Budownictwo i Architektura 22(3) 2023, 73-104
DOI: 10.35784/bud-arch.3820

Received: 06.07.2023; Revised: 25.08.2023;
Accepted: 20.09.2023; Available online: 29.09.2023

Orginal Article

A comparative analysis of the interrelation between the evolution in the structure of Armenian churches of the 4th-14th centuries and the three-layer "midis" masonry

Karen Azatyan [1], Ruben Azatyan [2], Anzhelika Manukian [3], Mane Melikyan [4]

[1] Department of Architectural Design and Design of Architectural Environment; Faculty of Architecture; National University of Architecture and Construction of Armenia (NUACA); Teryan 105 St, Yerevan, Armenia;
kazatyan@nuaca.am ORCID: 0000-0002-6764-5917
[2] "Azatyan" Architectural Studio; Street 29, Yerevan, Armenia
elizabethazatyan@gmail.com
[3] Faculty of Architecture (Conservation); La Sapienza of Rome; Piazza Borghese 9, 00186 Roma RM, Italy;
manukian.2053730@studenti.uniroma1.it ORCID: 0009-0002-7948-4310
[4] Independent researcher
melikyan.mane@gmail.com

Abstract: The article touches upon the interrelations between the structural elements and the building structure in architecture. The aim of the work is to generalize the peculiarities of "midis" masonry formation and to reveal its influence in the evolution process of the structure of Armenian medieval churches by a comparative analysis of different characteristics. In the work: the development of three-layer "midis" masonry was systematized, the phenomenon of shell structure and spatial integrity in the churches of the 4th-14th centuries was highlighted, the tendencies of evolution of the masonry monolithic nature and church structure integrity were revealed by a comparative analysis of volumetric and planning characteristics of different churches. The results allowed to formulate a certain sequence of interactions in different characteristics, which confirmed the relationship between the evolution of the masonry and the structure of the churches: the evolution of "midis" masonry led to the structural monolithic nature of the walls and the forms derived from it, which in turn led to the integrity of the stone building structure. The results can be useful in further research covering structural-compositional interrelations, including both heritage and modern architecture studies.

Keywords: Three-layer "midis" masonry, wall structure, medieval Armenian church structure, monolithic architecture, stone building structure, spatial integrity in architecture.

1. Introduction

The structural system is one of the main characteristics of each structure and each architectural work. The structural system is the basis of the structure existence, the form of its being, which greatly predetermines the image of the structure. Popov's notion of the principles of the building structure designing is presented in the work on the issues of composition in modern architecture. According to him, since the ancient times of architecture development, two principles of structure designing have existed and developed in parallel – integral (bearing shells) and differential (framework with self-bearing filling). In systems with an integral principle, each structural element combines both load-bearing and isolating functions. Such are shell, solid, monolithic (by structure, and not by making technology), hull structures. In the case of the differential principle, the load-bearing and isolating functions are distributed over different elements of the system. The differential principle is implemented in systems based on frame and mesh structures [1].

In comparing the integral and differential principles of construction, Popov also singles out their advantages and disadvantages. The main advantage of differential structure designing is the large variety of building materials, and the disadvantage is that a large number of spatial joints emerge, which make it difficult to achieve the efficiency of the combined work of the structure. Integral structures are simpler in their composition. They are made of a single material that is able to resist the influencing forces and at the same time serve as a thermal insulation barrier. The main problem here, with no doubt, is to find such a multi-functional material [1].

Structures of a single material in different historical periods were made of stone and wood, as well as of other artificially obtained materials, such as brick, concrete, reinforced concrete and metal [2-9]. Moreover, there are whole spatial environments in the world made of a single material, such as those found in rural areas of China's Hunan Province [10]. By no means, the use of a single material in such structures has influenced their volumetric-spatial and artistic solutions. The latter, regardless of the variety of creative approaches, have been endowed with a certain expression of unity.

The architecture of medieval Armenian churches deserves a special place within the framework of the above-mentioned, in the process of the development of which, we believe, the improvement of the three-layer wall, inherited from earlier times, played a significant role. Although these walls, called "midis", are three-layered, there is both bibliographic[1] and factual (numerous monuments undamaged by earthquakes, preserved large fragments from collapsed structures) evidence of their monolithic nature and strength. It is of interest to consider such a structure of a stone wall from the point of view of the "monolithic structures in composition" mentioned by Popov and to identify the elements of its influence on the development of the overall composition of the structure. In this respect, this paper attempts to highlight the interrelation between structural elements and the structure of a building in the complex process of architecture formation.

The elaboration of the research is based on the identification of certain issues arising from the topic and the study of related sources. Within the framework of the literature, in particular, the issues were considered in the following directions: interrelations between structural and artistic solutions in architecture [1, 11-14]; general issues of ensuring the

[1] Historian Tovma Artsruni (9th-10th centuries), in his work about the construction of Armenian churches and palaces, mentions the solidity and strength of the wall structure [47].

strength of structural systems and work efficiency [15, 16]; issues related to masonry and its structure [17-21]; questions about the composition of the core in three-layer walls, binding materials and their development, differentiation of the core, as well as its effect on masonry and overall structure [12, 16, 21, 22]; measures to ensure structure unity of the three-layer wall in Roman, Byzantine, and Syrian structures [12, 13, 23-28]; the process of gradual evolution of three-layer walls in Armenia [29-32]; peculiarities of “midis” masonry, the composition of its core, its homogeneity and monolithic nature in the structure of the structural elements [30, 31, 33]; general description of the structure of Armenian medieval churches [33-39] and typological classifications [30, 40]; some structural peculiarities of Roman, Iranian, Syrian, Byzantine, Italian and Armenian architecture and their parallels [7, 11, 23, 24, 31, 41, 42]; general issues concerning the use of materials in structures [7]; examples of structures made of a single material in the case of brick [5-7], in the case of wood [3, 4], in the case of reinforced concrete [8, 9]; generalizations related to technological research of monuments [21, 28, 43-46].

The scope of the observed directions is not small, but the discussions on the interconnection between the structural elements and the general structure of the building are limited, especially in the sense of the architecture of Armenian medieval churches. Such discussions, in particular, are available in the following sources: in the works of Mikaelyan and Sahinyan there are descriptions of the wall structure in different periods [29, 32]; Toramanyan’s and Harutyunyan’s works refer to the issues of the strength of the “midis” masonry wall [30, 33]; the structure of Armenian churches is analyzed in the works of Marr, Toramanyan, Sahinyan, Tokarski, Pabutchyan, Novello, Shakhkyan and Harutyunyan [30, 33-38, 40]; the topic of structural, compositional and artistic peculiarities of Armenian churches is also touched upon by Choisy and Strzygowski [23, 41, 42]; Isabekyan’s work examines the process of forming a three-layer Armenian wall as a structural monolithic element, and also puts forward the idea of interrelation between the wall expressive means and structural forms in Armenian architecture [31]. Our previous work is also devoted to the interaction of structural and artistic solutions of form making in the architecture of Armenian medieval churches, where the issue is discussed at the level of a separate component of the wall and the structure – the portal [14].

In the context of the mentioned issues, the aim of this work is to generalize the peculiarities of the formation of “midis” masonry and to reveal their influence in the evolution process of the structure of the Armenian medieval churches by a comparative analysis of different characteristics. Within the framework of the structure development of the wall and the churches, we find that more attention should be paid to the reflection of their interrelation in the characteristics expressing the qualitative features of the component element and the building.

The work was carried out on the basis of field observations, as well as on research of published and archival materials on the topic, by scientific methods of systematization, comparative analysis and generalization. The methodology is developed in the sequence of content development of the work consisting of 4 sections.

The first section examines the evolution of the wall structure of the “midis” masonry. Parallels of the three-layer walls composition and of the unity of the structure separate layers with the principles of Greek, Roman and Byzantine architecture make it possible to classify the “midis” three-layer wall structure (which is a prefabricated-monolithic structure from the making technology perspective) into a group of monolithic structures. In order to clarify this, the second section of the work touches upon the buildings with such a wall structure implemented in them.

The second section examines the evolution of the structural systems of Armenian churches in the th-14th centuries. The parallels between the development of the wall structure and the cover forms derived from it, as well as the appearance of new types of church buildings clearly show that the modifications in the structural system of churches lead to the formation of the shell structure of the buildings and to the integrity of exterior and interior spaces. This implies that the Armenian medieval churches can be classified into a group of integral structures from the point of view of the structure designing principle. Having arrived at this conclusion, we find it necessary to return to the "midis" masonry wall structure and analyse it from the point of view of the monolithic nature of the structure in the following section of the work.

The third section discusses some contrast between "midis", the facts of the separateness of stone masonry and inefficient interconnection of materials, basing on both the durability of many churches and the peculiarities revealed as a result of destructions, taking into account the volcanic tuff properties of the Armenian Highlands and some experts' observations on the implementation of the wall core. In the context of monolithic nature of "midis", the following are considered: deviation from the principles accepted in masonry walls; examples of monolithic structural elements without facing stones; use of a single-type masonry and the combination of bearing capacity, insulation and decoration functions in it; comparisons of construction technologies in Roman, Armenian and Italian temples. All of them are discussed in parallel with the improvement of the structural systems of buildings. In the context of the monolithic nature of structure and structural elements, parallels are drawn with the use of other materials: brick in Iranian and wood in Transcarpathian medieval architecture, reinforced concrete in modern architecture; the principle of integrity typical to the churches built with "midis" masonry is revealed in the exterior and interior spatial forms. The discussion strengthens the idea of the monolithic nature of "midis" masonry and as a result of it the fact of the formation of an entire volumetric-spatial stone shell in the structural systems of churches. This requires summarizing the peculiarities mentioned in terms of structure efficiency in the next section of the work.

The fourth section presents the characteristics of efficiency revealed in the implementation process of the structures, which appear as a result of the monolithic nature of "midis" masonry: reduction of material consumption; simplification of works; reduction of quality workforce; maximum use of mined stone and reduction of the volume of transported processed stone, lightening of auxiliary structures. The efficiency is also reflected in the evolution tendencies of the monolithic nature of the wall and the integrity of structures, which are presented in the schemes containing the comparative data shown in the last figure. The schemes reflect the tendencies of the monolithic nature of the wall and the integrity of structures in the 4th-14th centuries, and include changes in the following characteristics: volume of the facing stone, correlation of facing stone and core, wall thickness, building area. In addition, the following correlations are considered: building and useful area, material and building volumes, external surface and material volume, building area and external surface, building volume and building area, internal volume and floor area. The schemes are based on those volumetric and planning parameters of 30 Armenian churches built in different periods of the Middle Ages, which are most relevant to the issues raised in the research topic. Summarizing the results obtained in graphical schemes allows to formulate a certain sequence of interactions of different characteristics. This confirms the interrelation between the evolution of the monolithic nature of "midis" masonry and the integrity of structure of the churches.

The conducted research allows us to arrive at the conclusion that the evolution of the three-layer “midis” masonry led to the structural monolithic nature of the walls and forms derived from it, which in turn led to the formation of an integral principle of structure designing in a stone building. The generalization of the results makes it possible to detect the unresolved issues and the directions of the researches, which can contribute to further discussion of the questions posed in this work.

The textual part of the work is accompanied by the graphic material, where an attempt is made to identify the most important points of the substantive development of the research. The photos of the Armenian churches used in the figures were taken by the authors, except for St. Gevorg Church in Ardahan, which was taken from Strzygowski’s work. In the photos of other structures made of a single material, materials from the works of Voronina, Pugachenkova, Goberman, Lysiak and Topuridze were used. Drawings and schemes were made by the authors. They are compiled on the basis of measurement surveys made by the authors, as well as by A. Sahinyan, T. Toramanyan, Sh. Azatyan, Y. Tamanyan, B. Arzumanyan, H. Hakobyan, H. Khalpakhchyan, V. Harutyunyan, S. Mnatsakanyan, Sh. Mkrtchyan and on the analysis of the extracted data. Graphisoft’s BIM technology-based Archicad software simulation capabilities were used to perform the calculations in the research.

