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Building a Capital: New Evidence for Construction Techniques in Petra

Introduction

Approaching ancient building processes has always been associated with difficulties.[1] Usually, ancient buildings are preserved only as ruins and associated construction processes are no longer traceable. Therefore, one must search for small traces which provide evidence for certain construction processes, like construction lines, mason marks, or tool marks on single architectural blocks. In Petra, only the Qaṣr al-Bint (Zayadine *et al.* 2003) is preserved to such an extent that information on the construction of the building itself can be obtained from the extant remains. All other structures investigated so far could only be documented in their much more ruinous condition. Walls are only preserved up to a relatively low height, so that further information on the uprising wall structure, doorways and entrances, further storys, and the upper end of the buildings with entablature and roof can only be obtained from the collapsed building components. Investigations on the large buildings in the city center, not only the Qaṣr al-Bint but also the Great Temple (Joukowsky 1998; 2007; 2017a), the Temple of the Winged Lions (Hammond 1996) as well as the Nabataean-Roman villas on az-Zanṭūr (Bignasca 1996; Schmid and Kolb 2000; Kolb 2007; 2012) have provided a lot of information about

[1] In the course of the research on Nabataean capitals for my dissertation project 'Architecture and Architectural Decoration in Petra (Jordan)—Studies on the freestanding Nabataean architecture and their models', more than 250 capitals in and around Petra were examined in detail. Special credit goes to the North-Eastern Petra Project and its directors, for giving me the opportunity to conduct the study on this topic, and the American Center of Oriental Research (ACOR; now the American Center of Research) which gave me the permission to study the capitals of the Temple of the Winged Lions and to use them for comparison. All measurements used here, as far as they are not provided with an additional reference, originate from this research.

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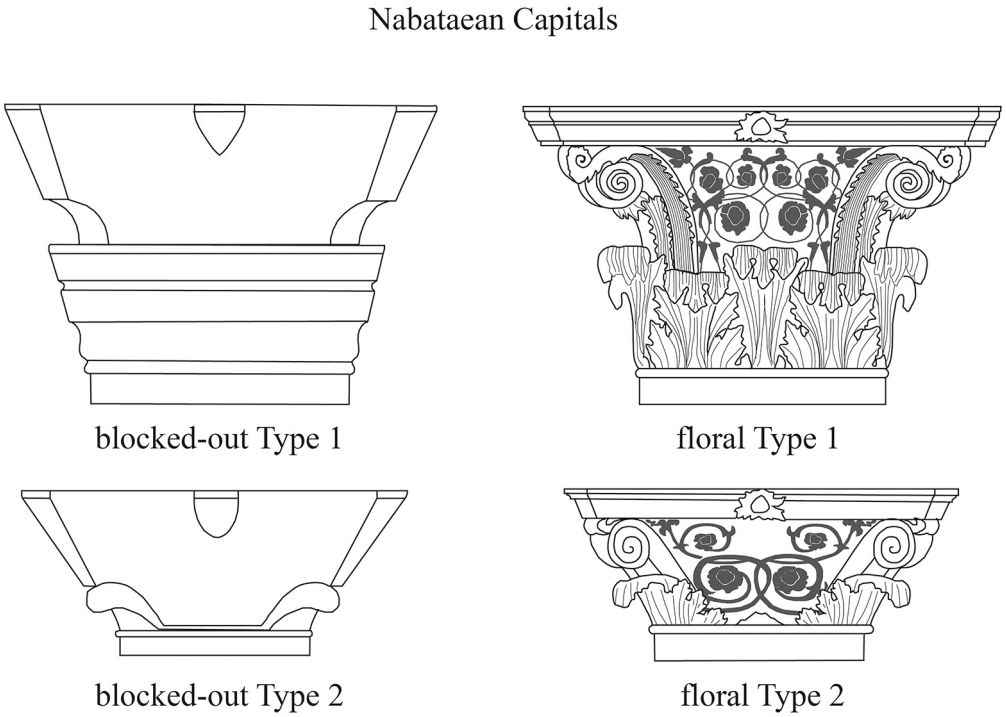


1. Nabataean blocked-out and floral capitals (by M. Dehner).

the construction of walls, floors, and the general layout of individual buildings. Furthermore, the investigations led to the identification of the Egyptian long cubit as the main unit of measurements which was used, at least, for the construction of the Qaṣr al-Bint (Zayadine *et al.* 2003: 77–80). This hypothesis has not been confirmed on other buildings yet. A comprehensive study on construction techniques in Petra was presented by Rababeh (2005) who gave an overlook mainly on the construction of columns, walls, floors, and roofs as well as the building material and quarries it was obtained from. A study of the quarrying work, material, and tools and the work carried out by the stonemasons in Petra is provided by Bessac (2007).

As mentioned above, the analysis of individual structural elements in particular provides indications of certain construction techniques. The following study is based on observations on capitals located in the area of the North-Eastern Petra Project, subsequently referred to as the NEPP, and the Temple of the Winged Lions, which have also been confirmed on other capitals in Petra. The Nabataean capital of Type 1 (Fig. 1) will be examined more closely, especially marks on them which can be interpreted as construction lines. The evaluation of the findings, in turn, makes it possible to shed more light on general developments concerning construction processes in Petra and to underscore the dependence on the construction material.

