. 2; (f)—presumed martyrium.

The proposed displacement of the central platform to the south is based on its position relative to the apse of the later Temple No. 3 (Figure 8c). Upon careful analysis of the relative position of the platform and the contour of Temple No. 2, it becomes evident that the platform is precisely centred with respect to the lines of the colonnades of Temple No. 2. Consequently, there is no necessity for the deformation of the apse, as illustrated in Figure 8b. If Temple No. 2 had a symmetrical semicircular (or polyhedral) apse with the same longitudinal walls (Figure 8e), the central platform would fit more organically than the actual asymmetrical apse.

This implies that the rationale behind this particular geometry may not lie in the positioning of the platform, but rather in the builders' desire to circumvent an obstacle in the way of constructing a symmetrical version of the apse. It is possible that this decision was made due to unforeseen circumstances during the construction process. Two possible scenarios can be considered. Firstly, the wall of the apse was moved inwards from the northeastern side to avoid an obstacle, which is likely to have been a tomb or a martyrium, synchronous to Temple No. 1. Secondly, the wall was moved outwards from the southeastern side to include similar object within the boundaries of the apse (see Figure 8f). The latter option leaves a small area that was initially outside the apse of Temple No. 1 and was then incorporated into the apse of Temple No. 2. Later, it was once again located outside the apse and enclosed by a partition between the fortress wall and Temple No. 3.

Thus, the proposed version assumes that the central platform was made after the completion of the construction of Basilica No. 2. These conclusions are based on speculation and lack supporting evidence. The Bichvinta expedition reports mention "graves lowered to the floor level" (5), but provide no further details. The excavated materials from the platform and baptistery have not been published.

It is important to note that the decision to alter the geometry of the apse should have been based on substantial evidence, as this significantly complicated the structural and technical aspects of the apse floor beams, the method of covering the roof of the apse with tiles and the junctions of the planes of the pyramidal roof.

Therefore, it is crucial to have solid grounds for making such a decision. Additionally, covering a space of 14 × 10 m with a tiled roof is a non-trivial task. At the same time, no additional supports for the apse floor were found archaeologically, which implies a complex construction of the asymmetrical roof.

During the 3D reconstruction, several variants of the apse roof were considered, including the construction of massive beams with the length of about 10 m. In this case, the beams converged from the corners of the apse to the centre of the west wall of the main nave with additional struts.

The main disadvantage of this option was the existence of obtuse angles between the roof overhang and the edge at the junction of the planes, which was contrary to the tile-laying technique and the correct organization of rainwater drainage. It can be assumed that an intermediate truss parallel to the eastern wall of the central nave and 2.2 m east of it existed, as the roof beams of the apse rested on the centre of the truss. A 3D reconstruction of the appearance of Temple No. 2 was made based on archaeologically confirmed factors such as the shape of the foundation, the points of the column supports and the longitudinal division of the building into apse, naos and narthex. The geometry of the temple was determined by these factors, resulting in an atypical appearance. The 3D model of the temple appears harmonious despite the asymmetry of the apse and naves, as revealed by a detailed study of the structure's plan (see Figure 9).

The structure of the walls, columns and roof trusses was modelled. The appearance of the floor mosaics was reconstructed. The mosaics, which were discovered during the excavations, were made using the Opus Tesselatum technique. Only 10.5% of the mosaics covering the floor of the temple were revealed through archaeological research. A reasonable reconstruction of the general appearance of the mosaic floor was created [20]. The reconstruction of the site was based on a number of factors: the direction of the dividing borders between the mosaic elements, the requirement of symmetry of individual sections, the keeping the theme of the ornament and the analysis of analogues in synchronous monuments. The reconstruction enhanced the realism of the interior and highlighted the rich decoration of this extraordinary site (Figure 10).

