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Abstract

The study of building stone cutting is still a new discipline, which is currently based on evolving methods of mechanoscopy and analytical trasology. The presented article is an extract of a study that systematically maps the stone-cutting work in the territory of Prague from the oldest buildings to the present day. The most used dimension stone of Romanesque Prague is "opoka". Although the opoka also occurs in other countries, its use as a predominant building material of monuments of this age is most common, especially in Prague. The systematic research of historic building stone cutting in the historic centre of Prague reveals the world of stonework from the earliest time. Individual traces of tools may be considered a historical source. Each work has its own unique pattern and bears traces of individual stonemason workshops, traditions, and training of the craftsman's predecessors. Stonework in 9th century Prague was gradually evolving from simple stone block modelling to sophisticated cutting of blocks in the 12th century. For the distinctive work of Prague, stonemasons rock face cutting was typical, which means they gradually obliquely cut the areas from the corners to the centre of the block. However, they did not use various decorative patterns so typical for European work. In Western Europe, the aim was to use innovative tooth tools that were highly effective in working with stone; nevertheless, in Prague, these tools did not become popular, although they were sporadically used as European craftsmen arrived in Prague. When studying the stone surface, the latest 3D modelling technology was used, and consequently, the models were used to create mechanoscopic analyses using Global Mapper software. Based on the identified traces and their shapes in connection with the dynamics of the hits, the tools used could be reconstructed.

Keywords: Prague, Romanesque houses, mechanoscopy, cutting stone, opoka

1. Introduction

The value of architectural monuments consists of many variables, including the traces of craftsmanship processing, which should be considered during conservation and restoration interventions. Traces of the work of stonemasons are an integral part of the expression of the monument. In addition to an aesthetic effect, these traces help to reveal the working practices of old masters and the development of the craft over time. Trace documentation also allows deducing the tool's shape and how to work with it. The above reasons explain the importance

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of studying and preserving traces of tools on the surfaces of historical buildings. The study of building stone cutting is still a new discipline, which is currently based on evolving methods of mechanoscopy and analytical trasology. The presented article is an extract of studies that systematically map the cutting work of stones in the territory of Prague from the oldest buildings to the present day. Prague's Romanesque houses are a phenomenon that has no comparison to the Czech environment. Documentation of their processing methods reveals the craft techniques of the end of the 12th and the first half of the 13th century. Our work is based on documentation and assessment of stone craftsmen processing traces of historical buildings in the Prague urban conservation zone. Data are collected and organised systematically according to historical periods, enabling the creation of a knowledge system providing a new way of performing research on architectural heritage.

2. Dimension Stone of Romanesque Prague

The main dimension and sculpting stone of Romanesque Prague was primarily opoka. Opoka is a clastic sedimentary stone, more precisely, a silty to sandy marlite often containing microscopic needles of silica mushrooms. Opoka is of Mesozoic (Late Cretaceous) age and relatively often occurs in Prague and its surroundings. It is characterised by easy extraction and workability. Opoka, as well as sandstone, have been present to a lesser extent in the highest part of a plateau, which is situated in the east-west direction from Petřín to Bílá Hora, and they are a part of the so-called Bílá Hora formation. The average thickness of this formation is 25 to 30 m. The centre of opoka excavation in Romanesque times was the eastern edge of the geological formation in Petřín. Its excavation there is documented in written form as early as the beginning of the 12th century, but the origins of mining are undoubtedly much older there (Rybařík, 2003). According to Rybařík (2011), the mining expansion in this area began after 1140, especially in connection with the foundation and construction of Strahov monastery, which gradually acquired the quarries. The position of opoka quarries is depicted in Figure 3.

