

Romanesque Historical Monuments Reconstruction by Using Original Materials and Recycling of Those That Have Lost Their Historical Value [†]

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Abstract: The aim of this paper is to present the way of reconstruction of historical monuments of Romanesque architecture by reusing and highlighting the original component materials, related to the subassemblies of the construction, respectively the recycling of those components that have lost their historical value. The Romanesque buildings are part of Romanian national cultural heritage and have been through controversial historical periods, and therefore have undergone important modifications or structural losses. The reconstruction or rehabilitation of the Romanesque historical buildings is a way of sustainable development by adapting the buildings to the new conditions of use.

Keywords: Romanesque architecture; cultural heritage; reconstruction; rehabilitation

1. Introduction

Romanesque architectural style developed in the first period of Middle Ages and spread over the whole Catholic Europe between 9th and 13th centuries. Romanesque style presents significant regional variations because of the availability of materials, technologies and the aesthetic tastes. It became the first international ecclesiastical architectural style; therefore, the greatest number of surviving Romanesque buildings are churches. Romanesque style was introduced to Transylvania from Hungary in the 12th and 13th century. The influence on architectural style was initially from Hungary and Germany, and later from France and Italy. Romanian Romanesque churches are generally small and modest churches, compared to the cathedrals from Europe or the following Gothic churches. The construction material was brick or stone depending on the local availability. In Italy, Poland, part of Germany and Netherlands, brick was used on a larger scale. In other areas, the churches were made of stone in small, irregular pieces bedded in thick mortar. In Transylvania, the builders of the period used preponderant quarry and river stones because of the local availability and numerous stone quarries and Roman ruins. Brick was used in the northeast of Transylvania where stone was not available. While a small number remain substantially intact, many churches were sympathetically restored, being extended and altered in different styles. We will take into consideration some examples of rehabilitation of these historical monuments.

If today's buildings are built with a clear differentiation between their architecture and structure, when talking about Romanesque historical monuments the relationship between the shape and structure of a building appears in a mutual conditioning. The massive load-bearing structure of the

Romanesque building gives the stability of these building over decades. Therefore, this study will include complex aspects related to the reconstruction and rehabilitation of the load-bearing structures of the Romanesque buildings, at the interface between history, art, architecture and structural engineering. Preliminary study on the structural problems of Romanesque churches will be carried out in order to define adequate techniques of interventions following the preservation and restoration principles. The use of traditional, modern and innovative materials and techniques is also discussed.

2. Structural Diagnosis

The reconstruction and rehabilitation of the load-bearing structures of Romanesque buildings require the knowledge of conception, of technical details or the materials and traditional technologies used. A deep understanding of the construction is mandatory when choosing the method of intervention based on the minimal intervention concept of historical monuments.

This research is carried out in two stages:

- structural diagnosis stage (identification of structural degradations);
- the stage of reconstruction and structural rehabilitation.

The structural diagnosis is based on the knowledge of each component of the load-bearing structure. The architectural components with impact on the structural subassemblies are also important, such as: door or window frames, details of floors or installations, the water-canal networks, the characteristics of the foundation land and its mechanical properties, etc. This phase requires collaboration of specialists in the field of architecture, engineering, topography, archeology or restoration. The common concern is to identify the characteristics of the Romanesque structures and to propose the optimal rehabilitation solutions.

The load bearing structure of a Romanesque church is composed by: thick walls made out of brick or stone, foundations, columns/piers, floors, barrel or groin vaults and roof trusses. These structural subassemblies are connected to each other in subunits with different spatial rigidities, which work together and give the mechanical behavior of the entire structure. The empirical-intuitive conception of the load-bearing structures, the quality of the interventions carried out during the utilization period, the extensions or modifications made during the exploitation, the quality of the used materials, the depth of the foundations and the geological conditions have an important influence on the mechanical behavior of Romanesque structures.

