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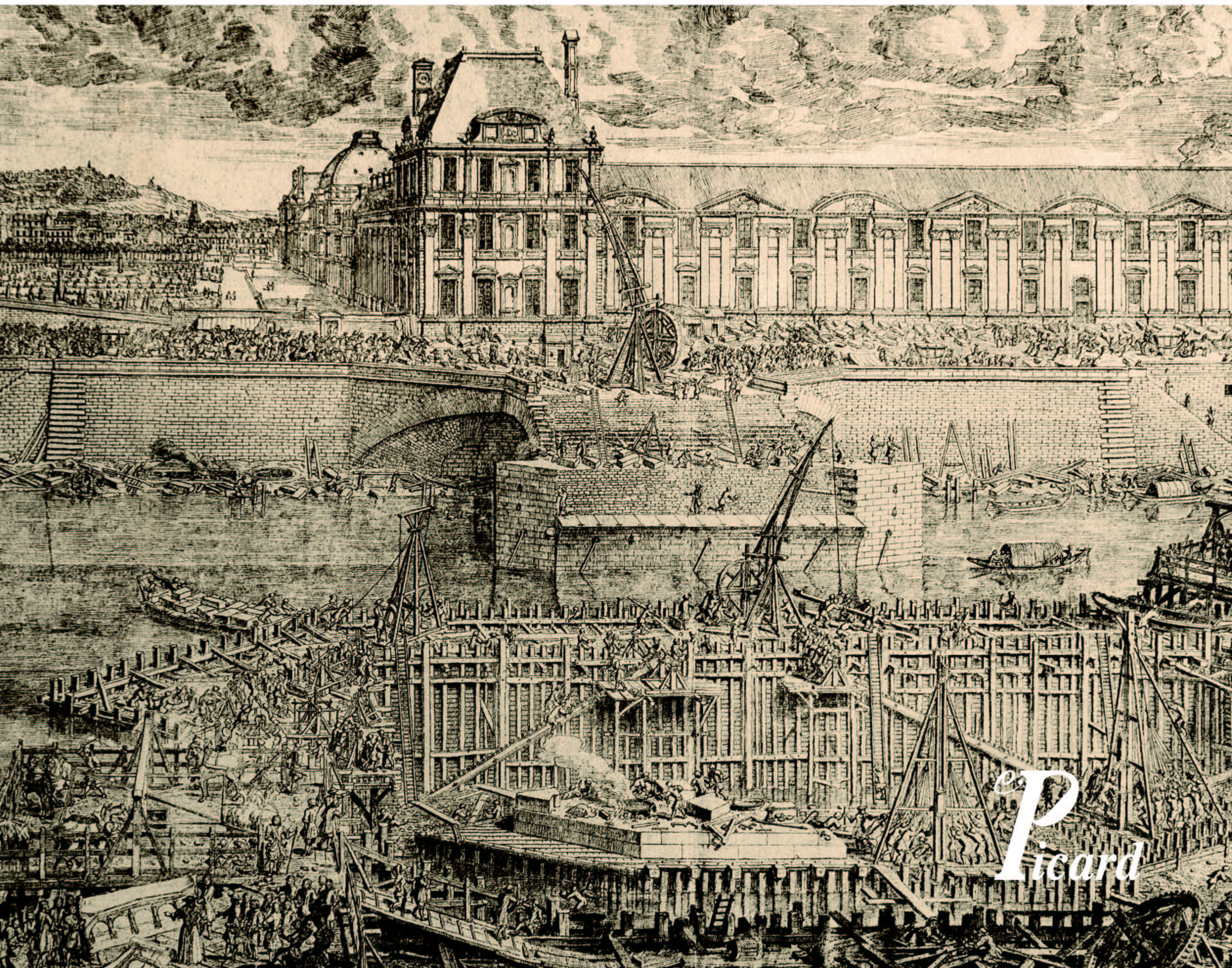

Masonry Constructions as Built Archives: An Innovative Analytical Approach to Reconstructing the Evolution of Imperial *Opus Testaceum* Brickwork in Rome

