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Reviewed Article:

Contribution to the Medieval Building Technology Based on the Reconstruction of a Rounded Church

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This article presents the experimental archaeological project to build a medieval rotunda reconstruction using rough stone building technology.
Here, a medieval rotunda reconstruction is presented by contemporary building technology. The rough stone building technology on an experimental archaeological project is demonstrated.
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> Documents of building plans and of designing technology from the Middle Ages are scarce. Most of the surviving documents are related to the work of construction and the implementation of the building work.

Introduction

The main subject of this paper is the building technology used during the 11th -12th centuries in the Carpathian basin for constructing churches made of uncut, rough stones. Initial information about this building technology came from miniatures and descriptions. However, these pictures only show constructions of cut stone buildings for the rich (Binding 1993). The information, therefore, is one sided. Knowledge of the medieval building technology is aided greatly by investigations into the medieval discoveries (wall excavations, archaeological discoveries, et cetera). Due to the very sketchy information available on this subject we are forced to rely on experimental reconstructions.

The early buildings and the simpler constructions, such as village churches, are mostly built of rough, uncut stones. In this case we can hardy collect information from the documents describing the building technology of the time. However, we can widen our knowledge by studying the building technology of earlier ages (Binding 1993, Istvánfi 1997, Hajnóczi 1976, Vitruv 1964, Tompos 1984, Zádor 2006). It is important to study building technology before the Middle Ages, because the building technology for the simpler (so called vernacular or country) folks has not changed very much in time (Istvánfi 1997). We also can gain further technological information with the help of experimental archaeology (Nemcsics 2009-1, Nemcsics 2009-2). As a demonstration project we are going to reconstruct a medieval round church from uncut rough stones by only using contemporary technology. In our ancestors' technology we often find the drive toward practicality. Following this principle helps us to find our way to the most likely solution.

This experimental building project started in 2003, when the author, with student help, set the task of reconstructing a medieval round church within the framework of a summer camp. The church can be reconstructed unambiguously by using the available data (diameter, wall thickness, window sizes, et cetera). The detailed background and the detailed planning are described in an earlier paper (Nemcsics 2008). Our aim was to present this reconstruction work as a building history/technology experiment so we tried to keep the authenticity of the process. To achieve this, for instance, the church planer and the builder were the same person. That was in no doubt the case in the past, when small village churches were built (Nemcsics 2008). During the building work brainstorms helped to develop the likely construction technology. We emphasize in this paper that the use of the consol-based scaffolding was only possible for buildings with walls constructed of interchangeable stones cut to regular sizes as shown on the miniatures. The use of irregular stones requires a completely different approach to scaffolding due to the "select and try" technology.

Some information on medieval sacral architecture

Introduction to the topic of round churches

Special types of the sacred buildings of the 11th-12th centuries are mostly rotundas. This type of church was very typical in the Carpathian-basin, but the majority of these churches do not survive in their original form. They were used in later construction works as chancels or demolished completely, and many of them were destroyed during the Ottoman occupation. Some of the converted, or partially demolished, churches were discovered during archaeological excavations. In our region, rotation-symmetrical and round churches with multiple symmetries are to be found in several places. According to wide-ranging investigations, the number of the rotundas the Carpathian-basin is very high (Gervers-Molnár 1972).

The architectural style of the Christian religious buildings reached a very uniform style by the 4th century (Guzsik 1980, Bonyer 1993). It evolved into the congregational church of a longitudinal building, called basilica ecclesiae, which has still an axial arrangement despite of its central part. Another, archaic form of church arrangement can be explained by the practice of an early cult. In these churches the baptism often took place near to the tombs of martyrs or saints. In this event, the congregation stood around the tomb or the place of cult significance. This custom could have led to the centralised building (Tompos & Zádor 1975, Tompos 1994). This central building is the so-called basilica or qua coemeterium (tomb church, martyrium, baptisterium). The Church of the Holy Tomb in Jerusalem (4th century) and the central church over the tomb of the Virgin Mary (Sancta Maria Rotunda) are splendid examples of these types of buildings (Gervers-Molnár 1972, Untermann 1989). These types of architectural monuments were built for the first time in the Byzantine Empire. The Byzantine influence can be found in the Italian churches of concentric arrangement like the San Stefano Rotondo in Rome and the San Lorenzo Maggiore in Milan, built in the 5th century. The same Byzantine influence can also be found in the concentric Eastern Slav Churches, spread around the Slavic speaking areas in the Balkan. In other parts of Europe large number of these churches of concentric design have been built at the seats of monarchs, in castles as royal chapels. An example is the chapel in the Palace of Aachen built in the 9th century (Gervers-Molnár 1972, Untermann 1989). Churches of concentric design can be found in other part of Europe as well (Untermann 1989).

Some remarks on the rotundas in the mediaeval Carpathian-basin

Among the ancient monuments of the 11th century in the Carpathian-basin a number of rotundas can be found, most of them only discovered through the accidental excavation of their foundations. These churches have mostly undivided naves, and an arched apse. These rotundas are primarily village parish churches (Untermann 1986, Nemcsics 2008). The rotundas in the Carpathian-basin and its proximity differ from the round churches in other parts of Europe not only in their construction but also in their smaller sizes (See Figure 1a and 1 b). It is very unlikely that these widespread and differently designed small rotundas in the Carpathian-basin were based on the larger Western European churches or the Byzantine basilicas of the ecclesiastic and secular centres. Most of the nave diameters of the rotundas in the region of Carpathian-basin fall between 5 and 7.5 m. Frequently an arched apse is added to the nave. The apses are often sector shaped (e.g. Kallósd, Nagytótlak, Szakolca), or crescent shaped (e.g. Őskü, Hidegség, Kisnána). The origin of these rotundas, whose numbers are estimated as 80 to 200 in the Carpathian-basin, is uncertain (Gervers-Molnár 1972, Nemcsics 2008). According to some views these small churches can still be traced back to an origin in the Western European or the Byzantine style (Gervers-Molnár 1972). In the following we will show that this view of copying is not necessarily the only explanation.

The concentrically designed architectural space characterises the early Hungarian buildings as a vernacular building arrangement (Istvánfi 1977, László 1999). We have to note however that in prehistoric as well as in ancient times people already erected buildings of rotational symmetry (Hajnóczy, 1976; Istvánfi, 1977, Nemcsics 2010). The Hungarian people in ancient times use to live in round, so called yurt, buildings. These buildings may have often served as places for liturgy considering that, according to archaeological data, Hungarians in the ninth century had already been affected by Christianity (László, 1999). Instead of looking for architectural analogies, one can explain the popularity of the rotundas simply by the building technology of the time. A large number of the churches of the Árpadian-age were probably built not from stone but from other, less durable, materials. In these early settlements, the circular churches were built of plastered wicker walling, discovered by archaeological excavations [Geda halom, Felhgyő (Kovalovszki 1957), Gerla Kőhegyes (Szatmári, 2005)]. The Hungarian names of these settlements often refer to the shape and the building methods of these round buildings [Kerekegyház- (Round-church), Sövényháza- (Hedge-home), Sövényegyháza- (Hedge-church), Kereki- (Round-hamlet), Kerekszenttamás- (Round-St. Thomas), Kerékboldogasszonyfalva- (Round-Virgin) etcetera] . There is written evidence that the priest visiting the congregation celebrated mass in these round buildings (Szabó 1969). The formation of the round churches could be the consequence of the traditional Hungarian living quarters, the yurts of rotational symmetry and the round places of liturgy.

According to archaeological evidence, the building form of rotational symmetry was always present in the early buildings of our ancestry, whether they were used for residential or liturgical purposes. The documentary evidence, which support that the damaged buildings had to be repaired, is an indication that a large number of the round churches were built, not of stone, but perishable materials (László 1999). This indicates that the simple view of the small congregational churches being copies or adaptations is not necessarily true. The unusually large number of round churches in the Carpathian-basin is also contradictory.

Further evidence against it is that the formation of the Middle Eastern and the Western European round churches are completely different, and they are more complex then the ones in the Carpathian-basin. We can draw the conclusion that the numerous round churches in the Carpathian-basin could be the result of the specific architectural culture and the early link with the Christian traditions.

Medieval building culture

Documents of building plans and of designing technology from the Middle Ages are scarce. Most of the surviving documents are related to the work of construction and the implementation of the building work. The pictures in the Codices illustrate the details of the building technique and the stages of its implementation (Cali 1963, Kottmann 1971, Binding 1993). In this paper we concentrate on the architectural data available on the round churches. The architecture of our ancestors always showed purposefulness and practicability (Nemcsics 1999). We used this principle as a starting point, and it helped us to find appropriate construction methods for the purpose. The roofing of the architectural space fundamentally determines the major dimensions of the building. The roofing of these medieval churches was either flat or arched. One can find examples of naves and chancels of oblong shapes with both types of covering. The arched apses are always vaulted. Due to the form of the architectural space, the logical roofing arrangement of the round churches is the vaulting. The supporting force of the vaulting (span), and the required height and width of the structure counteract this force, and will determine the maximum space enclosed. To implement a realistic reconstruction we have to know the planning method and study the architectural examples, survived in their original state. We have to note that rules covering the vaulting do not differentiate between barrel vaulted (triumphal arch) and rotation symmetric dome like roofing where, amongst other forces, additional annular forces are present as well. When the supporting forces are considered the roofing can be real or pseudo-vaulting, and the two can differ substantially when it comes to static design. Realistically, however, the similarity between the two roofing types is not only superficial or formal but functional as well, because the friction between the heavy stones of the pseudo vaulting can counteract the horizontal forces, similarly to the case of the real vaulting.