The most common deficiencies of the Romanesque structures are: vulnerability to horizontal loads, low anti-seismic conformation, lack of effective connections among the structural elements, presence of horizontal structures (floors and roofs) with poor in-plane stiffness; lack of longitudinal bracing subunit of the roof structure, lack of rigidity of the infrastructure compared to the need to embed the superstructure; stiffness asymmetries and irregular morphology, due to continuous modifications, stratifications and extensions occurring during the time; and low capacity for stretching and shear efforts (Figure 1).

The presence of curved elements along with the massiveness of the walls and pillars/pilasters generates gravitational actions, thrusts that produce significant bending stresses on the main load-bearing system (walls, pilasters, columns). The main structural degradations of the Romanesque ensembles are mostly due to these thrusts, being followed by the other causes like landslides, earthquakes and fires. A part of the Romanesque churches from Transylvania have one or two towers attached on the west end of the church. They produce distortions of seismic response that can lead to the detachment of the church tower and then to the danger of a collision of the two oscillating subunits: tower-nave. Examples can be found at the Evangelical churches from Roades and Rotbav where the towers collapsed in 2016. At Rotbav, the collapse of the tower led to the collapse of a part of the nave walls. Cracking or separation in the rigid bodies “tower-ship-altar” may also appear due to the differentiated settlements of the foundation land. It was found that the consolidation of the joint areas of these bodies with different rigidities and different pressures under the foundations would lead to those degradations in their vicinity.

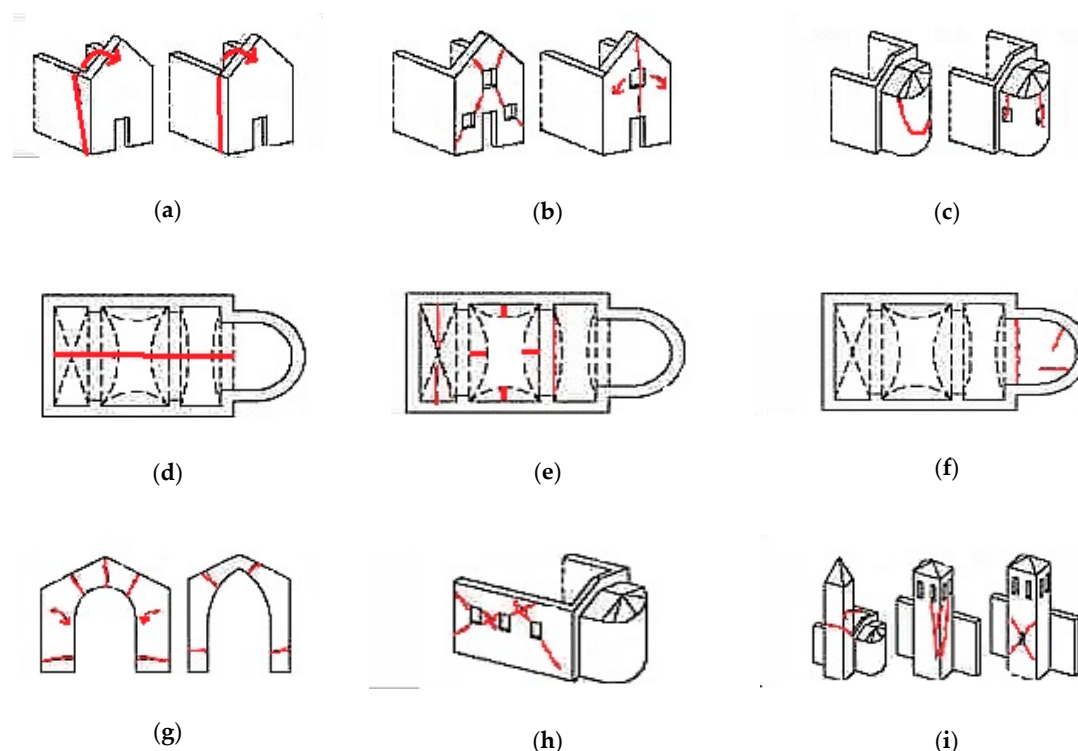


Figure 1. Failure mechanisms in Romanesque churches: (a) overturning of the facade; (b) shear mechanisms in the facade; (c) overturning of the apse; (d) transversal vibration of the nave; (e) vaults of the nave; (f) vaults in the presbytery or the apse; (g) triumphal arch; (h) shear failure of the walls; (i) bell tower.