Temple No. 3

Temple No. 3 was built over the remains of Temple No. 2, which was probably destroyed by fire, as evidenced by the traces found during excavations. The new basilica was built on the foundations of its predecessor, with the north, west and south walls remaining largely unchanged. The main alterations were made to the apse and narthex. The new pentahedral apse was integrated into the width of the central nave, while the narthex was shortened. The southern line of the colonnade, which separated the central and southern naves, was moved northwards so that the lateral naves were of equal width. This alteration shifted the central axis of the temple to the north, and as a result, the central platform, left over from Basilica No. 2, was shifted to the south, facing the southern side of the stylobate of the columns. The level of the floor between the platform and the apse wall was raised to match that of the platform. A bench-syntron, covered with ceramic tiles, was constructed along the entire wall of the apse. In the central part of the syntron, there was a bishop's pulpit (Figure 11).

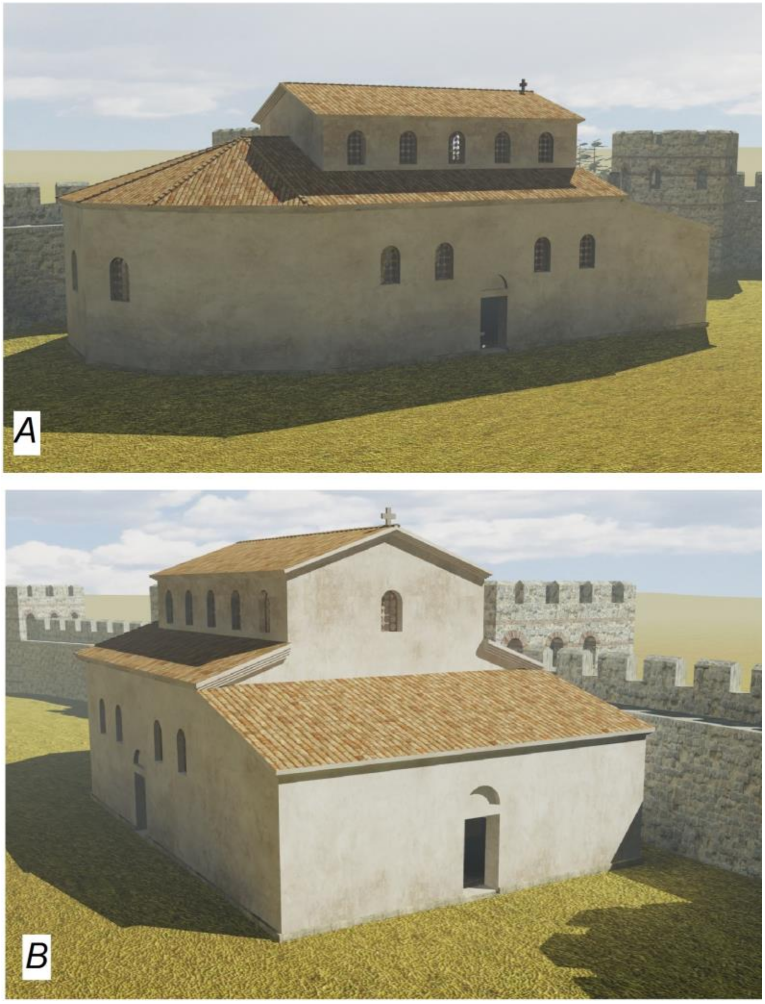

Figure 9. Pitiunt. Reconstruction of the exterior of Temple No. 2: (**A**)—view from the north, (**B**)—view from the northwest.

The central nave of the new church features strong pillars instead of columns for support. These pillars rest on stylobates that connect the partition of the narthex with the projections of the apse by means of single foundation bands. The level of the stylobates is approximately 0.2 m higher than the level of the floor. The mosaic floor was cut under the foundation trenches during the construction of new elements such as the stylobates of the pillars, the partition of the narthex, the apse and the eastern walls of the side aisles. Ceramic tiles and partly lime mortar mixed with broken pottery were used to replace the missing parts of the floor mosaic which were lost during the destruction of Temple No. 2 (Figure 12).