A comprehensive, architectural study of antiquity has been compiled by Vitrovius (1964). Its influence was still noticeable in the Middle Ages. The vaulting of the medieval buildings and its static design determined the major dimensions of the building (span, height etcetera). Vitruvius also described vaulted buildings in his book and drew the attention to the fundamental importance of the supports. There are documents from the 15thcentury setting out the rules of their design. These documents summarize the relations between the vaulted roofing and the supporting wall. One of these documents was authored by L.B. Alberti (Nemcsics 2008). These rules are applicable only when the arch over the span is not very large. These rules set the relationship between the span, the height of the construction and the width of the supporting wall. The width of the support must be a quarter of the length of the span. If the height of the construction is increased, the support must become wider. The rule calls for a ratio of four again. The thickness of the vaulting must be at least one tenth of the span (See Figure 2). Later on F. Blondel (Nemcsics 2008) laid down the same rule. These rules apply to bridges over the spans where the height of the support does not exceed the one and a half times the length of the span. The rule, depending on the height of the arch, recommends thinner or wider supporting walls due to the different forces. When the arch is a semi circle then the ratio becomes a quarter, leading to the same result as before. These rules originated in the 15th-16th centuries, and must have been known much earlier, because we find the same or similar rules applied in the buildings of antiquity. We can safely assume therefore, that these rules had been known and applied in the early Middle Ages. These rules, described here, fit the small round church architecture perfectly. In case of the churches of much smaller and much larger diameter, the real numerical values often deviate from the ones calculated from the rule. This indicates a deeper understanding of the design principles and not just the application of the rule of thumb (Bandmann 1949, Mainstone 1977, Cowan 1977, Bütter & Hampe 1977, Baker 1989). The formation of the vaulting also shows refined technical expertise. It is enough to look at the rule of relation of the minimum thickness of the vaulting to the span, or the increased cross section towards the supports, to see the link to the loading of the supports. In two dimensions, in a static construction under pressure, the load line must stay within the cross section for the system to stay stable. The real proof of the design is that these vaulted edifices are standing fast after hundreds of years.

Our knowledge of rotundas is broadening as, every so often, more round churches are discovered during excavations in the Carpathian basin (e.g. Abasár, Nádasd) (Nemcsics 2008). The walls, forming the base of the reconstruction described in this paper, have been recently discovered. The excavations on the hills of Öreg-Kovács, bordering the village of Baj, have been going on for the last ten years. This excavation is located on a forest-covered hill of Gerecse Mountain. During excavations a collection of findings came to light: a church, a cemetery, a mansion, and utility and workshop buildings. The church was identified as the parish church of the village of Kovácsi. That was verified by documentary evidence (Petényi 1992). During Ottoman invasion the village was depopulated and the houses were overgrown by the forest. All knowledge of the place was lost, and its location became unrecognisable. The foundations were covered by rubble and undergrowth. The remains were found by sheer accident. In the course of the excavations not only the stone built foundation was discovered but also hewn stones, graves and other various objects. There was an addition on the south side of the building, which was likely an ossuary. The excavation of the foundation stones made it obvious that the ossuary was not part of the original building but a later addition. Its wall was not jointed to the wall of the main building and its foundation is shallower than that of the church. Clearance of the rubble revealed an original fresco on the wall of the chancel and, in other places, small and larger fresco fragments became visible. Around the church there were more than two hundred graves. Scattered around the walls of the church there were some finely hewn stones mixed with rough pieces. The high of the surviving walling varied between 80 and 120 cm (See Figure 3). The stones of the wall were of limestone, quarried in the nearby quarry.

Estimating the principal dimensions of the church

The diameter of the nave of the excavated round church was 5 m, that of its apse was 2.4 m, and the thicknesses of the walls were 1.2 m and 0.8 m respectively. The height of the domed building is set by its diameter and the thickness of the supporting wall. The ratio between the heights of the nave and the apse is known from the data of churches of similar size. The static stability and the known data from other rotundas gave us the principal dimensions, such as the possible height of the church (Nemcsics 2008). We have refined this data by taking into account the dimensions of other similarly built churches. The apexes of the windows in the nave are usually in line with the lower edge of the dome, and as for the arch of the apse, the top of the arch should be in level with the lower lip of the nave's arch or below it. In our case, the diameter of the apse was known. Therefore, assuming 60 cm wall thickness, the height was calculated as 3.6 m. We found the wall thickness to be 80 cm, which again indicated over-design. The dome of the nave starts above the keystone of the major arch and the diameter of the nave is 5 m. The supporting wall would be 7.5 m assuming 1.25 m wall thickness. The position of the nave windows is usually about half the height of the wall (e.g. Kallósd, Szalonna) (See Figure 4). The details above set the principal dimensions of the building. The wall thickness of the apse could be less due to its smaller diameter and height, however because the building is made of rough stones, the thicker wall is preferable. The building was iterated into its final form by successive approximation. In our case, the over all size of the church exterior was 8.20 m. The upper arch of the vaulting was in line with the knee wall, as happens in most cases. The windows and the arch come up to the lower lip of the vaulting. The 1.6 m high windows are placed in the middle of the external walling. The orientation of the church, the location and the width of the entrance were determined from the foundation. The church was built from limestone, quarried locally.

The size of the windows was an important factor in determining the height of the church. From the burial ground around the church, tombstones, tomb cover stones and various other carved stones were recovered. Fragments of the windowsill were also recovered, and from its reconstruction the width of the window was determined. The angle between the inwards narrowing sidewalls of the window and the tangent of the curved external wall gave some idea for the identification of the side border stones of the windows. Because of the size of the stones and their similar shape it was possible to calculate the exact dimensions of the windows. The ratio between the windows' widths and heights mostly fell between certain limits. One stone less would have resulted in a too short window, whilst a stone too many would ended up with one of excess height. We managed to find the top arched stone of the window, which fitted exactly to the side stones underneath (See Figure 4).

In the reconstruction, we started with the technical principle that a rotunda must have vaulted covering. In our view, the principle governing rules in the architecture of our ancestors (buildings in early ages and in folk architecture) are the practicability and synergy (Nemcsics 1999). A flat roof matches an oblong shaped ground plan. A circular base would require timbers of various lengths for flat roofing, which seems impractical, therefore the vault covering is the logical solution. During excavation we recovered some of the plasterwork, with faded blue background colour, dotted with star formations. Painted plaster of this kind is only appropriate for a dome-like ceiling. In planning we assumed a real vault covering, the recovered stones however suggested the possibility of pseudo vaulting as an architectural solution.

We also recovered finely honed large stones with two plain parallel sides and one side double curved. By laying these stones on top of each other or side-by-side, they gave the impression of an exact arc. The radii of curvatures came to 2.5 and 5 m respectively. As part of the round churches we will find knee walls above the supports and fillings above the abutment. These parts serve multiple purposes (See Figure 2). The back filling or loading maintain stability by transferring the load above the support on to the supporting wall itself. Further to that, it maintains the necessary support for the roof frame above the dome.

Reconstructing the rotunda

The rotunda is being reconstructed not very far from the place of the excavation at Ágoston-liget. Here, under the supervision of the author, students in summer camps of one to two weeks in duration are doing the work, which started in 2003 (Nemcsics 2005, Nemcsics 2006). In the first year the foundations were laid, next year the construction of the walls followed (See Figure 5a - 5d, below in the Image Gallery). The building of the church is regarded as an archaeological experiment. We only use contemporary technology, used in that age. Two factors helped to find the right technological solutions, our aim to be as practical as possible and occasionally brainstorm during the building sessions. At the time rotundas were originally constructed, the planner and the builder were the same person, and this is same in our case (See Figure 6a - 6d, below in the Image Gallery) (Binding 1993, Guzsik 200, Nemcsics 2008). During this experiment in historical archaeology we gained a lot of information which otherwise would not have been available. Some examples are the work force and work time required for the church building, and the right application of technology. The miniatures, picturing the building technology of this age, show without exception more refined techniques of building walls from hewn stones. When rough stones are used for the walls the scaffolding is different, because the stones had to be selected and fitted individually. An idea of how to economise in the material in building scaffoldings for heavy loading only crystallized during the building process, as with finding a way of incrementing the height of the working platforms with the growing height of the wall. Further to that, we had to find ways to lift the heavy stones (50-200 kg) on the scaffolding and transfer them on the wall in their proper positions (See Figure 7a - 7d, below in the Image Gallery). To manhandle these stones required three to four men, and it would have been impossible to lift them manually. Our experience, gained in these exercises, widened our knowledge of medieval architecture and contemporary building technology.

Knowledge about the contemporary technology and scientific results from our experiments

The generalities of the building technology in the Middle Ages

Although the medieval architecture profited from the architectural knowledge of the preceding ages, it cannot be considered a straight copy. We can obtain information directly from manuscripts and miniatures, but they only reflect on a narrow part of the medieval building technology. These documents are usually the products of monastery workshops. The information in these documents is applicable to buildings that are partially or completely demolished already, while others are without any documentation (Jüttner 1935). These miniatures only depict the building methods of the rich elite of the time. The available information, therefore, is biased. The early buildings and the simpler constructions, like village churches, are often constructed from rough, uncut stones. The building technology depends strongly on the kind of stones (See Figure 8). The scientific work and the craftsmanship flourished in the monasteries. At the time the hand tools were developed already to a such a high standard that most of them can even be used today. The most important of them were the plumb line, the square, the mason's trowel, the flat trowel and the bricklayer's pick. A number of the stonemason's tools are also known from this age (Zádor 2006). The identification of these tools is helped not only by the documents and the miniatures but also the instruction signs cut into the stones as guides representing the tools used for the process (Binding 1993, Zádor 2006).
The compass takes an important position in this list of tools as an instrument for planning, drawing and measuring. Pantocrator is often pictured with a compass in his hand drawing the outline of the Earth (See Figure 9) (Binding 1993). The circle is the most perfect shape, and it is suppose to represent the exquisite completeness of Creation. In contrast with the well-documented tools, the division of the building work is less well known. Since the language of these documents is Latin, the interpretation and the concept can often get lost in the translation. The meanings of the words are often clarified only by the wider interpretation of the text (Jüttner 1935). The building work division and hierarchical structure is illustrated in Figure 10. The architect was not only the planer of the building, but he also actively participated in the building work. In case of smaller buildings he was also the master builder. The real function of the architect and the wider knowledge of his name depend on the size of the building work (See Figure 10) (Nemcsics 2010). At smaller building works the planer took

an active part in the construction work. Reliefs, picturing foundation work, confirm that the planer and the builder are often the same person (Nemcsics 2010).