3. Structural Consolidation

The structural consolidation on the Romanesque churches must be made with the main purpose of safeguarding the original structure through the use of compatible materials and traditional techniques that can be supplemented with scientifically grounded modern techniques. If the stability of a building is affected or there is the need of a change in destination's building, the structural modifications will be implemented through reversible solutions with the condition that the new elements have the same reliability with the original ones and they must be distinguishable.

3.1. Roof Structure

Preserved in a relatively small number, Romanesque roof structures are characterized by a structural concept limited to the construction of trusses, without any longitudinal bracing systems. On the longitudinal direction, the trusses are stabilized through the roofing support system. The transmission of the loads carried by the trusses to the supporting subunits is made through the simple wall-plates placed over the longitudinal walls [1].

Both Romanesque roof structures are in a good state of stability but there is need of rehabilitation in order to maintain and increase their durability. There are some subsequent interventions on these roof structures. For example, in the case of Vurpar church, temporary consolidations of the marginal north-western area have been made. The biological degradations have made the rafter tie-beam (nodurile caprior-coarda) nonfunctional; therefore, the decision was to place a metal band for carrying the load resulted from the tie-beam between the rafter and the tie-beam. Also, several reinforced concrete rings were placed below the wall plates (centura de beton armat sub cosoroaba). At Toarcia, the observed intervention method on the roof structure is the integrations of bracings made out of a single piece of wood in the rafters (Figure 2).



Figure 2. Romanesque roof structures: (a) roof structure Lutheran church in Vurpar; (b) roof structure Lutheran church in Toarcia.

3.2. Arches and Vaulting System

The early Romanesque builders developed the science of vaulting when they wanted to replace the wooden ceilings with vaulting structures with better resistance for fire danger. The most common vaults in Romanesque churches are the barrel (semicircular) vaults and the groin vaults—intersection of two barrel vaults (Figure 3). In the later Romanesque period, the ribbed and pointed vaults were also introduced. Vaults constructed of numerous blocks of material pressing against one another exert not only the accumulated downward weight of the material and of any superimposed load, but also a side thrust or tendency to spread. To avoid collapse, adequate resistance against this thrust must thus be concentrated at the haunches (lower portions) of the vault. The resistance may take the form of thickened walls at the haunches; of buttress placed at points of concentrated thrust as in Romanesque and Gothic architecture; or of vaults so placed that their thrusts oppose and counteract. This necessity has controlled the evolution of masonry vaulting and its use in buildings.

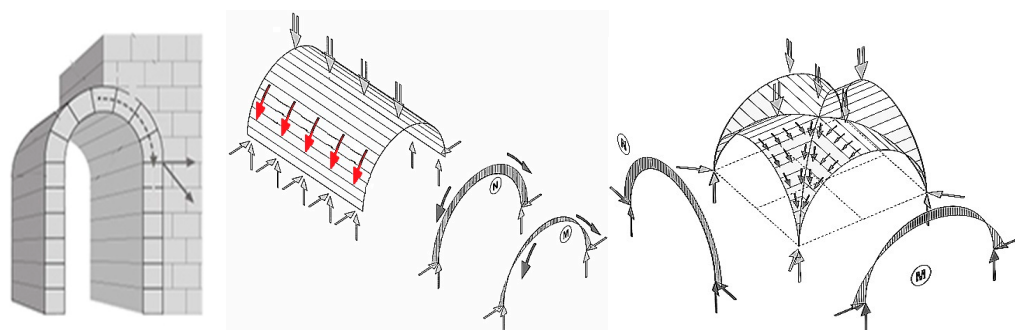


Figure 3. The thrusts of a barrel vault and a groin vault.