Photogrammetry was used to determine the dimensions of the temple: the total length along the central east–west axis is 28.9 m, the width across the axis is 14.5 m, and the width of the western facade is 14.6 m. The apse extends 4.7 m beyond the eastern wall. The plan's parallelogram is similar to that of Temple Nos. 1 and 2, with an angle of approximately 4 degrees. The temple walls have a thickness of 0.9–1.0 m.

The central and side aisles are 18.2 m long, and the apse has a depth of 4.7 m. The central nave is 6.0 m wide, while the northern and southern naves are 2.3 m and 2.2 m wide, respectively. The central nave was supported by five pairs of square-section pillars and two pairs of pilasters on stylobates that were 1.0 m wide. The distance between the pillars was 2.1 m. The narthex was shortened to 3.0 m compared to Temple No. 2, with a width of 12.6 m.

Figure 10. Pitiunt. Reconstruction of the interior of Basilica No. 2. (**A**)—mosaic of the naos, (**B**)—mosaic of the apse.

The appearance of Temple No. 3 corresponds to the Hellenistic model of a basilica. I.N. Tsitsishvili, the researcher of the Pitiunt temple complex, wrote: "One can imagine the Pitsunda basilica as a building with a high middle nave and a gable roof covered with tiles, lower side aisles and a narthex with single-pitched roofs leaning against the main body.

The multifaceted apse, apparently, had an independent pyramidal roof. The façades were probably devoid of decorations, which were concentrated inside" [5].

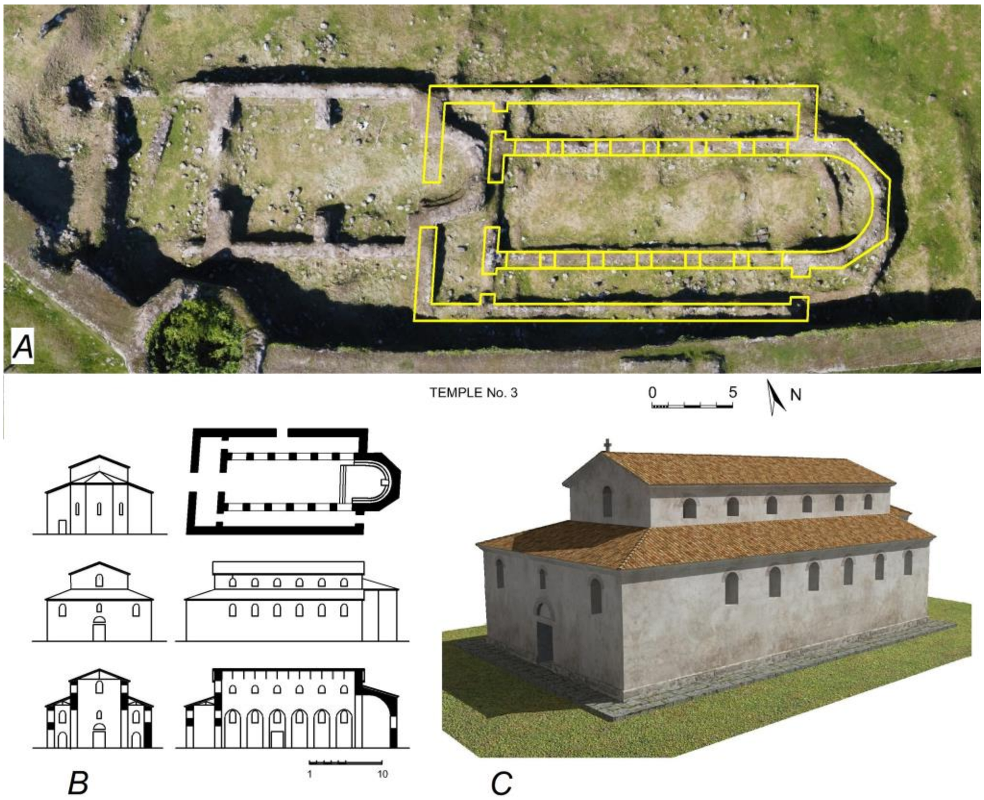

Figure 11. Pitiunt. Reconstruction of Temple No. 3: (**A**)—Outlines of the foundation of Temple No. 3; (**B**)—plan, facades and section; (**C**)—proposed exterior view.

