DESIGN AND CONSTRUCTION IN ROMAN IMPERIAL ARCHITECTURE

THE BATHS OF CARACALLA IN ROME

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ERRATA ET CORRIGENDA

p. 1, para. 2, l. 1: after "problems", insert "and".
p. 6, para. 2, l. 5: replace comma with full stop.
note 27: for "Section 4.2", read "Section 4.3".
p. 8, 4 lines from end: for "number", read "amount".
p. 9, para. 2, 2 lines up: for "and its", read "and in its".
p. 11, para. 2, l. 2: after "measurements", insert a comma.
p. 12, l. 1: before "quantitative", insert "the".
p. 16, 2 lines up: after "preferred", insert "to".
p. 39, line 8: for "Tetrachic", read "Tetrarchic".
p. 53, l. 6: before "extrados", insert "the".
p. 54, para. 2, l. 5: for "show", read "shown".
p. 57, para. 2, l. 2: after "Rm 16", insert "which".
p. 75, para. 2, l. 1: for "Critieria", read "Criteria".
note 19: for "1984a", read "1984".
p. 78, para. 2, l. 9: for "Romans", read "Roman".
p. 81, para. 2, l. 10: for "1:√2-1", read "1:(√2-1)".
p. 85, para. 4, l. 1: for "Section 1.2.3", read "Section 1.2.1".
p. 87, para. 2, l. 2: for "aloud", read "along".
note 35: for "survey", read "surveys".
p. 94, 3 lines from end: for "3 or 4 times", read "or 3 times".
p. 102, last para.: for "3.3.7" read "3.3.8".
p. 106, note 54: for "octogon", read "octagon".
p. 107, line 2: delete second "on the ".
p. 113, para. 3, l. 1: delete "that".
note 36, l. 1: for "consist", read "consistent".
p. 122, para. 2, l. 9: for "ships", read "ships'"; for "estimate", read "estimated".
l. 10: after "and", insert "for".
p. 123, note 13: for "Tschernia", read "Tchernia".
p. 132, para. 4, l. 6: for "by product", read "by-product".
p. 134, para. 3, l. 2: for "Section 1.3.3", read "Section 1.4".
l. 5: for "Section 1.6.1", read "Section 4.1.1".
p. 139, para. 2, l. 4: for "45" read "41.67".
p. 145, line 4: before "lifted", insert "be".
p. 152, l. 12: for "15 <u>denarii</u>/P^3, read "15 <u>denarii</u>/P^2.
note 115: for "Appendix 5", read "Appendix 4".
p. 153, l. 2: delete "are".
p. 156, l. 4: after "Baths", insert a comma.
p. 159, l. 4: after "girth", insert a comma.
p. 160, 2 lines up: after "(in cubits)", insert "and".
p. 161, note 137: for "lead", read "led".
p. 162, para. 2, l. 2: for "foundations", read "foundation".
note 140: for "rome", read "Rome".
p. 164, last line: for "Denbigshire", read "Denbighshire".
p. 168, 3 lines up: for "Section 1.6.3", read "Section 4.1.3".
p. 170, 2 lines up: for "Section 4.1.2", read "Section 4.2.2".
p. 179, note 48: for "Setälä 1975", read "Setälä 1977".
p. 177, para. 2, l. 4: for "Appendix 3", read "Appendix 2".

p. 178, note 46, l. 3: for "Honourary", read "honorary".
p. 185, l. 3: delete "both".
para. 2, l. 2: delete "the".
p. 189, last line: for "Section 1.3.3", read "Section 1.4".
p. 191, l. 6 after Table 11: after "solidi", insert "to".
p. 193, l. 2: for "Appendix 4, read "Appendix 3",
l. 3: for "Section 6.4.5", read "Section 6.5.1".
p. 194, para. 2, l. 3: delete "workings".
p. 196, 5 lines up: for "of", read "off".
p. 198, l. 6: delete last word in line.
p. 202, line 11: for "are", read "area".
p. 202, para. 2, l. 3: delete second full stop.
p. 206, para. 2, l. 2: for "Section 2.3.1", read "Section 2.5.2".
p. 207, l. 3: after "and", insert "seems".
4 lines from end: omit second "have".
p. 209, l. 5: for "creat", read "create".
p. 218, para. 3, l. 1: for "of use", read "of the use"; for "are", read "is".
l. 2: before "missed", insert "was".
p. 221, last line: after "Up", insert "to".
p. 223, para. 2, l. 7: before "bipedales", insert "of".
p. 229, para. 2, l. 7: for "butressing", read "buttressing".
p. 230, para. 2, l. 5: for "vunerable", read "vulnerable".
l. 6: delete first word of line.
last line of page: for "niche", read "niches".
p. 231, para. 2, l. 7: for "fron", read "from".
p. 233, line 4: after "part", insert "of".
p. 234, para. 2, l. 4: for "bipedales", read "bipedalis".
note 43, l. 1: for "wher", read "where".
p. 235, para. 2, l. 1: for "6.2.6", read "6.3.6".
p. 237, note 47: for "Section 6.4.5", read "Section 6.5.1".
p. 244, 2 lines up: for "is", read "was".
p. 245, para. 2, l. 5: for "scarecely", read "scarcely".
p. 248: para. 2, l. 4: for "someway", read "some way".
p. 249: delete all of first line.
p. 251, para. 2, l. 1: after "centering", insert "for".
p. 254, para. 2, l. 5: for "variously", read "various".
para. 2, last line: for "stucture", read "structure".
p. 257, line 2: for "clear the the", read "clear that the".
p. 258, l. 2: delete "fill in".
l. 4: after frigidarium, insert "filled in".
p. 259, last line: after "there", insert "are".
p. 261, para. 2, l. 5: for "Chpater 8", read "Chapter 8".
p. 262, para. 1, l. 10: after "already", insert "been".
p. 272, line 7: for "scare", read "scarce".
p. 274, para. 2, l. 3: for "not", read "nor".
p. 280, l. 3: for "logical", read "logic".
note 34: for "Lyttleton", read "Lyttelton".
p. 291, l. 3: after "relating", insert "to".
p. 312, note 32: for "1967", read "1969".

p. 316, note 39: for "1967", read "1969".
p. 333, note 53: delete section in square brackets.
p. 342, Table 27: 3rd and 4th totals should read 161,000 and 113,000 respectively.
p. 343, line 2: for "out to", read "should".
p. 344, l. 6: for "Section 2.4.2", read "Section 2.5.2".
p. 347, para. 2, l. 3: for "form", read "from".
p. 356, line 10: for "enroled", read "enrolled".
p. 358, note 22: for "Qulici", read "Quilici".
p. 361, l. 7: for "Section 4.1.1", read "Section 4.4.1".
p. 364, para. 2, 5 lines up: delete "the what must have".
p. 367, 2 lines up: for "though", read "thought".
p. 368, para. 2, l. 1: for "Section 8.4", read "Section 8.5".
p. 374, 2 lines up: for "mausolaea", read "mausolea".
p. 375, l. 1: for "fits", read "fit"; for "aim", read "aims".
p. 376, Screen between Rm 1 and the natatio, (1) A, l. 3: after "Hül.", insert "p. 33".
p. 378, Screens between Rms 8, 9, and 10, (1) A, l. 3. after "Hül.", insert "p. 28".
Screen 12/13, (1) A, l. 2: after "Hül.", insert "p. 28".
l. 3: delete line.
p. 380, 9 lines from end: for "moundings", read "mouldings".
p. 395, note 12: for "rough", read "roughly".

Bibliography:
p. 399, Blake 1947: for "rehistoric", read "Prehistoric".
p. 400, Bryant 1978/79: for "Archrchaeologica", read "Archaeologica".
p. 403: insert Delehaye, H. 1910, "Passio SS Quattuor Coronatorum", in C. De Smedt et al., Acta Sanctorum Novembris, III, Brussels.
p. 405, Geertman 1984a: for "1984a", read "1984"; for "LIX", read "59".
p. 409, Lyttleton 1974: for "Lyttleton", read "Lyttelton".
p. 410: insert Millar, F.G.B. 1984, "Condemnation to hard labour in the Roman empire, from the Julio-Claudians to Constantine, PBSR 52, 124-47.
p. 410, Nicole 1906: for "l/epoque", read "l'époque".
p. 411, Pearse 1975: for "roman", read "Roman".
p. 412, Rakob 1969: delete.
p. 413, Schwarz 1968: for "Schweig", read "Schweiz".
p. 414: insert Stevens, C.E. 1966, The Building of Hadrian's Wall, Cumberland and Westmorland Antiquarian and Archaeological Society, Extra Series, Vol. 20.
p. 414, Steinby 1974: for "datazion", read "datazione".

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ABSTRACT

My thesis is a study of the generating processes of Roman imperial architecture - the processes of design and construction - and of their economic and socio-political ramifications. The study concentrates on a single structure, the Baths of Caracalla in Rome (AD 211-216), regarded as one of the major achievements of the mature phase of Roman architecture and illustrative of the most sophisticated building technology available to Roman architects and builders.

A detailed survey of the standing remains forms the basis for a set of reconstruction drawings. By following the progress of the building from the architect's initial design to the production of materials, the actual construction, and finally the decoration which forms an integral part of the architect's concept, it has been possible to move away from traditional approaches to Roman architecture, based on the building as fact - a work of art or a compendium of construction techniques - and concentrate on the connections and interactions between the manifold elements of the building process. Furthermore the survey supplies the data which allows the building to be broken down into fixed quantities of materials and specific actions by builders. From this it has been possible to estimate the man-power required for both the materials and construction of the Baths, based on ethno-archaeological parallels from pre-twentieth century non-mechanised modes of materials production and construction in Europe. By applying the related prices and wages given in the Prices Edict of Diocletian to the man-power and materials some idea of the cost of the project can be obtained.

This analysis thus allows for the first time a detailed assessment of the economic and social impact of a major public building project in terms of the amount and type of labour required over a given period and distributed over the city, its immediate periphery, and more distant sites. In addition,

the position of public building can be examined with respect to other calls on imperial resources, and the economics of this particular form of euergetism explored.

STATUTARY DECLARATION

I, the undersigned, declare that the work contained in this thesis derives from my original research, and does not contain any work done by any other person except where due reference has been made.

I also declare that I am willing to make the copy of my thesis deposited at the Barr Smith library of the University of Adelaide available to scholars for loan and for photocopying within reasonable limits.

Janet DeLaine

27 April 1992

ACKNOWLEDGEMENTS

This thesis could not have been written without the help of a large number of people and the support of three institutions. My first debt of gratitude is to Frank Sear, my supervisor at the University of Adelaide and now Professor of Classics at the University of Melbourne. He first drew my attention to Roman architecture when I was an undergraduate at Adelaide, and provided me with an invaluable opportunity to gain experience in the field as part of the Australian Expedition to Pompeii of which he was co-director. When I then expressed an interest in working on the construction problems of some large-scale building in imperial Rome for my doctorate, it was he who pointed me firmly in the direction of the Baths of Caracalla, although neither of us, I believe, could have quite anticipated the results.

Most of my time from 1981 to 1986 was spent in the Classics Department of the University of Adelaide, originally as a postgraduate student and then as a full-time member of staff. I remember with gratitude the interest and encouragement shown me by all its members, first under Prof. John Trevaskis and later under his successor, Prof. Robert Ussher, and the efforts which were made to allow me as much time as possible in Rome. I am also grateful to the University itself for a Postgraduate Overseas Travel Award and a George Murray Overseas Travel Grant which enabled me to travel to Rome in 1985 and in 1986 to take up a Rome Scholarship.

The field work for the thesis was carried out over several visits to Rome between 1982 and 1988. On every occasion I was based at the British School at Rome, originally as a visitor and later as a Rome Scholar in Ancient, Medieval and Later Italian Studies. To its successive Directors David Whitehouse and Graeme Barker, librarians Luciana Valentini and Valerie Scott, secretary Maria-Pia Malvezzi, and to all the staff both academic and household, my sincere thanks are due for their help and encouragement, and for making the School feel very much a second home to me. In its Assistant Director Amanda Claridge I found a friend, without whose support - practical, academic, and moral - this project might never have come to fruition. A special word of thanks is due to Lucos Cozza, once head of the X Riparazione of the Comune di Roma and an Honourary Fellow of the British School, both for his practical help in arranging for his colleagues from the Servizio Giardino to bring their hydraulic lift to the site on two memorable occasions, and for his constant and lively interest in my " 'holes". I also wish to remember all the many individuals who passed through the School during the various periods in which I was in residence and with whom I was able to share my ideas and discuss my problems. They are too many to name; I only hope that anyone who recognises themselves in this context will take this as a token of my appreciation. In addition to Joan Barclay-Lloyd who gave me her invaluable advice on the later construction in the Baths, I must however mention the following who gave practical help with the long task of measuring the Baths, and without whom this thesis could not have existed: Jim Betteridge, Colin Blackmore, Rajen Desai, my mother Doris Fox, Michele George, Alison and Martin Hicks, Paul Horrocks, Judi Loach, Shayne Mitchell, Jenny Neale, John Patterson, Margaret Peart, John Peck, Cathy Roberts, Chris Saunders, Barbara and Nick Temple, Judith Toms, Mike Verknocke, David Watt, Mark Wilson-Jones, and Peter Wiseman. If in the ensuing years anyone's name has slipped from my records, my thanks should be taken as extending to them as well.

My study would, of course, been impossible without the co-operation of the Italian authorities. My greatest debt is to Dottoressa Irene Iacopi and Architetto Maria Letizia Conforto for permission to work on the site and access to areas not generally open to the public, and for admitting the mobile hydraulic lift with which I was able to examine the high vaults. I would also like to thank

Luca D'Elia, Maria Grazia Cecchini, Lorenzo Petrassi and Angelo Corazzi, and particularly Marina Piramonte and Alessandra Capo di Ferro for sharing their knowledge of the site with me during my long association with the Baths, and with the all the custodians who patiently opened closed doors and facilitated my access to the more obscure regions of the site on a day-to-day basis. I also had useful discussions with Gruni Jenewein of the Austrian Institute and Hubertus Manderscheid of the German Institute concerning their particular areas of interest in the Baths. Daniela Candilio at the Baths of Diocletian is also remembered with gratitude for giving me access to the new excavations and the scaffolding in the Planetarium, and for several stimulating exchanges over parallel problems concerning the two great thermae. The libraries of the American Academy and the German Archaeological Institute were invaluable, and I would like to extend a general thank you to their staff for their help, and especially to Karen Einaudi of the Fototeca Unione.

Since 1988, as a Junior Research Fellow at St John's College Oxford, I have been provided with a tranquil atmosphere in which to work and a freedom from pressure rare in the present academic climate, while from the members of her Senior Common Room, and particularly from Nicholas Purcell, I have had nothing but encouragement. Most of the actual writing has been done here as well as the reconstruction drawings. During this period I was able to present many of the ideas contained in this thesis to various seminar groups, and I would like to express my appreciation of the opportunities afforded me by the Ancient Architecture Discussion Group under the guidance of Jim Coulton and the Oxford Ancient History Graduate Seminar to present some of ideas in an earlier form.

Previous drafts of several of the chapters benefited from critical comments by several people, and I owe them especial thanks. Jim Coulton and Mark Wilson-Jones read the chapter on design, Clayton Fant and Susan Walker the section on marble, while Tim Potter and Margareta Steinby have read most of the original chapters on materials production and construction. I am particularly grateful to the latter for her helpful comments and general enthusiasm for the project. In addition the work as a whole profited from discussion with many friends and colleagues, of whom I would like to single out Simon Corcoran, Richard Duncan-Jones, Lynne Lancaster, and Inga Neilsen. Sheila Gibson gave generous advice on the architectural drawings, and much-appreciated moral support along the way. Danyon Rey prepared the final plan from my pencil drawing and Melanie Steiner the maps in Figures 49, 52, and 55.