The structural deficiencies of Romanesque vaults occur mostly as a result of: subsequent faulty interventions, lateral buckling/displacements of the vault's supports, the lack of horizontal connecting elements on the slabs level, the subsidence of the foundations and the decays of the masonry caused by moisture [2].

The structural consolidation of the vaults and the supporting elements system is mostly done through interventions that are meant to enhance the load-bearing capacity of the structure. This can be done through the increase of the cross-section of the deteriorated elements (encasement). Additional elements compatible with the original elements can be also introduced with the same purpose. Found in Romanesque churches are metal tension bars meant to take over the abutment loads from arched and vaulted structures. Metal tension bars/tie rods (*tiranti*) placed on the springing lines of the triumphal arches that separate the altar from the nave can be found in many churches of Transylvania (Herina, Avrig). In other cases, reinforced concrete ring-beams were placed on the slab's level. Indirect consolidations with additional structures may be also carried out with the purpose to discharge the weak original load-bearing structure of a part of the vertical loads.

The cross ribbed vault of brick at the Calvinist church in Sic was in bad condition due to the lack of a roof structure for the choir for a long period, which led to maceration of bricks on a considerable depth and cracks in the walls. Therefore, the intervention taken consisted of the replacement of macerated bricks, bonding-wedging-grouting and protective plaster on the backs of arches reinforced with geogrid [3].

3.3. System Walls-Piers-Columns

Historical load-bearing support structures such as load-bearing walls, columns and piers have a deficiency in taking over the efforts of stretching and shearing in the console. The walls of Romanesque churches are one of the most important components for the load-bearing structure. The thickness of the walls allows to carry the weight of the vaults. Otherwise, the wall could become unstable if the loads exceed the strength of the masonry, causing structural collapse.

Stone masonry walls have considerable vulnerability to horizontal seismic action, due to their weak mechanical properties and extensive irregularities. In brick masonry, the problem of long-term sustained loads (creep) acting on massive structures (towers, curtain walls, heavy pillars) may induce sudden unexpected collapse [4].

The alternation of columns and piers together with the walls are a very important structural feature of the Romanesque architecture, but sometimes they are used as decoration as well.

At the Evangelical church of Herina, after the 1886 earthquake, the walls were presenting multiple cracks. The adopted solution for consolidations was the insertion of reinforced concrete beams at the upper level of the walls under the roof line and grouting of cracks with lime paste. The same solution was adopted at the church of Strei. In the case of the Calvinist church in Sic, where the degradations in walls occurred due to unprofessional subsequent interventions and improper treatment of fissures (with cement mortar), the cracked walls needed rehabilitation on 80% of their surfaces. The adopted solutions have focused on reassuring continuity by bonding-wedging-grouting plus reinforcing with stainless helical bars [3].

3.4. Foundations

The subassemblies of foundations were made according to an empirical-intuitive conception and have the role of transmitting to the foundation ground the loads of the load-bearing structures. They were made mainly of stone or brick masonry, with lime mortar (up to M10) or clay mortars, with no protection against underground agents. The geometry of the foundations follows the plan design of the building and its construction was influenced by the nature of the foundation land or by the geographical position of the building. In Romanesque buildings, rigid surface foundations and continuous or isolated foundations were made. They were connected to each other by masonry arches through bonding-wedging technique. A major technological aspect that leads to the degradation of a Romanesque edifice is the deficient cooperation of the foundations made in different epochs that lead to unequal settlements. Foundations are exposed to aggressive soil moisture conditions. The problems that arise are related to the depth of foundation, which is often insufficient in relation to the depth of frost of the site and the depth of wetting of the clay with high contractions and swellings and in relation to the foundation ground. Thus, the foundations of the Romanesque structures do not ensure, most of the time, a rigid level of embedding in Romania.