The Nabataean Capital in Petra

The Nabataean capital, in its blocked-out version as well as the sculpted floral one, has a unique appearance. As several scholars have already pointed out, the two different forms are interrelated (McKenzie 1990: 116; Patrich 1996: 203–7; Netzer

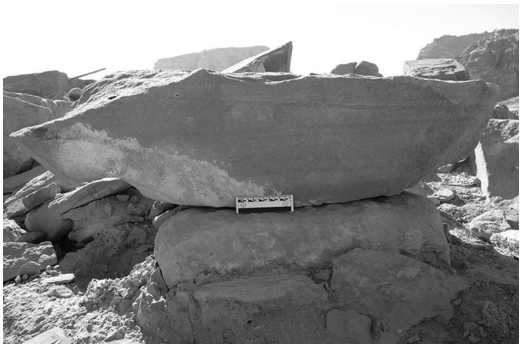
2003: 162; Grawehr 2017: 105). The blocked-out version is to be seen here as a simplified form of the floral one, whereas the floral Nabataean capital in its principal appearance is related to the Corinthian capital (Ronczewski 1932; Schlumberger 1933). Both capital forms were an integral part of the architectural decoration of freestanding buildings (Dehner 2020). At least three different types of Nabataean capitals can be identified (McKenzie 1990: 190; Patrich 1996: 197–200).

Both capital forms appear to be made of roughly the same dimensions with a lower diameter varying between 0.62 to 0.70 m. This can be seen in the examples of blocked-out capitals from the Roman Theater (Hammond 1965: 45), in the city's 'Central Area' (Parr 1957: 10–1), and in Structure 2 of the NEPP (Schmid *et al.* 2012: 91–3; Fiema *et al.* 2016: 750–2; Dehner 2020) as well as the floral Nabataean capital with examples in the Dionysian Hall (Bikai *et al.* 2008: 480–2 figs. 14, 16), on az-Zanṭūr IV (Kolb *et al.* 1999: 265) and in the Bâtiment B (Fournet 2017: 48 fig. B.10). Also, findings in Bâtiment B (Fournet 2017: 46–9 figs. 3, 5) and in the Nabataean/Roman Villa az-Zanṭūr IV (Kolb and Keller 2000: 358) prove the use of both forms in the same building. In terms of size, the capitals of the monumental temples in the city center were an exception. Especially on the entrances and building façades, floral capitals of much bigger dimensions were used regularly, as can be seen on the Qaṣr al-Bint (Zayadine *et al.* 2003: 160–1 figs. 26–27), the Great Temple (Hussein 2017: 123–6; Schluntz 1998: 226), and the Temple of the Winged Lions (Kanellopoulos 2004: 228).

Construction of the Nabataean Capital

The two capital forms do not only show similarities in their dimensions, but also in their general construction. Based on findings in Structure 2 of the NEPP area, the group of Nabataean blocked-out capitals was examined in more detail (Dehner 2020). The evidence shows a large number of half-capitals representing the upper segment of a Nabataean blocked-out capital of Type 1 with a height of 0.30 to 0.32 m (Fig. 2). In addition, there are several fragments of the lower segment with a lower diameter of 0.62 to 0.68 m (Fig. 3) which, however, consists of a complete drum with the outer faces being decorated with a sequence of moldings. The finds indicate that these capitals were composed by combining separately worked upper and lower elements of about the same height to form a single capital. Additionally, examples of a smaller capital order with a lower diameter of 0.25 to 0.30 m (Fig. 4), this time made out of one block, proves the use of blocked-out Type 1 capitals in more than one area of the same building. The upper and lower segments show the same height in both the smaller and larger capitals. All capitals in the NEPP area were made of sandstone.

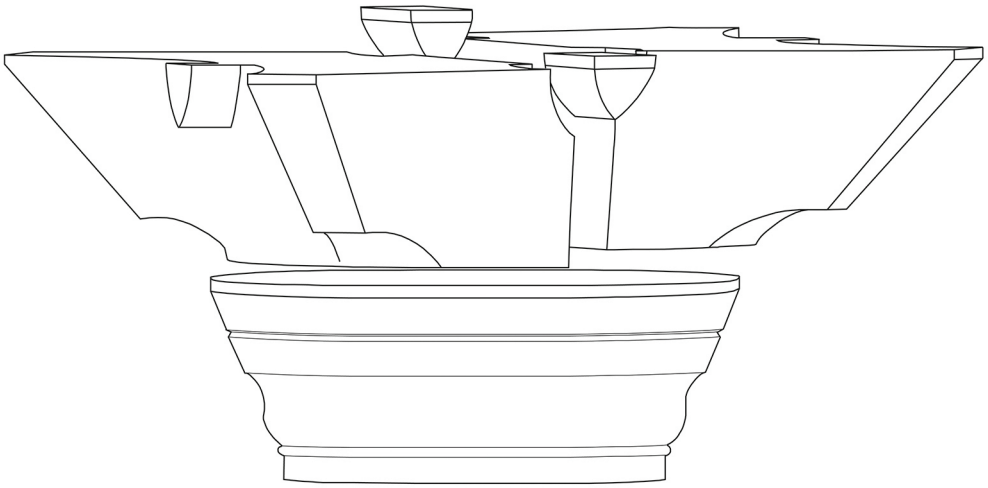
Looking at other examples of Nabataean capitals of freestanding buildings in the city center, it becomes apparent that this is not a singular phenomenon which is specific for the buildings in the NEPP area. Moreover, all examples of blocked-out and floral Type 1 capitals, once they reach a certain size, show a subdivision into separately carved upper and lower elements of about the same height. Additionally, the upper elements were always worked as half-capitals, which were placed back to back on the lower segment (Fig. 5). In addition to the NEPP area, this construction technique has also been observed for capitals in the Roman Theater (Hammond 1965: 45), in the Temple of the Winged Lions (Hammond 1977: 47), and the Dionysian Hall in al-Bayḍā (Bikai *et al.* 2008: 496). The examination of the capitals in recent years has shown that this construction technique was applied equally to all Type 1 capitals that had a lower diameter of at least 0.60 m.