Last but by no means least, David Wilkinson patiently read the various drafts and as usual saved me from obscurities of expression and woolliness of thought, while providing much of the moral support which kept me going over the last five years.

LIST OF ILLUSTRATIONS

All illustrations unless otherwise indicated are the work of the author. Numbers with the prefix JD refer to the author's photographs, followed by B for black and white, C for colour negatives.

Architectural Reconstruction (in pocket at back of Volume II)

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CHAPTER 1: AIMS AND METHODS

INTRODUCTION

The generating processes of Roman imperial architecture - the processes of design and construction - are not only fundamental to our understanding of that architecture but have wide-ranging social, economic, and ultimately political ramifications. This study explores both these processes and their implications by concentrating on a single structure, the Baths of Caracalla in Rome, chosen as a representative example of large-scale public construction in the imperial capital. This building is accepted as one of the major achievements of the mature phase of Roman architecture, and should represent the most sophisticated building technology available at any time to Roman architects and builders, while being neither particularly innovative nor eccentric in design or construction. The scale and complexity of the building would have challenged organization and resources; its imperial authorship ensured that the challenge was met. It stands thus as both paragon and paradigm in the universe of imperial construction, illustrating at one and the same time the capabilities and limitations of the Roman building industry.

The thesis is divided into nine chapters. This first chapter looks at the nature of the problem, at the general methodology where this is relevant to the thesis as a whole rather than to an isolated part of it. Chapter Two examines the history and chronology of the building itself, and discusses the evidence for the reconstruction which forms the basis for the rest of the thesis. The next five chapters follow the building project through the design procedures (Chap. 3), the production of materials including the problems of transport (Chaps 4 and 5), construction techniques and processes (Chap. 6), and the decoration (Chap. 7). The calculations of the quantities of materials and manpower necessary for the construction and decoration and the total costs of the building are found in Chapter 8, along with discussions on the logistics of the project. In the final chapter the economic and social implications are discussed.

1.1 THE NATURE OF THE PROBLEM

The wide-ranging importance of the large-scale imperial public building projects of the city Rome is beyond dispute. These buildings feature prominently in any stylistic account of Roman architecture,[1] and in any discussion of Roman building techniques;[2] they also play a substantial role in debates on the political and economic life of the city.[3] At the same time the individual buildings, however familiar in general terms or as ciphers in particular arguments, remain somehow elusive. Part of this is due precisely to their very familiarity, a familiarity that both intimates a detailed knowledge which does not in fact exist and at the same time suggests an exhaustion of possible avenues of approach which is far from being the case. Very few of the public monuments of imperial Rome, including the better preserved examples, have been the subject of exhaustive documentation, and in many cases we are still reliant on 19th century and even earlier surveys; detailed and wide-ranging analysis is even rarer.[4] The Pantheon is, of course, the exception which proves the rule.[5] While this state of affairs is beginning to change some fundamental problems remain and much potential continues unrecognised.

The Baths of Caracalla are a case in point. No handbook on Roman or even world architecture

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1 e.g. Ward-Perkins 1981; MacDonald 1982, 1986; Sear 1982.

2 e.g. Van Deman 1912; Blake 1947, 1959, 1973; Lugli 1957; Heres 1983; Adam 1984.

3 e.g. Strong 1968; Zanker 1968, 1972, 1988; Gros 1976, 1978; Skydsgaard 1983; Frank 1940.

4 Cf. MacDonald 1982: Preface and Ward-Perkins 1981: 500, note to bibliography B. The series Lavori et Studi archeologici put out by the Soprintendenza Archeologica di Roma is just one recent attempt to rectify this problem.

5 As well as the major monograph by De Fine Licht (1968), there are two detailed treatments by MacDonald (1976, 1982: 94-121), and various articles on its design (e.g. Geertman 1980; Davies 1987).

is complete without at least a plan of the building, but this usually takes the form of a very small scale and hardly dependable reconstruction (Fig. 1). The lack of a dependable modern survey which was deplored by Hamlin in 1942 was still troubling Ward-Perkins in 1970, and could be repeated in 1981.[6] The only monograph published this century examines a limited number of problems concerning the central block.[7] For the most part our knowledge relies on the 19th century surveys by Blouet (1828) and Iwanoff-Hülsen (1898), a series of short reports on the late 19th and early 20th century excavations,[8] and now a number of valuable preliminary reports on new excavations and studies carried out in the 1980's.[9] Only in the last twelve months have the first results of a major scientific survey carried out for the Soprintendenza Archeologica di Roma been published, and the full account is eagerly awaited.[10] Because they are remarkably well-preserved and the best representative of the "imperial type" of baths,[11] the Baths of Caracalla feature largely in all recent general books on the subject, but none of them provides an accurate ground plan for even the central block.[12]

The value of a new survey is thus indisputable. In addition to being a straightforward record, such a survey will increase our understanding of the nature of Roman architecture. Detailed analytical

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[6] Hamlin 1942: 25; Ward-Perkins 1981: 130, note 10, repeated from the first edition of 1970. For a detailed discussion of the sources see Section 2.2.

[7] Brödner 1951.

[8] Pellegrini 1867; Lanciani 1869, 1879, 1881; Rosa 1873; Savignoni 1901; De Angelis 1903; Ghislanzoni 1912.

[9] Cecchini and Jacopi 1983; Cecchini 1985; D'Elia 1985; Iacopi 1985a and b; Petrassi 1985; Jenewein 1983 and 1985; Manderscheid 1988.

[10] Conforto 1991: Fig. 1, Figs 4-7. Sadly there are several errors in the elevations, which no doubt will be corrected in the final version.

[11] The term was originally used by Krencker 1929: 180, and is now in common usage, cf. Nielsen 1990: 4.

[12] Heinz 1983: 124-41; Brödner 1983: 220-29; Pasquinucci 1987: 104-107; Nielsen 1990: I.53.

discussions of the aesthetics of Roman architecture are surprisingly rare,[13] and the lack of detailed monographs on the most important buildings must again be a contributory factor. Of late, scholarly interest has turned to questions of Roman design principles and practices which are fundamental to any broader interpretation of Roman aesthetics,[14] but with the usual exception of the Pantheon this has not been attempted for any of the major buildings of Rome. Since the Baths are well-preserved in elevation, a design analysis would contribute to our understanding of Roman interiors, and since they are representative of a narrow building type, their particular design process can be tested against other examples and thus illuminate the principles involved in the creation of the type. In order to understand fully the aesthetic intent of any building, however, it is not sufficient to stop at the design process - we must also take into account the finished decoration. This is particularly important for concrete construction, where the stripped remains do not even begin to suggest the original effects of light and colour contributed by the decoration; the Pantheon is again the telling exception, and even there the full impact of the central lighting is diminished by the now dull grey of the surface of the dome. Although only fragments of decoration remain in situ in the Baths of Caracalla, the whole scheme for the central block can be reconstructed in outline if not in detail, and its role in the architect's overall design assessed.

The Baths of Caracalla ought also to play an important role in our understanding of Roman construction, but have been surprisingly neglected. Most studies of building materials and techniques in Rome have mainly been concerned with cataloguing individual items and techniques, often as a means of establishing dating criteria[15] but also as simple compendia.[16] In this the

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[13] See the comments by MacDonald (1982: 191-93); his later work (1986) is clearly an attempt to fill this gap.

[14] e.g. the works of Rakob (1967, 1969, 1974, 1984), Boyle (1981), Jacobson (1986), Wilson-Jones (1989), and the collections of essays in Le dessin and Bauplanung.

[15] e.g. Van Deman 1912, Blake (1947, 1959, 1973), Lugli (1957), Heres (1983).

[16] e.g. Giovannoni (1925), Adam (1984), Giuliani (1990).

Severan period as a whole has been badly served, the final study by Blake and Bishop (1973) reaching only to the end of the Antonine period, while Heres' more recent study of late Roman construction after AD 200 does not even include the Baths of Caracalla in the catalogue. Severan construction is discussed briefly by both Van Deman and Lugli, but in neither case is the variety of wall facing found in the Baths recognised.[17] Certain features have attracted attention; Rivoira discusses the vaulting with particular emphasis on the spherical pendentives in the octagonal nymphaea of the outer precincts, while there is a large bibliography on the "cella solearis".[18] What is missing is a comprehensive account of the fabric of the building and an analysis of the building techniques, however often a picture of the caldarium facade or frigidarium may be used to illustrate the wonders of large-scale Roman construction.[19]

The emphasis of most studies into Roman construction is, as we have said, on the cataloguing of details and rarely on the consecutive process of construction. In fact, wherever scholars have tried to give an overall view of the Roman building industry or constructional problems of Roman architecture, the result is usually a lot of verbal hand-waving ("vast amounts of material"...."huge numbers of men"...."complex organisation".. .."enormous"....etc, etc).[20] One of the few exceptions is Cozzo's analysis of the Colosseum;[21] brief as it is, his study at least begins to come to terms with the question of the organisation of the work-force and the logistics of the construction process. The lack of similar (and more detailed) studies is to be deplored but does not surprise,[22]

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[17] See Section 6.3.2 for further details.

[18] Rivoira 1925: 168-76. For the "cella solearis" see Appendix 3 with bibliography.

[19] e.g. Adam 1984: 84, fig. 175.

[20] e.g. MacDonald 1982: 143-66.

[21] Cozzo 1928: 195-253. Other similar kinds of investigation include Stevens 1966 on Hadrian's Wall.

[22] Two contributing factors must be the unpopularity of any kind of study originating in Mussolini's Third Rome, and the general absence of scholars with Cozzo's background of engineering and archaeology.

since these can only be based on a detailed survey of the fabric of single well-preserved buildings. On the other hand, there are several studies of various aspects of the building industry based on the literary and epigraphical sources which contribute to our understanding of the role of architects, contractors, and the collegia, but as ever these are rarely applied to a specific building project.[23]

The same problems apply when we look at the supply of building materials. The local geography of Rome and the surrounding region is well-known, and the potential sources for most of the raw materials of construction identified.[24] The organisation of brick production for the city of Rome has been studied through the evidence of the brickstamps,[25] while literary sources provide the basis of our understanding of timber supplies,[26] It is not surprising that the only other case in which there have been detailed studies of the supply of materials is for the imperial marble quarries scattered around the empire, since these too are rich in epigraphical evidence.[27] On the other hand, the supply of lime and of the temporary materials for construction such as scaffolding, both of which were required in quantity but have left very few traces in the written record, have scarcely been considered by scholars in any but general terms. In addition, these studies are rarely related to the problems of a particular building project.[28] Exactly the same is true for the production of individual materials; while the methods have been studied in detail,[29] attempts to relate these to the requirements of a single building are almost unknown.

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[23] e.g. Pearse 1975; Martin 1989; Coarelli 1979.

[24] Ventriglia 1971; Blake 1947: 21-44; Lugli 1957: 400-401; Frank 1924.

[25] Bloch 1947; Helen 1975; Setälä 1977; Steinby 1978, 1982, etc.

[26] Meiggs 1982: Chapter 8.

[27] e.g. Bruzza 1870; Dubois 1908; Ward-Perkins 1951, 1980a, b; Fant 1988b, 1989. For further bibliography see Section 4.2.

[28] Steinby 1974 on the Hadrianic buildings north of the Forum at Ostia is an exception.

[29] e.g. lime - Dix 1982; stone - Bedon 1984, Kozelj 1988; iron - Cleere 1971, 1976; timber - Meiggs 1982.

Detailed studies of single buildings have great potential to contribute to our understanding of the value and role of public building in both the politics and economics of the empire.[30] Public building always held an essential place within the Greco-Roman tradition of aristocratic behaviour, as the most durable form of that munificence and liberality by which the aristocracy, in peacetime, both made manifest and reinforced its position of superiority.[31] While ostensibly a public benefaction, often with overtones of piety to gods, city, or family, the creation of a new public building was in fact an active expression of the power to command resources of raw materials, manpower, and specialized skills. The larger, more sumptuous, and more technically difficult and/or elaborate the building, i.e. the more resources expended in the undertaking, the greater the impact.[32]

The Roman emperors were, of course, full heirs to this tradition. The building activity - or lack of it - of the emperors is regularly commented upon in the literary sources along with other aspects of imperial liberality such as lavish games, cash distributions or other gifts to people and army, or rich dedications in the temples. In the city of Rome, at least, this largesse was in theory funded from the emperor's own private resources, including the spoils of war, rather than by the state, although in practice the line between patrimonium and imperial fiscus was not at all well-defined.[33] In the literary sources there seems to be a direct equation between the legitimate use of power and the good emperors - Augustus, Vespasian, Trajan - who demonstrated suitable munificence and yet left money in both patrimonium and fiscus, and between the misuse of power and the bad emperors - Caligula, Nero, Domitian - who squandered both sources of finance on

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[30] Cf. the article by Skydsgaard 1983, where he outlines the potential influence of building the Colosseum on the Roman economy and finishes with a plea for more detailed quantitative studies such as that of Cozzo.

[31] Cf. Strong 1968: 101; Veyne 1990: 25-26, 106-107, 361-66.

[32] Cf. Aelius Aristides Orationes XXVII.18-21 on the Temple of Zeus at Cyzicus.

[33] For the debate see Jones 1960: 99-114; Millar 1963; Brunt 1966.

private rather than public buildings and entertainment, and had to resort to proscription and extortion even to maintain the army.[34]

Clearly the economics of liberality were important to its effectiveness as a display of power, yet remarkably few figures for specific expenditures have survived in the written sources.[35] Those that have, for example in the Res Gestae of Augustus, refer almost entirely to cash gifts to the urban plebs of Rome or to the army.[36] Very few public building costs survive for Rome, and few of those that survive from elsewhere relate to actual remains, or allow us to extrapolate the probable costs of building projects in Rome itself.[37] Yet without even an estimate of the costs of construction it is not possible to evaluate the relative significance - in terms of political investment - attached to, say, building a set of baths compared with a distribution of cash to the urban plebs. In addition, as is now generally accepted, one of the attractions of public building compared with other forms of largesse was that it could provide consistent employment for a large number of both skilled and particularly unskilled labour over a substantial period of time.[38] It would be useful, therefore, not only to know the cost of these buildings, but also the amount and type of labour that would have been employed on their construction. Without literary evidence, this can only be done by detailed analysis of individual existing buildings such as the Baths of

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[34] This is a recurrent theme in Suetonius, and cf. Pliny, Panegyricus, 25-29, 36-43, 50-51. In general see Frank 1940: 4-88, with ancient sources.

[35] There is nothing to compare with, for example, the Greek building accounts studies by Burford 1969.

[36] See note 33.

[37] See Duncan-Jones 1982: 157-62, 90-93 for inscriptional evidence relating to building costs in Italy and Africa respectively. For Rome we have costs for the Aqua Marcia, and for the Aqua Claudia and Anio Novus.

[38] As demonstrated convincingly by Brunt 1980, and taken up inter alia by Garnsey 1981: 368-70, Steinby 1983: 221; Skydsgaard 1983: 225.