2. Results and discussion

2.1. The development of the “midis” three-layer masonry wall structure

The research, related to developed and current stone wall masonry worldwide, which includes 325 norms of seismic and stone structures, identifies the Armenian three-layer unique masonry included in the Soviet norms of the 1950s and the criteria for its use, which have been used since the Early Middle Ages to the present day [17]. Both in the pre-Christian period and in the Early Middle Ages, after that until nowadays, walls of the original three-layer structure were made in stone structures in Armenia. This method of wall building, which according to the knowledge on monuments passed down to us has been widely used since the 4th century in the architecture of Armenian churches, has survived to the present day without significant changes under the name of “midis” masonry.

Bhattacharya et al., distinguishing the three common categories of unreinforced masonry buildings – adobe, brick and stone, connect the peculiarities of their construction with the geographical location and the level of local knowledge [18, p. 53]. As for the natural stone, since ancient times there have been several forms of the wall structure made of it: single-layer, two-layer and three-layer. Due to the creation and use of metal tools, each of these wall structures had its own improvement and development. The binding mortars were also essential. According to Vitti, the spread of mortar during the Roman Empire, in particular, enabled the widespread use of new forms in architecture [16, p. 2]. The mortars were quite different from each other, as their creation was also conditioned by the occurrence of the materials in the area.

In Rome, where, as in the case of the Etruscans and Greeks, dry stone masonry was used in the early period, the widespread use of three-layer wall structures was associated with the development of mortar. The use of lime mortar composed of lime and sand in the wall masonry as a binding material started in the Republican period. It was used both in hewn and rough-hewn stone masonry. And already during the Imperial period, in parallel with the wide use of lime mortar as a binding material in the masonry, in Rome, as in other countries in the region, various three-layer wall structures began to be created everywhere.

From the Imperial period on, lime mortar has also been widely used in brick masonry [12, 21, 22].

According to Vitti, the Romans preferred lime mortar in the construction of walls and vaults from the 2nd century BC. Here he quotes Vitruvius, who mentions the acceleration of construction in the case of a three-layer wall with a lime mortar core [16, p. 7]. In Byzantium also lime mortar was used in stone masonry, where crushed brick tiles and sometimes brick powder were added to lime and sand [23, p. 8; 28, p. 4].

Lime mortar was used also in the construction of vaults. The widespread use of brick vaults with lime mortar began in Roman times and later developed in Byzantium. According to Vitti, builders in Greece used brick vaults as an alternative to concrete vaults, as thin layers of mortar between the bricks attained the necessary strength much faster than the entire mass of concrete [16].

It is important to note that different measures were taken to ensure the integrity of the separate layers of the structure in the three-layer walls. A typical example of them is the inclusion of wooden elements in the structural system. According to Choisy, the walls of Byzantine structures differ in a peculiarity concerning the ancient period of architecture by origin. As in the Mycenaean walls, in the Byzantine walls as well transversal and longitudinal timber ties were installed [23, p. 8]. In the same context, in the research on Byzantine church seismic strengthening issues it is noted that within almost all structures of these buildings, there are transversal timber ties (in the size of the entire thickness of the wall) placed at the feet of the main and the side vaults, as well as in the bases of the tholobate and the dome. And in case of dynamic forces, in order to maintain the stability of the building, timber belts are placed in the mass of the walls on several levels, mainly at the very level where the transversal timber ties are placed [24, p. 201].

From the point of view of strengthening the connection between layers in the wall structure, the principle of using stone headers and stretchers in the masonry is interesting. Such an example can be seen, in particular, in some structures of Umm el-Jimal during the Roman-Byzantine period. According to Al Rabady, this arrangement of stones allowed to bind three layers of the wall better and at the same time accelerate the construction process [25, p. 126-129]. There is an example of a three-layer masonry with stone headers and stretchers in Shayzar Castle, where the walls are laid with parallel, almost horizontal rows of hewn and rough-hewn stones. The walls here are constructed with abundant mortar and wedges used between the vertical joints. Meanwhile, in different rows of the masonry, there are round section stones which cover the entire thickness of the wall and connect the two facing layers [26, p. 187, 190, 200]. We can find original examples of wall masonry with stone headers, stretchers, and unique facade drawings formed by them in the folk architecture of the mountain regions of Syria and Jordan [27, p. 26-27].

Another way to strengthen the structure of a three-layer wall is to implement a row of brick between several rows of stone. Such solutions exist in the Byzantine churches preserved in Greece since the 10th century [12, p. 148]. And the research on the damages of one of the towers of the Theodosian Walls of Constantinople mentions an original Byzantine masonry of the 5th century, where 40cm heigh rows of brick are implemented between the equal number of hewn stone rows. The authors note that these rows are made across the entire thickness of the wall and firmly connect the structure at different levels [28, p. 4]. Examples of such masonry can also be seen in Syria. In Qasr Ibn Wardane, Weber considers the sequential use of hewn stone and brick in wall masonry in the 6th century buildings not only as a constructive measure, but also as an artistic solution [12, p. 148]. An example of the combined use of different masonry is considered by Italian specialists in the research on the revival of Byzantine monuments. The fact of various masonry used in the walls of Saint Nicholas Monastery in Southern Albania is discussed here. The lower rows of the church walls are made of large blocks of limestone, which have different heights on different facades. The central part of the walls is made of brick masonry with thick mortar joints. And in the upper part there is brick masonry with tuff block inserts, which, by the way, is two-layer masonry. The authors believe that such an approach to masonry was practiced as a basis for architectural decoration [13].

In the Armenian Highlands there are examples of three-layer structure walls in the Cyclopean fortresses preserved from the 3rd millennium BC. There the masonry consists of two large external raw stones, as well as small stones and soil filling between them [29, 30]. In the Urartian period, three-layer walls were made by the same principle as before, but the stones had been already worked from the outside, rough, sometimes neatly hewn. The vertical sides of the stones were wedge-shaped from the inside. The upper and lower sides were neatly hewn horizontally, and the core had been already filled with clay mortar [31]. Such forms of processing lateral vertical planes of the stones can be found in the Greek architecture of the 3rd-2nd centuries BC [12, p. 129]. Another example of a wall structure can be seen in the 3rd century walls of Garni Fortress, where in addition to the mortarless masonry with regular-shaped stone blocks typical of the Hellenistic period, there is also three-layer masonry. Here, the stone blocks with neatly hewn sides are rough-hewn only on the inside, and lime mortar is applied in the rather solid core of the wall, which binds the whole structure [32, p. 41]. It is noteworthy that such three-layer masonry with regular-shaped stone blocks can be found in the Byzantine cross-domed church of Daphni Monastery, built later – in the first half of the 11th century [21]. However, it should be noted that in this case, the main supporting part of the wall, like in the previous periods, is also the stone, not the mortar. Sahinyan considers this method of wall construction to be the initial stage of transition from the dry, mortarless walls of the previous periods to the walls with large a lime mortar core [32, p. 41].

Isabekyan states that in Armenia, in order to move from the three-layer wall structure of the Urartian period to the next stage, all that was left was to hew the horizontal sides of the facing stones in the shape of wedge and to replace the adobe mortar with lime concrete [31, p. 36], which had already been done in the 3rd century walls of Garni Fortress. Thus, the mentioned modifications of the masonry and its elements, from the Early Middle Ages, starting from the 4th century led to the formation of “midis” masonry (Fig. 1).

“Midis” masonry consists of three layers: stone in the outside layers and a binding material inside. The light and porous volcanic tuff spread in the Armenian Highlands is mostly used as a stone material. It is characteristic that only the facing surfaces of the stones are neatly hewn. For example, in contrast to the Umm el-Jimal structures already described, where the vertical planes of the stone joints in the three-layer masonry are 2-12 cm [25, pp. 126-129], in the “midis” masonry, except for the outside surface of the stone, the other sides are roughly hewn and wedge-shaped, due to which the outside edges of the stones in the masonry nearly join together and the wall is constructed with mortarless joints, although mortar reaches almost the outside surface of the wall from the inside. The stones resemble a cut pyramid, the cut tip of which goes through the wall, and the base forms the front side of the wall (Fig. 2). The core consists of a mixture of lime mortar, river sand and irregular shape stones. Both in the walls and in the cover elements, the stones at the core are placed in horizontal rows. A layer of sand-lime mortar is applied between the rows. In the structural elements the composition of the core is homogeneous, in contrast to some Byzantine structures, for example, where there is a differentiation of mortar according to the walls and covers [16, p. 12]. The change of the material takes place only in the filling parts of the roofs, above the structures of the covers, where volcanic slag or pumice is used instead of sand and stones to lighten the load (hollow spaces are also created in the core for the same purpose) [30, 33].

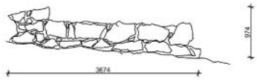
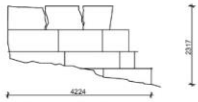
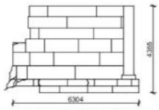
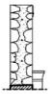
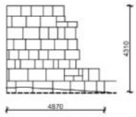
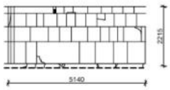
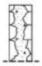
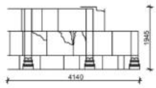
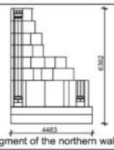
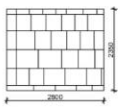
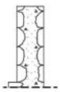
N	Date	Name	Elevation	Section	View
1	8th century B.C.	Teishebaini Fortress	 fragment of the Fortress wall on the right side of the entrance	 fragment of the Fortress wall on the right side of the entrance: horizontal section	
2	3rd century	Garni Fortress	 fragment of the Fortress wall on the left side of the entrance	 fragment of the Fortress wall on the left side of the entrance	
3	5th century	Yereruik Temple	 western fragment of the southern wall	 fragment of the western wall	
4	6th century	St. Astvatsatsin Church in Avan	 eastern fragment of the southern wall	 eastern fragment of the southern wall	
5	7th century	Ptghni Temple	 northern fragment of the western wall	 northern fragment of the western wall	
6	641	Zvatnots Temple	 north-western fragment of the exterior wall	 north-western fragment of the exterior wall	
7	11th century	Marmashen second Church	 fragment of the northern wall	 fragment of the northern wall	
8	1207	St. Astvatsatsin Church in Arzakan	 fragment of the northern wall	 fragment of the northern wall	

Fig. 1. The formation and the evolution of the three-layer structure of "midis" masonry wall, *Source:* own studies.

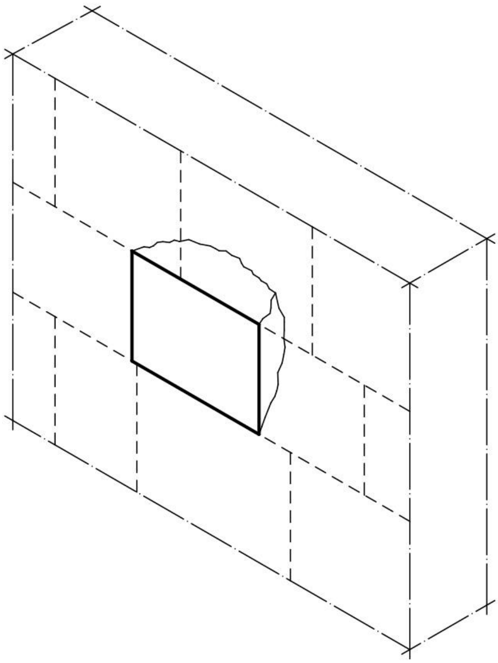


Fig. 2. The appearance of the stone used in the "midis" masonry, *Source:* own studies.

In the churches of the first period of the Early Middle Ages, the stones in wall masonry are long and stretched (in Yereruik Temple the length of individual stones reaches 3 meters). The heights of the rows do not differ much from each other, the horizontal joints are maintained constantly and permanently. Sometimes stretchers placed in a certain sequence are used [31]. However, in contrast to the examples of the already discussed Umm el-Jimal or Shayzar Castle, they do not cover the entire thickness of the wall, remain within the limits of mortar and apparently do not play a significant role in terms of increasing the level of the layer binding. Due to the mentioned circumstance, apparently, the stretchers do not spread and are not used in the later "midis" masonry at all. Besides, "midis" does not use the system of transversal and longitudinal timber ties common in Byzantine architecture. In fact, the connection of separate layers of the wall is created without additional elements. Along with the evolution of the wall structure, the size and the shape of the stones, as well as the drawing of the masonry change. The changes are reflected also in the structure of the forms derived from the wall (arches, vaults, domes). The size of the stones used in the filling reduces, their shape and arrangement (flat, arranged in clear rows) is somewhat regulated. Cowan believes that the master builders and architects of the past did not yet have the command of theoretical calculation methods, they simply relied on the analysis of the problems that arose during the operation of the structures [15, p. 51]. It can be assumed that the same logic was at the basis of the development process of "midis" masonry wall. This wall structure, gradually developing since ancient times, reached perfection in the architecture of Armenian churches in the High Middle Ages, during the 9th-14th centuries. This process of continuous evolution can be traced back to the examples of wall structures typical of the different periods shown in Figure 1.