Figure 12. Pitiunt. Variant of the interior of Temple No. 3.

This temple, probably dating from the second half of the fifth century, is an example of established Christian temple architecture and has many analogues in the Byzantine Empire, including Chersonesos. The architectural historian, Hans Buchwald, has identified the criteria for comparing the proportional ratios of the sizes of early Christian basilicas [29]. He has shown that the ratio of the main parameters in the design of basilicas follows the combination of the prime numbers, 1, 2, 3, 4—the so-called tetrads. This finding demonstrates the importance of prime numbers in the design of early Christian basilicas. Based on the methods and techniques proposed in [23], it was concluded that Basilica No. 3 has an architectural style similar to the first type: the ratio of the width to the total length of the basilica is 1:2, the ratio of the central nave is 1:3, and the ratio of the narthex is 1:4. Therefore, regarding this temple, it can be concluded that it is a typical design, which has many analogues in Chersonesos, Thrace, Greece, Crete, Cyprus, the island of Kos and especially in Asia Minor [30,31]. As most of these sites are in ruins, their height is unknown. However, the basilica of Sant'Apollinare in Classe (533–549), which is well preserved, has a similar plan with a proportional width and height of the central nave at 3:4. Therefore, we can estimate the probable height of Basilica No. 3 of Pitiunt to be about 11.3 m (see Figure 13).