Gerold Eßer
Vienna University of Technology, Austria

The Colosseum, Trajan's Market, the Baths of Caracalla and the Basilica of Maxentius: the monumental ruins of the imperial representational buildings mark the crystallisation points in a profound, centuries-long recasting of the appearance of the city of Rome (Fig. 1). The cores consist of practically indestructible *opus caementitium*, faced with hard, quasi-industrially produced fired bricks. This construction method, later called *opus testaceum*, was uniquely suited to surviving the passage of time. For us today, this means that we have at our disposal an extraordinary wealth of evidence for the building construction methods used in those times.

Given that even the building sites of classical antiquity were subject to market forces, the buildings are to be regarded as the outcome of rational decisions made on the basis of economy, durability and functionality. Particularly in the area of important imperial public buildings, where the pressure to be successful was exceptionally high, the conditions imposed by the market were certainly strictly observed. Large imperial building projects in which often many thousands of workers had to be organised and directed required the definition and implementation of standards applicable right across the site. To ensure the success of a major project these standards had to be laid down in series of technical regulations. The doctoral thesis on which the present paper is based examined the extent to which the organisation of large building sites influenced masonry constructions and whether, using the characteristics of the masonry that will be defined below, this influence can be read as a regulative on the erection of the structures.

Fig. 1: Basilica of Maxentius in Rome, 306-312 A.D.

The question of chronology

The existing methods of dating differ greatly in their precision and reliability. Scientific methods based on the examination of construction materials taken *in situ* from buildings focus on analysing phenomena and processes peculiar to the material character and composition of the building materials. As a rule they should all be approached with caution as regards dating: in many cases their dating relates to the time when the material examined was made and not directly to the period during which the building from which the mate-

rial was taken was erected. Here, precisely, lies the great appeal of dating-oriented analysis of brick masonry constructions: in comparison with building materials, masonry structures form so to speak the next, higher step in the process of creating a building. They are the building itself, or at the very least its essential and innermost core. If we can exploit this characteristic to arrive at a dating, then our results will reveal, very closely and directly, the point in time when a historic construction was built.

Problems in dating brickwork

If we view brickwork constructions as systems that, with their variations on an ideal model, practically make up the entire volume of a building, then we are confronted with an extensive and complex range of findings (Fig. 2). Not only can brickwork structures be read as the standard surface of a closed wall; they also display a variety of constructional details and with their core penetrate the third dimension of walls. Even if we succeed in fixing in time the canon of constructional possibilities of a certain building tradition on the basis of all the different variations used, the human inadequacies of those who carried out the work will still result in variations on this canon within certain accepted limits. Consequently strategies must be developed that define and describe the essential aspects of this enormous range of findings.

Fig. 2: Mausoleum of Helena Augusta, 320-325 A.D.: Typical late antique *testaceum* brickwork, area showing the standard bond.

Present state of research

The number of important contributions to the dating of urban Roman *testaceum* brickwork is not very large. The first and original attempt was published in an article by the American archaeologist E.B. Van Deman (Van Deman 1912), which appeared in two parts. In a concise work based on an enormous knowledge of antique monuments gathered over a period of decades, the author succeeded in producing a first classification by epochs of *caementicum* constructions within which brick-faced masonry structures form the most important category. In her analysis of various masonry typologies and epochs, the author develops a nomenclature to describe the characteristics relevant to defining a chronology.

Thereafter the most important publication has been G. Lugli's major work on Roman construction technology with its often lexically meticulous description of the technical aspects of Roman brickwork (Lugli 1957). Today's experts are somewhat critical of his attempts, on the basis of just a few characteristics, to fix the dates for the various typologies of Roman brickwork structures. A quarter of a century later the work by T.L. Heres, *Paries: A Proposal for a Dating System of Late-Antique Masonry Structures in Rome and Ostia,* introduced an improved system of documentation into the discussion on methodology (Heres 1982). However, this work has a serious flaw in its method: although dated and undated masonry structures are distinguished from each other, the reader is left unsure whether and on what basis given datings are accepted or questioned, and how the *dating system* presented, which ultimately seems to operate on the basis of intuitive comparisons, can be used to anchor buildings securely to a particular point in time.