Thus, from the point of view of making technology, the prefabricated monolithic three-layer “midis” wall construction can be classified as a monolithic structure according to its composition. In order to clarify the aforementioned, let us touch upon the structures implemented in such a wall structure.

2.2. The evolution of the structural systems of the churches in the 4th-14th centuries: consolidation of the shell structure and the space integrity

The temples of the first period of the Early Middle Ages, the knowledge of which has been passed down to us through reconstructions, originally had a simple geometric structure typical of masonry with regular-shaped stone blocks. The additions that appeared over time were conditioned by the tendency to obtain structures more expedient for the new rituals and ceremonies of the Christian religion. Toramanyan finds that some of the early Christian basilicas in Armenia initially consisted only of the prayer hall and the oldest structure (probably rectangular) of the apse [33, p. 131]. According to Sahinyan, Toramanyan came to this conclusion while studying the Tekor Temple [34]. Similar examples of reconstructed temples are the churches of Kasagh, Tekor, Yereruik and Odzun (Fig. 3). In particular, the simple three-nave basilica structure of the Tekor Temple, built in the 4th century, was later supplemented by external porticos, present-day apse with adjoining rooms, portals, the apse of the north facade and the dome [33]. The examinations of the Kasagh Basilica, also built in the 4th century, revealed that further additions were the portals, the attached trapezoid room on the east corner of the north wall, and the windows on the south façade [34]. The Yereruik Basilica, built in the 5th century, the structure of which Marr, Novello and Paboudjian touched upon in their critical analyses, also had a number of form making stages: the latest change is the portico added on the western facade with the adjoining rooms [35, 36]. The study of the 6th century domed basilica in Odzun confirms that the adjacent external portico are further additions [37, 38]. And indeed, if we remove the later additions from the present appearance of these temples, it will become clear that the temples originally had a simple basilica structure.

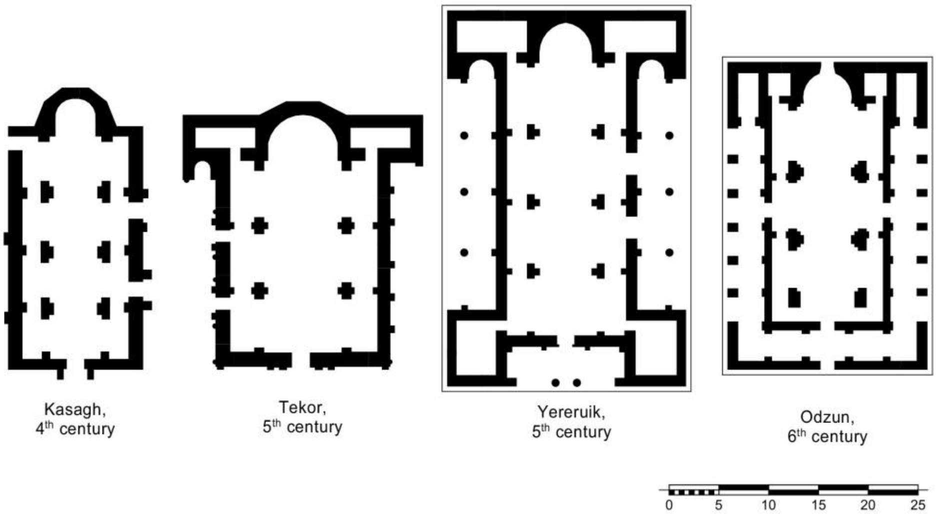


Fig. 3. The planning structure of the Early Middle Ages first period churches, *Source:* own studies.

Although Choisy, writing about the Syrian and Armenian architectural schools basing exclusively on the use of the stone, notes that in Armenia, until the central period of the Middle Ages, dry stone masonry was preserved [23, p. 15], actually, the temples discussed already had a three-layer wall structure with a lime mortar core [33-36, 38]. At the same time, it should be noted that in these structures, the rectangular plan and simple volumetric forms typical of a mortarless wall were preserved (Fig. 3).

In the temples of this period the walls have considerable thickness, for example in the Kasagh Basilica it is 140 cm, in Tsitsernavank Monastery – 150 cm. This is a continuation of the traditions of the mortarless wall. In contrast to Byzantine or Iranian architecture, where brick roofs were widely used [23, p. 8], the roofs of these temples were made of stone and sometimes of wood, which was covered with tiling. However, as early as the 4th century, wooden roofs in Armenia began to be rebuilt into stone ones [34]. The Early Middle Ages are also characterized by the fact that in this period on the base of the three-layer "midis" wall the cover forms derived from it were formed – arches, vaults, domes. In the Armenian churches the form of the transition from the square base to the circle one, as in Parthian architecture [7, p. 194], was the squinch. These individual forms, while evolving and acquiring common features, contribute to modification, development, and creation of new structural systems. And at the basis of all of them, in fact, is the "midis" masonry wall.

The wall structure and the cover elements acquire a new quality during the continuous evolution. The core in the wall structure becomes not only the connecting, but also the dominant, main supporting part. In particular, if the thickness of the stone in the wall section in 5th century Yereruik Temple is 68%, then in Talin, Zvartnots and Ptghni temples of the 7th century it is already 44-47% stone, more than a half is the core.

In parallel with the development of the wall structure in the 6th-7th centuries, new types of church buildings were created, with completely new structural systems different from the basilica. In typological classifications by Tokarsky and Harutyunyan [30, 40], the following types of churches are distinguished: tetraconch central-domed with cross plan (St. Astvatsatsin in Avan dated 6th century, St. Hripsime dated 618, etc.), domed hall (Ptghni Church dating to the 6th century, St. Grigor Cathedral of Arutch dating to 666, etc.), triconch domed basilica (Katoghike Church in Talin, Katoghike Church in Dvin dating to the 7th century, etc.), churches with multiple apses (Saint Zoravar Church in Yeghvard, St. Gevorg Church in Irind dating to the 7th century, etc.), cruciform central-domed on the extended square base of the dome (Mastara Church, St. Gevorg Church in Artik dating to the 7th century, etc.), domed basilica (Cathedral of Mren dating to 639-640, Bagavan Temple dating to 639, etc.), circular tetraconch (Zvartnots Cathedral dating to the 641, Lyakit Church dating to the 7th century, etc.), domed with cross plan and four free-standing columns (Bagaran Church dating to the 7th century, etc.), domed with cross plan (St. Stepanos of Lmbatavank dating to the 6th century, St. Stepanos of Agarak dating to the 7th century, etc.), (Fig. 4).

The structural systems of these churches are the result of the continuous development of the Armenian "midis" masonry wall. If the basilicas of the early period still retain the simple solutions typical of a mortarless wall, then the structures of the 6th-7th centuries obtain more complex planning and spatial forms (pronounced volumes of the apses, dome and structures under the dome), which are an effect of the usage of the opportunities provided by the "midis" structure. The size of the churches was significantly increasing in this period. Verticality begins to prevail in their composition: "space stretches upwards" says Maranci in describing the spatial perception of the Cathedral of Mren [39, p. 658].

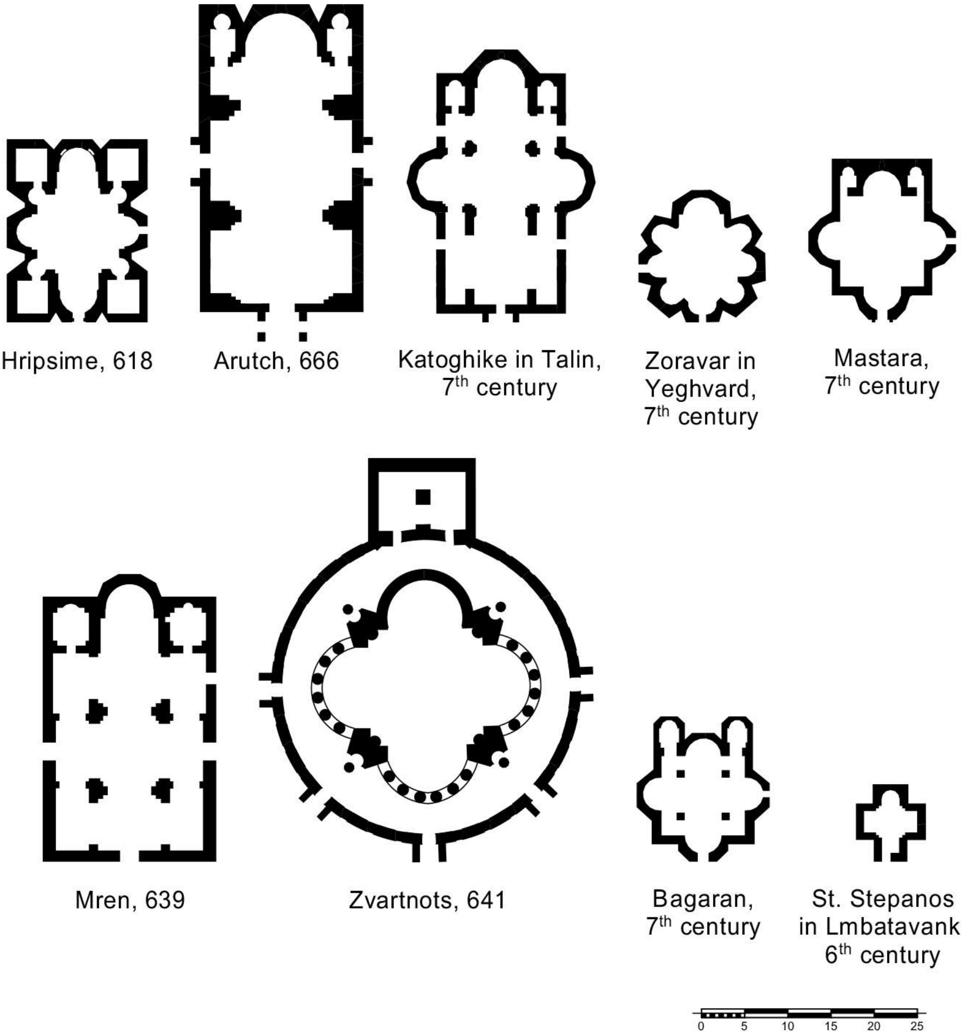


Fig. 4. The planning structure of the churches dating to the 6th-7th centuries, *Source*: own studies.

The wall thickness decreases during this period. From 140-150 cm of the temples dating to the 4th century it becomes, for example, 90 cm in the case of Zvartnots dating back to 641 and 95 cm in the case of Arutch dating to 666. We must also take into account the fact that these temples are more than three times bigger than the previous ones. In the structural systems of these new types of buildings, despite the more complex volumetric forms, some of the differentiated elements that existed in the previous period are often eliminated, in particular, the columns and pylons.

The structural systems of the churches created during the 6th-7th centuries, as in the case of their particular components [14], were continuously used and were more developed in the 9th-11th centuries. And in the 12th-14th centuries some of them became the main ones. These include the following types: domed halls (St. Astvatsatsin Church in Noratus dating to the 10th century, Katoghike Church in Marmashen dating to the 10th century, St. Nshan Church of Haghpat Monastery dating to 967, St. Astvatsatsin Church of Goshavank

Monastery dating to 1191, etc.), central-domed with four sacristies (St. Amenaprkich Church of Sanahin Monastery dating to the 10th century, St. Astvatsatsin Church of Dadivank Monastery dating to 1214, Katoghike Church of Geghardavank Monastery dating to 1215, Cathedral of St. Hovhannes Mkrtich in Gandzasar dating to 1216, etc.), churches with multiple apses (Church of St. Gregory of the Abughamrents in Ani dating to the 10th century, Church of St. Prkich in Ani, Hovvi Church in Ani dating to the 10th-11th centuries, etc), (Fig. 5). These churches are significantly smaller in size than the structures of the previous period. At the same time, they clearly express the wholeness of the external and internal artistic perception, "integrity of the external volume and the interior space", as Isabekyan describes it [31, p. 38]. In this sense, Brunov's observation is very typical. Referring to Choisy's comparisons of the Byzantine and Armenian architecture, the first of which he considers as an expression of inner essence, and the second as a disguise, Brunov notes that in fact the essence of the architecture of Armenian churches lies in the correlations of the expression of the space and the mass [23, p. 51-53, 81]. The integrity of the space is also stimulated by the fact that these structures already act as a unique shell created by the stone-lime-concrete alloy. The latter has different cross sections and shapes in different parts of the structure, depending on the need to withstand static-dynamic forces and to pass the loads evenly from the upper parts of the structure to the sub-base.