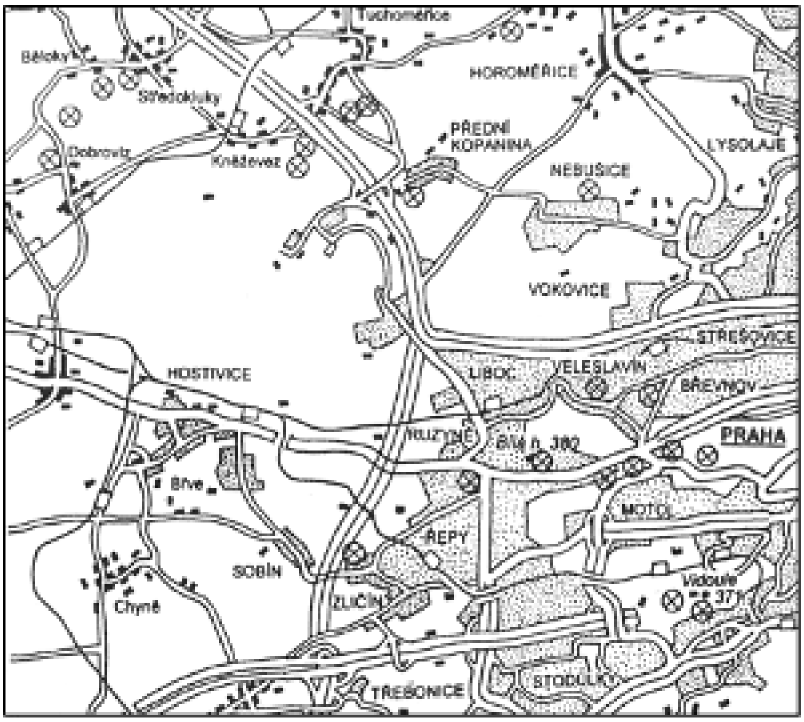

Figure 1. Opoka quarries in Prague and its nearest surroundings (taken from Kotlík et al., 2000).

Above all, Opoka was used to construct many sacral buildings, the oldest dating back to the 9th century. The Church of the Virgin Mary, the Rotunda of St. Vitus, and the Basilica of St. George may be mentioned as significant examples. The use of opoka for house and palace constructions is dated to the last quarter of the 12th century and, especially, the first third of the 13th century. These buildings were constructed using opoka mainly in the form of different-sized small ashlars and, except for the surfaces and arches, also from irregularly shaped stone pieces. Opoka found its application for most architectural elements. Unfortunately, these can nowadays be found only in the form of remnants of their ground floor parts. Opoka was also used, among other things, in the form of a crushed stone in the core of sandstone masonry during the construction of Judith's Bridge (Rybařík, 2011).

Apart from opoka, other rock types, especially sandstone, were used to a lesser extent. These were often used, e.g., for the construction of corner fittings or to make more complicated profiled elements, such as window openings, tympanums, various lintels, and column feet. There are various reasons for using sandstones instead of the more widely used opoka for such purposes. In contrast to opoka, it is easier and more common to break out larger sandstone blocks during extraction, which allows the production of stone elements of larger dimensions from one piece. At the same time, sandstones may be chosen for their specific structural elements and a higher degree of resistance to weathering processes, especially frost action. This is caused because, in contrast to opoka, they generally have approximately half water absorption (e.g. Tišlová, 2015), so less water is absorbed into their internal structure. The absorbed water is subjected to volume changes due to frost action, which consequently leads to rock damage. Using sandstones for constructional elements in which ground moisture could rise (e.g. the column's feet) was a logical choice, which was undoubtedly based on the experience of builders and stonemasons of the time.

Sandstones from Petřín, mostly of yellowish colour, are situated in the base of the Turonian Bílá Hora formation, which contains opoka. These sandstones were, with exceptions, less hard and quite crumbly; nonetheless, they were undoubtedly extracted in the pasty, as is evidenced by the presence of several abandoned quarries. One of the oldest sandstone applications in the architecture of Prague Castle settlement can be found in the Rotunda of St. Longin (1st half of 12th century); however, in this, as well as in other cases, there is no written evidence of the used rock origin (Rybařík, 2011). Another interesting rock used in the Romanesque time, whose origin is difficult to determine, is dark red to red ferruginous sandstone. This sandstone is especially hard and durable. According to Jan Zavřel, it was also used to construct Judith's Bridge (Zavřel, 2000a). Some blocks can be found in its remains to this day. Some individual architectural and other elements of the Romanesque age, which were made from this type of sandstone, can be found, for example, at Prague Castle (Rybařík, 2011). The origin of these rocks has been unknown for a long time because red sandstones are typical rocks of Permian origin that do not occur in Prague. A possible answer was provided by Jan Zavřel (2000b), who, based on a petrographic analysis of rocks from the paving and masonry of Judith's Bridge, concluded that these rocks were from the base of the Cretaceous Petřín Formation. Such rocks were found in sufficient thickness in Dejvice, under Hanspaulka or elsewhere on the edge of the Cretaceous cap, for example, between Petřín and Bílá Hora (Rybařík, 2011). Furthermore, sedimentary rocks, such as slate and quartzite, found their application in Romanesque architecture.