A number of subsequent works (Giuliani 1990, 19-24; Cecchelli 2001) clearly betray reservations about the known masonry-based dating methods. M. Cecchelli, for example, in her informative and well-structured catalogue section on early

Christian masonry, restricts herself to compiling and documenting all data of relevance to the building structures, ranging from the historical sources through details of research history to examinations of masonry structures following a strict standard.

A breath of fresh air was introduced into the discussion by a research direction that has been developed with remarkable success since the 1970s under the name *mensiochronology*, which analyses dimensions and uses modern statistical methods to evaluate mediaeval and modern bricks (Fossati 1984; Mannoni and Milanese 1988). Although hardly any note has as yet been taken of it in classical archaeology, this interdisciplinary initiative has in many parts of Italy already provided numerically substantiated proof, based on the economics of construction, of a direct connection between the dimensions of the bricks examined and the time when they were made.

Aim of the study

The challenging aim of the study is to reconsider the problem of determining the chronology of specific examples of antique urban Roman brickwork – a group of examples of *testaceum* brickwork from the period between Diocletian and Constantine[1] that have already been given fixed dates using other methods – under new methodical preconditions and asking different questions. Comparison of the samples of brickwork examined demanded strict selection based on the following criteria: belonging to a single region, having been commissioned by comparable clients, use of the same masonry techniques, and reliable dating. After all, only if we prove that the assumed development over a continuous period of time did in fact leave a recognisable mark on individual buildings can we justifiably attempt to put hitherto inadequately dated brickwork into a proven chronological order.

Documentation standard for *testaceum* brickwork

Taking into account existing methods that combine a verbal, qualitative description of the building structures with measurements and examinations of their constructional elements and a photographical, in part also photogrammetrical, documentation of representative sections of the brickwork, a procedure was developed that combines a series of new processes from the fields of surveying technology, computer science and statistics with the familiar methods of recording and evaluating masonry data. It produces results that allow masonry structures to be characterized in a differentiated and objective manner.

Photogrammetry

In the course of the study it proved possible to show that the use of tacheometric-assisted methods of planar image rectification and cylindrical development (Fig. 3) allow entire areas of brickwork to be surveyed and documented, true-to-scale and with the real colours. For the first time in the history of the comparative examination of brickwork, these methods also allow the numerical recording and analysis of entire walls as constructional systems. As well as being able to be used at different scales, ranging from detailed to general overview, the plan material produced in this way allows larger areas to be dealt with, improves the statistical basis of the recording of data, and increases the transparency and verifiability of the entire documentation.

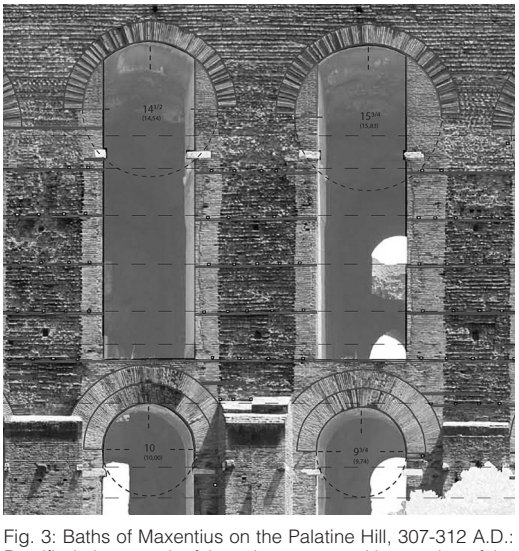

Fig. 3: Baths of Maxentius on the Palatine Hill, 307-312 A.D.: Rectified photograph of the substructures with mapping of the system characteristics, original scale of image 1:100.