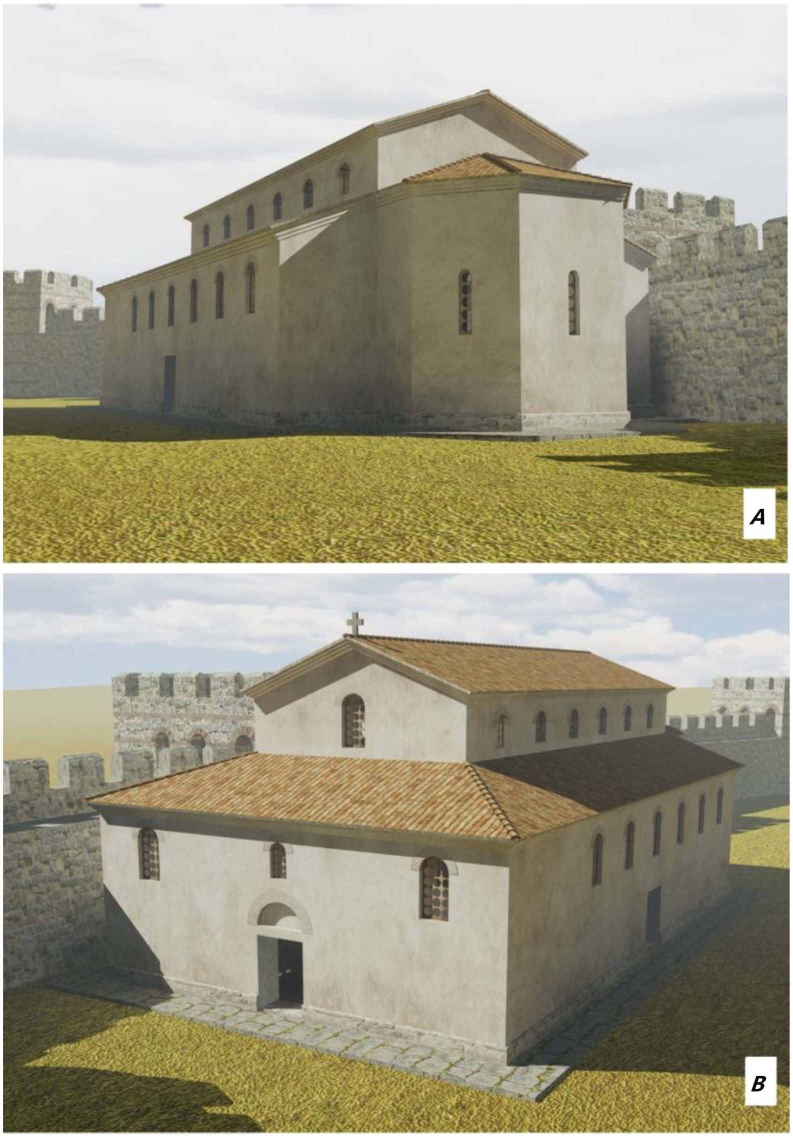

Figure 13. Pitiunt. Reconstruction of the exterior of Temple No. 3: (**A**)—view from the north-east, (**B**)—view from the north-west.

Similar conclusions can be reached using the geometric method of constructions based on the combination of squares, their diagonals and circles, as outlined in the work of V.M. Polevoy [24]. This method was used to determine the heights of the side aisles and other necessary parameters. The heights of the arches resting on the pillars and the height of the pillars themselves were determined based on the distance between the pillars. Other geometric measurements were obtained from structural considerations, strength requirements and ensuring adequate illumination of the aisles.

The thickness and width of the apse wall suggest that it could be covered with a conch, while the roof of the nave and narthex was constructed with rafters. Figure 14 shows a reconstruction of the apse section of the central nave, the two-stage synthron and the bishop's high seat in the centre. A portion of the apse mosaic was preserved, and the central platform now serves as the altar floor.

Figure 14. Pitiunt. Reconstruction of Temple No. 3. Altar part.

Comparing the interior designs of Temple Nos. 2 and 3, we can see how much the concept of the temple interior had changed, even though they were probably built less than a hundred years apart, and three out of four walls remained in the same place. Temple No. 2, which was airy and translucent with rich floor mosaics, has been transformed into a heavy structure with mighty pillars that block the view and visually divide the space of the naos.

The shape of the apse has changed, preventing the ritual circumambulation of the central platform, access to which is now restricted to the clergy.

There has been a change in architecture and a fundamental transformation of the liturgy. It is possible that the temples (Temple No. 2—second half of the fourth century; Temple No. 3—second half of the fifth century) were built at a time when the Arian cult was being replaced by the Orthodox one. There is, however, no archaeological or historical evidence either to confirm or to deny this hypothesis.

Temple No. 4

Temple No. 4 was a one-nave, one-apsed hall church with an advanced narthex. It had a trihedral projecting apse and a horseshoe-shaped altar. The church was moved to the west so that its apse took the place of the narthex of Temple No. 3.

This temple is distinguished from the previous ones by the presence of two pairs of strongly projecting pilasters on the long walls (see Figure 15.A). One pair divides the nave into two equal parts, while the other adjoins the western wall. The pilasters were probably supported by arches, forming vaulted niches in the long walls (see Figure 15.C).