Regarding igneous rocks, we can prove the use of diabase for the paving of Judith's bridge (Zavřel, 2000b; Březinová et al., 2006). We do not know the exact date of origin of this paving, but it did not form the oldest documented surface of the bridge deck (Zavřel, 2000b). It is possible that its laying dates to the first half of the 13th century. However, it is interesting that the obtained samples were subjected to a petrographic analysis and from the results, it is possible to conclude that the probable places of extraction may be located in Malá Chuchle, Karlík near Dobřichovice, or on the lower floor of the Lištice quarry near Beroun (Březinová et al., 2006). The quarry in Karlík is also indicated by the fact that it was owned by the Order of the Knights of the Cross with the Red Star, which took care of the maintenance of Judith's Bridge (Březinová et al., 1996).

3. Trace Identification

Methods of analytical trasology and mechanoscopy are used for the purposes of stone surface survey within our project. Stone trasology deals with traces in material, the subsequent reconstruction of tools, and the processes of stone working—also, trasology deals with the blade of the tool by itself. In addition to the actual analyses, it is crucial to create systematic catalogues of traces and copies of putative tools that will allow verification of the examined traces. Also, we must distinguish restoration interventions, which are sometimes the most challenging aspect of identifying original traces. This is true, especially in the case of the restoration interventions in the 19th century aimed at exact replicas of the objects in question so that entire spaces were cut or neatened. The documentation options and analyses are defined as relief photography and mechanoscopy.

3.1. Relief photography

One of the main photographic methods is relief photography. This is a photograph of the object in question with side illumination. The light is set perpendicular to the processing traces. Each trace thus creates a shadow that highlights the corresponding graphic pattern. This method is particularly suitable for basic orientation on the stone's surface. These photographs are also suitable for use in publication since directly illuminated photographs do not provide any insight into the treatment of the surface under study. Side illumination can be created either with a constant light or with a flash. Care should be taken when adjusting the intensity of the illumination so that the surface is not overexposed in the final photograph.

3.2. Mechanoscopy

The interpretation of data in terms of determining the actual trace is called a mechanoscopy. This analysis seeks to identify tool traces, reconstruct the tools that produced them, and outline the process of the stone working. As a result, the analyses aim to uncover the approach and procedure of historical craftsmen when making a given workpiece.

Mechanoscopy works with 3D imaged materials, so creating a 3D model of the examined object is essential. There is no need to revisit the object, and the space is available in X, Y, and Z coordinates. Currently, two methods are used for 3D modelling – laser scanning and photogrammetric scanning. For our modelling, we use multi-frame photogrammetry. The basis of this method is spatial analytical geometry in a chosen coordinate system. Firstly, we focus on the main points of the photographed object. These points are determined by trigonometric calculations in the polar coordinate system. The azimuth height angles are obtained using the camera, where the software calculates both angles from the position of the given point in the sensor. The key information is then the location of the unknown position of the camera. This can be calculated by the software when creating a continuous strip of photos with a minimum overlap of 50%. After obtaining all the required data, it is possible to construct a finer structure consisting of a triangular net from the initial cloud of points. This is a simple approximation of the object's shape. Such a net can then be replaced by corresponding cut-outs in the photograph.

The quality of photogrammetric scanning is determined mainly by the software and the quality of the sensor. The lens projects the image onto the sensor, which is made up of a mosaic of photocells called pixels. In principle, the sensor is a photoelectric element, producing a voltage corresponding to the intensity of light. The photocells are interconnected with a computer that is able to focus any photocell in X, Y coordinates. Ideally, the computer transfers the pixels in the matrix to memory so that each memory cell should correspond to an X, Y pixel. Nonetheless, in our case, everything depends on the quality of the sensor. In practice, the sensor does capture every point in X, Y but with little intensity. Hence, it greatly enhances its performance by sensing the immediate surroundings of the intensity of a given point. The result in the computer's memory is thus not the intensity value of points X, Y, but the arithmetic average of its surroundings. Laser scanning operates on a similar principle, except that the scanning is done directly. The laser is emitted from the static head, and it oscillates on the object. Again, this is not a point focusing but a numerical averaging of the point's surroundings. The distance of the sensor from the object is critical for this method. The longer the distance, the larger the laser oscillation. In handy scanning, the range of the beam is controlled by a camera system. However, if one has a good quality camera and lens, the focusing is of high standard, the surrounding area of the intensity of the point is reduced, and the structure of the object's surface is focused quite accurately.