Caracalla.[39]

It is surprising that buildings have not been seen in this light more often. Unlike the pottery or amphorae on which so much archaeological evidence for the Roman economy is based, with well-preserved buildings such as are relatively common in Rome we are at least sure of the size of the "deposit", of its date of "deposition", and of the fact that this is a primary rather than a secondary "deposit". In other words, the single building reduces the variables in the calculations, since it provides the quantities of materials and labour and, by being fixed in space, allows sensible assumptions about specific sources and transport requirements of building materials. The reconstruction of the original phase even of buildings with a long history is likely to be far more complete and accurate than any attempt to reconstruct the full extent and history of, for example, the great amphora deposit at Monte Testaccio. In addition, for buildings with a clearly identified construction period such as the Baths of Caracalla, the total quantities can be spread over a fixed time to establish the actual numbers of men required at any point. With the exception of a few materials such as marble and metals, buildings admittedly cannot tell us much about long-distance trade and economy; but they are ideally placed to inform on demands for both raw and worked materials, and for skilled and unskilled labour, in Rome itself and its closer and more distant environs.

Starting, therefore, from a detailed survey and reconstruction of the building itself, this thesis pursues two main objectives. The first is to identify the problems faced and the solutions found by the architects and builders of the Baths; design decisions, choices of materials and methods of construction, questions of organisation and logistics, and alternatives for decoration are all

[39] The recent attempt by Thornton and Thornton (1989) to create a pattern of manpower usage and to a lesser extent a pattern of expenditure on public building in the Julio-Claudian period is based primarily on an arbitrary set of relative values of dubious validity. See the reviews by Anderson (AJA 1990: 515), Herz (Gnomon 1991: 131-35), and Darwall-Smith (JRS 1991: 211-12).

investigated, as are the relationships between them. The second aim, following on from the first, is to quantify the individual materials and actions which went into the building of the Baths, and thus to quantify the producers themselves in their various categories, from quarryman to building labourer, from carter to decorator. Ultimately this will enable us to count the cost - in terms of human resources and monetary equivalents - of the emperor's decision to build.

1.2 GENERAL METHODOLOGY

1.2.1 The nature of the survey

Ideally this thesis should start from a complete measured survey of the whole complex. Unfortunately, as we have seen, at the time this thesis was begun no published survey existed in sufficient detail to form the basis for the kind of analysis proposed here, and the results of the Soprintendenza's survey were published too late and in insufficient detail to be used. Given the problems created by the scale of the building it has not been possible to produce such a detailed survey, requiring as it does access to sophisticated surveying equipment, extensive scaffolding, and a team of skilled draughtsmen - well beyond the resources of a doctoral student.

The documentation process followed does, I believe, provide an adequate substitute for the ideal situation. By concentrating on the original construction period it was possible to ignore the peripheral buildings and concern myself only with the substructures and the central bathing block (see Section 2.3.1). All accessible parts of the building were measured room-by-room in plan using thirty-metre tapes, and are accurate to the nearest centimetre.[40] The elevations were sketched roughly to scale, the main features such as door and window heights, vault springings, and the bonding courses (where visible), measured directly or with a theodolite. As far as possible a detailed photographic record was made, although difficulties were met due to the great height of

[40] Thanks are due to the British School at Rome for the loan of equipment, and to numerous of its residents and visitors who assisted in the survey (see Acknowledgements).

many of the walls and the relatively constricted space which limited the viewpoints. Opportunity was taken to examine some of the upper levels when scaffolding was in place, while on two occasions a hydraulic lift made it possible to examine some of the high vaults and the terraces.[41] The detailed reconstruction of this part of the Baths (Sheets 1-7) was then based primarily on the survey but supplemented as necessary from earlier materials; the sources and detailed arguments are presented in Chapter 2.

For the substructures, on the other hand, I have had to rely on published material supported by personal observation, but few new measurements since access even to those areas which can still be visited was limited. Fortunately, reasonable plans and sections of the structures under the central block exist, and the peripheral substructures can be reconstructed by combining different published sources.[42] Valuable information has been provided by a series of geological cores taken through the platform of the Baths as part of the Soprintendenza's recent programme of works at the site.[43]

1.2.2 Principles and Problems in Quantity Surveying

> "The prime cost of materials and labour, including land carriage, freightage, and all manner of incidental expenses, is the intrinsic value of every sort of work...And in order to find the value of labour, it will be requisite to ascertain what number of workmen, of moderate abilities, can execute given portions within given times, the value of which...added to the value of the prime cost, will...produce correct prices." [44]

This quote from Richard Elsam's The Practical Builder's Perpetual Price-book of 1825 contains

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[41] I am grateful to Prof. Lucos Cozza, formerly head of the archaeological service of the Comune di Roma and his colleagues from the Servizio Giardino for providing this service.

[42] Central block - De Angelis 1903. Peripheral structures - Blouet 1828; Iwanoff and Hülsen 1898: Tav. A; Ghislanzoni 1912; Cecchini 1985; D'Elia 1985, Iacopi 1985a.

[43] Petrassi 1985. I am grateful to Dott. Petrassi and Dott. Corazzo for discussing their work with me.

[44] Elsam 1825: 11.

the key to quantitative part of this thesis. The fundamental assumption is that it is possible to work back from a finished structure to its component elements, and to cost those elements. A building - any building - results from the application of a specific number and type of actions to a specific number and type of materials. In a society which uses non-mechanised modes of construction, any building can thus be expressed as a specific number of man-days over several categories of labour. The basic cost of the building is then the cost of this labour (varying from category to category according to the skill involved) plus the cost of materials, to which should be added some factor for profit. Since nearly all building materials in their natural state have no intrinsic value and their production is in turn definable in terms of human action, their cost is the cost of that action plus the costs of transport to the site and any profit.[45] The exceptions to this are few, but include large timbers and high status materials such as marble. If we can reconstruct a given building in detail, we should thus be able to reduce it to a specific series of, and a specific number of, identifiable actions lasting a specific time, and, if the price of labour is known, having a specific cost. It is, in reverse, the type of exercise described by Elsam and from which modern quantity surveyors make their living; nor was it unknown in the ancient world.[46]

1.2.3 Methods of "Deconstruction"

In practice, of course, there are a number of difficulties in applying this method to any ancient building. The first is that of reducing a building to its constructional elements ("deconstruction"), an exercise which obviously becomes more problematical as the complexity of the structure increases. The nature of the materials used affects the type of construction, and the ease with which its component elements can be determined. In this respect concrete and ashlar construction

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[45] This is, of course, one of the essential assumptions of Marxian economic theory, although Marx went further and eliminated the differences in labour which are of particular interest here.

[46] On ancient building surveyors (mensores aedificiorum) see De Caterini 1935: 276-77; Friggeri 1985. Among the numerous literary sources for the estimation of building costs see: Cato Rust. 14.3; Vitr. de arch. I.4; Quint. Inst. 11.21.18; Dio Cass. LX.11.3.

both have advantages and disadvantages.

The Baths of Caracalla are predominantly of concrete construction, but incorporate substantial columnar orders both as structural elements and as decoration. For the orders, it is relatively easy to identify and count the individual pieces but difficult to estimate the work put into preparing and setting them in place, since ease of working depends on the characteristics of the stone in question, and the individual items cannot usually be handled by a single person. A wall in brick-faced concrete, on the other hand, is composed of a brick and mortar skin of variable depth, a core of irregular fist-sized pieces of aggregate in abundant mortar, plus a certain amount of brick passing through the core in the form of arches and bonding courses. At the same time, the mortar is itself a composite material, and its finished overall volume does not as a rule equal the sum of the volumes of its component parts. Thus although its individual elements are small, the finished material is not easily reducible to its component parts, and it is easier to identify and count actions than to quantify materials.

A particular problem is presented by the materials which are used only during the construction process: ropes, poles and planks for scaffolding; timber and nails for foundation shoring and vault formwork; pulleys, ropes and cranes for lifting; baskets and hods for transport; and tools. Here it is difficult to determine the actual consumption of materials, since the time factor is important. For example, more formwork is required if all the vaults are laid at once than if the formwork can be moved from one place to another. Even if we decide on the frequency of reuse, we still need to take into account the viable life-span of the individual items.

1.3 MAN-POWER ANALYSIS

Once the quantities of materials have been identified, we are faced with the problem of assigning values to the actions concerned, in terms of both time taken and levels of skill. Only occasionally have such figures come down in the ancient literary sources, and those that exist refer almost exclusively to agricultural tasks, mostly from Columella. Although some of these activities, such as digging ditches and squaring timber, are of relevance to construction, there are sufficient problems related to the accuracy of the figures in general for it to be necessary to provide some independent checks.[47]

The solution to this, I believe, lies in an ethnological approach; not the familiar ethnography of primitive societies, but that of any complex urban society where large-scale construction is or was carried out without artificial means of power, i.e. virtually any urban society until the 20th century. For the production of materials, more recent ethnological studies of societies still or very lately using traditional methods of extraction and production can be added, and these are supplemented from the results of experimental archaeology. This kind of approach has already proved invaluable in ceramic studies,[48] and there is no reason that it should not be equally fruitful when applied to the building industry.

1.3.1 Sources

The precise data used to establish the work-units for any single building material or process are discussed in the relevant places below, but a few general comments need to be made here. The most useful sources of information on the labour constants for various building activities are a series of mainly 19th-century guides to building estimating. These describe tasks in some detail, and give a breakdown of the estimated costs. Many simply give the costs for the materials and wages, without any indication of the time taken for the task, and these are only of use for establishing relative times for various tasks. A few indicate the amount of work reasonably

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[47] See White 1965 for the internal inconsistencies in Columella's figures for various tasks, and cf. Duncan-Jones 1982: 327-33.

[48] See, for example, Peacock 1982.

expected of a man engaged in a specific occupation over a given time, and it is these which have provided the basic data for my analysis. On the whole I have used English sources, supplemented by some from France. No equivalents seem to have existed in Italy until well into the 20th century, although these would obviously would have been preferable as being more directly relevant to the situation in Rome.

The most detailed and comprehensive set of such constants is Hurst's Handbook for Architectural Surveyors of 1865, which was much referred to by contemporaries and quoted in later guides to building estimating, such as Rea's How to Estimate of 1902. I have used Hurst's figures wherever possible as a starting point, supplemented from other independent[49] accounts as and when necessary. Apart from the obvious convenience of working from a single source, it also has the advantage of being internally consistent. One of the problems with using these sources is establishing precisely what activity any given constant refers to (e.g. for a man digging, whether it include removing the earth from the hole and to what distance). This naturally makes any amalgamation of information from a number of sources difficult. On the whole, however, where it has been possible to check Hurst's figures against independent sources, they have always been of the same order of magnitude and usually within ±20%. This comparison holds good from the later 18th century (the earliest available figures) to the start of the 20th, but breaks down for figures referring to periods after the First World War. There seems to be a double explanation for this. Firstly, there was increased mechanization due to the growth in the use of both electricity and petrol motors in the building trade. Secondly, attitudes to labour changed and rather less was expected from a labourer for an hour's work; comparison between basic rates for a labourer digging and filling barrows per cubic yard in 1865 and 1951 shows that almost twice as long was

[49] Since so many later handbooks themselves were based on Hurst's figures, these were not deemed to provide an independent account. The continued use of Hurst's figures does however suggest that these were at least realistic.

allowed in the latter case.[50] I have therefore avoided sources later than 1910.

Slightly different sources are required for the production of building materials. Once more these include 19th-century treatises such as Dobson (1850) on brick and Burnell (1850) on lime and mortars. Since mechanization affected the production of building materials at a much earlier date than the construction process, these treatises are often more interested in the new rather than the old methods of production, but include the latter for comparison. In addition to the precise data provided by these treatises, I have also made use of less direct sources. The most important of these are the building accounts of Renaissance Florence and Baroque Rome. A recent study of the latter in relation to the 17th- and 18th-century building industry by Scavizzi (1983) has proved invaluable. Here both the materials used and the scale of operations - in the building of new St Peter's in Rome, for example - surely take us close to ancient Roman practices.

1.3.2 Assumptions

In order to make use of these later sources, ideally we need to show the relationship between the conditions prevalent in the Roman world and those in the ethnographic sources. This can, of course, only be done in a very general way given the limitations of the ancient evidence. Assumptions have to be made, for example, on the equivalence of the raw materials of building and the ease or otherwise of their extraction and processing, as well as on the conditions of labour. The results obtained will depend heavily on these initial assumptions, and can at best only represent one possible and hypothetical solution.

In defining the initial basic assumptions I have preferred choose the alternative which provides the greatest possible output, leading to the minimum result in terms of number of work-units and

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[50] Hurst (1865: 212-213) - 1.28 hours (0.070 + 0.058 = 0.128 days for a ten-hour day for loam); Bailey (1951: 17) - 2.25 hours.

ultimately therefore to the lowest possible cost. This will at least produce a secure base line both for manpower requirements and costs. The opposite - looking for the minimum output - would be ludicrous, and there is no sense in using an average of maximum and minimum. The only other real alternative would be to choose a "reasonable" figure in all instances, but the cumulative effect of a series of subjective estimates would leave the final figures less secure than they are anyway. I have not been as rigorous in assigning actual values for specific tasks, since most of the sources for these are themselves based on average values; in most cases, the chief criterion has been the compatibility of the ancient task as I perceive it with that described in the source. Where different sources have produced a range of values I have either taken an arithmetical average (e.g. in the fuel requirements for lime burning), or argued in detail for a reasonable figure (e.g. on manpower requirements for brick making).

The following general assumptions have been made:

1 The average output of a man at work at a given task, using equivalent tools, was the same during the Roman empire as during any later period before the 20th century. This applies both to manual labour such as digging, and to the capacity to handle loads either directly or through some mechanical device. The awareness of the relation between productivity under heavy labour and nutrition shown, for example, by Cato in the rations assigned to his slaves and implied also in Diocletian's Prices Edit where a workman's wage included food, strongly suggests that Roman workmen would not have suffered a serious nutritional disadvantage compared with those of later periods.[51] There is, of course, no way of knowing how hard Roman labourers did in fact work, but by assuming that all the men worked at all times to the best of their abilities, the resultant figures will naturally represent minimum levels of labour.

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[51] Cato, Agr., LVI. For the Prices Edict, Section 7.1, see Lauffer 1971: 118-19.

2 The average working year on the construction site is assumed to consist of nine months totalling 220 days. Frontinus (Aq. 123) gives the period for concrete construction as the Kalends of April to the Kalends of November, excepting the hottest days, because, as he quite rightly remarks, the setting of concrete is affected by extremes of heat and cold. Given the climate of Rome, there is no reason why this period could not be extended by two months to include March and November, as usual in the interests of minimising results. On the other hand, it is unlikely that the combination of adverse weather conditions (both excess heat and the typically Mediterranean torrential downpours) and allowance for feriae would have permitted work to be carried out every day of those nine months. In the first century BC there were 49 days set aside in the Roman calender for feriae, and these increased so much during the empire that Marcus Aurelius tried to limit them to 135.[52] Unfortunately we have no way of knowing to what extent the feriae affected public works or how many of the days which could be taken as "holidays" actually were. Did work on imperial building projects stop, for example, on days devoted to the imperial cult? Some cessation of labour is to be expected for the major Roman celebrations of the building season such as the Parilia on 21 April,[53] the Ludi Romani in September, the Ludi Plebei in November. The figure of 220 days was chosen because it both gives an average of at least one day off in eight (equivalent to the nundinae and roughly the average for the Republican feriae) with some to spare and it is the maximum number of days which could have been worked in the seven month season suggested by Frontinus. For work outside of the building site, such as the working of stone and timber, and for quarrying around Rome, it is assumed that a 12 month year of 290 days (i.e. allowing the same rate of days/month as the shorter season) was worked.