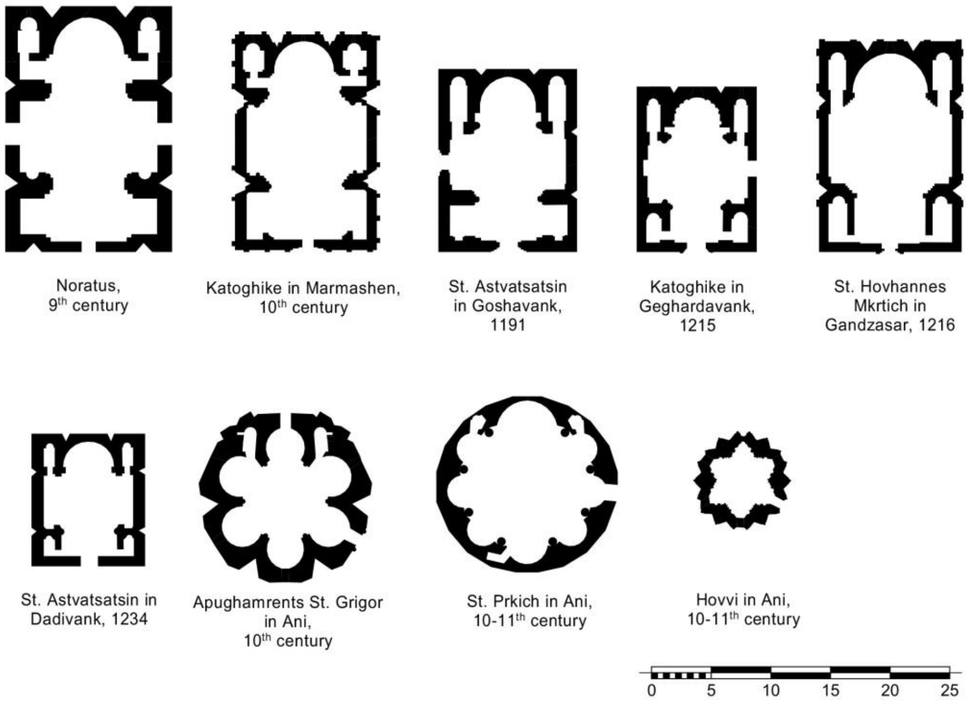


Fig. 5. The planning structure of the churches dating to the 9th-14th centuries, *Source:* own studies.

The mentioned developments are expressed also in artistic principles. Naeeni et al. note the aspiration to achieve "vagueness and ambiguity between structure and decoration" in regard to later Islamic, particularly Iranian, architecture [7; 11, p. 7]. In the architecture of the Armenian churches one can see a fundamentally different approach to merging the structural with the artistic. Here, the integrated artistic treatment of the shell, referring to both the exterior and interior spaces, forms and surfaces, truly corresponds to the structure designing of the shell itself.

The formation of shells is closely related also to the organization of the interior space of the structures. The chronological classification of the churches makes it possible to clearly trace the process of the interior space consolidation. The fragmentation of the interior space of the temples built in the 4th-5th centuries was skillfully overcome in the central-domed temples and is perfected in the domed halls and churches with multiple apses (Fig. 5). The domed hall and the church with multiple apses, which are different from each other according to the planning structure, have in common the idea of organizing the interior space, its integrity. The principle of treatment of the shell inner surface is also essential for the interior space integrity. It can be said with confidence that the treatment of the shell inner surface in almost all structures is subject to the idea of integral perception of space (Fig. 6).

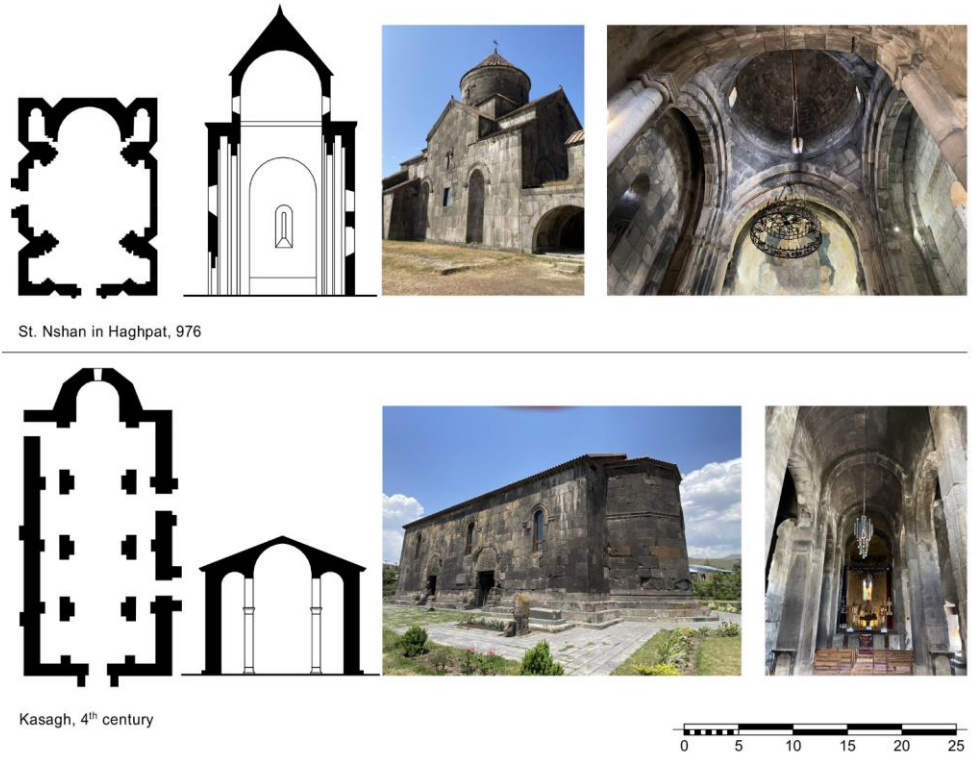


Fig. 6. Formation of the structural and the volumetric-spatial integrity through comparison between the 4th century Kasagh Basilica and the 10th century St. Nshan Church of Haghpat Monastery, *Source*: own studies.

Thus, it can be noticed that the integral principle in the architecture of the Armenian medieval churches is beyond the feature of a purely structural system. The reflection of the structure integrity in the approaches to the organization of the exterior and interior space, as well as to the artistic treatment of the form, endows the integral principle with the property of being a common structural feature. This conclusion implies the need to return to the "midis" masonry wall and to analyse it from the point of view of the structure integrity.

2.3. Contrasting "midis" and three-layer stone masonry walls: monolithic structures

As mentioned above, starting from the 7th century churches, the tendency to reduce the stone part in the wall structure has been noticeable (Fig. 1). Thus, from a structural point of view, the core becomes more important. In the 10th-11th centuries and later the monolithic masonry of the wall in Armenia was perfected to such an extent that the masters significantly deviated from the accepted principles of the wall masonry implementation. In the structure of the wall, the stones obtain any size, position, often also being vertical. Horizontal joints are disrupted, vertical joints are not connected, and the volume of facing stones decreases even in the case of larger sizes of external surface. Similar examples can be seen in Marmashen, Amberd, Haghpat and other churches (Fig. 7). Isabekyan's observation is very typical here: "[...] a single stone, even a row, has no independent significance, because the stones no longer have a tectonically logical form and arrangement: the height of the rows is disrupted, the position of the stones is more vertical than horizontal, they are placed irregularly" [31, p. 45]. In fact, the facing stones form a monolithic mass with the core, which further strengthens the essence of the solid stone shell. This shell, changing the thickness, position, shape, if necessary, forms the component elements of the structure: the wall, the arch, the vault, the dome and, in fact, their unity –the whole structure [31].

Fig. 7. Part of the northern wall of the Katoghike Church of Marmashen Monastery, *Source*: own studies.

Thus, the structure is created not through a simple arrangement of unit elements, but as if through merging. Changes in the composition of the wall gradually find expression in its appearance, which begins to reflect the monolithic nature of the wall (disruption of rows and vertical joints, use of different size stones). Along with the change in the composition of the wall, its thickness is reduced, which leads to a reduction in the weight of the structure. The development of the structural integrity of the wall and forms derived from it leads to the modifications and systematization of the general structural systems of the buildings. For example, if in Iran and Byzantium the domes were often placed directly on the structural elements of the transition from the square to the circle (squinches, spherical pendentives, etc.) [11; 23, p. 8], in Armenia they rely exclusively on the tholobates, contributing to a more even distribution of loads. The elevation of the dome, together with the under dome square and transition elements, leads also to the reflection of the internal structure in the external volumes and promotes the unified perception of the space. It should be noted here that it is due to the monolithic structure that in the Armenian churches built entirely of stone it was possible to implement the elements of the transition from the square base to the circle of the tholobate – the squinches, and later the pendentives. Thus, the monolithic nature of the wall and forms derived from it leads to the formation of the integral structure of the buildings.

Due to the monolithic structure, the buildings gradually become lighter, more rational in terms of implementation and material consumption. The tendency to reduce the wall thickness due to the reduction of the depth of the facing stones and the extension of the core specific weight increases the level of wall monolithic nature and lightens it. This is especially important in cover elements. The development of the structure of the wall and forms derived from it makes it possible to think and to implement monolithic structures even without hewn stone, a vivid example of which can be seen in the vaulted roofs of the auxiliary rooms built next to the fortified walls in Tatev Monastery. They are made of completely irregular stones (Fig. 8). According to Isabekyan, this is actually a concrete vault made on a formwork, without wedge-shaped stones [31, p. 41].

Fig. 8. The vaulted roofs of the auxiliary rooms adjoining the fortified walls in Tatev Monastery, *Source:* own studies.

It is interesting that if in Armenia from the Early to the High Middle Ages and even until nowadays, there has been essentially one type of stone masonry, which has evolved continuously over time, the same cannot be said unequivocally about the stone walls used in other countries of the region. In different countries, wall-building methods have developed in various directions at different times; during the development, there were different designs and combined applications of different wall structures at the same time.

In particular, there is no common approach in the whole structure of some exceptional Roman buildings: they are differentiated in order to improve the work of the structure. This is discussed in Alberti's contemplations on the structural relations between the wall and structure. He mentions that the most important parts of the wall are the corners, as well as the pylons and columns placed in the walls, which are supporting the beams and arches, which can be described as a "skeleton". And he calls "filling" whatever is located and spread among those main parts [19, p. 81-85]. The stratification of the Roman three-layer wall was probably due more to the making technology than to the material properties. In this context, Vitti points out that stone buildings made with lime mortar in the late Republican period of Rome were not endowed with sufficient structural stability. He connects this circumstance with the division of the wall into three parts (core and facing) and with insufficient homogeneity and density of the core [16, p. 8]. The differentiation of the core is also present in mortar used in the walls and vaults of the Byzantine buildings [16, p. 12]. In the context of the differentiation of the structural elements, one can consider the existence of a framework base in the Byzantine churches, where, according to Gavrilovich et al., in order to increase the resistance to static and seismic forces, the already discussed transversal and longitudinal timber ties were used [24, p. 210-211].

It is noteworthy that there does not seem to be such a differentiation between the structures of the walls and vaults of the Armenian medieval churches. On the large fragments in Ptghni, Zvartnots, and other temples, visual examination of the cross sections opened as a result of the building collapse has shown that core lime mortar was made on the principle of the same horizontal placement of stones in the filling and, most likely, had the same composition both in the walls and the vaults. This assertion will be resolved as a result of additional technical research and comparative analysis of the binding material composition in different parts of the structures.