2. Nabataean blocked-out half-capital of upper segment from NEPP area Structure 2 (by M. Dehner).

3. Nabataean blocked-out capital lower segment from NEPP area Structure 2 (by M. Dehner).

4. Nabataen blocked-out half-capital of smaller order from NEPP area Structure 2 (by M. Dehner).



5. Construction of a Nabataean blocked-out capital of Type 1 (by M. Dehner).

Construction Lines on Nabataean Capitals

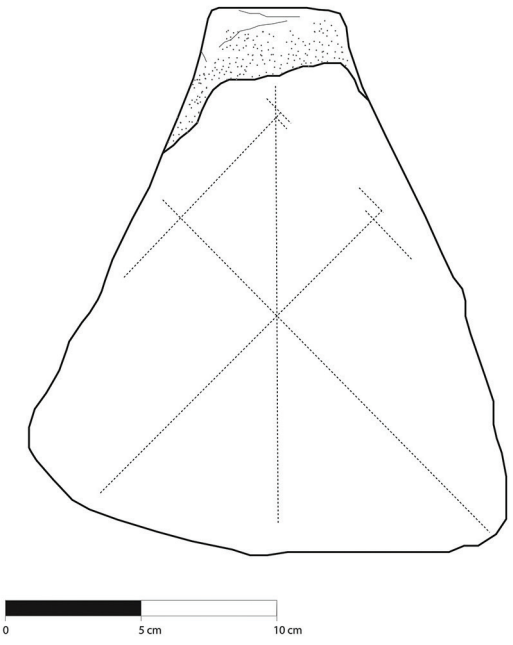
In addition to their size and construction mode, these capitals had another feature in common. Several examples of the upper segments show clearly recognizable, incised rectangular lines on their respective top surfaces and partly also on the bottom ones, which can be understood as supporting lines for capital production.

During the investigation of capitals in Structure 2 of the NEPP, fine lines were observed on the surface of different sandstone capitals (Fig. 6) showing regular intersecting lines at 45° and 90° angles to each other. These finds are mainly representatives of smaller capitals of an interior order of that building. The state of preservation of most capitals of larger dimensions in Structure 2 unfortunately does not allow further examples to be found, as their surfaces are too heavily eroded. Corrections of these lines can also be seen indicating a rather high degree of geometrical accuracy.

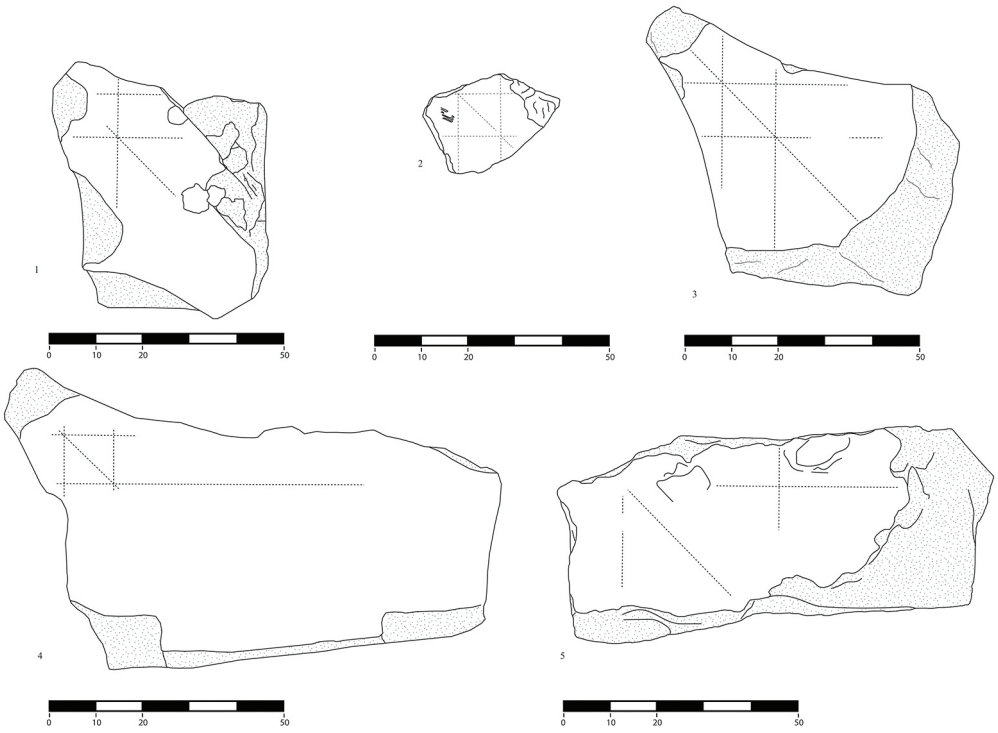
Comprehensive evidence of incised lines on capital surfaces can be found on examples at the Temple of the Winged Lions. While the aforementioned examples have only been blocked-out capitals, the temple area sees several limestone capitals or fragments of floral Type 1 capitals as well as several blocked-out sandstone capitals of Type 1 which show similar incised lines on the upper surfaces (Fig. 7). In some cases, such lines are also visible on the bottom surfaces. The half-capitals have a height between 0.32–0.35 m. They belong to capitals which, in total, have a height of 0.65 to 0.70 m with a lower diameter of the same dimensions. Several lower segments of blocked-out and floral capitals are preserved here. While representatives of both capital forms are gathered in the vicinity of the Temple of the Winged Lions, it is not clear whether they originally came from the same building. Nevertheless, both have the same dimensions and show similar traces of supporting lines on their respective surfaces.