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[52] See Michels 1967: 69-82 for the Republic and Salzman 1990: 120-185 for the empire.

[53] Converted to a festival in honour of the city of Rome by Hadrian, and said by Athenaeus (Deipnosophistae, 8.361f.) to have been celebrated by all who lived or chanced to be in Rome at the time. See Boatwright 1987: 121-33.

3 The average working day is assumed to be 12 hours. Burford uses a working day of 8 hours for calculating the number of men engaged in building the Temple of Asklepios at Epidauros,[54] but I believe this to be too short. Textile apprentices in Roman Egypt were expected to work from sunrise to sunset,[55] and this appears to have been the case in agriculture also. Columella (Rust., XI.ii.90-91) comments on the advisability of finding tasks which can be done on the farm by artificial light in the short winter days so as not to waste too much time. Since he gives the length of the day as 9 hours and the night as 15, Columella must be operating on a uniform 24 hour clock, and from the tasks given for the night hours he seems to be envisaging a total working day of about 11 hours;[56] there is an underlying assumption that all the daylight hours were normally used. Working days for builders in urbanised pre-20th century societies tended to vary between 10 and 12 hours e.g. Hurst assumes a 10-hour day, while modern Turkish quarrymen still work roughly 10 hours; a 12-hour shift is still often worked in the construction industry today, although part of this is now counted as "overtime". A 12-hour day presumes that builders made use of all the available daylight, a reasonable assumption for central Italy if construction was not normally carried out in the short winter months. For simplicity, I have applied this 12-hour day even to occupations such as quarrying which might have continued during the winter; the errors involved should not unduly affect the validity of the final figures, and always in the direction of minimum manpower requirements.

4 The maximum load that a man can carry over a short distance is assumed to be 51 kg, the

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[54] Burford 1969: 247

[55] P.O. 1647; BGU 1021; see Johnson 1936: 392.

[56] e.g. in XI.ii.12, where he envisages extra work both before dawn and after dark.

equivalent of the imperial hundredweight.[57] It is in fact unlikely that a man could carry such a load more than 40 to 50 metres, and the normal load for carrying over distances between 50 and 400 metres is perhaps little more than half that, say 25 to 30 kg.[58] Nevertheless, I have used the higher figure as a ceiling throughout, again in the interests of producing the highest possible output and the lowest possible figures for manpower requirements, although in fact the volume of material and the nature of the container carried often combine to reduce the load below this maximum.

1.3.3 The nature of the workforce

Two points require consideration here. Firstly, the post-classical sources for labour constants assume that this is provided by men rather than by women or children. On the whole, the physically heavy nature of building labour makes this a reasonable supposition for most of the workforce. There is, however, the likelihood that women and even quite young children could be employed in the production of some materials in the guise of fuel collectors[59] and for work of a lightweight nature, for example in producing ropes and baskets, or in the making of bricks. There is also little doubt that skilled workers were trained on the job, so that there is always an uncountable number of adolescents to take into consideration. Nevertheless, the nature of the manpower sources constrains me to assume that the workforce is composed entirely of men. In practice, this yet again works towards minimising the numbers employed, since a man can do the work of two women or boys, while it should not ultimately make much difference to the cost for the same reason.

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[57] Cf. Hurst 1865: 70. Cotterell/Kamminga 1990: 193-94 provide examples of even higher loads from the ethnographic record.

[58] See Landels 1978: 171.

[59] Cf. Apul., Met. VII, 17-20.

The second point is that I do not intend to make any distinction between slave and free labour, since the legal status of the workman is not likely to affect his potential output. The arguments for much unskilled labour being provided by the free urban poor are strong,[60] and now generally accepted. It is also clear that skilled workers, from architects to mosaicists, could be slave, freedman, or free-born, and while the best way to learn a trade was either as a slave or a young relative of an officinator, free-born boys were also taken as apprentices.[61] Consideration of the organisation of the workforce will be left until Chapter 9.

1.4 COST ANALYSIS

The most difficult problem is determining the cost of labour for any given ancient building. For the world of imperial Rome, this depends heavily on the Prices Edict of Diocletian, which provides a related set of maximum prices and wages covering many aspects of the building industry, as well as giving some indication of transport costs. With the discovery of the Aphrodisias and Aezani fragments the text is substantially complete, although some of the prices are missing, and the end of the section on transport is somewhat mutilated.[62]

Without the Edict it would be impossible to gain any idea of the absolute cost of, as opposed to the number of man-hours required for, the labour on the Baths. Since the cost of most building materials is directly and mainly related to the amount of labour required to produce them, plus the

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[60] Brunt 1980; Treggiari 1980.

[61] See Treggiari 1980: 49 and note 4; Pearse 1975: Chapters 4-6 for the status of architects, the members of the collegium of fabri tignuari, and ordinary building workers; Laucha 1984 for the status of mosaicists in Spain.

[62] For the most complete text, with apparatus criticus and translation, but no notes, see Giacchero 1974. Lauffer 1971 provides notes to the text as it stood at that date; the Aphrodisias fragments are given in an Appendix. Reynolds-Crawford 1977, and Crawford-Reynolds 1979 provide a new edition and commentary on the Aezani fragments, superseding that used by Giacchero.

costs of transport,[63] the Edict also helps us calculate the cost of these materials. The only real exceptions seem to be long building timbers, for obvious reasons, and marble, where fashion and status come into play.[64] Fortunately in both these cases the Edict supplies actual prices, as it does for other materials which are difficult to estimate in terms of labour, such as fuel or rope. In a few instances, particularly with regard to brick, the existence in the Edict of both prices for finished objects and wages should provide a rough check on the labour calculations.

Unfortunately, scholarly opinion so far is not agreed on the exact context, and therefore the precise relevance, of the individual prices given in the Edict. Since it sets a scale of maximum prices, the question arises of what relationship any of these have to actual market prices, and in what part - or parts - of the empire they were relevant. The findspots of the fragments, concentrated in Greece, Asia Minor, and the eastern Mediterranean, with only one (and that in Greek) from Italy and none from further west, strongly suggest an eastern origin and ambit for the Edict, most likely Diocletian's new capital at Nicomedia. Nevertheless, the inclusion of transport costs by sea between western ports, e.g. Africa to Spain, Rome to Gaul, suggests a more widespread relevance, although it should be noted that the actual ports mentioned (as opposed to general destinations) are all, Rome excepted, in the east.

A more profitable approach has been taken by Frézouls (1977) and Corbier (1985), by focusing on the relative values of items within the Prices Edict. One possible standard against which to compare prices is the price of corn, a standard also favoured by Duncan-Jones.[65] Despite the

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[63] Cf. the comments by Goldthwaite 1980: 124 with respect to the construction industry in Renaissance Florence.

[64] Even here the most costly marbles are either the hardest to work or travelled the greatest distance overland and/or by river before reaching the Mediterranean (see Section 4.3.5).

[65] Duncan-Jones 1978.

reservations of other scholars,[66] this is the only conceivable course to take if we wish to compare prices between different periods, or convert costs at the time of the Edict into their equivalents in any other period. The validity of assuming a stable relationship between the price of gold, corn, other staples, and labour, has been shown by Corbier in a recent article (1985). Her comparisons between wages and corn at the time of Augustus, Nero and in the Prices Edict shows that the price of corn, wine and oil increases slightly (10% or less for ordinary grades) with respect to gold between the time of Nero and the Edict, while wages decrease slightly (about 10% for the higher grades), although this difference would have been mitigated, particularly in the lower grades of pay, by the inclusion of food as part of the wage. The differences in relative values are not, to my belief, sufficient to invalidate the use of a corn standard, at least for wages. Although Corbier also shows that the differentials are greater for luxury goods, she only really considers spices, the prices of which would not be so closely related to simple labour and transport costs as would be the production of building materials. Therefore I have assumed that all building-related values from the Prices Edict can be converted into corn equivalents which were also valid at the time of Caracalla. Costs will thus be expressed initially in KM, the kastrensis modius of wheat, where each KM is equivalent to 100 denarii.

Prices for labour require a further adjustment. The Edict gives maximum wages for the skilled trades - masons, carpenters, lime-burners, marble workers, mosaicists (both floor and wall), wall painters, smiths, brick-makers, and stucco-workers - and for agricultural labourers, with whom unskilled building labourers can most probably be equated.[67] With the exception of brick-making which is paid as piece work, the wages are for a day's work, and all, including the brick-producer, are given food as well (pasto diurni). The skilled workmen all earn 50 denarii, or 0.5 KM, plus

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[66] e.g. Sperber 1978: 165-66, who doubts both the possibility of arguing from one section of the Edict to another, and the feasibility of converting to wheat equivalents.

[67] Prices Edict: 7.1-11, 15, 30.

food, although the "artists" - marble worker, wall mosaicists, and wall painter - earn 60 denarii; the unskilled worker receives only 25 denarii, 0.25 KM, plus food. If we assume that the food supplied is equal to the normal corn dole of 5 modii/month irrespective of the rate of pay, then, this is equivalent to an extra 0.11 KM/day.[68]

The costs determined from the Prices Edict are, of course, some kind of market costs. To what extent do these represent the "real" cost to the state? Clearly in the case of marble and bricks, where the raw materials at least are owned by the emperor and the extraction and production under imperial administration, the cost to the state should be no more than the cost of labour and transport. In the case of marble, there is some evidence that a part of the labour force consisted of condemned prisoners, that transport for major items could be requisioned, and that the state had a monopoly on certain types of this high status material, the distribution of which was restricted and presumably the price well above cost. At the same time, we are constrained into using the "market price" obtained through the Prices Edict, which ought to be much in excess of the cost to the state. Nevertheless, there is some justification for using the values of the Prices Edict. Some at least of the marble quarrymen were free, highly skilled, and hence presumably paid, while even the use of condemned prisoners is not without cost since they still need to be fed and demand a high level of supervision. More importantly, since marble could be bought openly, the use of it in imperial building schemes represents a depletion of resources and a loss of external income and thence a cost to the state.

The same arguments concerning the loss of income can be used for the brick, although since here the price has been calculated only in terms of labour and transport (see Section 5.4) the difference in cost to the state would not be as great. There is no clear evidence for any other of the sources

[68] See Duncan-Jones 1976 for the relationship 1 KM = 1.5 Italian modii. It is not necessarily the case that the food would be of the same value for different rates of pay, but this gives the lowest estimate. On this point and the value of these wages, see Frézouls 1977: 260-66.

of building materials around Rome being in imperial hands, although it would not be surprising if the state owned at least the major selce quarries and extensive stands of timber. Nevertheless, assuming that no condemned labour was used in the quarries, the state still had to pay the costs of extraction and transport, and the most likely mode of operation was the contract system used in brick production. In these cases some element of profit for the producers must have been included in the cost to the state, but we have no way of knowing what this might have been. On the other hand, by omitting this element and simply costing the actual labour, we are again tending towards the minimum case. Thus it seems reasonable to count the full cost of production and transport without any added element for profit as the "real" cost to the imperial purse, and to accept the price of marble as shown in the Edict as an equivalent loss of income, provided we realize that this does not always represent any actual outlay in terms of hard cash.

1.5 DEGREES OF ACCURACY

One difficulty with quantitative studies is determining the degree of accuracy at any particular stage of the calculations, especially where the base figures are both of widely different degrees of validity and of very different orders of magnitude. The problem is exacerbated when such different figures have to be multiplied together. The most useful method of identifying the degree of accuracy in such circumstances is by significant figures[69], as these function irrespective of orders of magnitude. In any calculation, the number of significant figures in the final result should never be more than that of its component elements, and would normally equal the component with the lowest number of significant figures. Where a digit represents an exact number (e.g. 3 represents the integer rather than, say, 3.00078), or an exact number within the range of significant figures of the calculation (e.g. 3.00078 to three significant figures is 3), the number of significant figures in the next element is taken. For extended series of interconnected calculations involving different

[69] Defined as the digits 1 to 9, plus any zeros appearing between them. Thus 3.15, 0.00703, and 45,600 all have three significant figures.

orders of magnitude, however, it is advisable to retain a higher number of significant figures in the intermediate stages than is strictly accurate to prevent distortion of the final results.

The measured survey of the central block on which much of this thesis is based is accurate to the nearest centimetre. Where the plan and elevations could not be measured and had to be scaled off earlier surveys or photographs, the accuracy cannot be assured beyond the first decimal place of a metre. Even so, over the largest single measurements this gives a minimum of three and a maximum of five significant figures. In calculating areas and volumes of construction and quantities of materials, however, the final figures are expressed only to three significant figures. The manpower figures from the 19th-century handbooks are given usually to three significant figures, but this is a false accuracy and particularly when applied to the ancient situation should only be considered valid to two figures at the most. However, because these represent very small units - usually fractions of days - and the quantities of materials and work in the building are usually in their hundreds of thousands of such units, these figures have been maintained in many of the intermediate stages of calculation to avoid the distorting affect of too much rounding up of the figures. The costs, on the other hand, have been calculated throughout to three significant figures. The final figures for both manpower and costs are likely to be correct to the first significant figure (i.e. they give the right order of magnitude) but doubtful in the second, perhaps as much as $\pm$ 50%. Nevertheless I have retained the second figure to give some indication of where I believe the actual figures may have lain.

CHAPTER TWO: THE BUILDING

INTRODUCTION

The site chosen for the baths, south of the Porta Capena along the Via Appia, was terraced to create a platform from which rose the bathing block proper surrounded by gardens. The garden is bordered by porticoes with libraries and other halls opening off, while extensive subterranean service areas are incorporated in the platform. The bathing block follows the normal pattern for the imperial thermae, with a cross-vaulted frigidarium at the centre of an axially symmetrical scheme flanked by a large open-air natatio and a circular domed caldarium. Secondary rooms - entrances, lounges, dressing rooms and hot rooms - are duplicated about the short axis while a pair of porticoed palaestrae close the transverse one.

Since it is not the purpose of the thesis to present a detailed description of the existing remains, this chapter concentrates on the basis for the reconstruction of the initial phase of the building, dating roughly to the period AD 212-216. The discussion will therefore concentrate on the terracing substructures, the subterranean service areas and the central bathing block, with very few comments on the buildings of the outer precinct. The chapter will look first at the present state of the building and the evidence from secondary sources. The dating of both the original structure and the later phases of the central block will be treated next, followed by specific problems of the restoration. The final section explains the presentation of the evidence and the reconstruction drawings.

2.1 THE PRESENT STATE (Fig. 2)

Although remarkably well-preserved in comparison with most other large-scale ancient structures in Rome, the Baths suffered a number of renovations during more than three centuries of operation, followed by fourteen centuries of neglect during which they were frequently mined for materials. During the last century the site has been a State monument, but extensive restoration and the invasion of part of the structure by the permanent installations of the Rome Opera have both helped to obscure many details.

The outer precinct has fared rather badly. Only an isolated pier remains of the upper level of barrel-vaulted chambers forming the entrance facade to the north, while the lower level chambers are overgrown and inaccessible (Fig. 3). None of the colonnade surrounding the garden remains in situ, although numerous fragments of red Assuan granite columns from it lie scattered about the garden area. The base of this colonnade was found during excavations early this century on the south side of the precinct, and more foundations have emerged in recent excavations in front of the eastern exhedra.[1] The rooms opening off the portico are quite well preserved on the west side (Fig. 4), but, with the exception of the octagonal room, very poorly on the east. Recent excavations in the south and east of the precinct have uncovered structures visible until last century (buildings of the east exhedra, stadium and cisterns), or discovered in excavations earlier this century and since reburied (monumental staircase to Aventine in SW corner, Fig. 5), and also new elements, particularly the series of service rooms behind the west library.[2] In the south-east corner of the platform, close to the central block, is a large exposed excavation of the 19th century with the remains of an imposing second century house.[3]

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[1] Ghislanzoni 1912: 314-15, Fig.1; Iacopi 1985a: 579, Fig.1.