Building technology using cut stones

The console-based scaffolding is specifically geared to construction work using regular shaped cut stones (See Figure 11 A). Building construction of this kind is characterized by the interchange-ability of the stones and the use of stones specifically cut to size and hewn to fit the place. For building a specific part of the wall the builder only needs a few stones, cut to size to fit the purpose, therefore there is no need for large number of stones to be stored on the scaffolding. As a result the scaffolding can be simpler and lighter, because they are not loaded by the great weight of the stones. This scaffolding is known not only from the illustrations, we can also deduce their construction from the holes made for the scaffolding beams, found on the remains of walls. The supporting beams were blocked in to the rising wall. The boardwalks were laid on the horizontal beams sticking out from the wall. The excess lengths of the beams were cut off. These scaffolding holes can be seen at Velemer church (Valter 2005). Some of the miniatures show the work division as well. The master builder was assisted by helpers. The building material is carried up by the unskilled workforce on ramps or ladders, or hoisted up by pulleys fixed to the higher beams. The heavier stones were hoisted up using a winch, supported by a tripod (See Figure 11 B). The stonemasons work at ground level, where others mixing the mortar (See Figure 12, below in the Image Gallery) (Binding 1993). The work division is the same as today's cooperative, un-mechanised building work.

Building technology using irregular uncut stones

There are no illustrations depicting building processes from uncut, random shaped stones. The possible reason for this is perhaps that it was only considered worth portraying the buildings made of cut stones of regular shape, for well to do people. Uncut stones of irregular shape were used only for simpler buildings like churches of poorer villages. The consol-based scaffoldings used for building of regular shape stones cannot be used for the irregular uncut stone constructions. To find the correct technology we relied on our results from experimental archaeology. In this paper we describe the rebuilding of a medieval church applying only medieval building technology (Nemcsics 2008, Nemcsics 2009). During this experiment we have gained experience in this medieval building technology, which otherwise would not have been possible to obtain.

The author, with the help of students, started this experimental archaeology project specifically to discover the medieval building technology used to construct these churches. This present effort is unusual because, so far, most of the archaeological building experiments have been carried out on buildings using plant material, adobe or earth as building material. The result of this experiment will be a lasting building, which needs a careful reconstruction, because the experiment cannot be repeated for practical reasons. The planning of the reconstruction was carried out by the author after a careful study of similar building constructions of the time.

The local quarries, the same used for the original churches, supplied the building materials for the foundation and the walls. In the first year we completed the foundation of the church. The year after we carried on with the building of the wall. The stones were built in to the walls without any cutting (See Figure 13 a and b, below in the Image Gallery). The two mantels of the wall have been made of larger selected stones, and between them random selection of smaller stones filled the gap. The lower 1.5 m height could be built from the ground from either side of the wall. The use of the uncut stones goes with some “try and see” to find the right stone. For one particular place, a number of stones had to be tried in various orientations before one finally fit. We can conclude that one needs a large number of stones present for the process of selection. This determines the method of the scaffolding erection. In this instance the scaffolding portrayed on the miniatures showing the regular cut stone buildings is not applicable.

Up to a certain height building the wall can be done without scaffolding (See Figure 14-1). The wall is wide enough to serve as a platform for the selection of stones, and the binding material can be loaded with relative ease on to the top of the wall for storing. Experience shows that it is enough to erect scaffoldings inside the church. The first scaffolding is annular, internally running around, supported by the inside wall (See Figure 14-2). The stones are heaped in the middle of the nave, so that people can walk around them. The builder looks at the heap, selects the stone and asks it to be handed to him. Only the selected stones will be placed on the scaffolding. This is followed by the process of positioning the stones through trial and error. This way the wall can be built up to the height of 3 m. The mid way scaffolding is a necessity, because the maximum height to lift the 50-200 kg uncut stones of irregular shape using manual labour is about 1.5 m. The next stage of the scaffolding, at 3 m height, will be a platform covering the whole area (See Figure 14-3). The stones will be lifted up to the platform by a hoist supported by a tripod. The wall building from the platform will follow the pattern of the one started from the ground, again up to another height of 1.5 m. The construction of the apse’s arch starts from this level. This is going to be described in the next section.

The strong and stable scaffolding, built of logs, serves as storage for the hoisted up stones (See Figure 15, below in the Image Gallery). The hexagonal scaffold arrangement suits the round building well. Above the entrance a 60 degree segment is left open. This is the logical location for the tripod with the pulley, serving as a hoist for lifting the large and heavy stones.

The operating rope goes outside, above the entrance, to the winch located in the front of the building. With the increased height of the wall an opening has to be left for the rope. On the front of the medieval churches one can often find a small window or a round opening above the entrance. That could have served this purpose in this technology. Of course, after the church was finished the opening could have been walled in, or the rope could have been lead in a different way. In one week we managed to build about 1- 1.5 m high wall. We concluded from this that, within one building season (from spring to autumn), a village church could have been built by a master builder with the whole village giving a helping hand to the effort.

The technology of building arched vaults

The possible technique of building arched vaulting is also demonstrated in the reconstruction of the rotunda. The building technology required to build a vault is completely different from what we have discussed so far in connection of erecting a wall. The wall could be built of stones that are entirely random in shape or by stones cut to size. The vaulting is a different proposition, because vaulting cannot be built of un-cut, shapeless stones. There are two kind of vaulting we are dealing with. The first is an axial symmetric, like the half cylindrical arch, used in the naves. The second is the half spherical dome-like formation over the nave, or one used to close the apse with a quarter of a sphere. The ribbed vaulting requires the use of a master shape. The vaulting with rotational symmetry either needs or does not need master shape, depending on whether it is a real or blind arcade.

The most critical part of a church is its vaulting. In terms of our archaeological building research, it was only in 2008 that we reached the stage were we could build the vaulting of the apse. To build the vault we needed stones with co-parallel sides. We used stones that could be split lamellar form. The master shape for the vaulting was reused, without re-cutting, since the use of one form of master shape for the whole building must have been an aim in the Middle Ages too. First we moulded the cylindrical part of the apse, joining the nave by using parallel positioned master shapes. After finishing this moulding we followed this with the moulding of the quarter spherical end part by using radially running master shapes (See Figure 16 B). The top of the master shapes was not boarded up, following the likely medieval example, because it would require a nicely carved wood cover. Further more, without the top boarding the master shapes could be easily removed. These shapes were positioned in two spans distances (Fig. 17/A). The stones in the vault were fastened above each other by trussing. The occasional underpinning and the friction between the stones made the erection of the vaulting possible. The building of the apse's vault was possible from the first erected scaffolding and the walls were wide enough to cater for the final installation of the arch stone (Fig. 17/B). It was necessary to use a half wall (knee wall) and wall filling (Nemcsics 2008). This is going to be discussed in detail in connection with technology of the nave's vaulting.

The technology of making vaults of rotational symmetry

The building of the nave has been progressing as described in the previous section. The vaulting starts from the plane of the upper part of the windows. This is the level of the second stage of the scaffolding. The possible techniques of building this need to be weighed up, considered very carefully and mentally turned over a number of times. The various ways of building the vaulting have been on the mind of the author ever since the beginning of the experiment, so the description in the following is the result of a matured mental process, going back a number of years. For functional reasons (the support for the forces in the walls, stability of the vaulting, the location of the roof truss et cetera) the half walls are necessities as we described earlier (Nemcsics 2008). These knee walls also have roles in the building process as well. As we have seen, scaffolding is erected inside the building, but the vaulting can only be built from the top of the supporting wall. At the same time the half wall provides a helpful position for the masonry work for the vaulting.

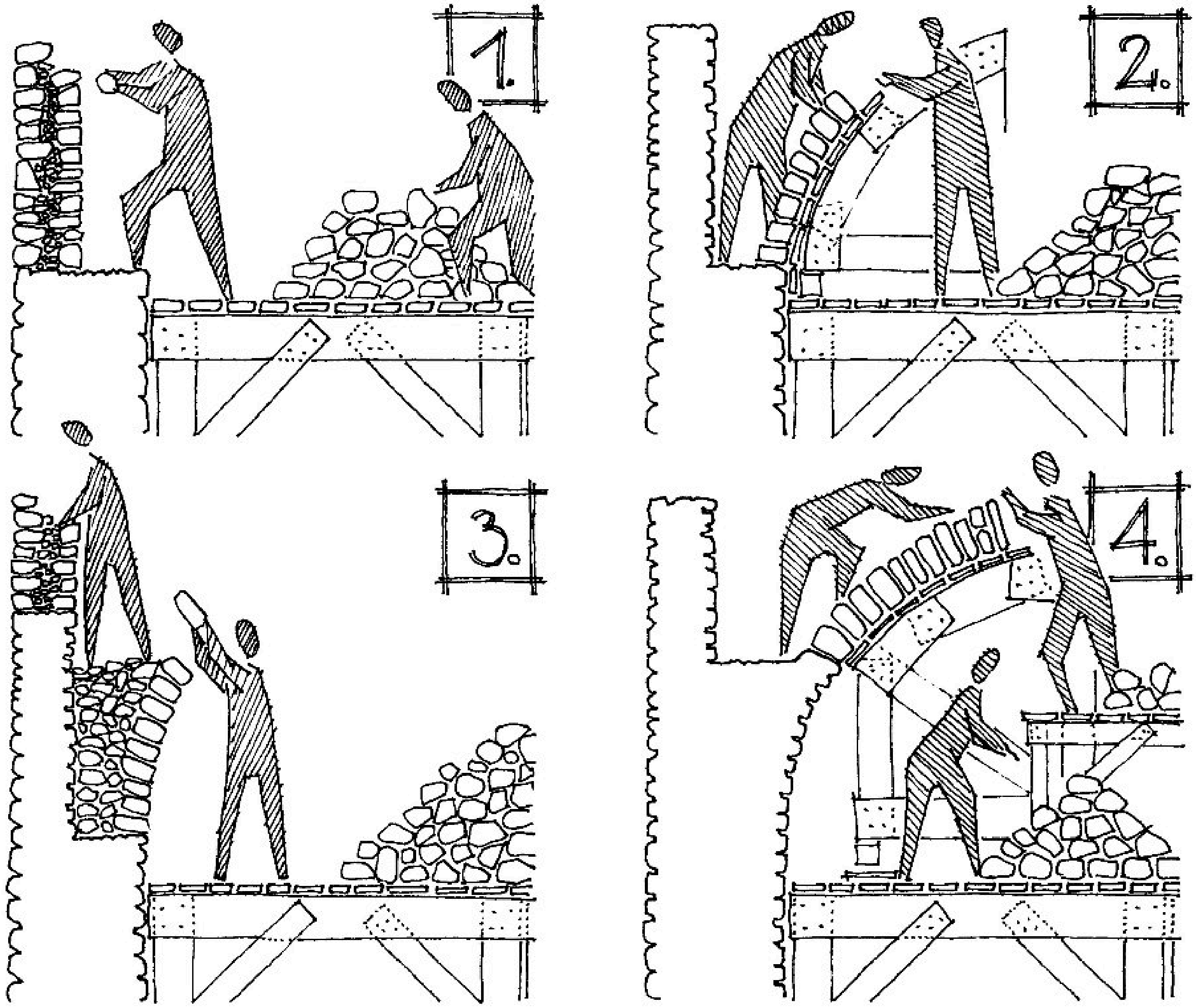

FIG 18. THE PROCESS OF BUILDING THE VAULTING OF THE NAVE. (1) BUILDING THE KNEE WALL (HALF WALL) FROM THE STAGE (2) BUILDING THE VAULT FROM THE STAGE. (3) KNEE WALL BUILDING FROM THE MANTLE WALLS FILLED WITH STONES. (4) BUILDING THE VAULT FROM THE MANTLE WALLS (FOR DETAILS SEE THE TEXT).