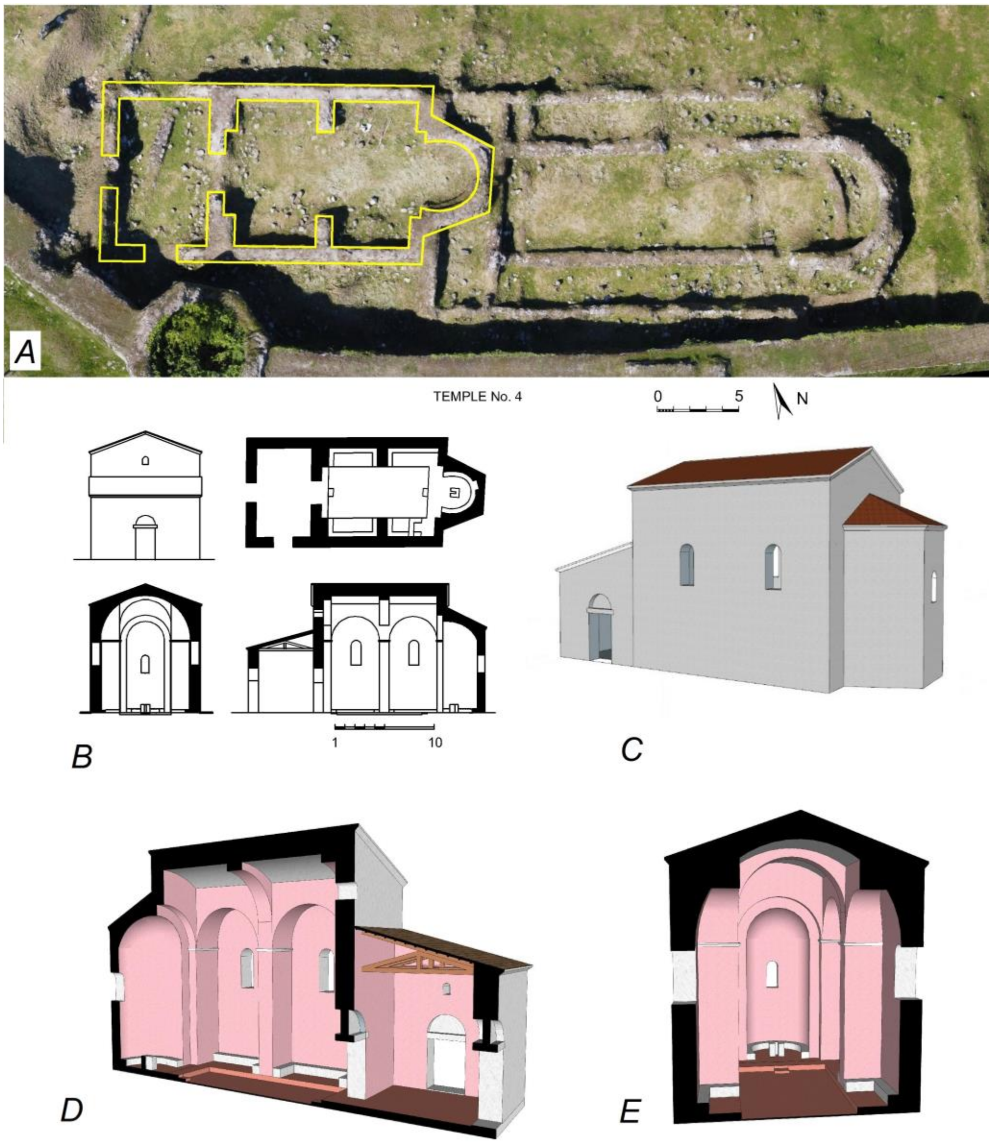

Figure 15. Pitiunt. Reconstruction of Temple No. 4: (**A**)—Outlines of the foundation of Temple No. 4; (**B**)—plan, facades, sections; (**C**)—exterior of the temple, (**D**)—longitudinal section, (**E**)—transverse section.

During the excavations in the temple, the remains of liturgical elements were discovered. A single-storey synthron was attached to the apse wall, and in the centre, there were the remains of a stone throne, with benches along the walls of the church (Figure 15.D). The spacious narthex had two doors: one in the west wall and the other in the south wall [10].

In different countries of the Christian East, small one-nave churches with pilasters in the longitudinal walls and a vault were built in the fifth–sixth centuries.

Churches of this type in the Caucasus typically have a rectangular external shape with a projecting apse, usually faceted. Analogues of this type of church can be found at Kusireti and Akaurta in Georgia. V.G. Khrushkova also mentions some churches in Armenia. Pilasters can be found in the longitudinal walls of various ancient buildings, such as the fifth-century basilica of Sveti Tskhoveli in Georgia, and in fourth- and fifth-century single-aisle vaulted churches in Syria, such as the fortress of Deir il-Kahf, Lubben and the church of Julian at Umm al-Jimal. Pilasters are also found in the monastic churches of Mar Saba and Castellion in Palestine [10].

Plontke-Luning has identified analogies between this temple and churches in Northern Mesopotamia from the fifth to the seventh century, such as Mar Kiriak in Arnas, Kefr Zeh or Mar Philoxenos in Midyat, as well as churches in Southern Armenia such as Tukh and Pashvatsk [11].