[2] For these excavations on behalf of the Soprintendenza Archeologica di Roma see Cecchini-Iacopi 1983; Cecchini 1985; D'Elia 1985; Iacopi 1985a; Manderscheid 1988.

[3] See Castagnoli 1949-1950; Carpano 1972; Iacopi 1985b.

The walls of the central block (Fig. 6) survive to almost their full height, with the exception of the four piers of the caldarium which project beyond the south boundary (Fig. 7), the block between caldarium and tepidarium (Fig. 8), the tepidarium itself, the corner piers of Rm 19, part of the wall and the pier between Rms 21 and 22, the piers 8/9/10, and the walls above most columnar screens. Not all of the block is equally accessible; permanent installations belonging to the Rome Opera obscure part or all of the area of the caldarium, tepidarium, Rms 15, 16, 18, 20E, and 23 (Fig. 9), while Rms 15, 16, and 17W are only visible for a brief time while the stage for the opera is being erected or dismantled, and access to these areas was necessarily limited.

Four general statements can be made about all surviving areas of the central block, with the noted exceptions:

1 None of the original vaulting remains intact in the above ground structures apart from Rms 2W (heavily restored), 7, 11, 16, NE and SE pools and north central bay of the frigidarium. The vault of Rm 17W is modern.

2 None of the elements of the columnar orders remain in situ, apart from a pilaster base in Rm 5/6W, a corbelled architrave block on the north facade over the door to Rm 5W, and the corbelled supports for the order framing the niche in the south central bay of the frigidarium. The architrave and frieze in the E palaestra are a reconstruction. Isolated fragments survive in various areas of the Baths and/or were recorded during the Renaissance or from later excavations.

3 None of the wall and vault decoration remains in situ, apart from very small fragments of marble dado in Rms 3W, 4/5/6, and 17E, one fragment of wall veneer in Rm 14W, a small area of painted stucco in Rm 8E, and several scattered glass mosaic tesserae in Rms

1W, 13, 14W, natatio pools, and frigidarium. Preparation layers for marble veneer and stucco or mosaic survive in many areas, sometimes preserving the pattern of the veneer.

4 Little of the brick facing remains, and there are extensive areas of modern refacing. The facing survives in most places below the level of the second bonding course in rooms where the vaulting has fallen (e.g. 1, 4/5/6, 14, 17, F), and below the level of the first bonding course or not at all in rooms where the vaults remain intact or were of brick and deliberately dismantled (2, 3a-d, 7, 11).[4] Some substantial patches of brick survive in other areas, particularly in the upper parts of the walls.

The reasons for this state of affairs are clear. Looting of the marble decoration began at least as early as the 11th or 12th century (when material from the Baths found its way into the fabric of the Duomo at Pisa,[5] and Sta Maria in Trastevere[6]) and continued into the Renaissance and later.[7] What remained in the central block appears to have been thoroughly stripped on behalf of Pope Paul III (Alessandro Farnese) in the 1540's. One surviving column from the frigidarium was given to Cosimo Medici in 1561. Despite Fea's battle with the Vatican authorities to stop such depredations in the 19th century, digging continued, and the Vatican haggled with the Conte di Velo over the material from his excavations of 1824-5.[8] Some of the marble must also have been used to feed lime-kilns at the Baths, one of which has been found in the west exhedra of the outer

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[4] Note the comment of Blouet (1828: Preface) that "toutes les parties inférieures...depuis plusiers siècles étaient enfouies sous 4 à 5 mètres de terre et décombres..."

[5] I am grateful to Dttssa Giovanna Tedeschi Grisanti for this information.

[6] Kinney 1986.

[7] Lanciani 1902-1904: passim.

[8] Fea's frustrations with the authorities comes out in his correspondence with the Vatican officials. See Biblioteca dell'Istituto della Storia dell'Arte e dell'Architettura, Mss Lanciani 117: 30, 76, etc. For the material from di Velo's excavations bought by di Velo or kept by the Vatican, see Gasparri 1983-1984: 137, and Mss Lanciani 116: 45, 50 for that left in the Baths.

precinct; other material went into the foundations of new St Peter's in Rome.[9] The brick of the walls was in turn picked off in many places, for reuse as a building material. Whole bipedales were also removed either from bonding courses or from solid brick barrel-vaults as in Rms 3a-d and some of the secondary vaults in the frigidarium and natatio. The absence of the vaulting over much of the central block is also due in part to the search for materials, in this case metal bars;[10] on close inspection, the cavities in the surviving vaults which once had these bars often show clear pick marks (Fig. 10).

The falling of the vaulting and the gradual accumulation of earth over the site protected the floors of the ground level rooms. The geometric mosaic floors of the cold rooms (Rms 1-12) have fared best. Most are of medium-sized tesserae, but those in Rms 1, 2E, and 8/9/10E are much coarser.[11] A similar coarse mosaic was uncovered in Rm 19E during minor excavations around the door to Rm 12E in 1982, but none of the floors of the other hot rooms are visible; Blouet, however, recorded traces of mosaic in Rms 14 and 17. The athlete mosaics from Rm 13 were removed to the Lateran following Conte di Velo's excavations.[12] Nothing survives of the floor of the frigidarium. Large areas of opus sectile were discovered when the caldarium was excavated in the late 1870's (Fig. 11), but none of this survives today.

The extensive service passages include galleries wide enough for two carts to pass plus one of the largest mithraea yet discovered in the city of Rome.[13] There are also narrow maintenance

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[9] See Ghislanzoni 1912: 310, E3 in Fig.1 for the lime kiln; Francia 1977: 102 for St Peter's.

[10] See Appendix 3.

[11] See Blouet 1828: Pl.IV, XIV; Guidobaldi 1983; Guidobaldi-Guidobaldi 1983: 242-47. Mosaics in Rm 2E and 8/9/10E were uncovered during excavations by the Soprintendenza in 1982-1983.

[12] Secchi 1843.

[13] e.g. Coarelli 1988: 335. For the mithraeum see Cosi 1979.

passages running around and under the central block, extending probably to the cisterns at the rear of the outer precinct; under them at a lower level are the major drains. Most of the substructures apart from the main service galleries, some of which have been restored for use by the Rome Opera, are not very accessible. Some can still be seen in the side of the old excavation of the second century house to the east of the central block (Fig. 12). Recent excavations by the Soprintendenza have revealed more, particularly in Rm 2E and in front of the eastern exhedra. A programme of investigation into the whole drainage and service system and a series of geological cores have provided further information on the substructures and foundations.[14]

2.2 SECONDARY SOURCES

2.2.1 Renaissance drawings

Rather more of the Baths remained intact in the 16th and 17th centuries than is visible at present, so that both sketches and architect's measured drawings can provide valuable information, although care must be exercised in their interpretation. The most useful drawings are those in the Collection Destailleur of the Staatliche Kunstbibliothek, Berlin.[15] The drawings are in two hands, and some seem to be copies of others; the labels are in French and Italian, and the measurements in a Parisian foot of 0.32 m. Although not correct in every detail, these drawings show an extraordinary knowledge of the Baths, including details of the tepidarium, caldarium, service courts and hypocausts which do not appear on other Renaissance drawings. Hülsen gives their date as c.1550, and it seems reasonable to associate these drawings with the extensive excavations carried out in the 1540's on behalf of Pope Paul III.[16] The almost contemporary sketches and reconstruction drawings made by Palladio are far less detailed, but do include a number of

[14] Cecchini 1985; Petrassi 1985. I am grateful to Dott. L. Petrassi and Dott. A. Corazzo for discussing their work with me.

[15] See Iwanoff and Hülsen 1898: 50-54 for a list of drawings and a brief discussion.

[16] For the excavations see Lanciani 1902-1904 (II): 180-84, and cf. Marvin 1983, and Gasparri 1984-1985.

measured sketches of architectural ornament.[17] There are also useful drawings by Peruzzi (in Rome 1503-36), Antonio da Sangallo the Younger (in Rome c.1495-1546), Giovanni Battista da Sangallo (c.1496-1546), Dosio (1560-69), Abaco (c.1510-1550),[18] and Andreas Coner,[19] and published engravings by Du Perac (Le rovine di Roma antica, 1575).

In trying to make use of these drawings, I have observed the following precautions:

1 The work of each artist is checked first for internal consistency. For example, the number and location of columns in the palaestrae vary considerably in the work of the Anonymous Destailleur,[20] and Palladio shows considerable differences in detail in his two plans of the central block.[21]

2 Details which cannot be verified against the existing remains are checked against other nearly contemporary drawings. Since it was not unusual for artists/architects to copy each other's drawings, weight is given to independent sketches which appear to have been taken on site.

3 Where no independent checks are possible, dimensioned sketches are given credence over reconstructions.

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[17] Zorzi 1959: 19-20, 68-70, figs 110-25.

[18] Peruzzi - Uffizi 476r.=Bartoli 1912-22: CLXXX.315; Sangallo the Younger - Uffizi 790, 1206, 1227, 1369v. = Bart. CCLXIX.454, CCXIV.359-60, CCXV.361-2; G.B. Sangallo - Uffizi 1133, 1381, 1656, 1657v, 4117 = Bart. CCCXIV.524, CCCXI.520, CCCXII.521, CCCXIII.522, CCCVI.504; Dosio - Uffizi 2563, 2558, 2577 = Bart. CDXXVII.778-9, CDXXVIII.781; Abaco - Uffizi 1093, 1544, 1545 = Bart. CCCLI.609-12.

[19] Ashby 1904: No. 22.

[20] Cf. Sheets 27 recto right, 28 verso, 31 recto.

[21] Zorzi 1959: figs 110 and 112. Note in particular the arrangement of the tepidarium and the columns in most rooms.

2.2.2 Later surveys

The most important work of the 19th century, and still the best published survey, is that by Abel Blouet, a French Prix de Rome architect, made during the Conte di Velo's excavations of 1824-5 and published in 1828. Blouet produced plans and elevations both of the actual remains and in reconstruction, as well as illustrations for the excavations. The accompanying text is very brief, but does give evidence, for example, for the widespread use of wall and vault mosaic. His survey is, however, of less value for this thesis than might be hoped, since there are inaccuracies in the plan and the elevations are impressionistic in detail. In addition, most areas of the central block were not much better preserved then than they are now. The excavations made in Rms 19-23, caldarium and tepidarium were few and unenlightening, and Blouet's sections did not include those rooms (Rms 15-18) which have suffered most from the installations of the Rome Opera except as part of the main longitudinal section. The reconstructions by Canina (1847-54) and Iwanoff (1847-9) add little to our knowledge. One problem common to all three architects is the tendency to "correct" any irregularities in the ostensibly symmetrical structure, either because only one side was measured and the other assumed to match, or, as can be proved in the work of Blouet where some of the inconsistencies are shown in the present state plans but not in the reconstructions, because contemporary architectural theory believed it should be so.

2.2.3 Excavation and research since 1870

Since the Baths became a State monument after the Risorgimento, no detailed survey of them has been published. The excavations of the late 19th and early 20th centuries cleared the whole complex to the ancient ground level and some of the subterranean passages, as well as uncovering part of the foundations.[22] Although never published in detail, they were reported briefly in

[22] Different areas of the substructures seem to have accessible at different times. Iwanoff-Hülsen 1898: Tav. A (Fig. 16) shows only the west galleries, De Angelis 1903: Tav. I (Fig. 13) only the east. After Ghislanzoni's excavations (1912) the western galleries were again accessible.

Notizie degli Scavi and other scholarly journals,[23] and plans were published of two of the later campaigns, De Angelis' survey of the substructures of the central block (Fig. 13) and Ghislanzoni's excavations of the peribolus and substructures between the central block and the western exhedra (Fig. 14). Unpublished weekly reports of the excavations of 1872-4 also survive in the Archivio Statale[24] and in Lanciani's manuscript collection in the Biblioteca dell'Istituto della Storia dell'Arte e dell'Architettura in Rome.[25]

The results of the earlier excavations were used by Hülsen in his commentary on Iwanoff's reconstruction of the Baths, published in 1898. While the reconstruction adds nothing to that of Blouet, Hülsen's account, which includes a list of brickstamps as well as a description of the more important areas, is invaluable. The publication also contains a detailed dimensioned plan drawn by Tognetti (Fig. 15) of the central section of the main block comprising Rms 14-16, 22-23, frigidarium, tepidarium and caldarium, which provides the only clear record of this important area now covered by the permanent stage for the Opera. In addition there is a plan (Fig. 16) of the whole complex which is still useful in that it shows rather more of the outer precinct surviving than the plan recently prepared by the Soprintendenza (Fig. 2). All these have been taken into account in the relative parts of the reconstruction, and use has also been made of other late 19th- and early 20th-century photographs, particularly those of Van Deman and Ashby, and in the collections of Alinari.

The Baths were discussed by Krencker (1929) and his pupil Brödner (1951), but they were mainly concerned with arguments concerning the "basilica thermarum". In the last 10 years the complex

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[23] Pellegrini 1867; Lanciani 1869, 1879, 1881; Rosa 1873; Savignoni 1901.

[24] Archivio dello Stato, Ministero della Istruzione Publica, Direzione Generale per Antichità e Belle Arti: Antichità e Scavi: Buste 100-102, Fas. 133-134.

[25] Mss. Lanciani 37: Pellegrini Codice Scavi 1873.

has begun once more to attract the attention of scholars. As already noted, a series of excavations and investigations, with a complementary programme of restoration, have recently been carried out by the Soprintendenza Archeologica di Roma. A thorough graphical documentation of the Baths has been completed, and the first results have just been published.[26] Studies have been begun on the architectural decoration and the water supply; here again only preliminary reports have been published.[27]

2.3 DATING

2.3.1 The original building

The dates usually assigned to the Baths of Caracalla lie within the limits AD 211-217, AD 212 for the starting date and AD 216 for the dedication usually being preferred.[28] The date of commencement is given by brickstamps,[29] virtually all of which can be assigned to the sole reign of Caracalla, apart from those of a much earlier date, or from later restorations. An uncertain identification of a stamp referring to the joint rule of Caracalla and Geta is the only evidence to suggest a date of AD 211 rather than AD 212, and the value of this has been doubted.[30] As Bloch rightly points out, however, the brickstamps show only that the building of the brick-faced substructures and drains cannot have been begun before 212.

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[26] Conforto 1991.

[27] Architectural ornament - Jenewein 1983, 1985; water supply - Manderscheid 1988.

[28] For example, Ward-Perkins 1981: 129-31, and Coarelli 1988: 332 both favour AD 212-216, while the official guide (Iacopi 1977: 66) prefers AD 206-216. The commencement date of AD 206 is derived from a quarry inscription on a block of marble found at the Baths, and has no value whatsoever. See Platner-Ashby 1929: 520, taken up by Bloch 1947: 303, note 228.

[29] Bloch 1947: 283-303, and see Appendix 2.

[30] CIL XV.1 769a, 4, recorded by Pighius and no longer extant. Bloch 1947: 291 suggests that this could in fact have been an example of CIL XV.1 769b where the erasure of the "GN" in "AUGG NN" had not in fact completely obliterated the letters; on the other hand, it would not be at all unusual to find bricks bearing stamps of an earlier date in any imperial building.