Graphical evaluation

Whereas the true-to-scale graphical evaluation of the system characteristics can be carried out in the usual manner by mapping the photo-plans, the evaluation of the standard elements of the regular areas of brickwork – the brick and the mortar joints – is facilitated and accelerated by using a process developed in the research field of image analysis: *semi-automatic, edge-precise segmenting* (Fig. 4). The method further developed for the questions examined here enables – like photogrammetry – large amounts of findings to be dealt with and thus also contributes to greater precision and reliability in the results of the examination. The further graphical development of the standard bond bricks in the rectified images has the advantage that these elements, along with their characteristics [height, length, shape], remain identifiable as *individual pieces* and can be depicted in illustrations showing their salient features.

Automated evaluation of the characteristic values of the standard bond

The graphical isolation of the bricks in the rectified images allows their characteristic values to be evaluated automatically [*extraction of characteristics*] and to be subsequently organised in tabular overviews. While this phase of the work meets the challenge posed by the large amounts of data, it also, and far more importantly, facilitates the identification of those parameters of bricks and mortar that can help answer the questions of building archaeology. In addition to the parameters of length and height that are generally required for each brick, further queries about characteristics can be defined. In addition to the *calculated visible area* of a brick, the automated calculation of the pixels produces a value for its *actual visible area*. Using the *form factor*, which works out the extent to which the actual surface of the brick differs from an ideal rectangle, we may determine its *degree of deformation* and for the first time give a value expressing the probability of a brick having been reused. The new method may well make it possible to establish other parameters defining the character of bricks.[2]

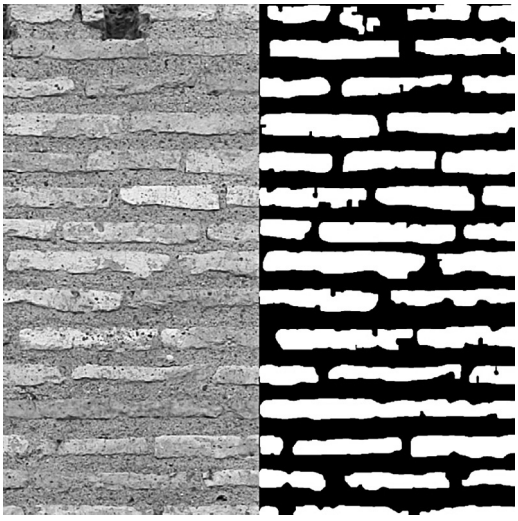

Fig. 4: Typical standard bond of late antique *testaceum* brickwork: Original image and result of the automatic segmenting.

Meaningful parameters can be defined not only for the element *brick* but also for the representative sections of masonry *per se*: by vertically and horizontally scanning the masonry images and with the help of new methods, the *mean horizontal joint thickness* and *vertical joint thickness* of a section of masonry can be determined with a high degree of reliability and accuracy. In areas of wall made up of bricks that have been recycled these values could not yet be measured by hand, as the imprecise values obtained differed too widely. The spread of these two parameters within a defined measured area also allows objective statements about the inhomogeneity of the brick material examined and about the extent to which it was reused. Using this knowledge of the actual areas of brick and mortar surfaces in a defined section of brickwork, it is possible to work out area-related values for the *proportion of brick* and the *proportion of mortar* in the section of wall. These parameters also represent something entirely new in the field of brickwork examination in that they can be used to establish precise surface values in the materials used on a given building site.

Manual evaluation of the characteristic values of special construction elements

Evaluating special constructional elements of a masonry bond – such as the bonding courses, scaffolding courses,[3] openings and masonry arches –

represents a second area for the derivation of masonry parameters (Fig. 3). It is based on the high-resolution photogrammetrical plan material produced at overview scale. As well as allowing a better handling of existing parameters, it also permits the definition of masonry characteristics that are either entirely new or that have so far only been partially numerically defined. So, for example, the characteristic of the *mean course height,* which determines the vertically measured denseness of the brick courses could, thanks to the possibility of making a continuous measurement of all brick courses in a defined area, be increased to a certainty level of 100%. In addition, constructional elements such as the *bonding courses* and *scaffolding courses* [along with the vertical distances between them], which structure the building process in a special way, could be introduced as new, numerically recorded and therefore highly accurate system characteristics. The information provided by this group of characteristics proved particularly significant in defining a building chronology in the area under examination.