The temple's dimensions, obtained through photogrammetry, are as follows: the total length along the east–west axis is 24.0 m, and the width across the axis is 11.0 m. The apse extends 3.9 m beyond the boundaries of the eastern wall. The Temple has a parallelogram plan in the western part—1° and in the eastern part—3°, which is due to the adjacency to the walls of Temple No. 3. The central nave is 10.9 m long and 9.0 m wide, with pilasters extending 1.9 m and a thickness of 0.7–1.0 m. The narthex has external dimensions of 11.0×6.6 m.

The temple walls were constructed using marine conglomerate blocks and boulders held together with lime mortar. Both the interior and exterior walls were thickly plastered. The temple ceiling was a vault supported by brick arches and covered with roof tiles.

To determine the vertical proportions of the temple, we used the partially preserved one-nave citadel church in Ani as an analogue, which has a nave width to height ratio of approximately 3:4. Although the preserved temple in Pashvatsk is closer in architectural terms, with significantly protruding pilasters and deep niches, its vertical proportions have not been established. Further studies are required to clarify the ratio of the width of the nave to its height. The ratio of the size of single-apsid temples with projecting pilasters should be studied separately.

4. Conclusions

The work carried out enabled the visualization of the appearance of the temples of the Pitiunt fortress with the highest possible authenticity. The reconstruction of the temples took into account the geometry of the preserved foundations of the temples, the remains of building structures and materials, archaeological materials, the architectural features of the synchronous sites and the engineering calculation of the power scheme of the buildings and roofs. The complexity of the applied approach allowed the visualization of the lost interiors and exteriors, providing a comprehensive perception of this important archaeological site. The results obtained allow for a better understanding of this site in the context of the history of the expansion of the Roman Empire in the eastern Black Sea region and the beginning of the spread of Christianity in this area. The work demonstrates that reconstruction and visualization require a meticulous and careful approach to studying the primary material. This approach helps to avoid gaps in knowledge due to the insufficient study of certain aspects in the final renderings. It also requires a detailed examination of the geometry of the reconstructed monument, leading to important conclusions about its unique features that were not reflected in the materials of previous researchers.

The study examined the interiors and appearance of the monuments, revealing the evolution of the church architecture in the local area from the fourth to the sixth centuries. This period saw the formation of the canons of early Christian architecture. Monuments from this time, particularly in the eastern Black Sea region, are scarce, making this study of significant practical interest.

The work conducted enabled us to trace the evolution of the purpose of the complex over two centuries. The first temple served as the pulpit of Bishop Stratophilus, who participated in the First Council of Nicaea in 325. The second temple was built as a dedication to the holy martyrs, whose cult began to develop widely precisely in the second half of the fourth century. During this period, many Christians who were martyred during the persecutions under Emperor Diocletian were canonized. The plot of the mosaic triptych found in the apse of Temple No. 2 supports this assumption. In front of the platform, there is a panel with a date palm, symbolizing the act of faith. The mosaic of the platform shows the monogram of Christ in the centre, framed by a rich acanthus frieze and a dedicatory inscription in Greek. According to some experts, the temple may have been dedicated to the holy martyr, Orentius, who was exiled to Pitiunt for his faith and died on the way. The third part of the triptych was located behind the platform, depicting a deer with birds and a fountain of living water, symbolizing paradise. Probably built during the economic heyday of Pitiunt, this was the richest temple.

The third and fourth temples served as the typical city church. While the first three temples were influenced by the Hellenistic school, the fourth temple already showed distinct features of oriental architecture. There was a noticeable change in the liturgy during the two centuries of the temple complex's existence.

By combining all the available facts, a comprehensive picture of that epoch can be obtained, as reflected in the history of the remote fortress of Pitiunt. The architectural features discovered are consistent with the historical events that occurred in the Empire at that time, as well as with the developing and evolving Christian dogmas and related liturgical rules. The findings of this work provide a substantial addition to the existing scientific material, enabling its widespread use in museum exhibitions, educational programmes and excursions.

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