Consideration of the process of building and brick-making allows us to be more specific. Since the bricks were stamped after being formed but before they had dried, and brick-making was restricted to the drier months of the year (see Section 5.3.4), the earliest the bricks could have been ready would have been, say, May AD 212,[31] but it is by no means certain that they were in use as early as this. On the other hand, we have no stamps from the very lowest levels of the sub-floor walls, which were faced with brick to a maximum depth of 8 m below ground level,[32] some 2.5 m below the drains which give the earliest evidence. Before the first of these sub-floor walls was begun, the Baths had to be designed, the land acquired, the site terraced, the building surveyed, and the foundations dug and filled. If bricks were first used in early summer AD 212, then the foundations ought to have been laid the previous year. In addition, AD 212-213 is the date of the dedicatory inscription of the Aqua Antoniniana, the branch line of the Marcia which fed the Baths,[33] and this also must have been begun some time earlier. Both of these factors suggest to me that the decision to build the Baths must have been taken by early AD 211 at the latest; what better occasion than the accession of Caracalla and Geta following the death of Septimius Severus in February AD 211?

The date of construction (aedificavit) is given by Jerome as AD 216, and this is usually interpreted

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[31] Barnes argues that the date of Geta's murder is very probably 26 December AD 211 (1968: 522-5), convincingly refuting the usually accepted date of February AD 212. The clay for the bricks would have been dug and allowed to weather through the winter, ready for the summer brick producing season.

[32] I am grateful to Dttsse Marina Piramonte and Alessandra Capo di Ferro for this information.

[33] CIL VI 1245 = ILS 98. *Imp(erator) caes(ar) M(arcus) Aurellius Antoninus Pius Felix Aug(ustus) Parth(icus) Maxim(us)/Brit(annicus) Maximus Pontifex Maximus/aquam Marciam variis kasibus impeditam purgato fonte excisis/ et perforatis/ montibus restituta forma adquisito etiam fonte novo antoniniano/in sacram urbem suam perducendam curavit.*
The titles of Caracalla do not include Germanicus, and thus the date of the inscription must be before 20 May AD 213 when this appears in the acta of the Arval Brethren (CIL VI 2085, ll.11-19). It should not surprise that this date is so much earlier than the opening of the Baths; the water was surely needed for construction. (See below, Section 6.1.1) It is generally accepted that the addition of a new source was related to the construction of the Baths, although the inscription does not mention them specifically.

as the date of dedication.[34] The Historia Augusta (Heliogab. XVII.9) states explicitly that Caracalla dedicated the Baths "et lavando et populum admittendo", but since Caracalla left Rome for the east early in AD 214 and did not return this would allow an impossibly short time for the construction. Jerome's date agrees well with the evidence from the central block, where brickstamps of Caracalla are to be found in all parts, including the upper levels and hypocaust floors which naturally belong to the last stages of construction. It is far from clear, however, whether the central block was totally finished in all its decoration by the time of its dedication, but it is hard to imagine, as Guidobaldi has tentatively suggested, that many of the mosaic floors in the subsidiary areas, including most of the entrances and the palaestrae, were only finished later.[35] In fact it seems unlikely that the Baths would be dedicated before the main bathing block could be used, which would require almost all of the decoration to be complete.

It is now accepted, on the other hand, that the buildings of the outer precinct were not complete at the time of dedication of the Baths. The statements in the Historia Augusta that Elagabalus began, and Severus Alexander completed and decorated, porticos in the Baths of Caracalla must refer to the colonnades and subsidiary rooms of the outer precinct, where the total absence of brickstamps, the less accurate laying of the bricks, and the use of tile-topped putlog holes strongly suggest a later phase.[36] Recent work in and behind the west library, however, has shown that some at least of the retaining wall forming the south side of the precinct was constructed at the

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[34] Hieron. ab Abr. 2231, and cf. Chron. Min. 147. Aur. Vict. Caes. 21 states that the Baths were completed before Caracalla's death in AD 217. The absence of Caracalla, who was in Syria in 216, would not, of course, have prevented the dedication of the building.

[35] Guidobaldi 1983: 498-99, although by p.500 he seems to have decided that the mosaics in the Baths of Caracalla are earlier than those in the Baths of Alexander Severus.

[36] Bloch 1947: 301; Lugli 1957: 612. Steinby (1986: 108), however, suggests that the peripheral buildings were rebuilt by Aurelian (see below).

time of Caracalla, as might have been expected.[37]

2.3.2 Later antique restorations

According to the literary sources, some porticoes belonging to the Baths were burnt and repaired under Aurelian.[38] A recent study of the architectural decoration of the Baths, not yet complete, has shown evidence for Aurelianic restoration in some cornices from the palaestrae colonnades (Rms 12), which may have been those referred to in the sources.[39] Several capitals also appear to date from the later third century, particularly the figured Composite capitals from the frigidarium pools which are not a matching set.[40] A number of Tetrachic brickstamps, none found in situ, attest some early 4th century restorations.[41]

Further restorations took place under Constantine or, more probably, his sons. Although only one brickstamp firmly dated to that period has been recorded, again not in situ,[42] a monumental inscription on an architrave the curve of which fits that of the apse added to the caldarium (Fig. 17) dates this major alteration to the central block.[43] Interestingly, the circular caldarium of the

[37] The work on the library has not yet been published. I am grateful to Dttssa Marina Piramonte, Dttssa Alessandra Capo di Ferro, and Dott. Luca D'Elia for information on their investigations.

[38] Chron. Min. 148.

[39] Jenewein 1983. The cornices can be identified as those from Blouet's Fouille N (1828: Pl. IV), i.e. from the palaestrae colonnades.

[40] Von Mercklin 1962: 158-60, no. 385a-d.

[41] CIL XV.1 1594d,18; 1631,6; 1643a,1, to which can now be added 1579b, 18; 1580a (Ghislanzoni 1912: 310); and 1610, 9. See Steinby 1986: 117-18, 122-3, and 139-141 for discussion.

[42] CIL XV.1 1542,3 = Appendix 3, no. 197. See Steinby 1986: 113-14 for a date under Constans and Constantius rather than Constantine.

[43] *[munifice]NTIA . DDD . NNN . [con]STANTINI MAXIMI VICTORIS AVG . ET/ CETERA EXIMIVM [mu]NIFICENTIVS ETIAM QVAM AMPLITVDO/.......FIERI DISPO[s]VIT . AC DEDICAVIT.* Colini 1939: 211; Degrassi 1962: 354-5.

Baths of Constantine also had a projecting semi-circular apse set on the main axis.[44] Most of the apse and contiguous reinforcing wall of the caldarium rotunda in the Baths of Caracalla have disappeared, but the supporting walls in the service passages below show typically Constantinian brickwork. The brickwork of the cistern walls in Rm 23 immediately behind the plunge pools of the frigidarium, and of the reinforcing pier in the south corner of Rm 10E, is very similar to that of the Constantinian apse, and should be roughly of the same date.[45] Various secondary walls behind the surviving west caldarium pool, now largely buried under rubbish, may also belong to this phase.

The latest datable restorations took place under Theodoric; a brickstamp bearing his name was found at the bottom of one the stairs of the caldarium piers, and several others were found during the excavations of 1881.[46] It is likely that the second reinforcing ring of the outer edge of the caldarium belongs to this restoration, as may some of the alterations to the west caldarium pool. Of less certain, but definitely post-Constantinian date, are the repairs to the opus sectile floor of the caldarium.[47] Late restorations of some of the mosaics of the terraces over the palaestrae porticoes have also been noted recently.[48]

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[44] For Palladio's plan of the Baths of Constantine, see Zorzi 1959: Fig.84, and Figs 85-86, 88 for elevations. For once we can be sure that the apse which Palladio shows in the Baths of Constantine is not an invention based on the Baths of Caracalla, since this was not discovered until the late 19th century (cf. Zorzi 1959: Figs 110, 112).

[45] The bricks are all short lengths, of uneven thickness, and set in relatively wide mortar joints; the modulus ranges from 5:270 to 5:320, with the brick within the range 28-40 mm, average 33 mm, and mortar 19-35 mm, av. 25 mm. I am grateful to Dr Joan Barclay-Lloyd for examining this brickwork with me. For Constantinian construction, see Heres 1983: 110-14 and relevant catalogue entries.

[46] Lanciani 1879: 15; 1881: 90.

[47] Cf. Lanciani 1879: 40, who dates it to the second half of the fourth or the beginning of the fifth century.

[48] Fabbrini 1983: 52-53.

2.3.3 The later mosaic floors

Although F. and A. Guidobaldi have recently suggested that the coarse mosaic floors in Rms 1 (Fig. 18), 2E, 8/9/10, and 19E are part of the original decoration,[49] it seems more likely that they are later restorations. One of their main arguments, that there is no evidence for earlier floors, can now be refuted. Minor excavations by the Soprintendenza on the east side of Rm 2E uncovered a section of mosaic with a giallo antico roundel in a green porphyry frame, with tesserae of 20 to 30 mm, while the small surviving area of mosaic on the west side of 2E, and that in Rm 2W, has a different pattern of "ashlar" blocks in pale marble with dark joints, all using smaller (10 to 12 mm) tesserae. Unfortunately, the subsidence of the floor in Rm 2E, and the fragmentary nature of the mosaic remains, make it impossible to tell whether the coarse mosaic was a repair to the floor or a replacement laid over it. Nevertheless, it seems clear that one of the mosaics must be later than the other.

Coarse mosaics with elements of green or red porphyry from numerous examples in the late buildings in Ostia have been dated to the late third or early fourth centuries; the mosaic in the frigidarium of the Baths of the Philosopher, a main field of green porphyry with a border and corners of grey/white marble, is very similar to that in Rms 1 of the Baths of Caracalla and has a terminus post quem of the mid-3rd century.[50] Confirmation of this dating comes also from the Baths of Diocletian, where the recently rediscovered mosaics from the palaestrae portico at the Via Cernaia site are not only of this type, but also very close in design to the corresponding mosaics in the Baths of Caracalla.[51] None of Guidobaldi's other third-century examples of these coarse mosaics can be dated securely before the time of Caracalla, and most of them seem to belong to

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[49] Guidobaldi-Guidobaldi 1983: 242-47.

[50] Becatti 1959: 358-59 for the general discussion, and 211-13 for the Baths of the Philosopher.

[51] Candilio 1985: 528 and Bulian 1985: 519, figs 18, 19; Guidobaldi-Guidobaldi 1983: 248-49.

the middle third of the century.[52] In the light of these arguments, I prefer to see all these mosaics of coarse tesserae in the Baths of Caracalla as pertaining to later restorations, and possibly to either the Tetrarchic or Constantinian phases identified from brick-stamps, although the time of Aurelian is also possible among the recognised periods of restoration.

2.3.4 Alterations in Rms 17 and 19

Rm 17 shows several signs of alterations. A large round-headed opening in the south wall was filled in to create a lower, narrower opening or niche, which was in turn filled in, leaving only a small segmental niche (Fig. 19). The first fill at least would appear to be contemporary with the original construction, to judge from the nature of both core and brickwork, and from the congruency of the bonding courses. Little brick facing survives on the second fill, and there are no bonding courses, making it very difficult to date, although it too may represent a change of mind during construction. Equally difficult to date is the door furthest from the palaestra in the south wall, which has no lintel or relieving arch, and has clearly been cut through after the main structure had been completed (Fig. 20). The existence of these doors in both 17E and 17W and the careful shaping of them (allowing for the later loss of the brick facing, the width of the doors is very nearly that of the original door in the south wall) suggests that they were part of a reorganisation of the rooms rather than post-antique alterations.

Evidence for further alterations can be seen in the vaulting of Rm 17E, that in 17W being a modern restoration. Where the cross-vault springs from the corner piers, it is clear that there were two periods of vaulting: the original vault, tiled lined and originally with a network of metal bars, forming the inner surface, and a second layer, also tile lined, of which only a short section remains above each pier (Fig. 21). The rest of the outer layer must have been destroyed when the metal bars were robbed out. This again is impossible to date. The base of the niche on the north wall

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[52] Guidobaldi-Guidobaldi 1983: 249-52.

of 17E was also lowered at some stage, although this was not the case in Rm 17W.

Finally, the pool in 17E was built against the tubuli and wall veneer of the north wall, and again possibly represents a later alteration (Fig. 22). Two other factors also point to this conclusion. Although the pool is in a heated room, and against a heated wall, the usual semi-circular opening for the testudo of a heated pool is missing, the only possible location of this being in the thickness of the wedge behind Rm 13; nor is there any evidence for a heat exchange tank set in the floor of the pool, an alternative device anyway used normally only in larger pools. In addition, Blouet does not show the hypocausts in Rm 17 extending under the pool, in which case no hot gases could have reached the wall tubes behind it.[53] The pool must therefore have been unheated, and it is likely that at the time the pool was operational, the wall behind it would have been unheated also. There are also formal reasons to doubt that the pool is an original feature. None of the other imperial thermae appear to have had similar small pools opening off the palaestrae, and the construction of the pool - set against a wall but otherwise free-standing - is itself unusual. Apart from large swimming pools set in the centre of a room or portico, pools in bath buildings of all sizes, with few other exceptions, are usually enclosed on three sides and the normal practice is to vault these independently; sometimes they form an integral part of the structure, as is the case in the Baths of Caracalla with the frigidarium and tepidarium pools. The one possible parallel, in Rm III of the Kaiserthermen in Trier, is a reconstruction based on those in the Baths of Caracalla.[54]

Some of the same arguments can be used to suggest that the pool in Rm 19 is also a later addition, although the case is not as clear. The present pool in Rm 19E is heavily restored, but during excavations in 1982 some of the original construction was revealed, making it clear that the wall

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[53] Blouet 1828: Pl.IV, Fouille H. The extent of the excavations shown on the plan and in the two sections should have been sufficient to confirm the details of the hypocausts, but unfortunately these can no longer be checked.

[54] Krencker et al. 1929: 102-109.

of the pool was built against the main structure (Fig. 23). While the lower part of the pool wall is in reasonably neat brickwork, the upper part, possibly a post-antique reconstruction, is of very rough rubble. Unfortunately it was not possible to examine the brick closely, and the excavation has not yet been published. Only short spurs of the pool in Rm 19W survive, both in brick-faced concrete but with insufficient surviving to date the construction.

2.4 THE PRESENTATION OF THE EVIDENCE

2.4.1 The reconstruction drawings of the central block

The survey of the central block provides the basis for the reconstruction drawings in Sheets 1-7. These drawings represent the state of the original building of AD 211-216 and omit later additions and alterations. In order to show as much of the construction detail as possible but at the same time give an idea of the finished building, the drawings represent a nominal moment after construction was complete but before the final decoration. Thus all the structural columns and some of the purely decorative ones have been added, but not the wall and vault treatments. The complex aedicular facade of the natatio has been shown at various stages of construction. The depiction of basic details such as arches, columns, and bonding courses is schematic, so that no attempt has been made to represent, for example, the individual bricks in any arch. The bonding courses are depicted as light broken horizontal lines across the surface of the walls. No attempt has been made to show the brick facing and smaller details such as putlog holes have also been omitted.