In the context of the aforementioned, it is interesting to try to draw parallels between the integration of the structure and structural elements with the cases of the use of other materials. Hejazi mentions that "the use of materials in buildings is a work of the spirit to impose the celestial form upon matter" [7, p. 191]. It can be added that the material used is also a reflection of the region and the time period, as in each country, of course, first of all, preference is given to the use of locally available materials that meet the technological requirements of the time. From this point of view, a typical example of monolithic nature and wholly integrated brick built structure, is the Samanid Mausoleum built in Bukhara at the turn of the 9th-10th centuries, which seriously influenced later Islamic architecture and is one of the jewels of Persian architecture [6, 7]. The walls of this square-base central-domed structure are made in full depth with a solid masonry of bricks, without a core. The walls are shaped from the outside and the inside with a unified artistic solution of brick masonry with different drawings. Thus, this masonry simultaneously serves structural and aesthetic purposes. And despite the amazing variety of decoration, its form making, according to Pugachenkova, is inseparable from the construction basis of the structure [5, p. 120-121].

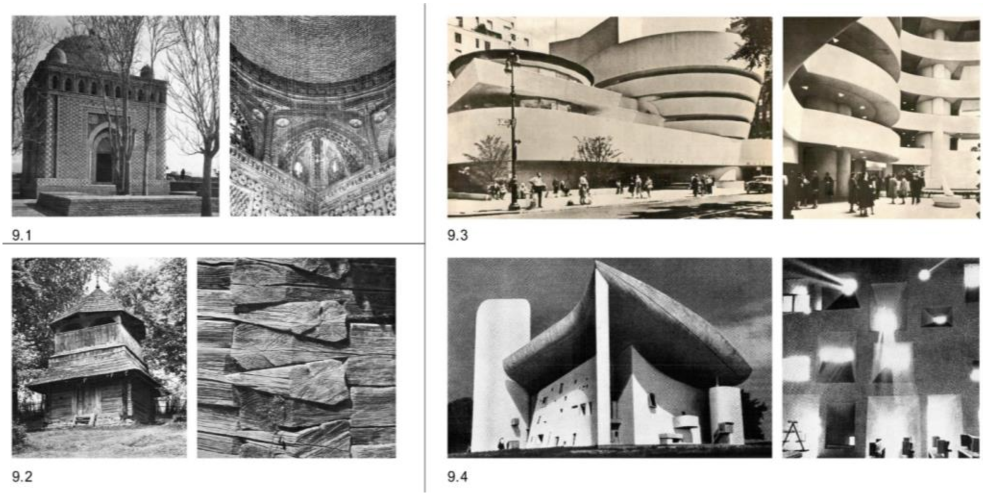


Fig. 9. Integration of the structure and the structural elements in the case of the use of different materials. Examples of integrated structural systems. 9.1) Brick. The Samanid Mausoleum, Bukhara, 10th century. General view and interior. 9.2) Wood. Church buildings in Transcarpathia. The Belfry of the Church of St. Elijah, 1792, Village of Roztoka, Mezhgorsky District, General view and the Church of the Intercession of the Virgin, 1792, Village of Kanora, Volovetz District. The intersection angle of the walls. 9.3) Reinforced concrete. Museum of Modern Art, New-York, 1957. General view and interior. 9.4) Reinforced concrete. Chapel , *Source* [4-6]; [8]; [9].

From the point of view of the material and its implementation, the wooden sacral architecture of the highlanders living in Transcarpathia of Ukraine is interesting. The Carpathians are a land of preserving cultural and area studies complexes, with completely unique wooden churches, which, in fact, do not have their equivalents in other parts of Ukraine [3]. The preserved temples mostly refer to the 18th century. They are all samples of folk art. Here we can also notice integration of the structure and the structural elements. All the supporting, insulating and decorative elements of the churches are made of wood, no other materials have been used. The halls are covered with pyramidally installed ties. In the description of the roofs, Goberman mentions that it seems as if reaching the required height, the walls deviate sharply and join together, forming a tent-roof and covering the interior space of the temple [4, p. 24]. The observation of Taras is also interesting. He finds that the architectural expression here is created both by the contrast of equal masses and by the inclination of the walls, which he considers are for the imaginary increase of height in the interior and the provision of monumentality in the exterior [3, p. 131]. It should be noted that in churches with a tent-roof, built exclusively of wood, the interior space completely corresponds to the exterior form. In terms of the structural integration, Goberman's observation is highly typical. "This is an ideal case when a perfect architectural construction, having no 'dead' spacing, acts as a shell separating from the outer medium what part of it is needed by Man" [4, p. 24].

Variants of whole monolithic shells can also be found in the 20th century reinforced concrete structures. One such example, particularly, is the Museum of Modern Art in New York. The whole main structure of the museum building – the outer and inner walls, covers, banisters – are included in one volume made with a single material – reinforced concrete, spirally rising from the bottom to the top [8]. The reinforced concrete structure of

Ronchamp Chapel is solved with the same idea of integration, but in a different way. Here, the walls, obtaining various planning and spatial forms and transforming into roofs, organize the unified interior space of the church hall [9].

Despite the significant difference between materials and technologies, all the mentioned cases are characterized by the idea of the integration of structural elements, which is also expressed in the wholeness of the perception of volumes and interior space. In fact, by the same model, the integrity of the wall basis and facing was originally set and preserved throughout the development in the architecture of the Armenian medieval churches. Due to the peculiarities of the wall structure and materials, this integrity is very unique in its forms and solutions. Isabekyan, in his work on wall tectonics in Armenian architecture, drawing parallels with other countries, touches upon several observations made in various researches [31], some of which we consider appropriate to quote here. Particularly interesting is the following description of the ancient Roman architecture by Choisy: "The separation of the main and decorative works is especially clear in the Roman masonry. While some builders elevate the building, others decorate it, plaster it, face it with marble, and enrich it with more or less elegant decoration, which does not derive from any necessity". In the same context, Choisy refers to the architecture of the Italian Renaissance. "The idea of separating the decoration of a building applied in Rome and its structure has never been used as widely as in Italy in the 16th century. [...] The unfinished buildings of that time were mostly built of raw stone masonry, in which chases were left for later installation of cornices, frames, and other decorative elements, which was done after the building was finished" [41, p. 132-135]. Strzygowski's comparison of the integrity and the separation of functions in the structural elements of the building is also noteworthy, which he analyzes in the parallels between the Armenian and Italian medieval architecture. According to him, "[...] in order to obtain a structure in Armenian architecture, a facing is necessary. The phenomenon we observe in Florence, that the churches with open core have been waiting for their facing for centuries, and in part are still waiting, is impossible in Armenia, because in order to obtain a wall there, it is necessary to have a facing" [42, p. 354].

However, interestingly, an earlier period researcher Alberti, for example, did not particularly believe in the monolithic nature of a three-layer wall with concrete core. He believed that the wall must have a skeleton, which is its basis, and what lies between the main parts comprises the filling [19]. At the same time, Alberti does not touch upon the Armenian "midis" masonry. This means that his opinion probably refers only to the three-layer walls used in Europe. And the "midis" masonry walls, like the covers, are monolithic structural elements, where the bearing capacity, insulation and finishing functions are combined.

Some modern researchers also touch upon the heterogeneity of stone masonries, substantiating the fact that they are mechanically complex and heterogeneous materials. This is explained by the deterioration of the component materials, the various properties of stone and mortar and poor mutual binding [20, 21], which leads, in particular, to the inability to withstand horizontal loads caused by earthquakes and results in disintegration [18].

However, what is also interesting, many examples of a three-layer wall of "midis" masonry show the exact opposite. It is difficult to doubt the seismic resistance of Armenian churches from the point of view of using a three-layer unreinforced wall. For example, standing not far from the Zvartnots Cathedral (641), in all probability destroyed by the earthquake, St. Hripsime (618) and St. Gayane (630) churches were not destroyed by earthquakes. Many other churches of medieval Armenia (St. Katoghike in Yerevan, Mastara, Haghpat, Sanahin, Makaravank, Geghardavank, etc.) were not destroyed by seismic shocks. Since the same technology of wall and cover implementation was used in all the churches of this period, it is obvious that the reasons for the destruction of certain churches cannot be unconditionally attributed to the weakness of the three-layer wall structure. We think it will be possible to clarify the reasons for them within the framework of complex studies including comparative analyses of the types of structures, the composition of structural elements and the quality of the work done. As for the “midis” masonry, in buildings constructed with this technology more than 1000 years ago, it is obvious to the naked eye that the materials are well-bonded. Examples of the monolithic nature and strength of “midis” are the already discussed complete large fragments of the shell preserved near the Zvartnots and Ptghni temples (the facing stones together with the core). The large fragments that fell from a great height about 1000 years ago were not only unaffected by the fall, but to this day, being in the open air, have been preserved without losing their entirety (Fig. 10). A completely different example of the monolithic nature of “midis” can be observed in St. Gevorg Church in Ardahan. The fate of the church is currently unknown, but a photograph from the early 20th century presented by Strzygowski [42, p. 4] shows that most of the building’s hewn stones were some time artificially removed from the core (for vandalism, robbery, or other reasons, not exactly known), but the building, nevertheless, remained standing (Fig. 11). In his book on the history of Armenian architecture, Harutyunyan writes, citing Toramanyan’s research on construction technique in Armenia, that the monolithic nature of the wall is the result of the creation of a lime-concrete core between two faces using liquid mortar as well as applying hydraulic additives (stone fragments, volcanic slag, pumice, etc.) in it [30]. According to Harutyunyan, the formation of a fundamentally new quality of the three-layer wall with a core including small stone filling, lime-concrete, and lime mortar is a result of the special attention paid to the quality of lime (ordinary, hydraulic) and the purity of sand (pumice sand, tuff sand, river sand) from organic particles (carefully washed before use). These measures, together with the centuries-old carbonation processes in the lime-concrete, have created the strength of the monolithic three-layer wall [30, 33]. It can be added here that the porosity of the volcanic tuff of Armenia greatly contributed to the monolithic nature of the wall, as a result of which lime mortar, penetrating into the stone, created the maximum binding between the facing stones and the core.

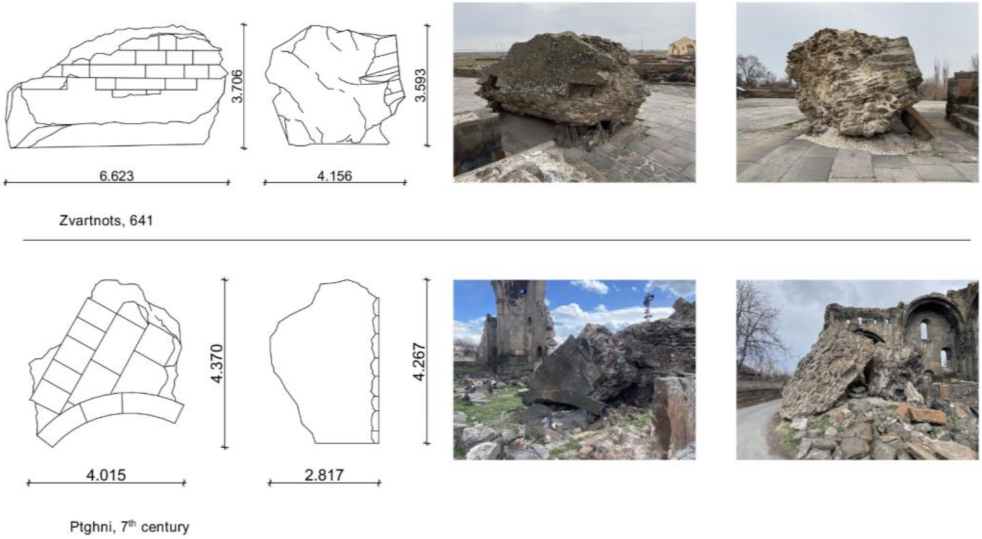


Fig. 10. Large fragments preserved from Zvartnots and Ptghni temples, *Source:* own studies.

Fig. 11. St. Gevorg Church in Ardahan, *Source* [42].