Statistical calculation methods

Through the use of statistical methods it was possible to calculate a series of *standard [specific] values* for the individual characteristics, allowing a considerable increase in the reliability and precision of information conveyed by the values.

Building catalogue

The results of the examinations of masonry carried out at selected building sites from the relevant period were compiled in a catalogue consisting of ten building-based sections, and were compared with the historical and archaeological source material required for identifying and dating the masonry. The characteristics and values of the examination parameters depicted here in systematic form present the *building site standard* that characterizes the individual buildings, and allow direct comparisons of the brickwork examined to be made.

Reconstructing the chronology of the brickwork structures examined

After all the buildings [building sites] had been systematically recorded in the manner described above and classified according to the occurrence of the masonry characteristics retrieved, the values calculated were organised in a table. Correlating the data with the factor time made it possible to follow the development of the values during the period covered by this study [298-345 A.D.]. This also allowed unimportant characteristics to be distinguished from important ones.

Brick lengths and heights

One hardly surprising result of the study is that the parameters usually sought in comparative examinations of masonry, *brick length* and *brick height*, say hardly anything about developments during the period covered by the study (Fig. 5). As the spread of both characteristics in all the buildings examined is very high, it can be safely assumed that a homogenous brick material from a contemporary production source is not dominant in any of the cases examined.

Proportion of mortar

By contrast, all the parameters relating to joint mortar have shown clear development tendencies, which in the period between the earliest Diocletian building in Rome, the *Curia Iulia,* and the late Constantinian Mausoleum of Constantina reveal a perceptible increase in the relative amount of mortar used in brick faces. The results of the study reveal that the surface-related proportion

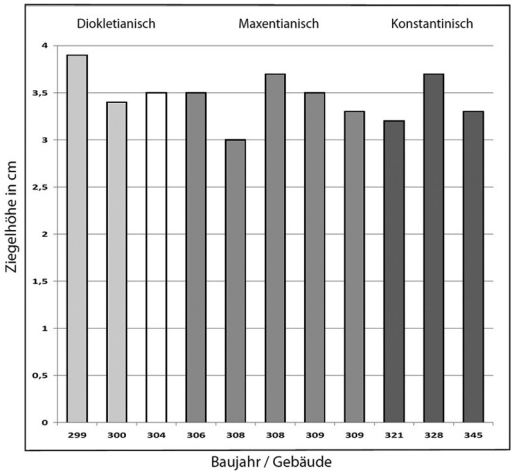

Fig. 5: Comparison of the ten buildings from the period covered by the study [horizontal axis] according to the characteristic of the mean *brick height* [vertical axis]: The characteristic is not of significance for the reconstruction of the chronology.

of mortar in the Diocletian era was in the range 32-46%, under Maxentius 45-51%, and in the Constantinian buildings as high as 50-55%.[4]

Height of the horizontal joints

The development of the values for the height of the horizontal joints is even steadier and therefore, given the current data situation, even more suitable for defining a chronology (Fig. 6). The Diocletian buildings have horizontal joints measuring 1.4-2.2cm in height, the large Maxentian inner city projects have joints with a constant height of 2.4cm, and from the last of the Maxentian projects to all the Constantinian building sites the joint height increases further to 2.6-2.7cm[5].

Course heights

With relatively constant brick heights, the material reveals a for the most part highly informative development as regards the characteristic *course height* – including brick and horizontal mortar bond. Whereas Diocletian course heights are on average 5.2-5.7cm, and the three Maxentian large inner city projects have courses with an average height of 6cm from the Mausoleum of Maxentius erected in the late Maxentian era to the top storey of the Mausoleum of Constantina the figure increases to 6.2-6.6cm.