The decision to illustrate the main building by means of a schematic reconstruction rather than a present state drawing was taken for two main reasons. Firstly, it makes it clear that this is in no way intended as a substitute for the kind of survey already done for the Soprintendenza Archeologica di Roma.[55] Secondly, it allows the integration of earlier material with the actual

[55] See Conforto 1991: Figs 4-7 for this.

survey to fill the inevitable gaps and hence produce the complete reconstruction required for the quantitative analysis. This decision has, however, led to the problem of distinguishing between the existing remains and the reconstructed elements in the drawings. On the whole I have tried to keep this to a minimum in the interest of clarity. For the plan, since the evidence for the parts not covered by the actual survey is extremely good, no distinctions have been made in the drawing at all; the present state is shown in Fig. 2. In the elevations a broken line indicates the height and extent of the existing structure.

The use of a relatively small scale of 1:250 for the original drawings was determined mainly by the relationship between the size of the building and that of the largest standard sheets of drawing film. At this scale measurements can only be plotted accurately to the first decimal place of a metre. Although the survey proper is generally accurate to the second decimal place, the extent to which the drawings are based on measurements scaled from photographs or data which can no longer be checked and are of uncertain accuracy would anyway make a reconstruction at a larger scale of doubtful value. The rooms have been given new labels, since none of the existing published schemes make it possible to designate all spaces with sufficient precision. By adopting a site north parallel to the main short axis, it was possible give the rooms which are repeated on both sides of this a single series of axis arabic numerals - from 1 to 23 - distinguished by east (E) and west (W), with the subsidiary spaces of Room 3 being designated 3a-d. This simplifies any references to specific rooms. The simple singular numeral, e.g. Rm 19, refers to both (or either) of the two rooms of that number, but where it is necessary to differentiate between the two they become Rm 19E and Rm 19W. Thus we avoid the ambivalence of having to say, for example, the piers in the corners of Rms 19, where each Rm 19 has only one corner pier. For the four rooms on the central axis I have used the conventional labels of natatio, frigidarium, tepidarium, and caldarium. I make no apology for this inconsistency. Of the other rooms, however, only Rm 12 which I believe was the palaestra and Rm 3 which was almost certainly an apodyterium, have any clearly identified function which can be given an obvious label.

2.4.2 Platform and Substructures

No attempt has been made to produce detailed reconstruction drawings of the substructures, as these would be based entirely on the earlier surveys. Instead, a schematic plan and sections have been prepared illustrating the excavations for the terraces, and the general form and levels of the various foundations and substructures, with the central block shown in outline only (Sheets 8-9). The plans were drawn at a scale of 1:1000, a quarter that of the central block reconstructions, allowing the relation between the two to be easily determined. For the sections, the vertical scale is shown at twice the horizontal scale, in order to make the details legible.

The various areas and sectors of the substructures have also been given new labels, although individual spaces have not. The terraces and levels are indicated by letters, the structures by Roman numerals. Again, areas which are repeated on both sides of the central axis have the same number distinguished by east or west. In general discussion the major types of substructures are given descriptive labels which perhaps require a few words of definition. Foundations are all the parts of the substructures which are cut into the terraces at whatever level and filled from above. The built substructures are those parts built up from the foundations in brick-faced concrete which serve to support a main structure at platform level, whether or not these form accessible and usable spaces in their own right. The terracing substructures are those which serve to contain the fill of the platform without supporting any further structure, again independent of whether they are accessible or not. The service galleries are the large passages which run under the platform at the level of the first terrace and are connected to the built substructures of the west exhedra. The maintenance passages are the smaller passages which run at the highest level under and around the central block and continue towards the cisterns at the southern edge of the platform. The drains are the smallest passages, but include the emissarium or main drain running below the maintenance passages.

2.5 RECONSTRUCTION

2.5.1 Geology and earlier topography of the site

The Baths sit on an outcropping of the Pleistocene Siciliano formation, comprising layers of compact grey-green clays,[56] which overlooks the valley between the Piccolo Aventino and the Caelian. The valley was cut into these strata by runoff from the surrounding hills, forming a stream which joined the Tiber just beyond the Circus Maximus. In the slope of the Piccolo Aventino behind the Baths the Siciliano clays continue to a height of approximately 8 metres above the platform, topped by the semi-lithoidal tufa which concludes the Siciliano formation.

It is no longer possible to determine the extent to which the natural topography was altered to create the platform for the Baths. The line of the hill behind the Baths conforms far too closely to the shape of the platform for it to be natural, suggesting that a large amount of material has been removed. In the 1912 excavations, however, earlier structures resting on the natural clay at a height of only 0.9 m above the platform level were recorded in the centre of the space between the western library and the "stadium".[57] It is not impossible that the hill had been cut back at some earlier date, and the existence of a ready-made terrace influenced the siting of the Baths.

The Hadrianic house incorporated in the substructures just east of the central block, the floor of which is roughly 7.5 metres below the level of the platform, provides at least one clear indication of the pre-existent levels.[58] Its full extent is not known, but it clearly continued towards the

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[56] Geological information has been derived from Ventriglia 1971 and Petrassi 1985.

[57] Ghislanzoni 1912: 313, 315.

[58] According to Castagnoli 1949-1950: 169 the house lies about 10 m below the platform, but the new survey shows this as 7.5 m.

north, and probably also towards the south. The fact that the east wall of the peristyle had an intercapedine of tiles suggests that on this side the house was cut into the hillside.[59] The base of the barrel-vaulted substructures facing the Via Appia, approximately 10 m below the platform and roughly at the same level as the ancient road in front of the platform, probably indicates the lowest point of the site.[60] These two points and the structures at the rear of the precinct mentioned above give an average slope over the site of 1 in 27 which will be used as the basis for further calculations.

2.5.2 The aqueduct

The inscription recording restoration to the Aqua Marcia by Caracalla was added to the Augustan arch over the Via Tiburtina, and can be dated to sometime between February AD 212 and May AD 213 (see Section 2.3.1). Work of definitely Severan date, some of which has close parallels in the Baths of Caracalla, has been identified by Van Deman in several places along the lower course of the Aqua Marcia, and can be safely taken to belong to this programme of restoration.[61]

The total length of the Antoniniana is some 6 to 7 km, about a tenth of which appears to have been built on arches or solid substructures, the rest being underground, and the construction also appears to have included a settling tank identified by Parker at Tor Fiscale. The branch line appears to have left the Marcia some three miles south of the city just beyond Tor Fiscale, and have followed a gently curving path crossing the Via Latina to a point about half a mile outside the later walls where it ran on substructures and then arches before turning towards the Via Appia. The Appia was crossed by means of a monumental arch, the so-called "Arco di Druso", after which the aqueduct ran in an easterly direction following the ridge and then turned to run beside the Via

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[59] Carpano 1972: 113, 120.

[60] See Blouet 1828: Pl. VIII for the facade and Castagnoli 1949/50: 73 for road level

[61] Van Deman 1934: 99-100, 135-36.

Ardeatina until it reached the Baths.[62] The surviving brickwork of the cisterns fed by the Aqua Antoniniana is the same as that of the remaining arches of the aqueduct itself, still visible in Viale G. Baccelli, and is comparable to that of the central block.

2.5.3 Foundations and substructures

Our knowledge of the foundations and substructures of the Baths can only be partial. While those that were accessible in antiquity are reasonably well documented, we have to rely on geological cores to provide details of the lower levels.[63] These show that the foundations extent to a maximum depth of 14.5 m below the platform level, and allow three distinct phases of construction to be recognised (Sheets 8 and 9). The first step was to create two level terraces (A and B) parallel to the front of the present platform. The lower terrace, 8 m below the platform level, extended across the full width of the site and ran from the front to the back of the central block, including the projecting part of the caldarium and the galleries. The second terrace, at about 6 m below the platform level, continued from here at least as far as the north wall of Rm IV and probably to the rear of the precinct.[64] It seems reasonable to assume that the width of the terraces would have been rather greater than required for the final building to allow for ease of access and manoeuvrability, and that the sides were ramped.

The foundations proper, of selce caementa in a grey pozzolanic mortar, were cut into these terraces, as was the main drain, its floor being about 10.5 m below the present ground level of the

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[62] Van Deman 1934: 144-46; Ashby 1935: 156-58. For the section inside the walls see Lanciani 1893-1901: fasc. 41, 42, 45, 46. For the "Arco di Druso" see Rosi 1932.

[63] Petrassi 1985. A more detailed analysis and interpretation will only be possible with the full publication of the geological survey.

[64] The existence of substructures under the west library, as suggested by D'Elia 1985: 596-97, would presuppose a lower terrace here. Further excavation is needed in these areas to settle this problem.

central block.[65] Under the central block they were cut 6.5 m into the lower terrace, while under the peripheral buildings, and presumably under the front terracing, they were 4.5 m deep. There seem to have been no proper foundations under the drains or the galleries south of the central block; instead they sat on a levelling course of brown sandy earth containing fragments of broken brick and pottery.[66] Although there is no direct evidence for the form which the foundations took, some details can be inferred from the nature of the substructures, and by analogy with other buildings. De Angelis' survey (Fig. 13) indicates that the substructures followed the plan of the superstructure but were continuous under all openings or colonnades. In addition they were solid under the barrel-vaulted spaces flanking the frigidarium, and there were extra cross walls linking the foundations of the giant orders in both frigidarium and natatio. It seems reasonable to assume that the foundations are slightly wider than the substructures they support. Although the survey did not include the caldarium, analogy with the Pantheon would suggest that the foundations took the form of a solid ring of concrete somewhat wider than the drum.[67] The foundation plan for the outer precinct can be deduced in a similar manner from the plan of the substructures.

The built substructures fall into three broad categories. In the central block, brick-faced concrete sub-walls served simply as an extension of the foundations to support the corresponding walls and columns of the superstructure. The areas between these sub-walls were filled up with a mixture of sandy earth and broken terracotta, interspersed with layers of cemented material. The substructures on three sides of the platform acted to retain the fill. Those at the front consisted of a series of parallel cross-vaulted chambers, open towards the Via Nova but filled in behind[68]; those at the sides, extending as far as the octagonal rooms in the lateral exhedrae, were also cross-

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[65] De Angelis 1903: Tav. II, section E-F.

[66] Petrassi 1985.

[67] Cf. De fine Licht 1968: 89-92.

[68] See Blouet Pl. VI and VIII.

vaulted and some at least were accessible.[69] On the east side the inner and outer long walls, which eventually supported the portico of the precinct, continue beyond the octagonal room, but the space between was divided by slender cross walls and then filled in with rubble containing material ranging in date from the fourth century BC to the early third century AD as well as fragments of wall painting and floor mosaic. The third set of substructures are the service galleries, some of which - those under the exhedrae - also act as substructures to the rooms above. The long barrel-vaulted chambers parallel to the south face of the central block, which have no supporting function and thus no need of proper foundations, are also connected to the corridors under the caldarium which serviced the hypocaust, and thence to the service courts Rms 15 and 17.

Finally there are the major maintenance passages and drains, which run from the cisterns at the rear of the precinct across to the central block, around its outer perimeter, and along its major long axis (Fig. 13). The main drain runs along the longitudinal axis of the central block at a maximum depth of approximately 10.5 m to a point halfway between the block and the outer precinct, at which point it turns north, presumably to join the main sewer which emptied into the Tiber just beyond the Circus Maximus.[70] Most of the runoff from the roofs of the central block was channelled into smaller peripheral drains at a depth of about 6 m below the platform, while that from the palaestrae and the pools inside the bathing block was fed by smaller and higher channels eventually into the main drain. Above the main and peripheral drains, at a roughly uniform level of 3.5 m below the platform, a barrel-vaulted passage, just tall enough for a man to walk upright, gave access to the actual drains through inspection shafts, and presumably also carried the main water pipes. These passages were accessible both from the platform outside the central block by

[69] See Cecchini 1985: 585-88 for the east side and Ghislanzoni 1912: 317-22 for the west. A large mithraeum was inserted in the west side.

[70] I am grateful to Dott. L. Petrassi for this information.

narrow stairs, and from the subterranean galleries by way of the service courts Rms 15.

2.5.4 The central block (Sheets 1-7)

On the whole the reconstruction of the central block can be checked against the existing remains or well-published material.[71] The absence of the original wall surface in many places and of the columnar orders has meant that some assumptions had to be made in order to produce a ground plan. Where it was not possible to deduce the original line from at least a small stretch either at ground level or above, 0.15 m (roughly the distance from the face to the point of a triangular facing brick) was added to the thickness of the wall; the validity of this was confirmed by walls where some of the facing remained. All curves in plan which could not be measured were assumed to be segments of a circle, and the same extra thickness applied if no original radius could be measured. Columns were assumed to be evenly spaced unless there was specific evidence to the contrary; a wider central intercolumniation is found in the screens 1/N, F pools, and 14/F.[72] In calculating the interaxial spacing, allowance was made for the ends of the walls being treated as pilasters by adding the width of a base to the size of the actual opening. This results in equal spaces between the sides of the wall and the sides of the bases, and is the general pattern shown in Rms 4/5/6, 8/9/10, and 13 according to Blouet's measurements; when the decoration was finished, however, the outer intercolumniations would have been shorter by the width of the pilaster base plus the thickness of the pilaster veneer. As a general rule, symmetry was only presumed as a last resort.

Further assumptions about the finished state of the building were necessary in working out the

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[71] See now especially Conforto 1991: Figs 1, 4-7.

[72] For 1/N see Blouet 1828: Pl.IV; for F/pools, Blouet Pl. IV, confirmed from existing remains; for 14/F see the measured drawing by Antonio da Sangallo the Younger, Uffizi Arch 1206 recto = Iwanoff and Hülsen 1898: Taf. N.

elevations to allow the complete quantification of materials and man-power involved in the construction. The plan at various levels of the upper parts of the building often had to be deduced from photographs when direct access was not possible. This was only feasible because of the use of bipedales in bonding course and arches, providing a built-in scale at the right perspective for the photographs. The finished height of most rooms was calculated by completing the curve of a vault and adding a suitable thickness to reach to extrados. In addition, a maximum height was assumed for all parts of the central block except for the rooms on the main axis (N, F, T, C), and the outer wall of the block taken to this height on all sides. The highest point measured was 23.05 m at the top of the window arch to Rm 1W on the north facade; the maximum has therefore been assumed to be 23.9 m - 81 Roman feet or 18 bonding course units - although 23.6 m, or 80 Roman feet is feasible. As with the plan, all incomplete curves in elevation were assumed to be sections of circles.

The columnar orders, and the detailing of columnar screens, provided particular difficulties. Numerous architectural fragments were drawn during the Renaissance, and by Blouet and Canina, while others were uncovered in later excavations; many fragments still survive on the site. A study is being made at present by an Austrian scholar of all the architectural ornament relating to the Baths, and it would have been otiose to duplicate this research.[73] Nevertheless it has been necessary at least to identify the sizes of the orders used in various places, and try if possible to assign some of the fragments to their original positions. The major clues to the height of any order are the impressions left in the concrete where the ends of the entablature were embedded. While these are not always easy to interpret, they do provide limits on the height of the columns used. Since it is clear that all the columns except those of the hot rooms and the caldarium were either Corinthian or Composite, the recent important work by Wilson-Jones (1989b) on the design of the Corinthian order can be used to assign groups of capital, shaft and base to each set of cuttings.

[73] See Jenewein 1983 for an outline of the project, and some preliminary results.

Where one column element does not survive, its dimensions can be calculated; if neither base nor capital survive, a theoretical division between the two can be made. Except where easily identified, I have not tried to sort out the various divisions of the entablatures, since the total height can often be worked out from the cuttings, and the distribution between architrave, frieze and cornice does not appear to follow any identifiable rules. In using Wilson-Jones' theories, I have assumed that they apply equally to the Composite order, although he concentrated solely on the Corinthian order. This may have led to some errors in the theoretical computations, but there are sufficient other checks (from fixed heights, known association of elements, etc) to satisfy me that these will be negligible for the purposes of calculating quantities of marble used or time taken to carve details. A catalogue of the orders is given in Appendix 1.