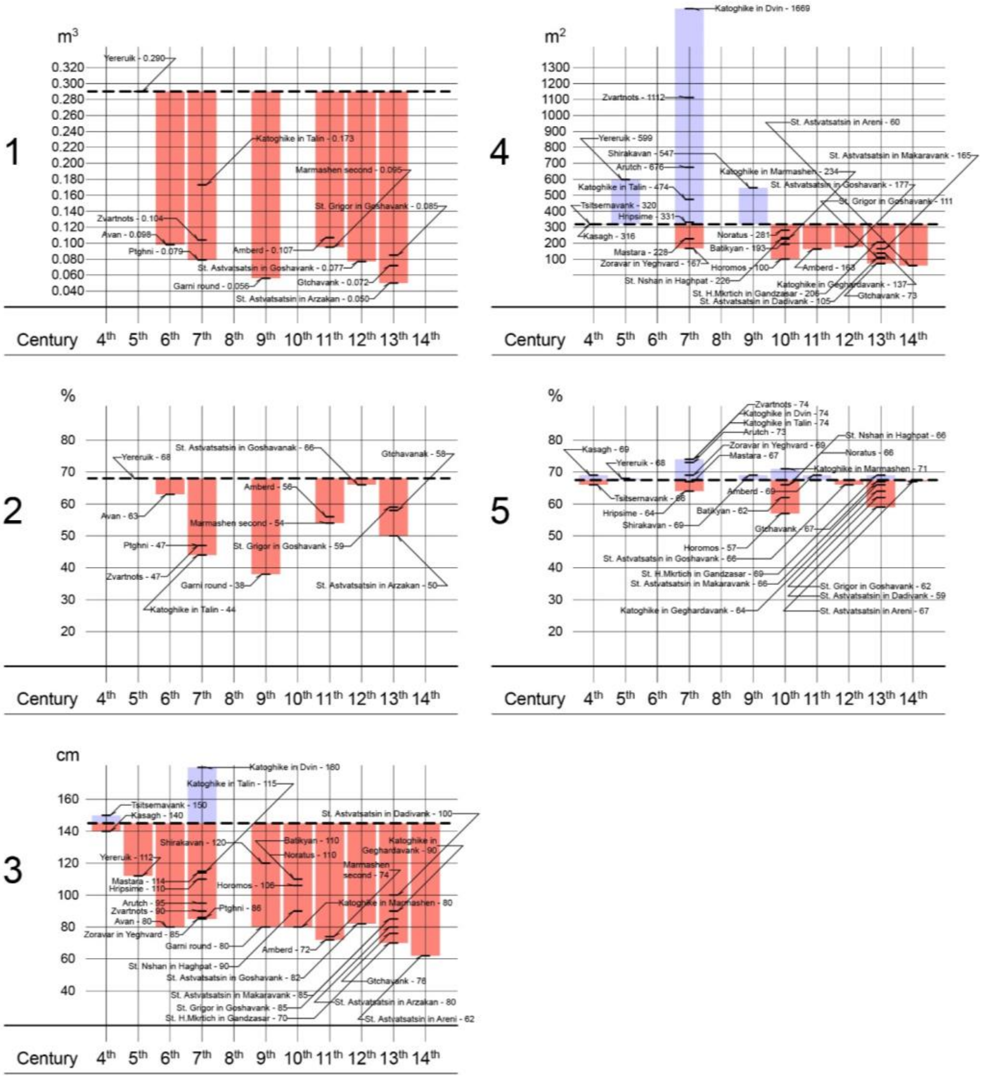
Thus, the good binding of the materials has created homogeneity in the wall and cover structures, which, we believe, needs even more in-depth research in terms of the possibilities of material interaction in three-layer walls. In a study of earthquake damages to a medieval monument, Flora et al. precisely note that with today's opportunities to interpret and simulate the seismic effects on structures, it would be a cultural mistake not to take advantage of these tools in the activities related to heritage structures [28, p. 22]. A number of our partners' works include research data obtained with radar, borescope, acoustic and other methods, often using the principles of complete or partial experimental model-making or digital modelling of the structures. The obtained results made it possible to reveal with great accuracy the composition and the cross section morphology of the walls and other structural elements of historical buildings [21, 43, 44], as well as to identify the causes of damages and to evaluate the degrees of seismic vulnerability of the structures [45, 46]. Such in-depth technical studies of Armenian churches will allow for more accurate estimations and conclusions about the possibilities of the mutual work of materials, as well as efficiency of different structural systems of churches in the event of seismic forces, the composition of structural elements and materials in different parts of the building.

The discussion on consolidation of the volumetric and spatial integrity in the churches as a result of the monolithic nature of "midis" masonry implies summarizing the aforementioned from the point of view of the structure efficiency, referring also to its reflection on the technical and economic processes of building construction.

2.4. Effectiveness

The consolidation of the monolithic nature of the "midis" masonry had a certain impact on the increasing of the construction efficiency and economic processes. In particular, the gradual decrease of the three-layer structure thickness automatically led to a decrease in total material consumption, which, of course, should leed to a shortening of construction terms and expenses, simplification of work, as well as a reduction in the share of quality work. In this regard, Vitti states that the fact that facing stones were worked on only one side in the three-layer wall with a lime mortar core, in contrast to the dry masonry with regular-shaped stone blocks, contributed to the creation of monumental architecture by a less skilled workmanship [16, p. 7]. The reduction of the facing stone volume in the structure of the wall, naturally, should leed to a reduction in the volume of stone mined and transported in the quarry, which, in turn, had a significant impact on the construction prime cost. It is not difficult to conclude that the increase in the volume of lime-concrete in the structure of the wall would allow the stone mined in the quarry and the stone waste generated during the processing to be fully utilized in the core. From the point of view of increasing the efficiency of construction, the fact that the weight of one individual stone decreased as a result of the reduction of the thickness of the facing stones, must have played a significant role. It would not only lead to an increase in productivity, but also lightened and simplified decks and elevating mechanisms. The full use of stone was facilitated also by the already presented technique of using facing stones of different sizes and positions.

In order to summarize the discussed ideas, we have revealed the volumetric and planning characteristics of some Armenian churches built in different periods of the Middle Ages. We find that these characteristics are most relevant to the issues raised in the research topic. The graphic schemes based on their comparison, presented in Figure 12, definitely reflect the phenomenon of the consolidation of the monolithic nature and structural integrity of the wall in the Armenian medieval churches, as well as the effectiveness of the economic criteria and the organization of construction. The characteristics of the studied churches are presented in Table 1. Their total number is 30, out of which 9 were observed with complete data (shaded lines).


1
m3
Century 4th 5th 6th 7th 8th 9th 10th 11th 12th 13th 14th
4
m2
Katoghike in Dvin - 1669
Zvartnots - 1112
Century 4th 5th 6th 7th 8th 9th 10th 11th 12th 13th 14th
2
%
Century 4th 5th 6th 7th 8th 9th 10th 11th 12th 13th 14th
5
%
Century 4th 5th 6th 7th 8th 9th 10th 11th 12th 13th 14th
3
cm
Katoghike in Dvin - 180
Century 4th 5th 6th 7th 8th 9th 10th 11th 12th 13th 14th

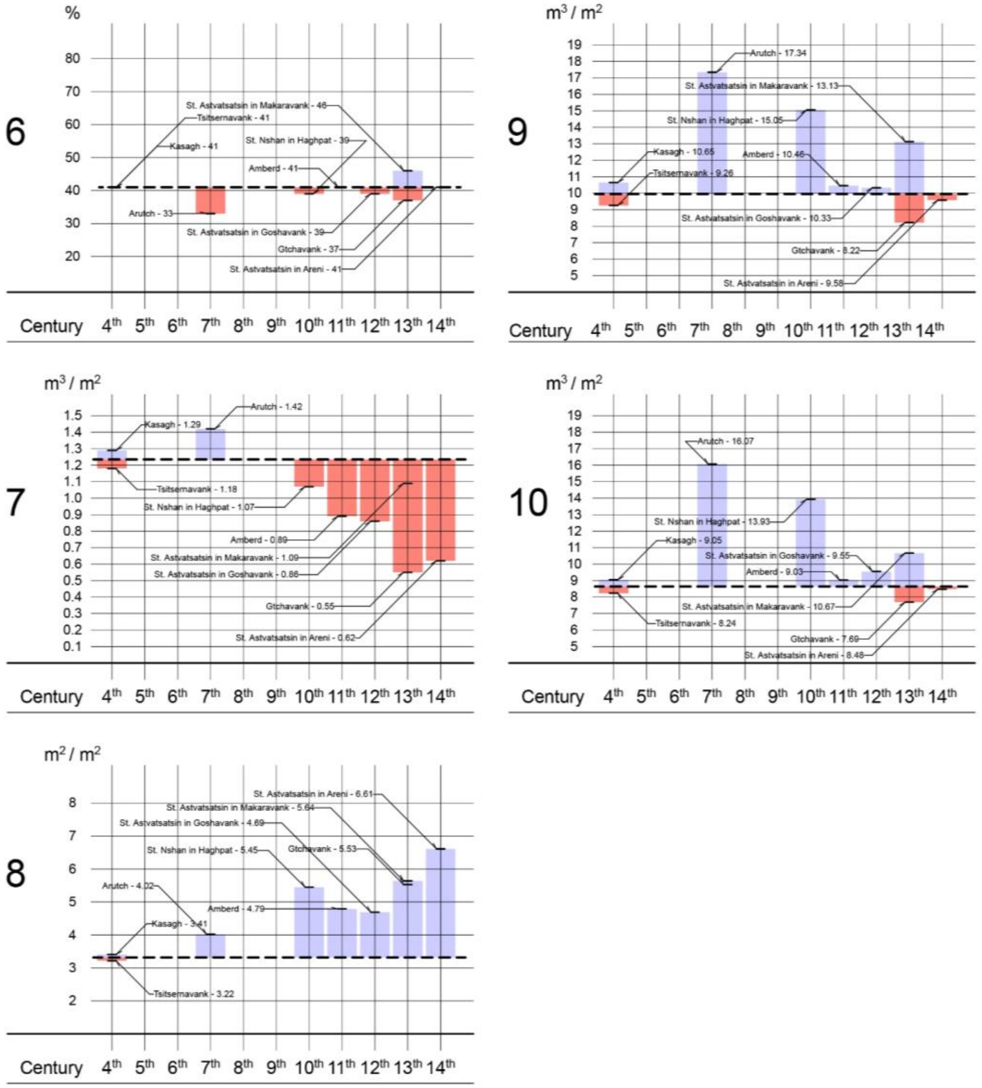


Fig. 12. Tendencies of the evolution of the monolithic nature of the wall and integrity of structure in the 4th-14th centuries. 12.1) The volume of facing stone. 12.2) The correlation of facing stone and core. 12.3) The wall thickness. 12.4) The building area. 12.5) The correlation of building and useful area. 12.6) The correlation of material and building volumes. 12.7) The correlation of external surface and material volume. 12.8) The correlation of building area and external surface. 12.9) The correlation of building volume and area. 12.10) The correlation of internal volume and floor area, *Source:* own studies.

The graphs show the chronology in the horizontal direction and the data of the observed characteristics in the vertical direction. The black, bold dashed line underlines the horizontal of the earliest index of the given characteristics, in relation to which the tendencies of growth and decrease in the following periods are presented in blue and red columns, respectively. Let us try to discuss the peculiarities of the variation of each characteristics by the principle of comparison with the earliest index.

The first 3 schemes are aimed at revealing the evolution tendencies of the monolithic nature of the "midis" masonry wall.

Scheme 12.1 shows the change in the volume of the facing stones based on the data of 12 churches. The absolute decreasing tendency is obvious there. The scheme shows that along with a certain reduction in the size of the face surface of the stones, a sharp decrease in thickness has led to a significant reduction in the volume of stone blocks used. The horizontal dashed line is taken by the index of Yereruik Temple of the 5th century. If in Talin Katoghike Church of the 7th century the decrease is 1.7 times, then in St. Astvatsatsin Church in Arzakan of the 13th century – 5.8 times.