The various stages of the building process can be followed in Figure 18. As the first step, the half walls, which are narrower than the proper walls, are built up to the possible height (See Figure 18-1). Following this, we mould and build the lower part of the rotational symmetric vaulting (See Figure 18-2). This is followed by the filling of the mantles from the scaffolding. The wall filling is required for the continuation of the building process, because it serves as the support for the half way scaffolding (See Figure 18-3). From the wall filling we finish the knee wall, and from this we finish the vaulting (See Figure 18-4). We must not forget that the building of the vaulting is happening in greater height. Part of the wall is occupied by the thickness of the vault. Only a narrow ledge is left for the transportation of the heavy stones. The half wall represents here a great help for safety. We can add to the functions of the half wall listed earlier (finishing the brow, safeguarding from split, taking the weight forces to the walls, support for the roof truss) this new building technological function.

Keywords construction of building
stone working
architecture
church
sculpture

Country Hungary

Summary

Contribution to the medieval building technology based on the reconstruction of a rounded church

In the Carpathian-basin many of the early-medieval church types were the rotundas, but the majority of these churches have not survived in their original form. Most of these churches were modified into larger churches, or were destroyed during the Ottoman invasion. This paper proves that the rotundas in the Carpathian-basin are not the result of adoption. Their large numbers, characterised by their small sizes and special forms, supports this supposition. We can enhance our knowledge of the medieval building technology from the miniatures depicting building processes and from contemporary descriptions. These, however, are restricted entirely to picturing churches and fortifications constructed of cut and hewn stones. These miniatures only depict the building methods of the rich elite of the time. The available information therefore is biased. The early buildings and the simpler constructions, like village churches are often constructed from rough, uncut stones. The road to the discovery of this kind of building technology is via experimental archaeology. Further information to the structure of the foundations and the wall construction can be gained from the results of archaeological digs and wall excavations. We demonstrated the rough stone building technology on an experimental archaeological project. This paper discussed the reconstruction work of a rotunda in the mountains of Gerecse. During excavation, not only

the hewn stones of the foundation walling were found, but other findings come to light as well. The reconstruction plan of the church was assisted by these findings and also by data of other similar churches surviving in their original form. The church was reconstructed not far from the place of the excavation using contemporary technology. This experimental reconstruction of a round church made of rough stones shed light on a number of details of the building technology of the time.

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Gallery Image

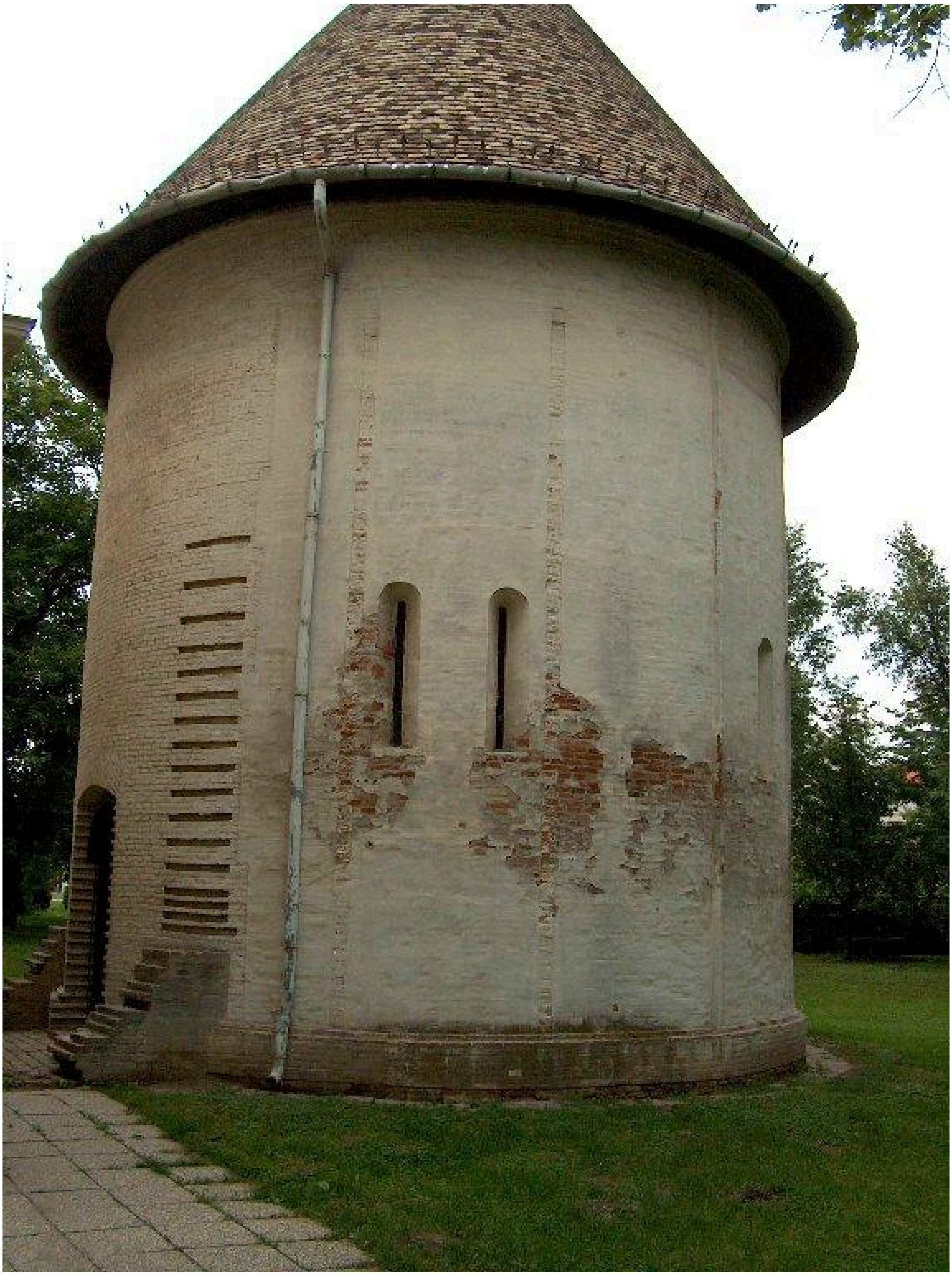

FIG 1A. THE BEST KNOWN CHURCHES SURVIVING IN THEIR ORIGINAL STATE FROM ÁRPÁD-AGE: KISZOMBOR.


FIG 1B. THE BEST KNOWN CHURCHES SURVIVING IN THEIR ORIGINAL STATE FROM ÁRPÁD-AGE: NAGYTÓTLAK.

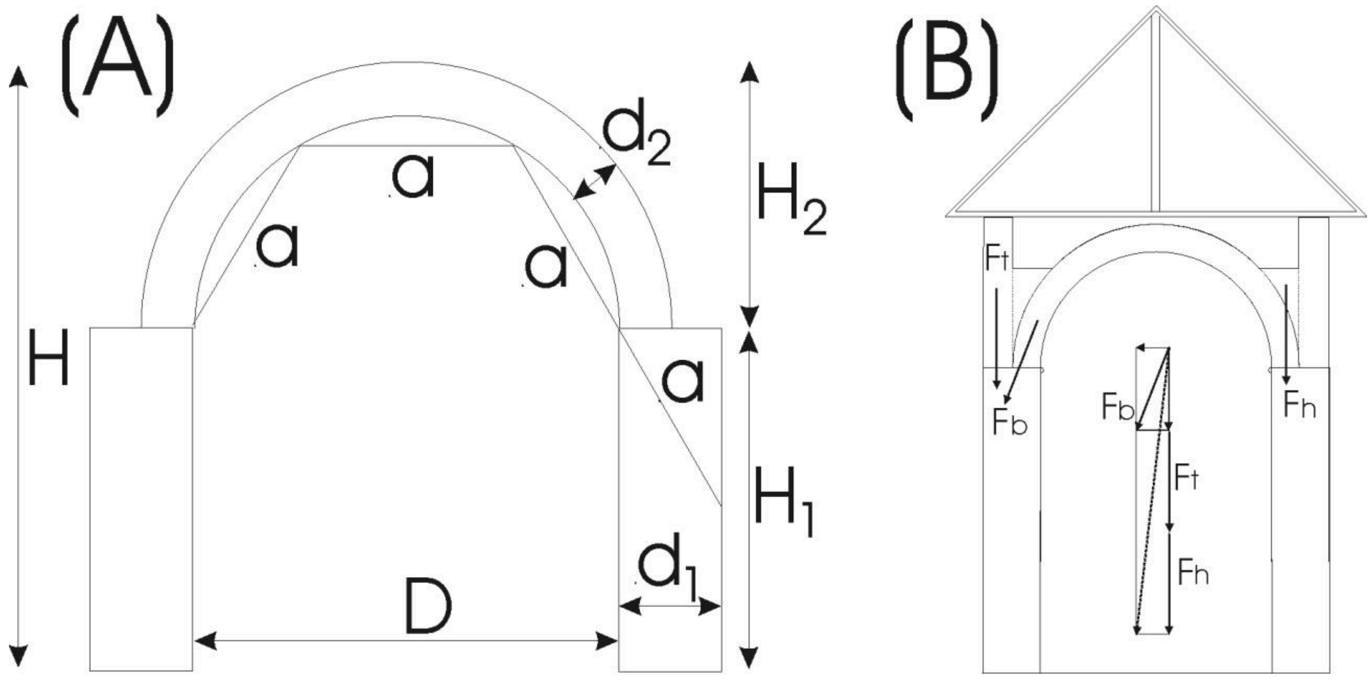

FIG 2. ILLUSTRATION OF THE ALBERTI RULE (A) AND THE MULTIFUNCTION OF THE FILLING BETWEEN THE KNEE AND THE BACK WALL (B).