In contrast, in laser hand scanners, where the scanning range of the laser is stable, there is a significant blurring of the image in the detail. Thus, such a method precludes working in a millimetre dimensional setting. At present, a photogrammetric examination of the object is significantly more suitable for mechanoscopy (Cihla, 2019).

The data is processed by exporting a TXT file in an orthogonal section to the Global Mapper software, in which we further process the data using a hypsometric or contour. The selected trace is cut both longitudinally to determine the dynamics of the strike and transversally to generate the optimal shape of the tool blade. As an example, we present Figure 2, where the typical triangular shape of a dynamic impact of a pointed handle tool is shown by a contour map. The hypsometric image shows the line of cut AB, whose trajectory indicates a blow in the backswing with a handle tool. We can also indicate the type of tool in the position of the expected angle of impact on the stone, in this case, 45°, and also schematically outline the shape of the trace.

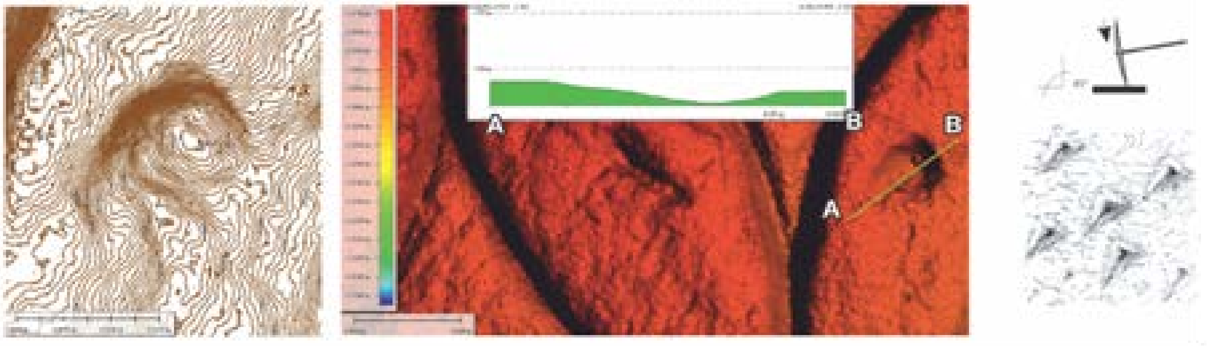

Figure 2. Example of contour map of a double-pick blow trace, hypsometric image with longitudinal section of the trace, schematic representation of a typical double-pick trace, triangular shape. (J.Valach)

Every trace of a stone tool found requires inspection. This is only possible by experimenting with the tool. That is why there are copies of the stone tools in question and efforts to imitate the way of working with them. Each work with a given tool has its own characteristics, reflected in the trace on the respective surface. Creating a catalogue of historical traces of stone working is the result of understanding the ways of working with stone tools in a historical context.

4. Results and Discussion

One of the results of the research into the workmanship of Romanesque houses in Prague is the discovery that the most basic stone tool was the handle tool, evidenced by the frequency of its use. This is in contrast to contemporary stonemasonry, where a hand and wide chisel perform the most critical role in the realignment of the face. The handle tool was used for the rough working of the block and its finer finishing. The regular combination of these two types of cutting edges (pick and straight blade) clearly suggests the common use of the so-called axe with a pick. What we consider to be a very professional approach of the stonemasons is using only one tool in the overall processing of the stone. Sophisticated work and routine led the Prague stonemasons to use an axe with a pick for roughing the block, creating an auxiliary trail and even for the final realignment of the surface.

The standard shaping of a block began with creating a straight, smooth trail at one of the longer edges of the stone block. The stonemason would carve the trail with regular blows of a wooden mallet on a narrow chisel. In the same plane, which the stonemason controlled with a ruler, a perimeter trail was cut at the edge on the shorter side of the block and then on both remaining sides. The perimeter trail on all four edges marked the plane of one of the block's faces. The other faces were worked the same way, while the squareness of the block was measured and monitored using a protractor. A double-pick was often used to finish the base work of the inner surfaces of the stone block. Only to finally realign all the sides of the block into a uniform surface with a characteristic pattern of working marks did the stonemason use a smooth or serrated axe or a smooth, broad or narrower serrated chisel, see Figure 3. More demanding architectural elements or parts were also processed and finished with these tools, but sometimes, these pieces were ground and polished.