Another half-capital of a Type 1 Nabataean capital on the Katūt Hill again shows the same incised lines on both the top and bottom (Fig. 8). The construction supporting lines on this capital constitute the best preserved example in Petra so far. This half-capital has a height of 0.32 m and belongs to a capital which must have crowned a column drum with a diameter of 0.60 to 0.70 m.

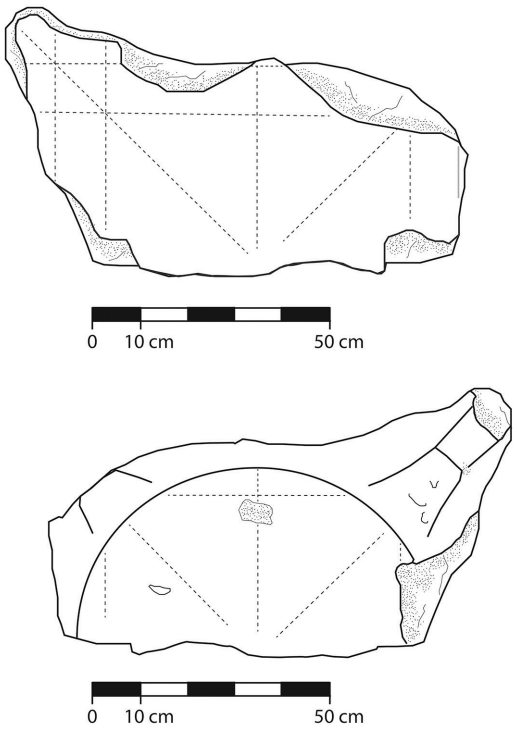
Such incised lines on capitals were further observed on the top surfaces of several capitals in the Dionysian Hall (Bikai *et al.* 2008: 480 fig. 14, 497–498 cat. no. 9). They remain preserved on capitals of a larger order with diameters of 0.64 m and a smaller order of about 0.30 m. Here, the high degree of geometrical accuracy



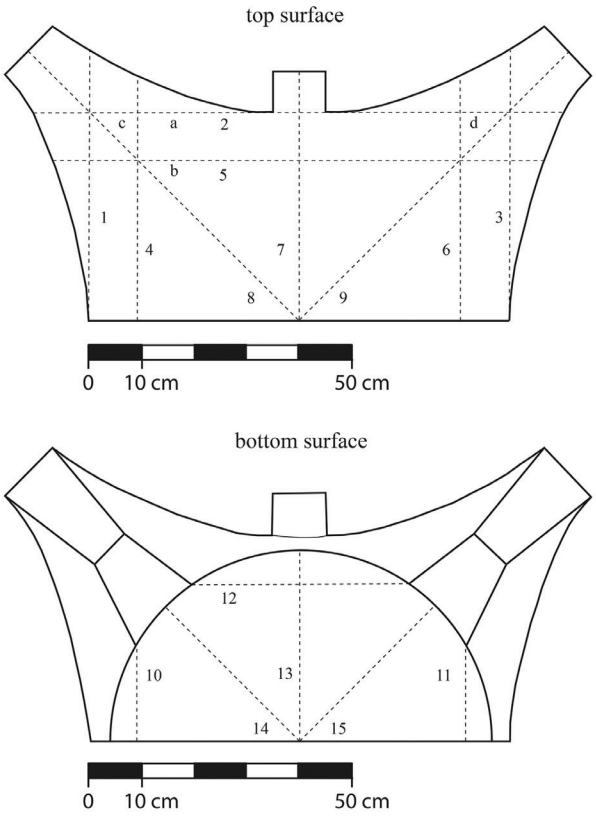
6. Supporting lines on an abacus fragment from the NEPP area (by M. Dehner).



7. Supporting lines on upper surfaces of Nabataean blocked-out capital from the TWL area (No. 1, 3, 4–5) and in the NEPP area (No. 2)



8. Supporting lines on a Nabataean blocked-out capital from the Katūt Hill (by M. Dehner).



9. Schematic illustration of construction lines on Nabataean capitals' top and bottom surfaces (by M. Dehner).

is underlined by the fact that the intervals between the lines on the smaller capitals are exactly half of those of corresponding lines on the larger capitals. Further examples on az-Zanṭūr,[2] in the gallery in front of the Nazzāl Camp, and other places in the city center that were registered during the examination of all capitals in the city center prove that the use of such supporting lines was quite common in capital production in Petra.

The lines on those capitals that show them on their top surfaces are fine, orthogonal lines (1–9 on Fig. 9) of 1–3 mm width and form two rectangles, a larger (a) and a smaller one (b) inside the first, as well as two small squares (c, d). Diagonal lines bisect each rectangle (7, 8) and run towards the center of the abacus corners. In most examples, an additional line marks a vertical axis through the middle of the block (9), cutting the rectangles in half. This line corresponds to the radius of the capital at the point where it intersects with the larger rectangle. It continues to the edge of the block, where it marks the center and probably also the length of the abacus flower. The bottom end of this last line is where the two diagonal lines (7, 8) meet. On various capitals, corrections of the lines can be seen. The distance between lines 1 and 3, the shorter sides of the larger rectangle (a), appears to indicate the width or upper diameter of the capital. Towards the front of the abacus, there goes a connecting line (2) between the two lines on the short sides of the half-capital (1, 3). The larger rectangle also indicates the point up to

[2] M. Grawehr shared a drawing of a capital with such incised lines from az-Zanṭūr IV which also shows several adjustments on the top surface. U. Bellwald confirmed the observations on az-Zanṭūr as well.