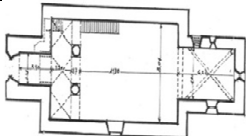

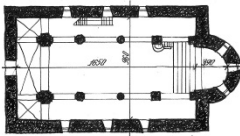
Degradations in foundations of the church in Sic were due to the soil conditions (uneven settling), unprofessional previous interventions or insufficient foundations depth. For the consolidation, the underpinning and micro-piles system was used [3].

Interventions like sub base grouting were carried out at many of the Romanesque churches due to the degradations over time of the material or the insufficient depth. At Strei, the durations of this intervention had caused cracks in the masonry and movement of the vault with dislocation in the ribs (Table 1).

4. Case Studies

Case Studies—Three Romanesque Churches from Transylvania and Interventions Applied over Time.

Table 1. Summary of applied interventions.

	Reformed Church Santamarie-Orlea, HD	Orthodox Church of Strei, HD	Evangelical Church of Herina, BN
Date	1270–1280	End of 13th century	End of 12th century–beginning of 13th century
Model	Central Europe and Italy (cistercian style)	Santamarie-Orlea, HD	Hungary: Akos, Lébény, Jak and Zsambék; Transylvania: Acas and Capleni (Benectidine basilica)
LMI Code	HD-II-m-A-03445	HD-II-m-A-03452	BN-II-m-A-01661
Actual state	It is open to visit but not for liturgical services	Liturgical services are not performed (exception September 8)	It belongs to the Bistrita-Nasaud Museum Complex
Plan	 -hall church-rectangular -rectangular nave with square choir and bell tower	 -hall church-rectangular -rectangular nave with square choir and bell tower	 -basilical plan with central nave and two lateral naves, semicircular apse and two towers at the west end
Material	Rough stone and waist stone bound with thick mortar Facing stones at the corners	Rough stone masonry mixed with bricks Cut facing stones for the exterior intersections of the nave walls	Brick masonry Pillars of shaped stone Foundation-stone
Load-bearing structure	-load-bearing walls made out of stone -wooden roof timber -pointed vault (choir) -groin vault (tower) -octagonal piers with cubic capitals -stone foundations	-load-bearing walls made out of stone (thickness 85–99 cm) and bricks bound with lime mortar for door areas -wooden floor -pointed vault (choir) with stone ribs -groin vault (tower) -rough stone foundations with lime mortar	-load-bearing brick walls (thickness 1.00–1.30 m) -wooden roof timber (naves) -cross vault (choir) -barrel vault -octagonal, circular, square, cross-shaped pillars (shaped stone) -stone foundations
Interventions history	Early 20th century -restoration works: -the decorative elements carved from	Restoration 1895 1969–1972 DMI— mural painting restoration; restoration	1692/1748: the roofs of the naves were replaced