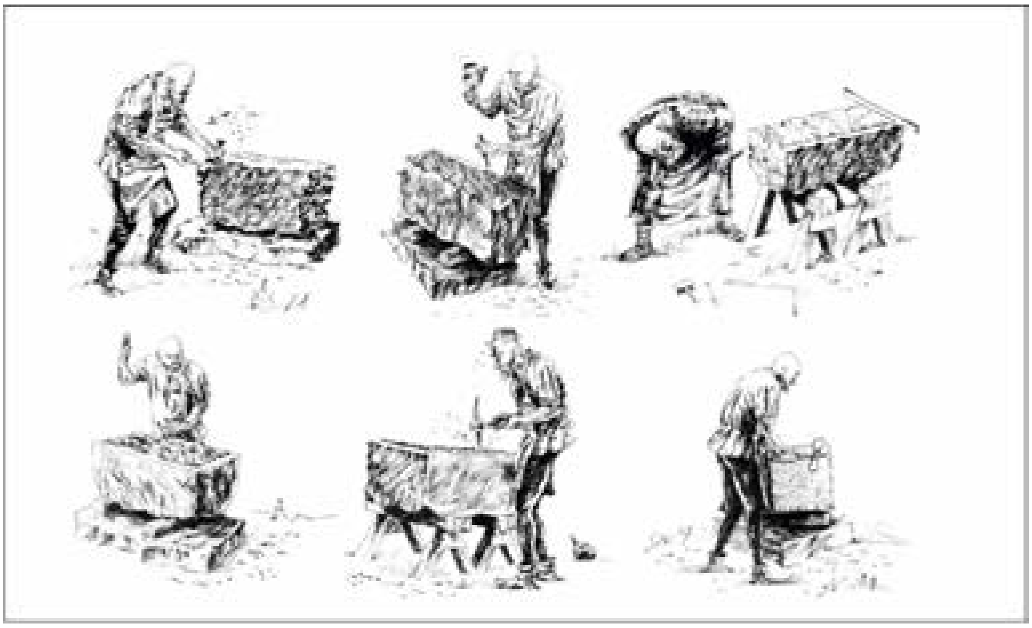

Figure 3. 1 – Edging with a pitcher. 2 – Formation of the perimeter trail. 3 – Inspection of the surface evenness using a ruler. 4, 5 – Removal of excess material using a hand chisel or double-pick. 6 – Realignment of the face with an axe.

In order to compare stonework and craftsmanship in Romanesque Prague, it is necessary to look for unifying elements of craft production at that time. The key elements were the selection of the material and the working process. Romanesque Prague's buildings are made of marlstone opoka, in part because this material was easily available and also extremely practical. It was very well and easily quarried, even divided (split), regardless of the layering. Buildings could then be constructed relatively quickly. Stoneworking was straightforward but also approached with great care, even if it is not apparent at first glance.