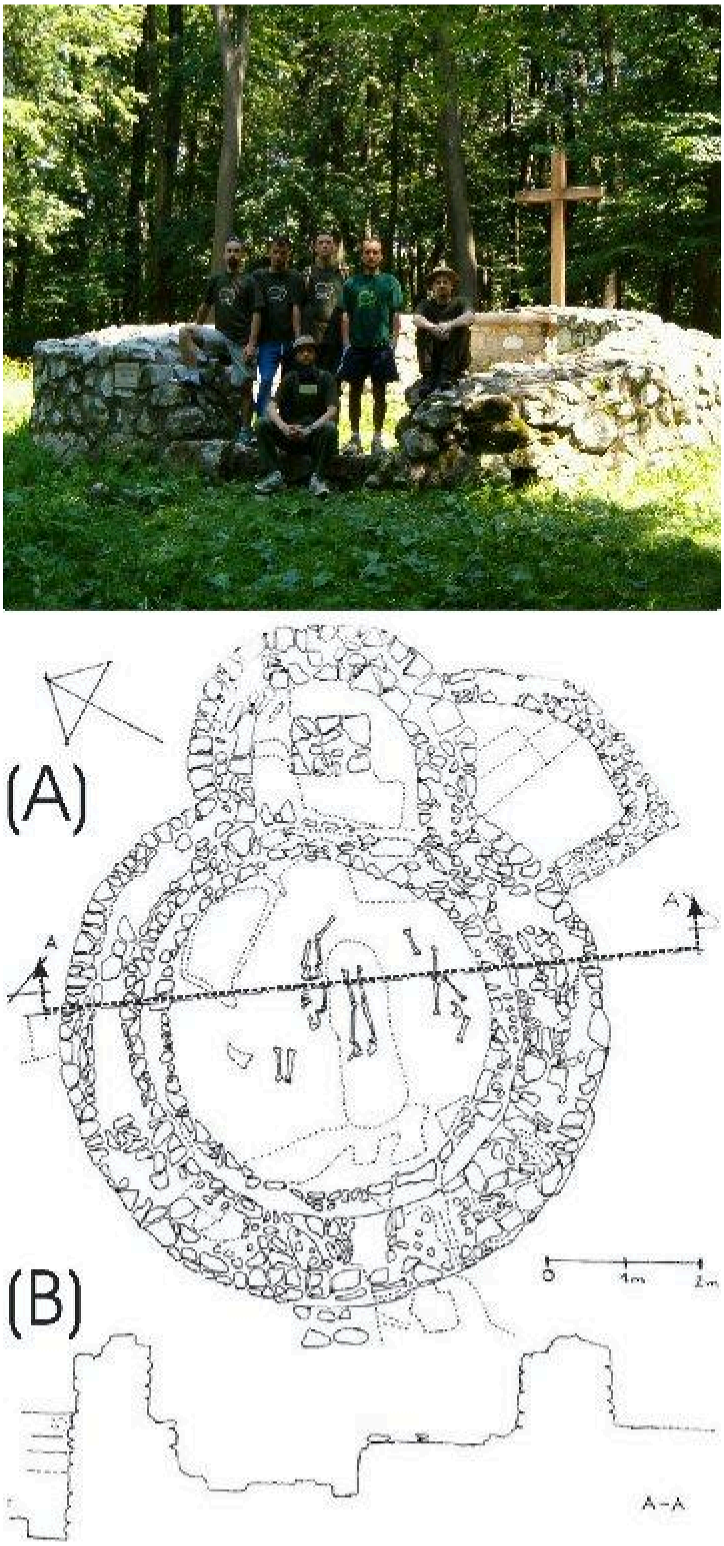

FIG 3. UPPER PART: PICTURE FROM THE RUINE; LOWER PART: THE EXCAVATED FOUNDATION (A) AND ITS CROSS-SECTION (B).

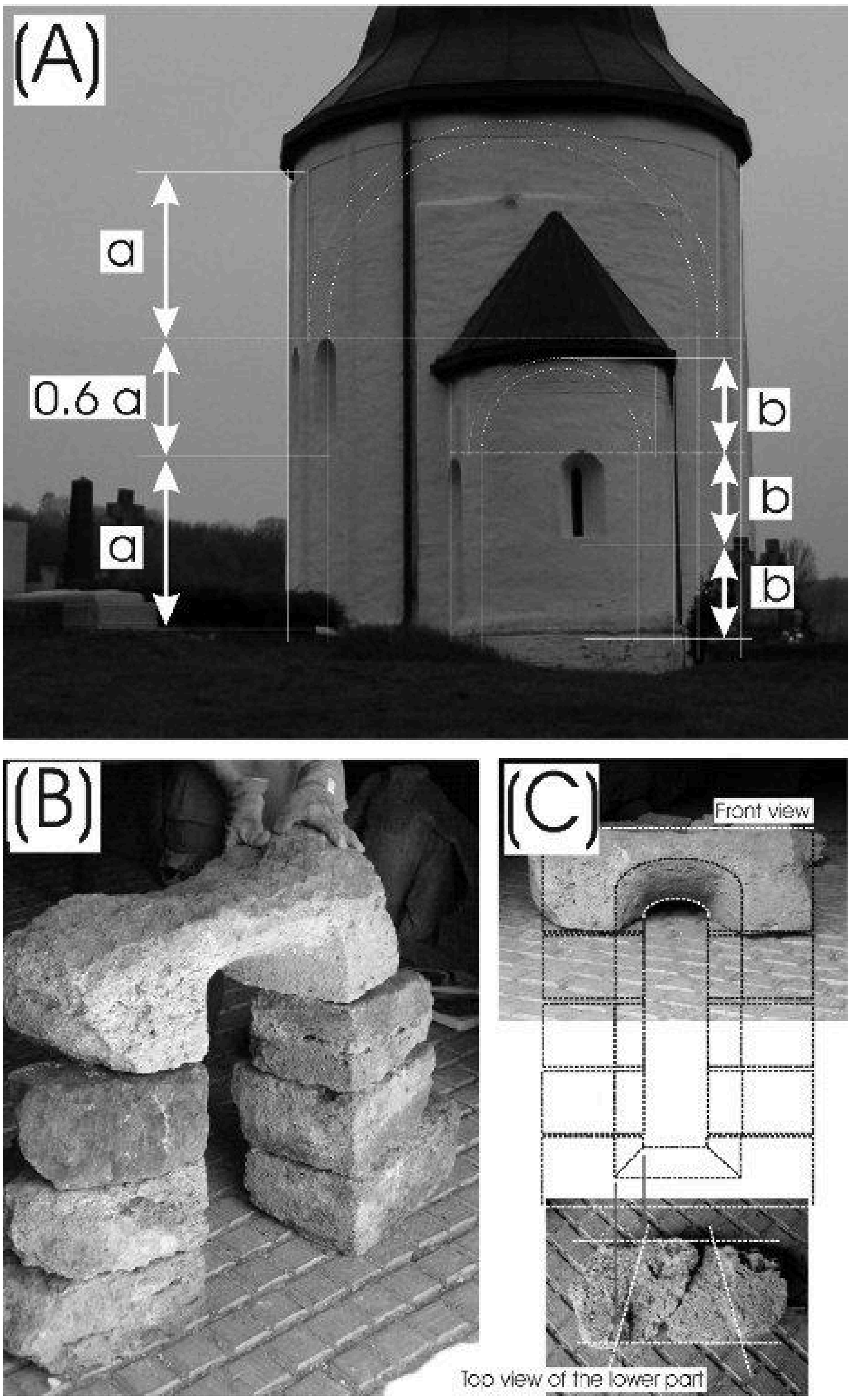

FIG 4. (A) THE POSITION OF THE WINDOWS IS OFTEN AROUND THE HALF HEIGHT OF THE WALL, (B-C) THE RECONSTRUCTION OF THE WINDOW SIZE.

FIG 5A. PICTURES FROM DIFFERENT STAGES OF THE RECONSTRUCTION.

FIG 5B. PICTURES FROM DIFFERENT STAGES OF THE RECONSTRUCTION - WALLING FROM LOW (CA. 1.5 M HIGH) SCAFFOLDING.

FIG 5C. PICTURES FROM DIFFERENT STAGES OF THE RECONSTRUCTION - STONE LIFTING BY WINDER.

FIG 5D. PICTURES FROM DIFFERENT STAGES OF THE RECONSTRUCTION - PICTURE OF THE BUILDING TEAM IN FRONT OF THE MASONRY.

FIG 6A. PICTURES FROM DIFFERENT STAGES OF THE GATE - ARCH RECONSTRUCTION: DRAWING OF THE PATTERN.

FIG 6B. PICTURES FROM DIFFERENT STAGES OF THE GATE - ARCH RECONSTRUCTION: CUTTING OF THE RELIEF.

FIG 6C. PICTURES FROM DIFFERENT STAGES OF THE GATE - ARCH RECONSTRUCTION: TRANSPORT OF THE VERY HEAVY HEWN STONES.

FIG 6D. PICTURES FROM DIFFERENT STAGES OF THE GATE - ARCH RECONSTRUCTION: WINDOWS AND THE ENTRANCE) IN THE WALLING.

FIG 7A. FURTHER PICTURES FROM ADVANCED STAGES OF THE RECONSTRUCTION - TRANSPORT OF THE UNHEWN HEAVY STONES.

FIG 7B. FURTHER PICTURES FROM ADVANCED STAGES OF THE RECONSTRUCTION - BUILDING OF THE APSE VAULT.

FIG 7C. FURTHER PICTURES FROM ADVANCED STAGES OF THE RECONSTRUCTION - THE VAULTING OF THE APSE IS COVERED BY THE KNEE WALL.