Scheme 12.2 shows the change in the correlation of facing stone and lime-concrete core in the wall cross section based on the data of the same 12 churches. The data on the percentage of the stone section in the wall thickness are presented, where the absolute decreasing tendency is also obvious. The data show that the increase in the volume of the core has led to a certain reduction of the stone in the wall cross section. The horizontal dashed line is taken by the index of Yereruik Temple of the 5th century. If in St. Astvatsatsin Church in Avan of the 6th century the decrease is only 1.1 times, then already in the round church at Garni of the 9th century – 1.8 times. In Gtchavank, St. Grigor Church in Goshavank Monastery and St. Astvatsatsin Church in Arzakan dating to the 13th century – 1.2-1.4 times. The absence of data from the 4th and 14th centuries in the schemes 12.1 and 12.2 is connected with the absence or inaccessibility of structures with open sections of the wall, which, however, we think could not have a significant impact in terms of determining the general direction of the evolution.

Scheme 12.3 shows the change in the wall thickness based on the data of 30 churches, where the decreasing tendency is also obvious. The horizontal dashed line is taken by the mean index of Tsitsernavank and Kasagh temples of the 4th century. If in Yereruik Temple of the 5th century the decrease is 1.3 times, then already in St. – Astvatsatsin Church in Areni of the 14th century – 2.3 times. Only in Dvin Katoghike Church of the 7th century, contrary to the index in the 30 observed churches, there is a tendency of growth, which is probably conditioned by the very large size of the structure.

The following 7 schemes are aimed at revealing the evolution tendencies of the structural integrity of the churches.

Scheme 12.4 shows the change in the plan dimensions of the building based on the data of 25 churches, which is expressed in the data of the building area. The scheme shows that during the 4th-7th centuries a sharp increase was observed, which weakened already in the 9th century and significantly decreased starting from the 10th century. The horizontal dashed line is taken by the mean index of Tsitsernavank and Kasagh temples of the 4th century. If in Yereruik of the 5th century the growth is 1.9 times, and in Zvartnots and Dvin temples of the 7th century 3.5 and 5.3 times respectively, then in Shirakavan of the 9th century the growth is only 1.7 times. The next decrease in the Monastery of Horomos of the 10th century is 3.2 times, and in St. Astvatsatsin Church in Areni of the 14th century – 5.3 times.

Scheme 12.5 shows the change in the correlation of building and useful areas based on the data of the same 25 churches, which is expressed as the percentage of useful area in the total building area at zero level. The data show that this index does not change significantly in general, the tendencies of increase and decrease do not reach noticeable degrees. The horizontal dashed line is taken by the mean index of Tsitsernavank and Kasagh temples of the 4th century. The maximum growth is noticeable in Zvartnots, Dvin and Talin temples of the 7th century and amounts to 1.1 times. The maximum decrease is in the Monastery of Horomos of the 10th century – 1.2 times. The data of St. Astvatsatsin Church in Areni of the 14th century is almost the same as in Tsitsernavank and Kasagh temples of the 4th century.

Scheme 12.6 shows the change in the correlation of the material and the building volumes based on the data of 9 churches (the data of the same 9 churches are included in all subsequent schemes). The indexes of the percentage of the material volume in the total building volume are identified. The data show that there are no expressed tendencies of increase or decrease in this index as well. The horizontal dashed line is taken by the identical index of Tsitsernavank and Kasagh temples of the 4th century. The maximum growth is in St. Astvatsatsin Church of Makaravanak of the 13th century – 1.1 times, the maximum decrease is in Arutch Temple of the 7th century – 1.2 times. The data of St. Astvatsatsin Church in Areni of the 14th century is identical to Tsitsernavank and Kasagh temples of the 4th century.

Scheme 12.7 shows the change of the quantity of material per unit surface area of the building, which is expressed by the ratio of the total volume of the material to the area of the external surface of the building. The data generally show a decreasing tendency. The horizontal dashed line is taken by the mean index of Tsitsernavank and Kasagh temples of the 4th century. If in St. Nshan Church of Haghpat Monastery of the 10th century the decrease amounts to 1.2 times, then in Gtchavank of the 13th century – 2.3 times, and in St. Astvatsatsin Church in Areni of the 14th century – 2.0 times. The exception is Arutch Temple of the 7th century, where there is a growth – 1.2 times.

Scheme 12.8 shows the change of the external surface area of the building per unit of building area, which is expressed by the ratio of the external surface area to the building area. The scheme shows the obvious tendency of growth. The horizontal dashed line is taken by the mean index of Tsitsernavank and Kasagh temples of the 4th century. If in Arutch Temple of the 7th century the growth is 1.2 times, then in St. Nshan Church of Haghpat Monastery of the 10th century, it is already 1.6 times, and in St. Astvatsatsin Church in Areni of the 14th century – 2.0 times.

Scheme 12.9 shows the change in the correlation of volumetric and planning dimensions of the building. It is expressed by the quantity of volume per unit of building area (the ratio of the volume to the building area). The data show a general growth tendency. The horizontal dashed line is taken by the mean index of Tsitsernavank and Kasagh temples of the 4th century. The maximum growth is in Arutch Temple of the 7th century – 1.7 times. In St. Nshan Church of Haghpat Monastery of the 10th century, the growth is 1.6 times, in St. Astvatsatsin Church in Makaravank of the 13th century - 1.2 times. Gtchavank of the 13th century is a certain exception, where there is a decrease of 1.1 times. The data of St. Astvatsatsin Church in Areni of the 14th century are almost the same as of the temples of the 4th century.

Summarizing the results obtained in the Schemes 12.1-12.3, it can be stated that there was a reduction in the volume of the facing stone blocks and in their share in cross section of the wall, in parallel with which the total wall thickness decreased. The mentioned circumstances confirm the tendency of gradually increasing the level of wall strength and monolithic nature. The summary of the results obtained in the schemes 12.4-12.10 allows to prove that: the plan dimensions of the building initially increased sharply, then significantly decreased; the ratio of the building and useful area, as well as the material and the building volumes generally remained stable; the quantity of material per unit area of the external surface generally decreased; the volume and the external surface per unit building area, as well as the interior space per unit floor area, generally increased. The general comparison of the mentioned features makes it clear that despite the significant changes in the building planning dimensions and in parallel stability of the building and useful area, correlations of material and building volumes, there are noticeable changes in both internal and external volumetric indexes. They confirm the increase of verticality in the structures, the phenomenon of expansion of the external volume and interior space. And the decrease of the material per unit area of the surface and the growth of the surface area per unit building area justify the shell nature of the building structure.

Table 1. Volumetric and planning characteristics of the Armenian churches built in different periods of the Middle Ages; *Source*: own study.

№	Name	Construction time	Building area,	Useful area	Outer surface	Volume	Material volume	Wall thickness	Average sizes of stones in masonry (height, length, thickness)
		century, year	m^2	m^2	m^2	m^3	m^3	cm	cm
1	Tsitsernavank	4th	320	212	1031	2963	1217	150	60X80X-
2	Kasagh	4th	316	218	1078	3365	1392	140	60X90X-
3	Yereruik	5th	599	405	-	-	-	112	61X125X38
4	Avan	6th	-	-	-	-	-	80	56X70X25
5	Katoghike in Dvin	7th, 608	1669	1232	-	-	-	180	-
6	Hripsime	7th, 618	331	212	-	-	-	110	-
7	Zvartnots	7th, 641	1112	824	-	-	-	90	62X80X21
8	Arutch	7th, 666	676	490	2718	11723	3851	95	55X82X-
9	Katoghike in Talin	7th	474	351	-	-	-	115	77X90X25
10	Mastara	7th	228	153	-	-	-	114	-
11	Zoravar in Yeghvard	7th	167	115	-	-	-	85	-
12	Ptghni	7th	-	-	-	-	-	86	66X60X20
13	Shirakavan	9th, 897	547	378	-	-	-	120	-
14	Garni round church	9th	-	-	-	-	-	80	50X75X15
15	Noratus	10th, 901	281	186	-	-	-	110	-
16	Horomos	10th, 953	100	57	-	-	-	106	-
17	St. Nshan in Haghpat	10th, 967	226	150	1232	3402	1312	90	67X73X-
18	Katoghike in Marmashen	10th, 994	234	167	-	-	-	80	102X89X-
19	Batikyan	10th	193	119	-	-	-	110	-
20	Amberd	11th, 1026	163	112	780	1705	694	72	89X60X20
21	Marmashen second church	11th	-	-	-	-	-	74	79X60X20
22	St. Astvatsatsin in Goshavank	12th, 1191	177	117	830	1828	711	82	55X52X27
23	St. Astvatsatsin in Makaravank	13th, 1204	165	109	931	2167	1004	85	58X61X-
24	St. Astvatsatsin in Arzakan	13th, 1207	-	-	-	-	-	80	51X49X20

25	St. Grigor in Goshavank	13th, 1209	111	69	-	-	-	85	55X62X25
26	St. Astvatsatsin in Dadivank	13th, 1214	105	62	-	-	-	100	-
27	Katoghike in Geghardavank	13th, 1215	137	87	-	-	-	90	-
28	St. Hovhannes Mkrtich in Gandzasar	13th, 1216	206	143	-	-	-	70	-
29	Gtchavank	13th, 1241	73	49	404	600	223	76	53X62X22
30	St. Astvatsatsin in Areni	14th, 1339	60	40	397	575	236	62	37X35X-

3. Conclusion

In this research relevant to interconnections between structural elements and the structure in the complex process of architecture formation completed by methods of systematization, comparative analysis and generalization, an attempt has been made to identify some elements of interrelation in the process of the evolution of the “midis” masonry structure and the structural system of the Armenian medieval churches.

Summarizing the work, the results of which are compiled in the comparative data obtained in 10 graphic schemes, it can be mentioned that in the Armenian churches of the 4th-14th centuries: 1) the reduction of the volume of the facing stones contributed to the reduction of the stone in the wall cross section and to the increase of the significance of the core, 2) this resulted in an increase in the level of wall monolithic nature and overall strength and made it possible to reduce the wall thickness, 3) the generated qualities of the wall structure were also expressed in the cover forms derived from it, 4) the high level of integration of the structural elements ensured the combination of bearing, insulating and decorative functions in the walls, 5) the mentioned circumstances led to the formation of the shell nature of the structure in the total volume of the building, the formation of structural integrity and to the expansion of the external volume and the interior space. Naturally, with the inclusion of a larger database, both the averaged horizontal of the earliest index and the columns reflecting the upward and downward tendencies will have some adjustments. However, in the observed examples, the general tendencies that are already evident in 10 different characteristics, we find, cannot be significantly changed. Already at this level of research, they confirm the relation between the evolution processes of the “midis” masonry monolithic nature and the structural integrity of the churches. Thus, the interrelation between the revealed features of efficiency of the composition of the structural elements and the spatial and planning solutions of the building substantiates that the evolution of three-layered “midis” masonry led to the structural monolithic nature of the walls and the forms derived from it, which in turn led to the integral principle of structure designing in the stone building.

At the same time, the results of the work in turn raise a number of new questions. In particular, the data in Table 1 show that there are very large differences in the dimensions of the churches (planning and volumetric). For example, Katoghike Church in Dvin is 27.8 times larger in building area, and Arutch Temple is 20.0 times larger in volume from St. Astvatsatsin Church in Areni. However, the schemes 12.5 and 12.6 clearly show that in the case of a significant difference in the dimensions of the plan and the volumes the ratio of the building and useful area, as well as the material and the building volumes are constant.

On the other hand, if we make a visual comparison between the schemes 12.4, 12.7, 12.9, 12.10, we can see some regularities in the dynamics of the changes of the correlation between the planning dimensions of the buildings and the surface area – material volume, external volume – building area, interior space – floor area. They are reflected in the general picture of growth during the 4th-7th centuries, and then gradually decreasing from the 9th century. However, the same cannot be stated with certainty in the case of the building area – surface area ratio shown in scheme 12.8, where a continuous upward tendency is noticeable. The mentioned facts give the impression that some characteristics are affected, but some characteristics are not affected by the changes in the building dimensions. From this point of view, in further research, it will be expedient to analyze these characteristics in separate groups according to the building dimensions. The comparison of the data obtained for the groups of churches of different sizes, which should include the data of a larger number of buildings, we think, will help to find clearer answers to the above questions. In the research, it will be necessary also to take into account the types of structures in a certain way, as their structural differences, in all likelihood, should also affect the efficiency of the volumetric and planning characteristics.