<p>stone and were replaced by rigid and unsightly concrete elements;</p> <p>-the stone pyramid of the initial covering of the tower was replaced with a hybrid roof sieve helmet on a wooden frame;</p> <p>-raising the floor level;</p> <p>1957-repair project</p> <p>1974-general restoration project to restore the monument to its original appearance and iconographic restoration</p> <p>Repairs:</p> <p>-eaves repair</p> <p>-gutters and downspouts</p> <p>-restoration of the tower roof</p> <p>-plastering the facades while preserving the painted layer</p> <p>-floor restoration</p> <p>-repair of the enclosure wall</p> <p>Consolidation:</p> <p>-sub base grouting for the wall church and for the enclosure wall</p> <p>-concrete topping of the vaults</p> <p>-bounding of the timber frame [4]</p>	<p>and consolidation for the monument and for the protected area (prior archeological research)</p> <p>Maintenance/repair interventions:</p> <p>-replacing the shingle roof with one with tiles</p> <p>-rehabilitation of the stone floor at the original level</p> <p>-ditches for rainwater</p> <p>-protection of the area: drainage ditches + underground sewerage</p> <p>-interior and exterior lighting (with provisions for painting protection)</p> <p>Consolidation works:</p> <p>1966–1972:</p> <p>-sub base grouting at the apse of the altar (because of the long duration resulted: cracks in the masonry + movement of the vault and dislocation and damaged in the ribs);</p> <p>-consolidation of the ribs of the altar vault (through U-shaped steel bracelets, fixed in the reinforced concrete used to consolidate the vault)</p> <p>-consolidation of walls by using concrete bracings [5]</p> <p>-execution of a new wooden ceiling with moving his position to a upper level according to the level of the old floor)</p> <p>-injecting cracks with fluid mortar</p> <p>-2000-archaeological research</p>	<p>1886: the church was closed—danger of collapse</p> <p>1887–1989:</p> <p>-the elevation of the southern tower</p> <p>- interventions for consolidation with metal tie rods for the efforts that led to the cracking of the building;</p> <p>-metal tie rods were placed at the superior part of the nave’s walls and the choir</p> <p>But the cracks were not injected</p> <p>-restoration of portals</p> <p>1994–1999 DSMAI-consolidation-repair interventions</p> <p>-the cracks were injected with cement paste; wedging the wall</p> <p>-repair of metal tile roofing (tower) and roof tile roofs (ship) + eaves (50 cm)</p> <p>-gutters and downspouts</p> <p>-redone of the plasters with lime mortar</p> <p>Structural consolidation:</p> <p>-reinforced concrete bracings at the top of the walls of the central nave, anchored by the walls of the towers through metal tie rods</p> <p>-metal tie rods on the east wall</p> <p>-braces on the supporting beams of the ships floors anchored in reinforced concrete bracings and connected diagonally with metal tie rods or wooden cabinets (horizontal washer) [6]</p>
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5. Conclusions

The restoration of historical monuments has become a very important issue in the preservation of cities and communities. Well-preserved and maintained historical buildings improve the quality of community life with which they coexist. The Historic Monuments List drafted by the Ministry of Culture and National Heritage of Romania in 2015 lists 110 monuments built in the 12th–13th centuries [7,8]. Most of these monuments were built initially in Romanesque style but they have undergone additions or transformations in the following centuries; therefore, it is challenging to find the monuments that have kept their originality. The reconstruction and rehabilitation of the evangelical church of Herina was a necessity after the 1886 earthquake. The church of Sic was in an advanced state of degradation due to unprofessional subsequent interventions [9]. Even if the solutions adopted are questionable in correlation with today's principles, nowadays these churches stand as some of the most representative monuments for Romanesque architecture. Following these examples, we would like to raise awareness about the need of conservation or reutilization of the abandoned medieval churches. For example, in Cluj County, the actual state of the church of Nima (uncovered) affects the valuable mural paintings that can be seen on the walls [10]. Even if the monument was cleared out of the vegetation from inside and a roof over the altar was realized in 2006, a complex restoration of the monument was not possible yet due to lack of financial resources.

We should also look into the importance of the reconstruction of the several fortresses built between the 13th–15th centuries. A major reconstruction project for the Bologa Fortress was begun in 2016. The restorations of the stone churches of Santamarie Orlea and Strei have had an important impact on increasing tourism in this area. An approach on the research of small village churches in Romania may reveal the importance of including these almost abandoned churches on a so-called Romanesque Route (following the example of Germany, Portugal, Spain, France) and later on, their insertion on the TRANSROMANICA-The Romanesque Route of European Heritage, along with the St. Michael's Cathedral from Alba Iulia.

The reconstruction and the reutilization, along with some modern intervention techniques, are raising divisive opinions but we must take into consideration that reconstruction is motivated by an interest in value preservation and, in some cases, is imposed by functional needs.

Conflicts of Interest: The authors declare no conflict of interest.

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