FIG 7D. PICTURES FROM ADVANCED STAGES OF THE RECONSTRUCTION - THE VAULTING STARTS IN LINE WITH THE UPPER LEVEL OF THE WINDOWS.

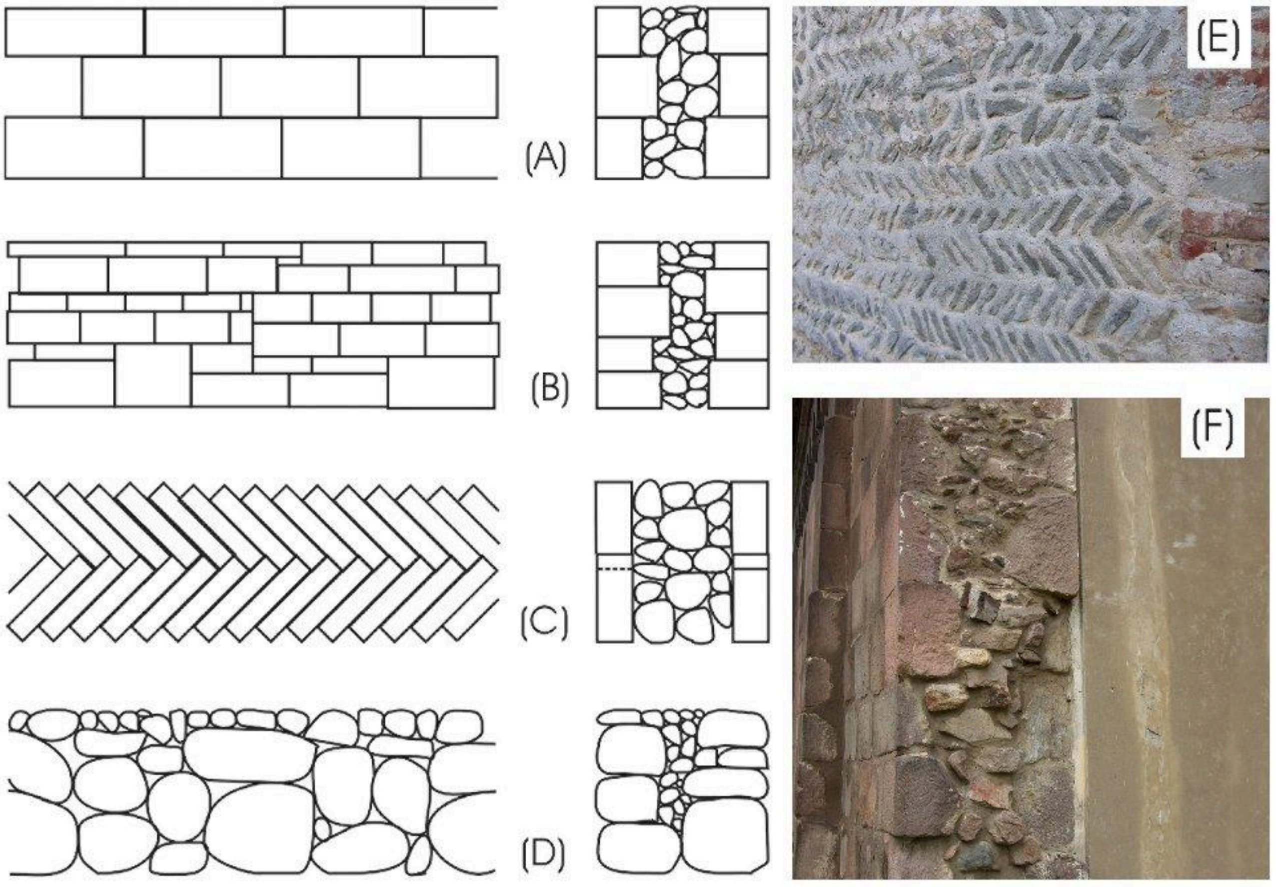

FIG 8. LEFT PART, VARIOUS TYPES OF WALLING; RIGHT PART, MEDIEVAL WALL STRUCTURES.

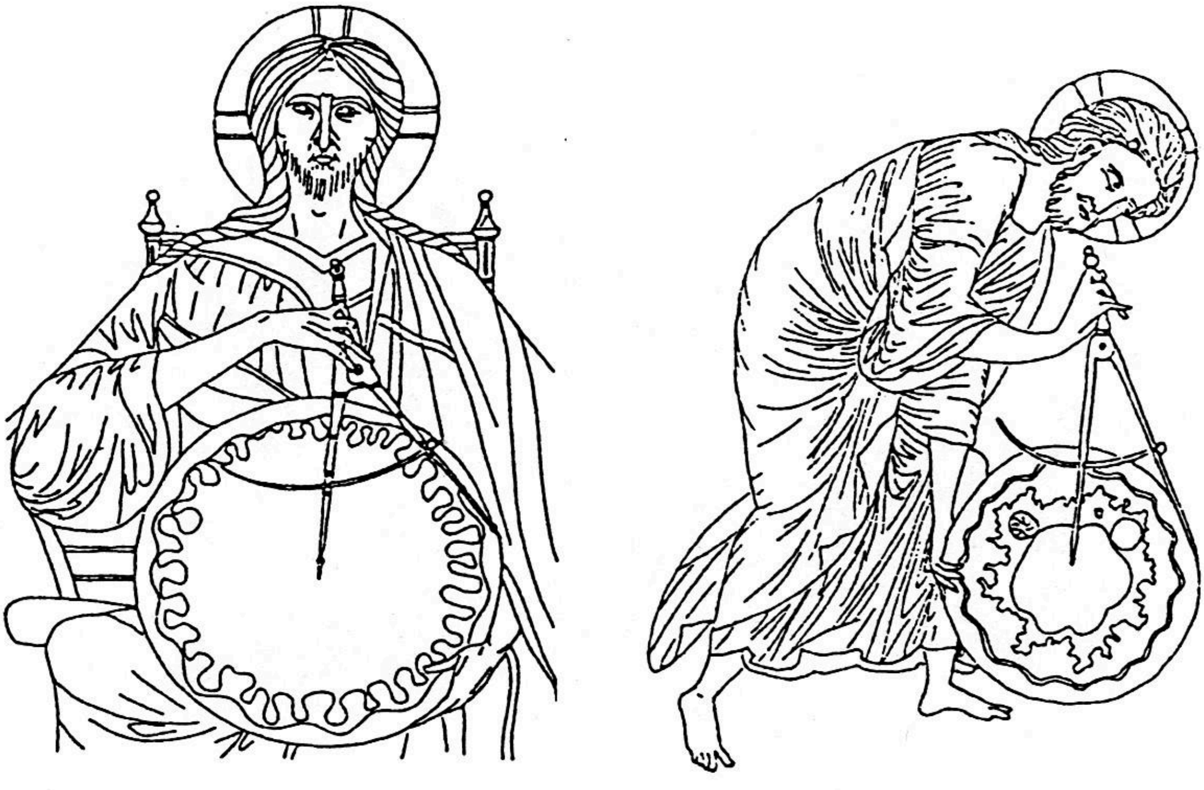

FIG 9. THE PAIR OF COMPASSES WAS AN IMPORTANT DRAWING AND MEASURING INSTRUMENT IN THE MEDIEVAL BUILDING TECHNOLOGY.

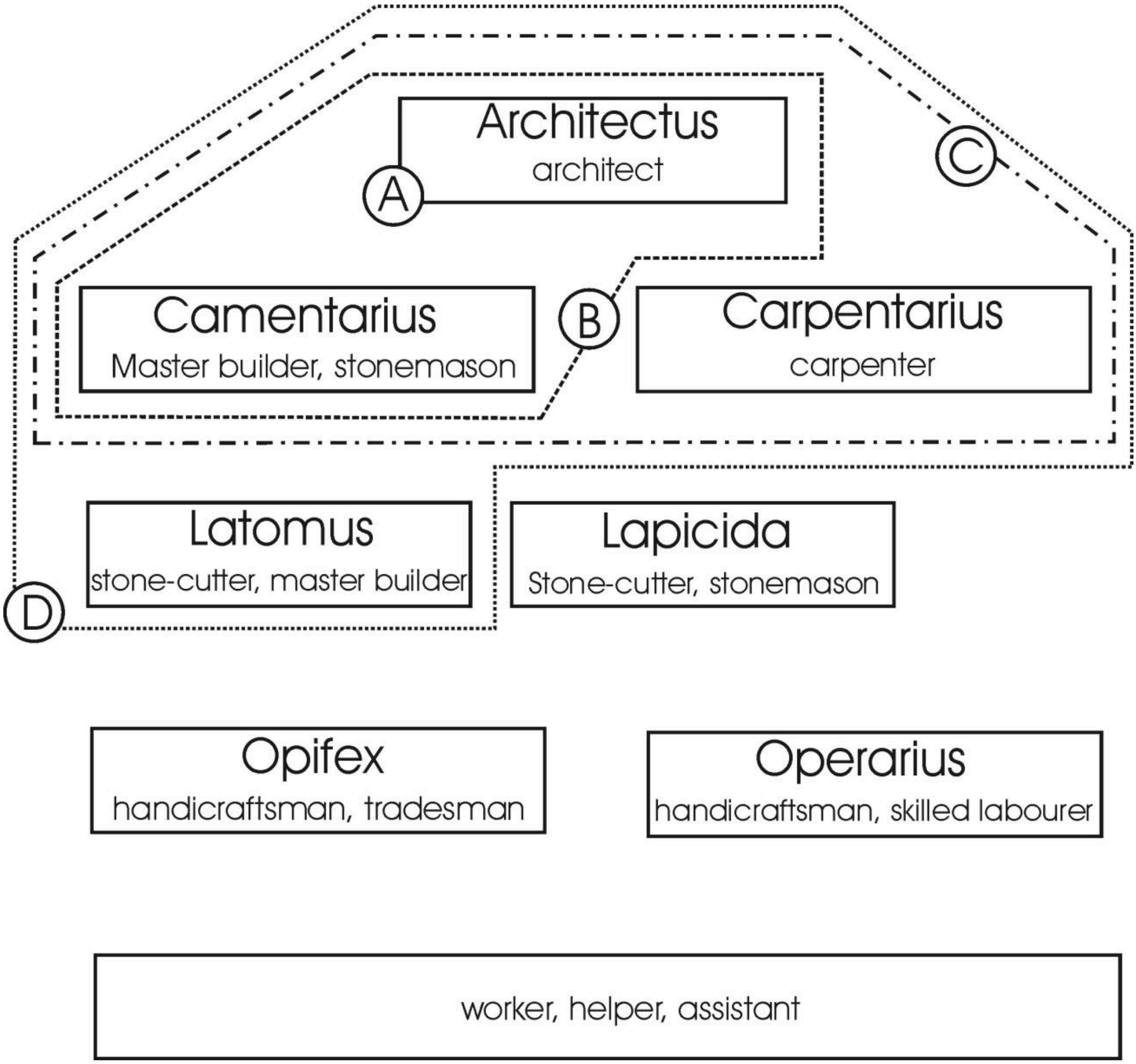

FIG 10. THE HIERARCHY IN THE WORK FORCE AND THE DIVISION OF THE LABOUR ARE BASED ON DESCRIPTIONS OF THE TIME.