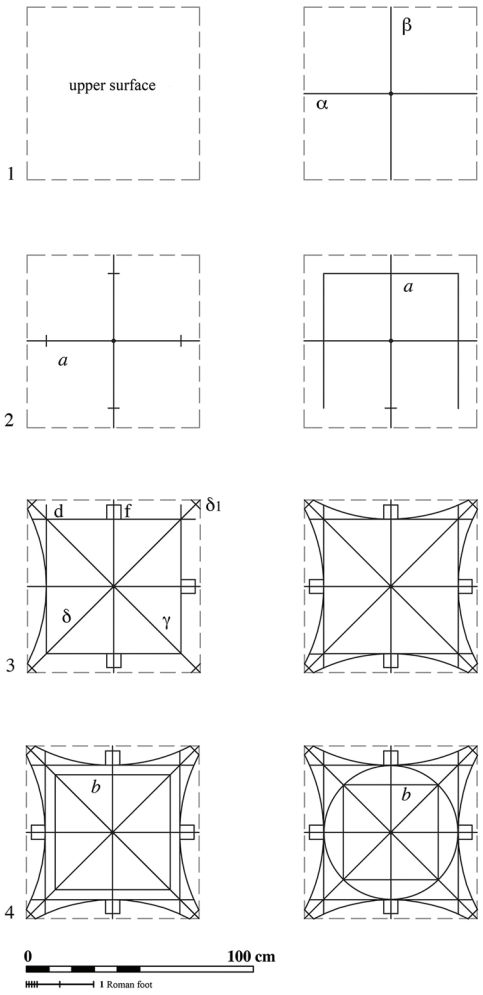
which the concave curvature of the abacus was going to be executed. After crossing each other, the lines (1–3) continue until they reach the edges of the block. Another three lines (4–6), which run parallel to the respective lines of the larger rectangle, form a second, smaller rectangle (b). As with the larger one, the lines of the smaller rectangle continue to the end of the block. Thus, two small squares (c, d) are formed between the corners of rectangle a and b. The two diagonal lines (7, 8) that cross the intersections of both the smaller and larger rectangle on each side, and by that cut the squares (c, d) in half, seem to indicate the length of the abacus corners.

While the larger rectangle seems to define the limits of the concave part of the abacus, an explanation for the use of the smaller rectangle is not immediately apparent. The distance between the shorter sides of the smaller rectangle does not correspond to the lower diameter of the upper segment, as one would expect. However, it is apparent that the lines of the smaller rectangle correspond to the ones on the bottom surface (10–13) of the same block, which so far were found preserved only in three findings of blocked-out capitals. The incised lines on the bottom surface run parallel to each other on the short sides (10, 11). Another one (12) runs orthogonally to those last ones, parallel to the backside. This line again creates a kind of rectangle, even though the intersection of the lines is not visible anymore in any of the three examples. Each of these lines ends at the base of the volutes. A central line (13) marks the central axis as well as the lower radius of the block. With regards to its use, the smaller rectangle appears to be an indicator of the diameter of the corresponding column and the lower diameter of the capital's lower segment.

Construction Lines on Corinthian Capitals in the Mediterranean World

Capitals with incised supporting lines are not a new observation and they are not unique to Petra. In fact, they are known from various places throughout the Greek and Roman Mediterranean world (Toma 2015: 812 n. 7) and always show a similar layout as the examples in Petra. All around the Mediterranean Sea from Italica in Spain (Ahrens 2005: 116–7 pl. 101) to Priene in Turkey, Sabratha and Leptis Magna in Libya (Toma 2015: 812–5, figs. 2, 4, 6), or Dionysias in Egypt (Pensabene 1993: 236–7), incised lines can be found—especially on Corinthian capitals. In contrast to the examples in Petra, most of the Corinthian capitals were produced out of one block. The capitals from Dionysias, on the other hand, are made of limestone and consist of two separate segments. While the construction of the capitals is different from that at Petra, the layout of the incised lines on the surfaces is very similar for all of them.

N. Toma (2014; 2015) has discussed the purpose of such lines, which she defined as construction lines, on marble capitals in more detail. She has outlined the possible process of applying these lines to the stone block as follows (2015: 814–15): In a first step, two orthogonal lines (α, β on Fig. 10) were incised on the upper surface of the stone to determine the center of the block, followed by the second step, during which the capital's height was projected by marking it on the orthogonal axis, resulting in a square (a) with the center of the block in the middle. In theory, the height of the capital should equal the axial width of the abacus. This characteristic is known as the 'cross-section rule', which according to Wilson Jones applies to two thirds of all Corinthian capitals (Wilson Jones 2000: 145). After that second step, the concave shape of the abacus was outlined and the diagonal width of the abacus was marked (γ, δ). The square (a) created in the previous step indicates the diameter and at the same time the lowest point of the concave curvature of the abacus. The corners of the abacus are



10. Proposed incision sequence of construction lines on Corinthian capitals (Toma 2015: 817 fig. 8).

projecting from the corners of the square (a). Additionally, the dimensions of the projecting abacus flower (f) were marked during this step. In a last step, a second smaller square (b) is created to show the diameter of the capital's bottom side and thus the diameter of the column it would be placed on.