The issue of the “midis” monolithic nature should be the subject of a separate study, which implies in-depth technological researches. They will allow for a clearer assessment of the possibilities of the interaction of materials, the composition of the materials and structural elements in different parts of the structure and the effectiveness of different systems of the structure of stone buildings. It will also be necessary to touch upon the issues of construction work quality due to the destruction of buildings constructed with the same technology.

It will be interesting to study the issues of interconnection of the evolution of the structural elements and structure within the framework of Byzantine, Iranian, Syrian monumental buildings, which will allow to combine the results obtained in this work with medieval architecture of other countries in the region. It will be no less interesting to try to address the topic of the interconnection of the evolution of the structural elements and structure in the architecture of buildings constructed with implementation of a single material and on the basis of the integral principle of structure designing in more in-depth research. Here it will be important to pay special attention to the issues of the formation of the monolithic structures not by making technology, but according to the structure, adding metal structures to the stone, brick, wood, and reinforced concrete discussed in this article. These structures, perhaps, can also be included in this list. Such research will allow us to draw more solid parallels in the discussion of the architecture of structures built at different times, in different cultures and under different technological opportunities.

The issues of organizing the construction of medieval churches considered in the work may be the subject of a separate research. Within their framework, it will be possible to examine the peculiarities of the evolution of the structural element and the general structure revealed in this work from another point of view – that of practical reality, and to form a clearer idea of the degree of influence of the economic element on the development of the architecture. Maybe the demand for economic expediency led to an increase in the efficiency of the structure?

Thus, the results of the work can be useful not only in elaborating further research covering the structural-compositional interrelations of the material, component element and total building development, but also the economic requirements in architecture and the peculiarities of construction organization, which can include the framework of both heritage and modern architecture.

Funding

The research was carried out with the financial support of the RA Science Committee. The authors extend their gratitude to Ashot Gevorgyan, Siranush Hovhannisian and Arpine Abgaryan for their support in the preparation of the work.

References

[1] Kirillova L., Pokrovskiy I., Rozhin I., Kompozicia v sovremennoy arkhitekture [Composition in modern architecture], Moscow: Central Research Institute of Theory and History of Architecture, Stroyizdat, 1973.

[2] Kirch P., Carpenter A., Ruggles C., “Kukuipahu: A Unique Hawaiian Monumental Structure Utilizing Cut-and-Dressed Stone Masonry”, Rapa Nui Journal, vol. 32, no. 1, 2019, pp. 37-57. https://doi.org/10.1353/rnj.2019.0000

[3] Taras Y., “Schools of Folk Temple Building, Types and Groups of Carpathian Churches”, Architectural Studies, vol. 5, no. 2, 2019, pp.122-148. https://doi.org/10.23939/as2019.02.121

[4] Goberman D., Wooden Architectural Monuments of Trans-Carpathia. Leningrad: Aurora, 1970.

[5] Puganchenkova G., Samarkand. Bukhara, Moscow: Iskusstvo, 1968.

[6] Voronina V., Architectural Monuments of Middle Asia. Bokhara, Samarkand, Leningrad: Aurora, 1969.

[7] Hejazi M., Hejazi B., Hejazi S., “Evolution of Persian traditional architecture through the history”, Journal of Architecture and Urbanism, vol. 39(3), pp. 188-207, 2015. https://doi.org/10.3846/20297955.2015.1088415

[8] Lysiak W., Frank Lloyd Wright, Berlin: Henschelverlag, 1983.

[9] Le Corbusier, Arkhitektura XX veka [Architecture of the 20th century], transl. Topuridze, Moscow: Progress, 1977.

[10] Zhong M., “Research on Traditional Stone Buildings in West Hunan Rural Areas”, Advanced Materials Research, vol. 450-51, 2012, pp. 218-22. https://doi.org/10.4028/www.scientific.net/AMR.450-451.218

[11] Naeeni D., Esfahani H., Hosseini I., “Recognising Karbandi in Iran’s Architecture and a Review of its Decorative-Structural Role”, International Journal of Architectural Heritage, 2017. https://doi.org/10.1080/05786967.2017.1406789

[12] Weber Th., Rock and Order, Stone Masonry in a Historical Context, Stone and architecture in the mountainous regions of Jordan and Syria. Amman - Damascus - Berlin: DAAD, 2012, pp. 121-56.

[13] Brumana R., Oreni O., Cuca B., Binda L., Condoleo P., Triggiani M., “Strategy for Integrated Surveying Techniques Finalized to Interpretive Models in a Byzantine Church”, International Journal of Architectural Heritage, vol. 8:6, 2014. https://doi.org/10.1080/15583058.2012.756077

[14] Azatyan K., Azatyan R., Yolyan A., Smelkov O., “The Impact of the Constructive Solution on the Formation of the Portal in the Architecture of Armenian Churches of 4th-7th Centuries”, Yerevan: JAER no. 2., 2021. https://doi.org/10.54338/27382656-2021.2-1

[15] Cowan H., “Structural Design by Observation of Failures How the Gothic Master Masons Determined the Dimensions of their Structures”, Architectural Science Review, vol. 35(2), 1992, pp. 51-58. https://doi.org/10.1080/00038628.1992.9696713

[16] Vitti P., “Mortars and masonry - structural lime and gypsum mortars in Antiquity and Middle Ages”, Archaeological & Anthropological Sciences, vol. 13:164, 2021. https://doi.org/10.1007/s12520-021-01408-y

[17] Schildkamp M., Silvestri S., Araki Y., “Rubble Stone Masonry Buildings With Cement Mortar: Design Specifications in Seismic and Masonry Codes Worldwide”, Frontiers In Built Environment, vol. 6:590520, 2020. https://doi.org/10.3389/fbuil.2020.590520

[18] Bhattacharya S., Nayak S., Dutta S., “A critical review of retrofitting methods for unreinforced masonry structures”, International Journal of Disaster Risk Reduction, vol. 7, 2014, pp. 51–67. https://doi.org/10.1016/j.ijdrr.2013.12.004

[19] Alberti L., Desyat’ knig o zodchestve [Ten books on architecture], vol 1. Moscow: Publishing House of the All-Union Academy of Architecture, 1935.

[20] D’Altri A., Sarhosis V., Milani G., Rots J., Cattari S., Lagomarsino S., Sacco E., Tralli A., Castellazzi G., Miranda S., “Modeling Strategies for the Computational Analysis of Unreinforced Masonry Structures”, Review and Classification, Archives of Computational Methods in Engineering, vol. 27, 2019, pp. 1153–85. https://doi.org/10.1007/s11831-019-09351-x

[21] Vintzileou E., Miltiadou-Fezans A. “Mechanical properties of three-leaf stone masonry grouted with ternary or hydraulic lime-based grouts”, Engineering Structures, vol 30(8), 2008, pp. 2265-76. https://doi.org/10.1016/j.engstruct.2007.11.003

[22] Choisy A., Histoire De L'Architecture [History of Architecture], vol I. Paris: 1935.

[23] Choisy A., Histoire De L'Architecture [History of Architecture], vol II. Paris: 1937.

[24] Gavrilovic P., Sendova V., Ginell W., “Seismic strengthening and repair of Byzantine churches”, Journal of Earthquake Engineering, vol. 3(2), 1999, pp. 199-235. https://doi.org/10.1080/13632469909350345

[25] Rabady R., “Ancient masonry structures within an integrated approach: the reinforced corbelled flat roofs of Umm el-Jimal”, The International Journal for the History of Engineering & Technology, vol. 89(1-2), 2019, pp. 122-141. https://doi.org/10.1080/17581206.2020.1782616

[26] Tonghini C., Donato E., Montevecchi N., Nucciotti M., “The Evolution of Masonry Technique in Islamic Military Architecture: the Evidence from Shayzar”, Levant, vol. 35(1), 2003, pp. 179-212. https://doi.org/10.1179/lev.2003.35.1.179

[27] Jäger J., Stone and architecture in the mountainous regions of Jordan and Syria. Amman - Damascus - Berlin: DAAD, 2012, pp. 13-60.

[28] Flora A., Chiaradonna A., Sanctis L., Lignola G., Nappa V., Oztoprak S., Ramaglia G., Sargin S., “Understanding the Damages Caused by the 1999 Kocaeli Earthquake on One of the Towers of the Theodosian Walls of Constantinople”, International Journal of Architectural Heritage, vol. 16:7, 2021, pp. 1076-1100. https://doi.org/10.1080/15583058.2020.1864512

[29] Mikaelian G., Sevani avazani kiklopyan amrotsּner [Cyclopean fortresses in the basin of lake Sevan]. Yerevan: Publishing house of the Academy of Sciences of the Armenian Soviet Socialist Republic, 1968.

[30] Harut’yunyan V., Haykakan chartarapetut’yan patmut’yun [History of Armenian architecture]. Yerevan: Luys, 1992.

[31] Isabekyan H., Pati tektonikan haykakan chartarapetut’yan mej [Wall tectonics in Armenian architecture]. Yerevan: Collection of Armenian art scientific articles of the Academy of Sciences of the Armenian Soviet Socialist Republic, vol. 1, 1974, pp. 36-47.

[32] Sahinyan A., Garrnii antik karruycneri chartarapetut’yunə [The architecture of Garni ancient buildings]. Yerevan: Academy of Sciences of the Armenian Soviet Socialist Republic, 1938, p. 261.

[33] Toramanyan T., Nyut’er haykakan chartarapetut’yan patmut’yan [Materials on the history of Armenian architecture], Yerevan: Armfan, 1942.

[34] Sahinyan A., K’asaghi bazilikayi chartarapetut’yunə [Architecture of the Kasagh Basilica], Yerevan: Academy of Sciences of the Armenian Soviet Socialist Republic, 1955.

[35] Marr N., Yereruyskaya bazilika. Armyanskiy khram V-VI vv. v okrestnostyakh Ani [Ererouk basilica. Armenian temple of the 5th-6th centuries near Ani], Yerevan: Academy of Sciences of the Armenian Soviet Socialist Republic, 1968.

[36] Paboudjian P., Novello A., The "Ererouk" basilica, Milano: Ares, 1977.

[37] Shakhkyan G., Lori: patmut'yan k'arakert ejer [Lori: Petrified pages of history], Yerevan: Soviet Writer, 1988.

[38] Shakhkyan G., 1983, Odzun yekeghets'in [The church of Odzun], Yerevan: Soviet writer, 1983.

[39] Maranci C., "Building Churches in Armenia: Art at the Borders of Empire and the Edge of the Canon", The Art Bulletin, vol. 88(4), 2006, pp. 656-675. https://doi.org/10.1080/00043079.2006.10786313

[40] Tokarskiy N., Arkhitektura Armenii IV-XIV vv. [Architecture of Armenia IV-XIV centuries], Yerevan: Armgosizdat, 1961.

[41] Choisy A., Stroitelnoe iskusstvo drevnix rimlyan [L'art de bâtir chez les Romains]. Moscow: Publishing House of the All-Union Academy of Architecture, 1938.

[42] Strzygowski J., Die Baukunst der Armenier und Europa [The architecture of the Armenians and Europe]. Wien: A. Schroll & Co., G.m.b.H., 1918.

[43] Palieraki V., Vintzileou E., Miltiadou-Fezans A., "The use of radar technique and boroscopy in investigating historic masonry: Application of the techniques in Byzantine monuments in Greece", Antalya: International Symposium on Studies on Historical Heritage, 2007, pp. 403-410.

[44] Manzo A., Cantini L., Chesi C., Parisi M., "Italian Middle Byzantine Churches: A Comparison Through Masonry Quality Analysis", International Journal of Architectural Heritage, vol. 15:10, 2021, pp. 1474-1491. https://doi.org/10.1080/15583058.2019.1700321

[45] Borri A., Castori G., "Damage and Seismic Vulnerability of the Portal of Palazzo Dei Priori", International Journal of Architectural Heritage: Conservation, Analysis, and Restoration, vol. 5(2), 2011, pp. 219-240. https://doi.org/10.1080/15583050903511606

[46] Nikooravesh M., Soltani M.m, Mohammadi E., "Seismic Retrofitting of Persian Arched Walls by Centercore Method: Experimental and Numerical Investigation", International Journal of Architecture Heritage, vol. 17(3), 2021, pp. 450-471. https://doi.org/10.1080/15583058.2021.1933261

[47] Artsruni T., History of Artsrunyats House. Yerevan, Armenia: Yerevan: Soviet Writer, 1978, p. 295.