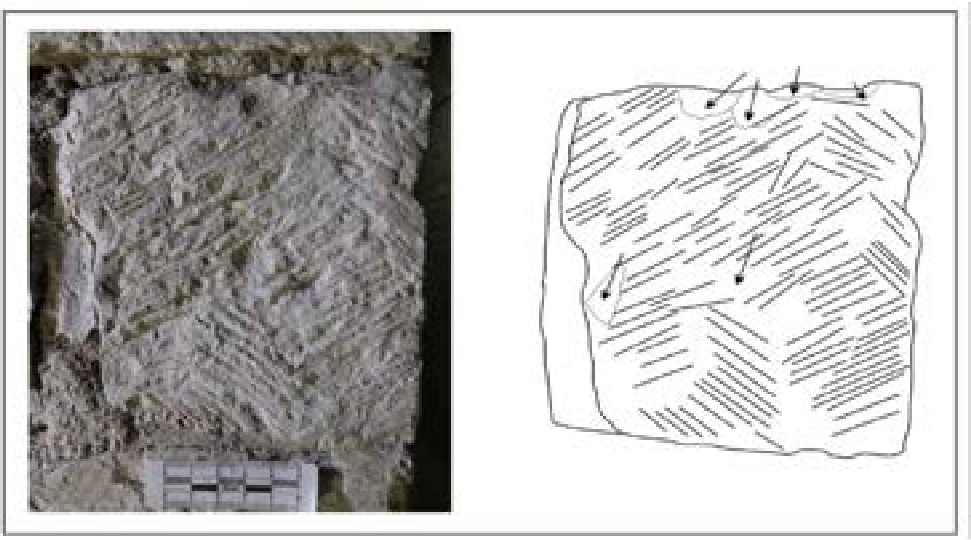

Figure 4. Prague Castle, third courtyard, Church of St Bartholomew, ½ of the 12th century (Maříková Kubková, J. et al., 2019, 104). Diagonal graphic pattern during the processing of the face. (M. Cihla) This style was gradually manifested in the buildings of St George's Basilica and, for example, in the construction of the Black Tower at Prague Castle. Both buildings, begun in the 1240s, adopted this style.

The development in the stone working process can be felt as early as the 10th century when efforts began to be made to smooth the face surface from unwanted protrusions. We can witness such work, for example, in the stone wall of the oldest fortification of Prague Castle. Although the face shows no traces of working, the bedding surfaces have been carefully edged with a pointed handle tool. However, very soon, a particular style emerged in the area of Prague Castle, involving a systematic approach to treating the face. For example, this style can be observed in the relics of St. Bartholomew's Church, now located under the third courtyard. Figure 4 shows the working system in the final processing of the face, whereby a straight-bladed axe was used to realign the surfaces from the corners towards the centre gradually. The stone's position also characterises the work method presented in the same Figure during working. Its face is fixed horizontally, and an axe with a straight blade cuts the surface at a 45° angle or sometimes even at a perpendicular angle. The same work style was applied, for example, in the construction of the Strahov monastery. It mostly concerns, however, the peripheral masonry. This treatment of the face, which we may call the diagonally central graphic pattern, accompanies the treatment of Romanesque buildings throughout their construction.

Another type of processing used in the Prague area is using an axe with a straight blade but with the face tilted so that the stonecutter does not cut perpendicularly but at a slight angle. As a result, the notches are wider. In many cases, the trail is even retained, which was not observed in the previous years. The trail was usually cut across in the final face treatment. A typical example is the Basilica of St. George, where these treatment methods are present, see Figure 5. The realignment of the final surface is done between two trails, either in diagonal or radial rows. In Romanesque houses, this style is prevalent in forming corner blocks, openings and niches, where the trails are usually preserved (at least two of the entire perimeter of the block).

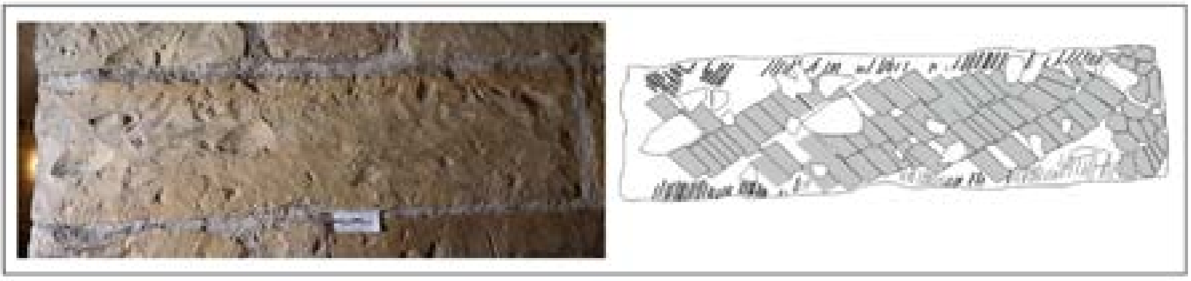

Figure 5. Prague Castle, Basilica of St. George, SE corner of the north arcade wall of the main nave, after 1142 AD. A neat trail cut by the edge of an axe diagonally in rows. Wide notches indicate mutual inclination of block and axe, less than 45°. (M. Cihla)

The third method, identified in Romanesque houses, has its predecessor again in the area of Prague Castle, in the Church of St. Bartholomew, see Figure 6. However, it concerns the corner reinforcement and a different material, in this case, sandstone of larger dimensions than the opoka block. The face is predefined with a regular trail using a chisel. Later, the face was realigned again with a chisel in parallel rows, even over the side trails. Such a method is not so common but also occurs in the corner reinforcement of the palettes and openings of Romanesque houses.