According to Toma, the construction lines bundled the dimensions for carving the abacus and the lower diameter but gave no hint for the proportion of the elevation of the capital (2015: 816), which had to be communicated in another way. The incised lines would be applied on a roughly dressed quarry block with a fine iron point, while it was inclined on one of its sides with the upper surface facing the craftsman. This way, it would have been relatively easy for the craftsman to apply the lines on the upper surface that was facing him (2014: 89–90; 2015: 816). After projecting the center of the top surface onto the bottom one on the same vertical axis, possibly by an incision on one of the side surfaces of the block (Wilson Jones 1991: 116 fig. 15 iii; Toma 2015: 816), the actual processing of the capital started with the bottom part, for which the block was turned over onto its top. The two rows of acanthus leaves were roughly carved before the capital was turned over again and the shape of the abacus and the decoration of the upper part were roughly formed to obtain a half-fabricate. To continue with the detailed processing of the decorative elements the block was turned onto its top again in order to carve the acanthus leaves properly, followed by the decoration of the upper part. In her description, Toma follows the general procedure already described by Asgari in the course of his work in the quarries of Proconnesus (1988: 115–6 fig. 1). Although such construction lines have been preserved only on a limited number of capitals, which is probably owed to weathering and the final surface smoothing of the stones, they were originally applied to all capitals and were not limited to one prototype (Toma 2015: 816).

Although the construction lines of the capitals in Petra display a lot of similarities, it can be assumed that the production process differed due to the construction technique of working the upper and lower segments of capitals separately. Before a proposal for the production methods of a capital is made, it is necessary to have a

look at the available stone material in Petra and the quarrying technique for obtaining it. These two factors inevitably determine the construction technique and the carving process of the individual segments.

The Influence of the Quarrying Work on Specific Building Elements in Petra

Ancient building activities always depended on the locally available materials. Rababeh (2005: 31) and Bessac (2007: 36) have clearly emphasized this fact in their studies on Nabataean construction and stonecutting techniques. In Petra, this means that mostly the locally available sandstone was used for the construction of the freestanding buildings (Rababeh 2005: 37; Bessac 2007: 33–4). In addition, limestone originating from the area of the modern town of Wādī Mūsā (Rababeh 2005: 40) was used for several building elements, such as the floral Nabataean capitals (Hammond 1996; Schluntz 1998: 226; Hussein 2017: 123; Rababeh 2017: 46–7), some bases, and for pavement slabs (Rababeh 2005: 39). But compared to sandstone, which was used for wall stones, column drums, entablature elements, and also blocked-out Nabataean capitals, the use of limestone was rare. Thus, the building material and especially the extraction methods in the quarry determined the possibilities of stonecutting and production of individual building elements, which means that monumental architectural blocks or building elements are rarely found in Petra.

The size of a rectangular block, which was how stone was usually extracted from the quarry, is given at an average dimension of about 1.50×2.00×0.60 m, rarely larger (Rababeh 2005: 62, 77). This block then determines the size of the building elements that can be produced from it. Considering that this is a raw stone that also needs to be processed, it quickly becomes clear that the production of monumental building elements was hardly possible from the above mentioned dimensions of a single block.

Due to the quarrying methods, a maximum size for individual building units is therefore inevitable. At the Qaṣr al-Bint and the Temple of the Winged Lions, this means that decorative elements, such as metopes and triglyphs of the frieze and monumental cornices above them, were constructed from several different blocks (Hammond 1996: pls. 16, 18; Zayadine *et al.* 2003: 17–8, 51, 162–4 pl. 28–30). In general, no monolith columns were used in Petra. The monumental column drums of the Qaṣr al-Bint's pronaos with a diameter of 2.00 m and a height of sometimes more than 1.20 m are the absolute exception (Zayadine *et al.* 2003: 18, 135–6; Kanellopoulos 2004: 236). The rational and commonly used solution for the construction of monumental columns was realized by producing flat column discs that were much larger in width than in height, as featured at the Great Temple (Rababeh 2005: 126; 2017: 59) and the Temple of the Winged Lions (Hammond 1996: 48). Also, regular columns were constructed using column drums, which had varying heights between 0.20 and 0.60 cm, regardless of the diameter of the column. The common diameters of columns used in all other buildings were between 0.60 and 0.75 m. The average size of an ashlar was 0.40 to 0.60 m in height, with a width of 0.30 to 0.40 m and a varying length of 0.30 to 1.00 m (Rababeh 2005: 113). These dimensions were the same everywhere, whether the stone was cut for a temple building or a mansion or regular house in Petra.

Yet, not only the size of common ashlars, column drums, frieze and cornice elements, or parts of the entablature, also the construction of the Nabataean blocked-out and floral capital, as shown above, was affected by the limiting parameters set by the stone material and the quarrying. Given the average dimension of a quarry block, the splitting of a capital into an upper and a lower segment is almost inevitable if the final

result is to surpass a lower diameter of 0.50 m. Considering that the height of the capital usually corresponds more or less with the diameter of the column, and also taking into account the lateral length of the abacus, which is about 35% bigger than the diameter, it becomes obvious that constructing a capital larger than 0.70×0.50×0.50 m out of a regular rectangular block from the quarry would have been difficult. The common diameter of most capitals in the city center ranges from 0.62 to 0.70 m, as mentioned above. The height also varies within the same dimensions. With a lateral abacus length of 1.05 to 1.15 m and an adding stone mass that is lost during the cutting process, it becomes clear that capitals of a certain diameter were produced in at least two segments, an upper and lower one. If the capital had a larger diameter than 0.60 m, the upper part was additionally produced as two half-capitals (see Fig. 5). Instead of one full upper part, three or more likely four standardized half-capitals, whether blocked-out or floral, were obtained from a 2.00×1.50×0.60 m rectangular, raw block.