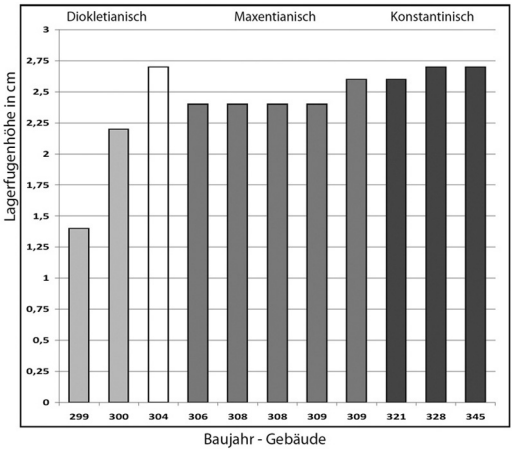

Fig. 6: Comparison of the ten buildings from the period covered by the study [vertical axis] according to the characteristic of the mean *horizontal joint thickness*: This characteristic is of major significance for the reconstruction of the chronology.

System parameters

A second group of masonry characteristics first used systematically in the course of this study shows in an equally clear manner the development of the *opus testaceum* in the period under review from Diocletian to Constantine. In the group of *system parameters* it was in particular the characteristics *distance between bonding courses*, *distance between scaffolding courses* and *combination of bonding and scaffolding courses* that were able to provide a numerical description of the building chronology (Fig. 7).

Bonding courses

Whereas in the *Curia Iulia* we can recognise a standard and clearly consciously intended vertical distance between the *bonding courses* of somewhat more than 4¼ ft [4.34 RF = 128.5cm], in the period between the erection of the Baths of

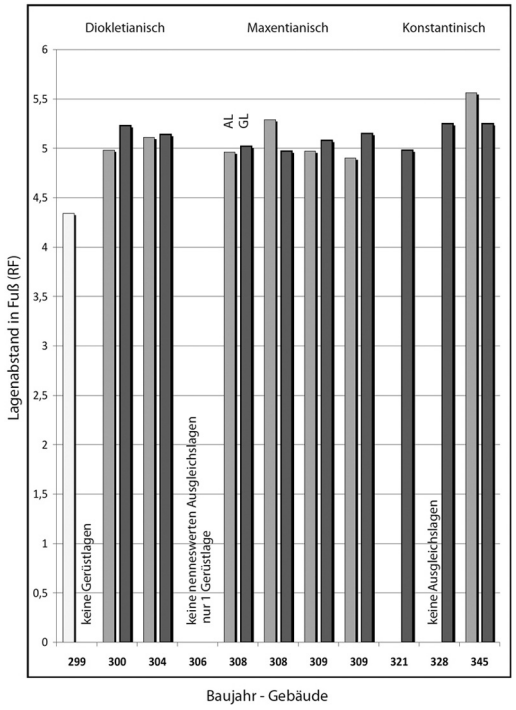

Fig. 7: Comparison of the ten buildings from the period covered by the study [horizontal axis] according to the system characteristics *distance between the bonding courses* [left-hand column of each building] and *distance between the scaffolding courses* [right-hand column of each building]: This characteristic is of major significance for the reconstruction of the chronology.

Diocletian and the Mausoleum of Maxentius this value oscillates in the range 5-5¼ ft [4.90-5.29 RF = 145.0-156.5cm], with the figure approximating closely to five ft [4.98 RF = 147.5cm] in five of the six buildings concerned. In the only Constantinian building in which, with some reservations, we can talk of a standard distance aimed for in 50% of the cases, the mean distance between the bonding courses is by contrast somewhat more than 5½ ft [5.56 RF = 164.5cm].

Distance between the scaffolding courses

The *distance between scaffolding courses* reveals a similar picture: in the Maxentian period the standard distance was almost exactly five ft [5.05 RF = 149.5cm]. The enclosing walls of the Baths of Diocletian [5.14 RF] and the Mausoleum of Helena [4.98 RF], which mark the start and end of this period, can also be allotted to this group of buildings, whereas before and after this core period the mean distance between scaffolding platforms is exactly 5¼ ft.