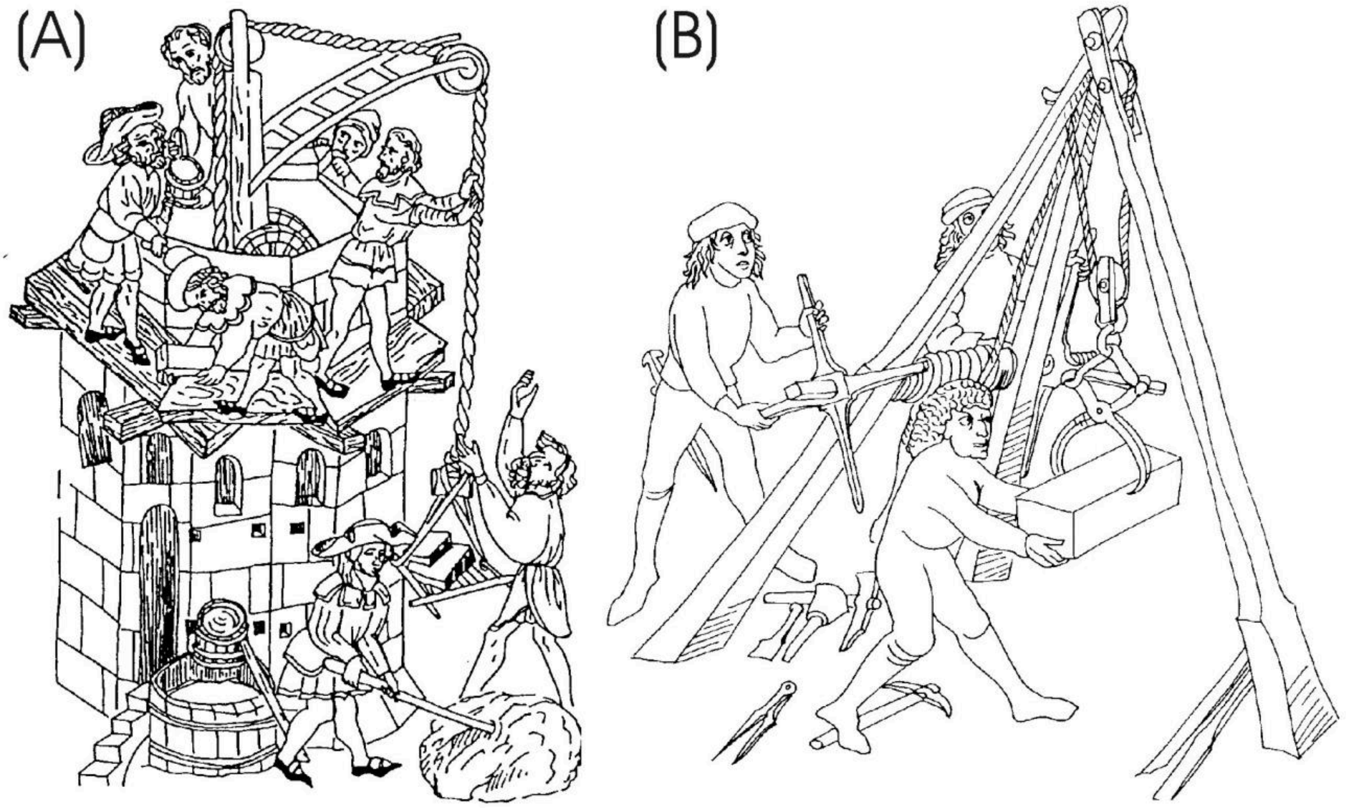

FIG 11. THE MINIATURES SHOW THE PROCESS OF WALL BUILDING USING STONES CUT TO REGULAR SHAPE.

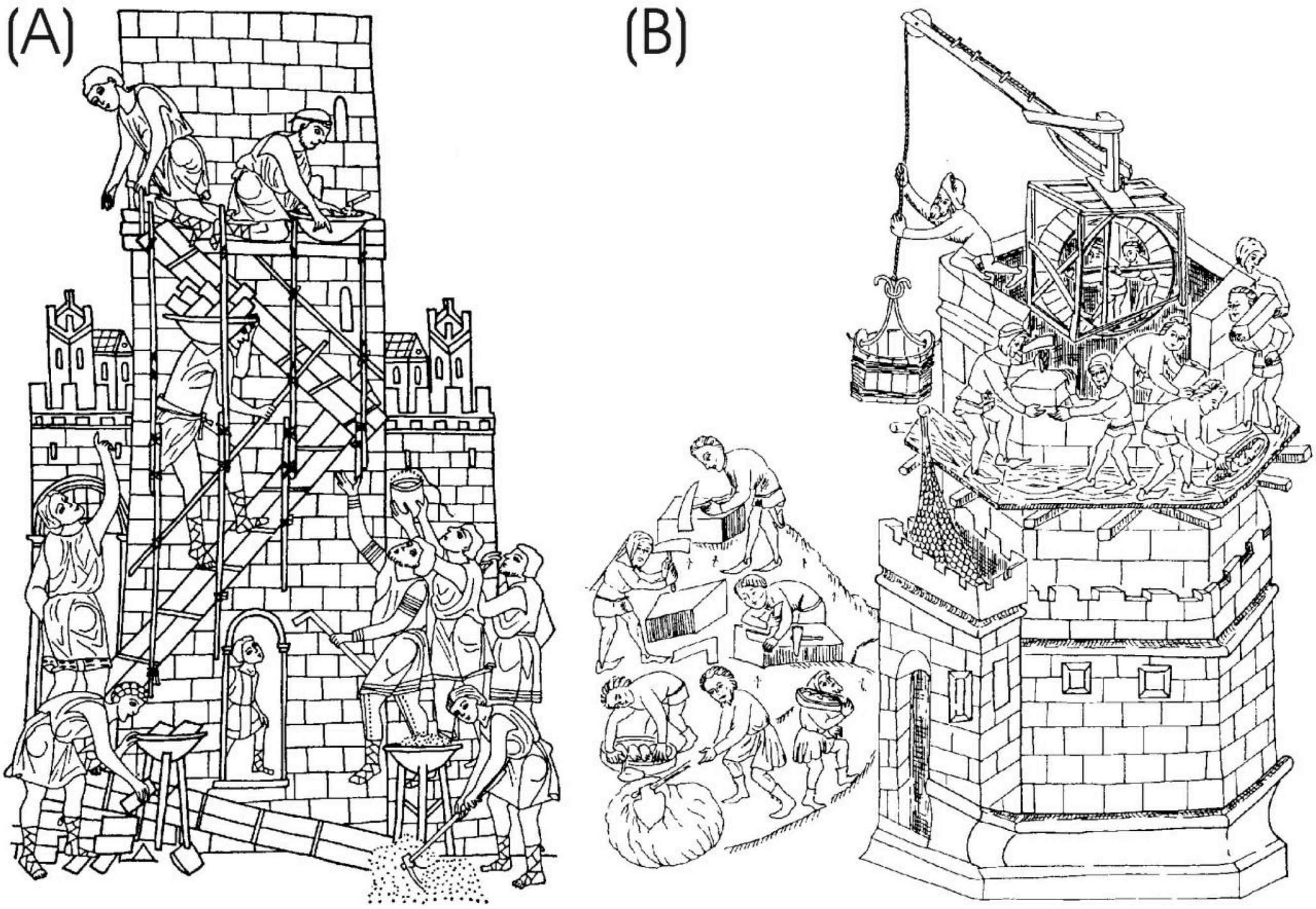

FIG 12. THE MINIATURES OF THE MEDIEVAL SCRIPTURES DEPICT WELL ORGANISED BUILDING PROCESSES

FIG 13A. THE WALLING OF THE ROTUNDA FROM IRREGULAR UN-CUT STONES: THE SCAFFOLDING INSIDE THE BUILDING.

FIG 13B. THE BUILDING OF THE WALLS CAN BE DONE FROM THE WIDE WALLS IN GREATER HEIGHTS.