The standardized manufacturing process was not limited to sandstone quarries. The equal dimensions of sandstone capitals from Structure 2 in the NEPP area and limestone capitals in the Temple of the Winged Lions or the Dionysian Hall indicate that the quarrying procedures in the limestone quarries were the same as in the sandstone quarries. Also, the incised lines and the general construction of a capital from three single elements show that the floral Nabataean Type 1 capitals were produced in the same way as the blocked-out ones. Therefore, the Nabataeans seem to have used the same quarrying methods in limestone quarries as in the sandstone quarries, even though the former would have allowed the production of capitals from one single block due to its different material quality. Even so, the Nabataean craftsmen intentionally decided to produce capitals from harder material in the same way as the sandstone ones. This becomes particularly evident when looking at the floral Nabataean Type 1 limestone capitals of the peristyle building in the so-called Great Temple. With basic measurements of 1.50×1.50×2.00 m (Hussein 2017: 125), these have monumental dimensions. Consequently, they are constructed of six individual elements: the lower segment is divided into two parts and the upper segment into four parts. Thus, the size of an individual block is reduced to such an extent that the craftsmen can work with familiar block sizes despite the ultimately monumental dimensions.

Interestingly, the aforementioned "cross-section rule", which relates the axial width of the abacus to the height of the final capital, does not apply in Petra. Various capitals in the NEPP and the Temple of the Winged Lions with a combined height of the lower and upper segments of 0.64 to 0.70 m and a lower diameter between 0.62 and 0.70 m usually have an abacus diameter of 0.80 and 0.84 m. As it seems, it is rather the column diameter which corresponds to the height of the capital. Thus, the upper diameter of a capital is about 30% larger than the column diameter. The same can be said about the monumental capitals of the so-called Great Temple. As a result, the Nabatean capital Type 1 appears more compact and heavier than the Corinthian normal capital. The question must remain open whether this is also to be seen as a consequence of the quarrying processes, or rather as an expression of the Nabataean concept of proportion.

Building a Capital

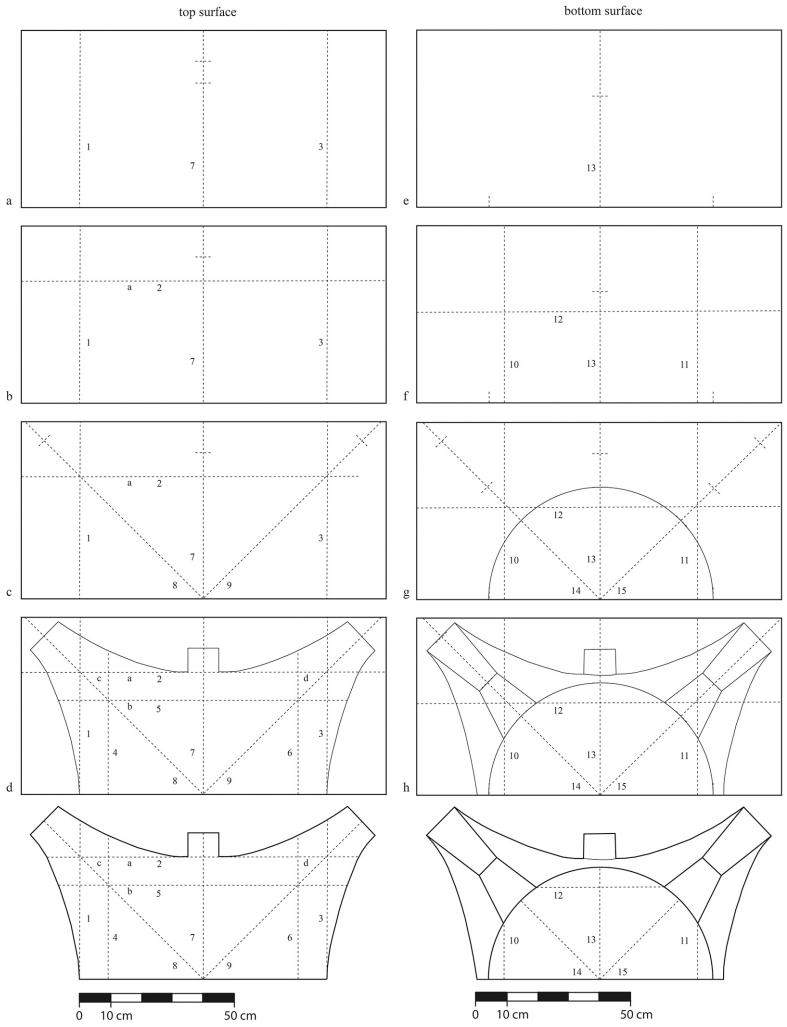
At this point, a brief overview of the entire production process of a Nabataean capital will be given, whereby the production of Corinthian capitals in the Greco-Roman world will be considered in comparison, as Toma has outlined it. As already shown, the first significant difference results from

the building material, at least concerning the blocked-out version of the Nabataean capital which was usually carved out of sandstone. Nevertheless, the construction lines on the top surface follow the same geometrical principles as Toma has shown for capital production in the Mediterranean world, whose capitals were usually cut from a single block. It is obvious that the Nabataean craftsmen adopted the system used by stonemasons in other places, yet adapted it to the requirements of their own local sandstone. The general height of one half-capital of the upper segment in Petra is 0.32 to 0.35 m, with a depth of 0.35 to 0.40 m and a lateral width of the abacus of 1.05 to 1.15 m. Since the lower and upper segments of the capitals have roughly the same height, the composite height of a complete capital would be 0.64 to 0.70 m.