The two system parameters of *distance between bonding courses* and *distance between scaffolding courses* also describe a core area in which the mean standard interval lies very close to five ft. In the case of the distance between bonding courses this period can be extended backward to include the central building of the Baths of Diocletian, while with respect to the distance between scaffolding platforms it can be extended forwards to include the Mausoleum of Helena. If the enclosing walls of the Baths of Diocletian are included in this era, the overlapping area of the two core periods exactly matches the Maxentian construction period,[6] during which both parameters reached a mean figure of precisely five ft, while at the same time the number of distances that clearly exceed this standard figure decreases to a minimum.

Combination of bonding courses and scaffolding courses

What these figures describe – namely a complete convergence of the two system distances governing the construction process – is confirmed in practice: the logical regular combination of the system courses at intervals of five ft can only be identified and proven in the Maxentian construction period. If we follow this system parameter of a *combination of bonding courses and scaffolding courses*, not only do the four Maxentian buildings but also the enclosing walls of the Baths of Diocletian belong to the core period of the study. All other buildings follow different systems. For instance, the standard in the Constantinian buildings examined reveals an efficient method in which bonding courses are used only where special demands of the construction require them, which was thus clearly an attempt to establish a universal, statics-based kind of structural design.

Maxentian building standard

However, the Maxentian standard goes far beyond guidelines determined solely by structural requirements. The system used between 306 and 312 A.D. betrays the pursuit of a building process that could be checked at any time throughout the building site and that through the regular and combined use of the two different system courses was calculated to impose on the growing building a rhythm clearly visible to all involved in the construction work. As this new standard made it easier than ever before to coordinate the many different groups of workers in order to meet certain fixed interim goals, it may be regarded as having been the fruit of experience and a conscious attempt to increase the efficiency of building site organisation. Amongst the building sites where this standard is employed, the outer precinct of the Baths of Diocletian, probably the earliest fourth-century example of that building standard, was clearly an area of experiment for the new procedure.[7] A short time later, presumably following the seamless re-engagement of the building firms and architects who erected the baths, what emerged here as a highly promising form of organisation, structuring the building process and shortening the construction period, was to be brought to perfection in the large representational buildings of Maxentius.

Acknowledgements

I should like to express my heartfelt thanks to the supervisors of my dissertation, Prof. Dr. Marina Döring-Williams and Prof. Dr. Johannes Cramer, who as experts in the Roman subject matter were invaluable discussion partners.

Notes

1. The study encompasses the following ten reliably dated buildings from the Tetrarchan and Constantinian epochs: Curia Iulia 298-303 A.D.; Baths of Diocletian 298-305/306 A.D.; Mausoleum Tor de Schiavi 305-309 A.D.; Baths of Maxentius on the Palatine Hill 307-312 A.D.; Temple of Venus and Roma 308-312 A.D.; Basilica of Maxentius 308-312 A.D.; Mausoleum of Maxentius 308-312 A.D.; Mausoleum of Helena Augusta 320-325 A.D.; S. Croce in Gerusalemme 326-330 A.D.; Mausoleum of Constantina Augusta 340-350 A.D.

2. For example work on a *rotation factor* has been started that shows the position of a brick in its mortar bed; a value that allows important statements to be made about the *horizontality* of the bricks in the course.

3. These brick courses are marked by holes in which the timbers that supported the scaffolding used in erecting the walls were once fixed.

4. Here once again the value of the *Curia Julia* appears important, which with a proportion of mortar amounting to only 32% is far below that of all other buildings.

5. This characteristic – just like the proportion of mortar above – also shows that as regards the way they are built the Baths of Diocletian are far more similar to the Maxentian buildings than to the Diocletian *Curia Julia,* which has horizontal joints 1.4cm thick, a figures far below that of all other buildings.

6. An extensive discussion on a possible late dating of this second phase of construction of the Baths can be found in Esser 2008, 188–206 in Chapter 4.2 "Diokletiansthermen."

7. The same standard was achieved a century earlier in the construction of the Baths of Caracalla starting from 212 A.D. This must however have been forgotten in the intervening period, as there was probably no documentation of the way the building site was organized.

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