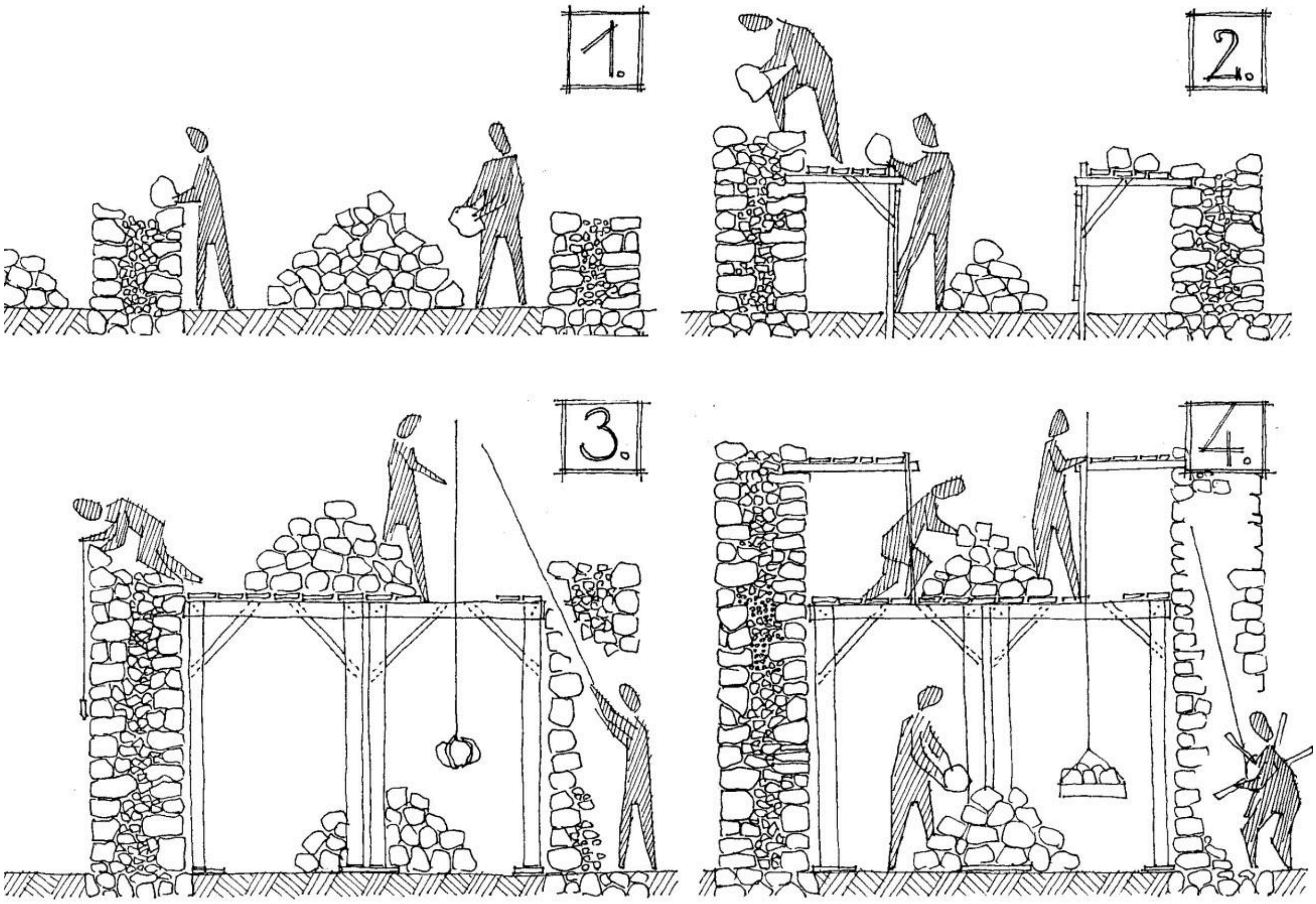

FIG 14. THE LARGE NUMBER OF STONES USED, REQUIRES STRONG AND STABLE SCAFFOLDING INSIDE THE BUILDING.

FIG 15A. THE OFTEN HEAVY AND LARGE STONES ARE LIFTED UP TO THE PLATFORM BY HOIST FIXED TO A TRIPOD.

FIG 15B. IT IS ADVISABLE TO POSITION THE TRIPOD BEHIND THE ENTRANCE OF THE BUILDING.

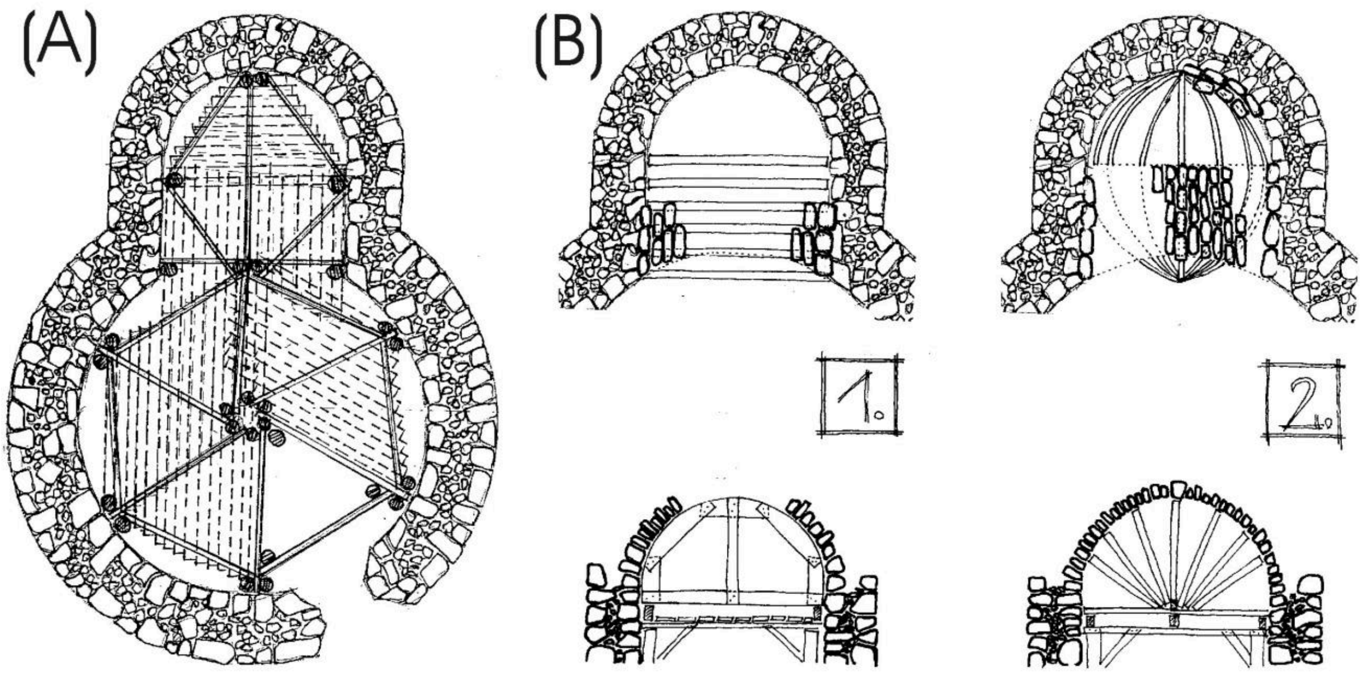

FIG 16. THE HEXAGONALLY SHAPED DECKING FITS WELL TO THE INSIDE OF THE ROUND CHURCH.

FIG 17A. THE ERECTION OF THE APSE VAULTING - MASTER SHAPES POSITIONED 25-30 CM FROM EACH OTHER.

FIG 17B. THE ERECTION OF THE APSE VAULTING - THE APSE VAULT BUILDING CARRIED OUT FROM THE EXISTING WALL.

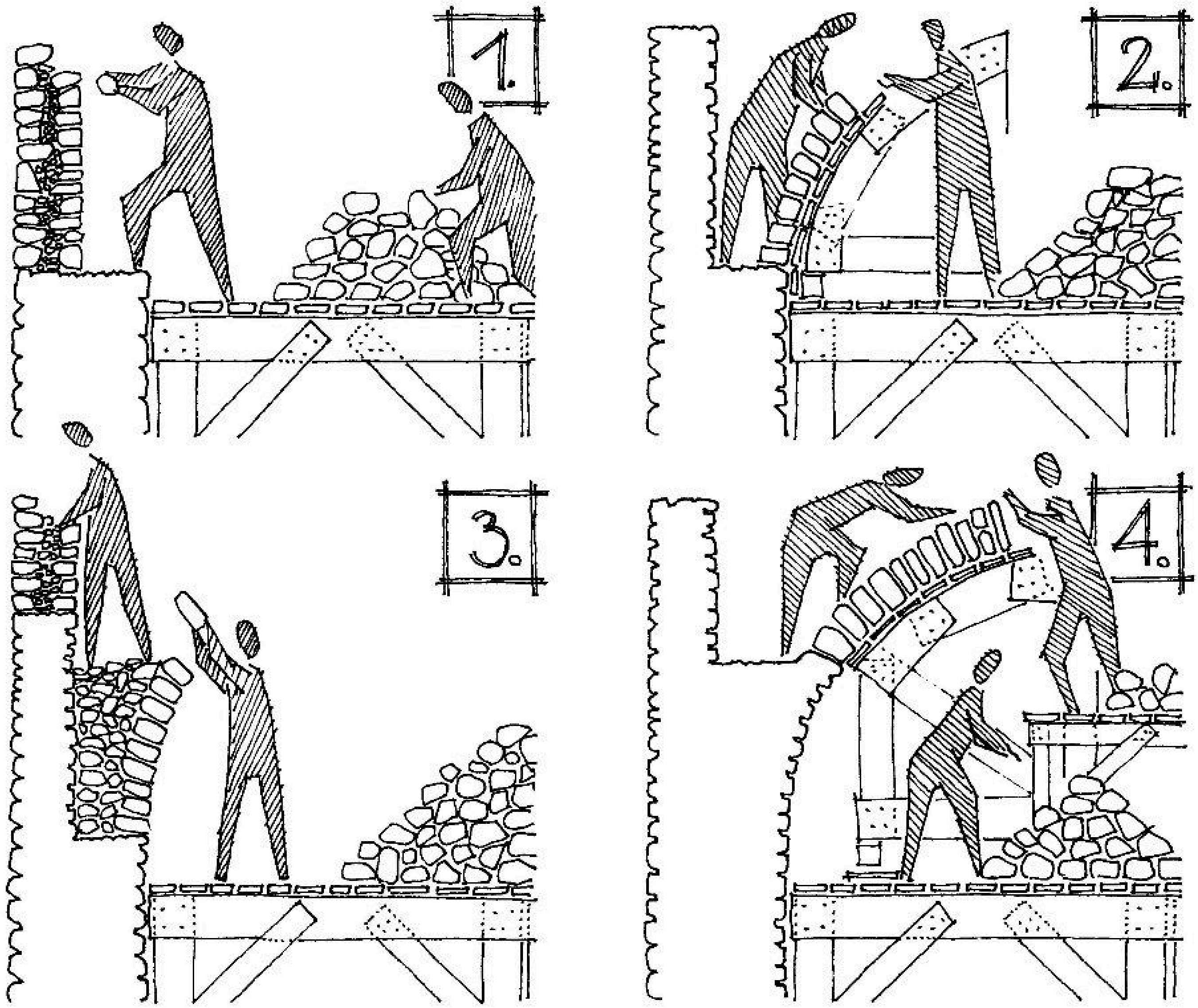

FIG 18. THE PROCESS OF BUILDING THE VAULTING OF THE NAVE.