After the stone block was extracted from the quarry in its rectangular raw shape, it was divided into three or four blocks, each roughly the size of an upper segment. The lower segments with a size of 0.90×0.90×0.32 m were made from another block. In order to avoid great loss of material, the block could have been cut smaller from the quarry already to begin with. Both upper and lower segment needed to be reduced in weight as much as possible to give them the approximate dimensions of the final product. Whether the capitals were then processed in the quarry, in a central workshop in the city, or directly at the construction site cannot be said. The next step in the production of an upper segment was most probably determining the height. In contrast to the production of a capital from a single block, it was not possible to define the overall dimensions of the whole capital directly on the block. Therefore, it was necessary to have fixed guidelines for the overall dimensions of the specific capital elements regarding height, length, and depth. After determining the height, the backside of the capital was straightened, followed by the smoothing of the top and bottom surfaces to prepare them for the application of the construction lines. These two steps may as well have been reversed. The incised lines were then applied to the top surface using a type of drawing nail or iron point. This step resembles the common practice in other places. The size of the blocks would have made it necessary that they were lying on their bottom side and raised on substructures to make them more accessible as the construction lines were applied.

The central axis of the abacus was defined by the backside of the block, the later half-capital. Thereon, the width of the abacus was marked by lines (Fig. 11a). Those were extended by perpendicular lines (1, 3) running towards the front of the block. From the center of the backside, a third line (7) was marked in a right angle to it which also ran to the front of the block, determining the maximum extension of the abacus flowers. The two outer lines (1, 3) were orthogonally connected by another line (2), defining the radius as well as the deepest part of the concave abacus on the front (Fig. 11b). Once these lines formed a rectangle, two diagonal lines (8, 9) were drawn from the bottom of the central axis, intersecting the corners of the rectangle and defining the diagonal width of the abacus (Fig. 11c). Finally, the curvature of the concave sides of the abacus and the smaller rectangle was established accordingly (Fig. 11d).

In a next step, the block was probably turned onto its backside. This would have made the bottom surface of the block accessible for incising the central axis of the block and determining the lower diameter of the upper segment and radius (Fig. 11e). The projection of the central axis could have been realized by an incision along the front surface. After that, the two vertical lines (10, 11) indicating the column diameter would have been established followed by the



11. Proposed incision sequence of construction lines on Nabataean half-capitals (by M. Dehner).

horizontal line (12) which connects both (Fig. 11f). Once these three lines form a rectangle, again, two diagonal lines (14, 15) could have been drawn from the bottom of the central axis, marking the rough measurements of the volute (Fig. 11g). Whether there was a carved preliminary drawing of the form of the *kalathos*, including the volutes or the shape of the abacus, cannot be said (Fig. 11h). It can be assumed that after all supporting lines were established the rough shape of the abacus was worked first in a concave swing with the lowest point close to the large rectangle on the top surface. Once the shape of the abacus was established, the capital was cut out of the block from bottom to top. Subsequently, the volutes were worked out from bottom to top, using the lines on the bottom surface before the surface on the sides was smoothed or the floral decoration was carved out.

Individual processing stages for the lower segment of the capital cannot be

reconstructed yet. It can be assumed that the processing started with the smoothing of the support surface on the top and the definition of the diameter. It is not unlikely that the column shaft on the bottom side was established in correspondence with the upper diameter. Processing the profile of a blocked-out capital or the acanthus leaves of a floral capital may have been done in the same way as Asgari and Toma have shown for Corinthian capitals in the Mediterranean world. Finally, the two parts of the upper segment were placed back to back on the lower capital element which was placed first on the column.

Conclusion

The procedure for capital production outlined here is the result of observations made on the extraction process in the quarries and the capital finds in Petra. So far, this process can only be generalized for Type 1 capitals. No construction lines have so far been identified on Nabataean capitals of Type 2. Considering the similarity in appearance to the upper part of the Type 1 capitals as well as the fact that Type 2 capitals were mainly used as pilaster capitals and, therefore, were worked as half-capitals, it can be assumed that those were produced in a similar way. Capitals of other types, like the Pseudoionic one and the Elephant-headed capitals in the so-called Great Temple (Dimitrov 2013; Joukowsky 2017b), were special designs and did not reach a height of more than 0.60 m and were consequently carved out of one block. Nabataean capitals of Type 1 and 2, whether blocked-out or floral ones, were the dominant capitals in Petra. The incised supporting lines on the surfaces of the capitals clearly show that the Nabataeans adopted geometrical principles of capital production from other areas. These were transferred and adapted to the needs of the local quarries and the resulting stone processing. The manufacturing process remains roughly the same but varies in detail. The production of a capital with separately worked lower and upper segments also makes it easier to handle the geometrically divergent design of the same than producing a capital from a single block. Both elements can be manufactured as individual parts in serial production. If one considers the wide distribution of capitals of roughly the same dimensions, one can certainly postulate that these were worked in a standardized mass production. The production process is certainly an indicator of this assumption.

However, some questions remain open regarding the proportions of the capital as well as those of the whole column, including base and capital. As it was shown, the "cross section rule" as one of the most common rules of proportion for Corinthian capitals was not adopted from other places of production. Furthermore, there are some difficulties regarding the size of single capital segments which, although very similar in their basic dimensions, show no identical proportions. It would seem that height and width are the only constant measurements, though they still vary by a few centimeters. Whether there was a common standard of measurement or an effective table of proportions cannot be said with certainty on the basis of these findings. When looking at the ancient units of measurement, especially the Egyptian long cubit, which was identified as the unit of measurement at the Qaṣr al-Bint, it is not possible to determine such a unit for a single building element, as these are usually no longer preserved in their original dimensions due to damages, and the original measurements can only be estimated.

Nevertheless, a clear uniform procedure is noticeable and an optimization and standardization of already existing manufacturing processes can be observed both in stone extraction and in the capital production. At the same time, the evidence also shows that the blocked-out capital, also in combination with the floral Nabataean

capital, experienced a much wider distribution in freestanding architecture in Petra than often assumed in the past.

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