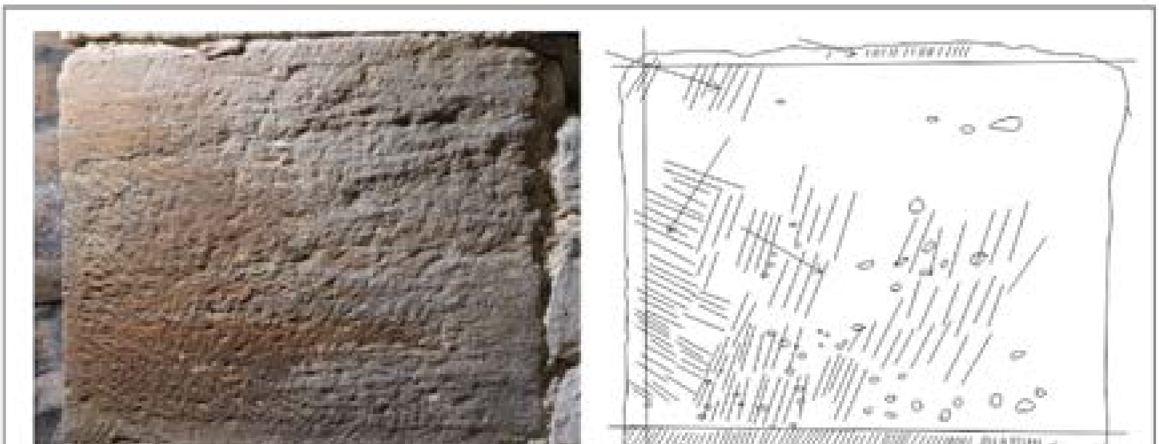

Figure 6. Prague Castle, Church of St Bartholomew, SE corner reinforcement, 11th century. A neat chisel-worked trail. The face itself was carefully realigned with a chisel in parallel rows. (M. Cihla)

All the methods mentioned above of surface working are more than typical and accompany the entire construction activity in the 11th and 12th centuries, not only in Romanesque houses but in all types of Romanesque buildings we have documented. It all originated at Prague Castle, and gradually, most Prague stonemasons acquired and retained this knowledge for an extended period. The uniform style of work thus cultivated evokes the idea of an artisan stone workshop, school, or smithy that educated stonemasons. These stonemasons were then hired for most of the buildings in Prague. Although new craft impulses came to Prague at that time, they never became dominant over the gradually established shape of Prague stone art.

An example is the construction of Strahov Monastery, initiated in the 1240s. In terms of stonework, foreign influences are identifiable in this construction. They are manifested both by the face processing and tools that have not been used before. Interestingly, these exceptions mostly apply to features such as niche lintels, reinforcement, or more sophisticated capped columns. The perimeter masonry is worked exclusively by the well-known Prague technique. The faces are characterised by a wide trail and careful parallel working with an axe or adze. Among the tools identified as a foreign influence is the so-called polka, which is typically double-bladed – one blade is axe-like and the other transverse, adze-like. Another foreign tool typically contained teeth and was innovative for its time. The tool was used quite often in the west of the Czech territory but not in Prague and with the departure of the stonemason from Strahov. Although serrated tools did not take root in Prague in the 11th and 12th centuries, their time came with the construction company's arrival and the Agnes Monastery's building in the 1330s. The revolutionary use of serrated tools influenced the Prague stonework for the entire 13th and 14th centuries. Nonetheless, the first described style of work, the so-called diagonal-centred graphic pattern, also appears, e.g., in the Romanesque castle in Roudnice, i.e., in the 1280s.

5. Conclusion

In summary, the knowledge system of tools' traces continuously expands through new data acquisition during construction surveys and will become a self-contained source of knowledge and research. The accumulated knowledge enables the search for new contexts and patterns in developing stonemason crafts and construction methods of a long historical period and an extensive construction area of Prague. In the Romanesque times, the most basic stone tool was the handle tool. This is in contrast to contemporary stonemasonry, where a hand and wide chisel perform the most critical role in the realignment of the.

The most widespread way of stone face treatment was the diagonally central graphic pattern, accompanying the treatment of Romanesque buildings throughout their construction. Another type of processing used in the Prague area is using an axe with a straight blade but with the face tilted so that the stonecutter does not cut perpendicularly but at a slight angle. The third method, which was identified in Romanesque houses, is the use of a chisel. The other surface processing methods are very rare.

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Conflict of Interests

The author declares no potential conflict of interest was reported by the author.

Endnotes

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