It is difficult to correlate the cuttings which survive for the screens in Rms 19-22 with those necessary for a Corinthian or Composite order. As Hülsen already noted in 1898, the drawings of Fra Giocondo and the Anonymous Destailleur show Tuscan capitals for some of these rooms and for the caldarium.[74] Blouet also shows a highly decorated Tuscan capital among other fragments in his frontispiece, although it does not feature among the architectural details show in his Pl. XII. The cuttings in the pier Rms 19/20W and 20/21W would accommodate a Tuscan order with 25 foot columns on a low plinth.

Determining what happened above the entablature in a columnar screen is more difficult. In Rms 19 and 13 there were groups of windows crowned with shallow segmental arches as shown by the springing of the outer arches. Rms 21 and 22, on the other hand, had wide arched openings above the columnar screens, while the screen between Rms 1 and 2 was a solid wall. Where no evidence survives to favour any one of these possible solutions, I have opted for the simplest case, which for screens between adjacent rooms (e.g. Rms 4/5/6, 8/9/10) is an open arch.

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[74] Fra Giocondo - Uffizi 1538 = Bartoli 1912-1922: XLVI.74; Anon. Dest. - Bl. 27v., 29v. 30r.

There are a number of other aspects of the reconstruction which either have been the subject of controversy in the past, or for which the accepted interpretation requires challenging. The starting point for all the subsequent discussion must be the work of Krencker, and of his pupil Erika Brödner,[75] who believed that Rm 12 was a covered basilical hall, and not an open palaestra as had always previously been thought. While on the whole I shall be arguing for a return to earlier more straightforward interpretations, the continuing belief in the Krencker/Brödner theories prompts rather more argument than might otherwise be warranted, and each particular problem will thus be treated separately below.

2.5.5 Access to the palaestra terraces and Rms 17-18

One of the difficulties facing Krencker in accepting that Rm 12 was a palaestra, and the terrace over the surrounding portico a public promenade terrace for watching the games below, was the lack of a major staircase leading up to the terrace.[76] Brödner's investigations found only a possible access route from the 5.5 m higher terrace over Rms 4/5/6, across a narrow overpass at the end of the terrace over Rm 7, and down a staircase of the other side of that terrace. Tschira, in his review of Brödner, argued that these terraces could not have been public spaces, despite the decoration, mainly because of this unlikely and insufficient access.[77] While I believe that he was right in doubting the nature of the access, there is no denying that the portico terraces, with their figured mosaic floors and marble wall veneer, must have been important public spaces.

The answer is to look for a major staircase in areas which have previously been overlooked. In the Baths of Trajan, there were staircases either side of the semi-circular exhedrae on the outer side of the two palaestrae, which must have given access to the terraces over the flanking entrance halls

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[75] Krencker et al. 1929: 274-79; Brödner 1951. Taken up most recently by Nielsen 1990: 50, 54.

[76] Krencker et al. 1929: 275-76.

[77] Tschira Gnomon 1956: 629.

and thence to the portico terraces themselves.[78] For the Baths of Diocletian, Brödner argued that there were spiral staircases in the corners of the apodyterium opening onto the palaestrae porticoes, the doors of which were later blocked, but this is far from proven.[79] In the Baths of Caracalla, the only space which lies in a similar relationship to the palaestra portico and has no clear other function is Rm 18.

This room has been variously explained. Hülsen believed that it was a cold water bath, since the floor was 2 m deeper than those of the surrounding rooms; Brödner, on the contrary, thought that it was a heated passage, with the hypocaust connected with that of Rm 20 and fed from a praefurnium in Rm 16.[80] If this was a heated room - and the present state makes it impossible to check earlier findings - what was its function? Rm 18 has four entrances: one from the palaestra, one from Rm 20, and two from Rm 17. If Rm 18 was just a passage, its only function apart from forming a link between the two heated Rms 17 and 20 (which could have been achieved simply by making Rm 17 larger) would have been to allow access to Rm 20 from the palaestra through a heat-lock. Given the length of Rm 18, it is then strange that it does not also give access to Rm 21. As has already been noted, however, the second door in Rm 17 is a later alteration, unfortunately impossible to date; without this second opening, all the movement is confined to the end closest to the palaestra, making the length of Rm 18 even more unnecessary. If Rm 18 in fact contained a staircase to the promenade terrace starting behind the line of the doors to Rms 20 and 17 closest to the palaestra, the second door, at whatever time it was cut through, would then merely give access to the space under the stairs.

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[78] Shown in the drawings of the Anonymous Destailleur. Although the west exhedra survives, the details of the staircases are not all easy to interpret. See De Fine Licht 1974: 38-40, Figs 6, 44-45 and Taf. III.

[79] Brödner 1951: 21. A drawing by Du Perac (Brödner's Taf. 21b) shows a blocked doorway, but this must have led to the long room alongside the natatio, not to the staircase.

[80] Iwanoff and Hülsen 1898: 29-30; Brödner 1951: 34.

Fortunately, there are several pieces of evidence which support this interpretation. Although both Rms 18 themselves are inaccessible, I was able to examine the terraces above them, and above Rms 16.[81] The doorway which leads from the portico terrace to that over Rm 18 rises by five steps which still retain traces of marble veneer (Fig. 24), while the terrace itself is paved with black and white mosaic, of which only traces remain. Taken together these facts strongly suggest that the door and the terrace over Rm 18 were part of the public areas of the Baths.[82] The terrace over Rm 16 is at a lower level than that over Rm 18, except for a short section at the opposite end to Rm 18. Unfortunately the terraces over both Rms 16 are modern restorations, but in the face of the wall between Rm 18 and the terrace over Rm 16 can be seen a double tile arch marking the end of a raking vault (Fig. 25). This opening between Rm 18 and the upper level of Rm 16 is shown on at least three Renaissance drawings. In Peruzzi's plan of the Baths, the opening leads to a stair over Rm 16, with a ?landing at the far end (Fig. 26); Abaco, however, shows only the opening and marks it "lumen" (Fig. 27). One of the measured drawings by the Anonymous Destailleur shows a section through Rms 11, 12, 18, 16, 23E, T, and 23W, with the height of this opening given, and the heights of the cross-walls of the upper levels of Rm 16E, which rise in steps away from Rm 18 (Fig. 28), and this fits well with Blouet's longitudinal section (Pl. VIII).

These drawings show a uniform slope between the floor of Rm 18 just beyond the doors to Rms 20 and 17, the opening in the wall, and the walls of Rm 16 would easily accommodate a staircase. On the other hand, it is not clear either from the drawings or from the present state of the building how, or at what level, the stair would have turned back to give access to the terrace over Rm 18. Traces of a ledge survive along the south wall of Rm 16 terrace, and it may have been that the stair filled only part of the width of that terrace, with a return on either side. It is worth noting

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[81] I was able to visit the terraces above Rms 16 and 18W using an hydraulic lift, thanks to Prof. Lucos Cozza and his associates from the Servizio Giardino of the Comune di Roma; scaffolding erected by the Soprintendenza as part of a programme of restoration made those above Rms 16 and 18E accessible.

[82] Cf. also the comments by Fabbrini 1983: 51, note 1, although she follows this idea no further.

that the lower terrace levels over the first two thirds of both Rms 16 west and east are entirely modern reconstructions, and that the Anonymous Destailleur shows them, but not the last third, without any roof. It is not impossible that some of the stair was in wood, which would explain its total disappearance. Making Rm 18 into a staircase does, however, make it difficult to know why it should have been a heated space; it is unfortunate that the evidence for this can no longer be examined, since the floors in both rooms have been completely rebuilt.

If Rm 18 can be seen as a major stair giving access to the promenade terrace of Rm 12, then this should throw some light on the arrangement of Rm 17. The second door in the south wall, cut through at a later date would then lead into the space under the stair - perhaps for storage. The filling in of the window in the south wall may have been necessary once the staircase in Rm 18 was fitted, and the original design was found not to work. The insertion of a staircase to the promenade terraces at this point of the bathing sequence is interesting. Rm 17 with its pool is usually seen as a private bath, or a bath for the athletes practising in the palaestra. If, as I have already suggested, the pool is a later addition, what function is left to Rm 17? The heating can only ever have been moderate, as there is evidence for wall tubes only on the north wall, while fragments of wall veneer set directly against the walls confirm that the other walls were not heated. In addition, with direct access now not only to Rm 20 but also to the portico terraces, Rm 17 becomes ideally suited for an oiling room, with the space under the stair, perhaps heated, being used to store the oil for immediate use.

2.5.6 The extent of the hypocaust floors and Rms 19-22

Brödner's plan of the Baths of Caracalla shows hypocausts in all rooms except 3, 7, 9, 11, 12, F, N and the service areas 15, 16, and 23, and in this she is following Blouet.[83] Although Von Gerkan cast some doubt on the extent of the hypocausts in his review of Brödner, her ideas have

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83 Brödner 1951: Taf.1 and pp. 34-35, 38-39, based on Blouet 1828: Pl.IV.

generally been accepted.[84] The recent excavations in Rms 2E and 8/9/10E, however, have proved that there were no hypocausts in these rooms at least, and point strongly to the need to reevaluate previous evidence.

In the excavations of 1824-5, only small areas of the central block were exposed, as indicated on Blouet's present state plan (his Pl. IV). Rather than each individual sondage being given its own label, all the excavations in any type of area were given the same letter, e.g. all excavations in the porticoes of both Rms 12 were designated "Fouille N". The detail drawings of the excavations use these generic labels, as does the accompanying text, so that it can be difficult to distinguish the particular sondage to which they refer, and thus the precise evidence that Blouet used to identify the hypocausts. Fortunately, within the area of each sondage, Blouet indicated the nature and extent of the floor surface found. Only in Rm 17W (Fouille H) is there clear evidence that he saw both fragments of the upper mosaic surface and the bipedales forming the floor of the hypocaust; given that the praefurnium from Rm 15 was also excavated, there is no doubt that this room was heated. In Rm 14 (Fouille E) and the tepidarium (Fouille D) he found the bipedales of the hypocaust, and in 14 also the corner of the mosaic floor. The hypocausts of both these are also independently attested, that in Rm 14 appearing on the plan of De Angelis (Fig. 13), the other being visible in situ in the centre of the tepidarium.

These are, however, the only places where Blouet's word cannot be doubted. Although he draws hypocausts in the section of Fouille N (Rm 12 portico) and in Rm 2 as well as Rm 14 in the section of Fouille E, in neither does he show any areas of bipedales on the plan, and in both cases he shows much of the mosaic floors intact. This is also the case with the floors of Rms 1, 3a-d, 4/5/6, and 8/9/10, where only in the text does he state that these had "Mosaïques portées sur des petits piliers". It has already been noted that Rms 2 and 8/9/10 have been shown not to have had

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[84] Von Gerkan BJ 1951: 132-35. For a recent reiteration of Brödner's ideas see Heinz 1983: 133-38.

hypocausts, and it is my contention that this is also the case with these remaining rooms.

How could this error have arisen? In the present state of the site, all the floors under discussion which are still visible have subsided. In Rm 2E the mosaic rested on a narrow hard packing layer, below which was about 1 m of loose fill of pozzolana and building rubble. It is not difficult to imagine how these two factors might have led Blouet to believe that what he was seeing was the collapse of hypocausts, particularly if the excavations were not continued down to a solid layer. After all, for comparison he had the solid packing which he notes under the central part of Rm 12, as well as the evidence of the brick-faced sub-floor walls, usually associated with hypocaust construction, under all openings and the palaestra colonnade.

The discussion so far has ignored Rms 19-22, which Krencker, followed by Brödner, believed were all heated dry sweating rooms - an interpretation which has found widespread acceptance. He based his theory on analogy with other bath buildings, but found confirmation in the hypocausts shown in the drawings of the Anonymous Destailleur. Blouet makes no mention of hypocausts under Rms 19-22, but only that traces of mosaic floors were found in Rms 19 and 20 (Fouilles O and P respectively). In contrast, his reconstructed section through Rms 5/12/20 does show a hypocaust. The hypocaust in Rm 19E at least has been confirmed by recent excavation, and there is little reason to doubt that the remaining rooms on the south face were also heated, although the extent of tubulation is arguable and the praefurnia have not yet been identified.[85]

In arguing that there were hypocausts under the porticos of Rm 12 Brödner points to the supposed excess of down-drains in that area, and some of these she interprets as flues for the hypocausts of

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[85] It is to be hoped that traces of the praefurnia will emerge from further excavation planned by the Soprintendenza in the relevant service passages.

Rms 20 as well as the portico.[86] That these small slots at ground level passing under the walls of Rms 20 to join the down-drains in Rm 12 could have ever acted as flues is highly unlikely, since the walls must have been covered with tubuli to well above head height, and it is at this level that the flues would be expected. In fact, the series of circular pipes to be seen in Rms 20 in the crown of the niche vaults (Fig. 29), the lower part of the apse vaults, and the north walls can only be interpreted as flues for the heating system. The remains of similar flues can be seen on either side of the vault of Rms 21 at the north end and in the north wall of Rm 22E; it is also possible that the larger triangular-headed openings which pass horizontally through the upper parts of the walls and vaults of Rms 20-22 (Fig. 30) were in some way connected with the operation of the flue system, as was probably also the case in Rms 17. The absence of any obvious flues in the walls of Rms 19 could be one argument against their being heated, but in this case we can assume that the room functioned as heliocaminus and had no tubulation,[87] the flues thus starting below the level of the paving and being incorporated in the thickness of the walls. The two small relieving arches at the base of the north wall of Rm 19E may indicate their position. Similarly, the location of the flues in Rms 14, which also lacked wall heating, are most probably indicated by the small relieving arches at the base of the north wall of both rooms (Fig. 31), opposite, that is, the praefurnium in Rm 15.

Accepting that Rms 19-22 are heated, two further problems remain. Although all four rooms are normally restored with columns in their wide openings, Krencker did not believe that heated rooms could function efficiently unless completely closed, and thus restored glazed windows between the columns; traces of curtain walls in the openings of Rms 19 and 20W were adduced in evidence.[88] He believed that these formed part of the original construction, but only further excavation could

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[86] Brödner 1951: 28-35.

[87] Cf. the octagonal room in the Forum Baths at Ostia (Thatcher 1956: 195-99).

[88] Krencker et al. 1929: 271, fig. 401.

clarify this point. On the other hand, Thatcher, using radiant heat analysis, was able to show that the equivalent rooms in the Terme del Foro at Ostia would be sufficiently heated even during the winter if their large windows were unglazed.[89] His results, however, depended on the high window sills, which prevented cooling draughts affecting the bather. In contrast, apart from those in the windows of the caldarium, the bases of the columns in the hot rooms of the Baths of Caracalla are always shown at ground level or on a low plinth, and a recent article by Broise has shown how slight might be the evidence for glazing.[90] The evidence then is inconclusive, but I am inclined to accept that the openings could have been glazed.

The second problem concerns the roofing of Rm 19 and the central part of Rm 20. Neither of these two spaces preserves any trace of the springing of the cross-vault suggested in both cases by the corner piers. In Rms 19, the piers continue vertically for the full remaining height of the room (Fig. 32), nearly 22 m in both cases, compared with an assumed maximum height of 23.05 m. In Rms 20, however, the piers finish roughly above the springing of the segmental domes of the apses, at a height between 13 and 15 m, but the state of the remains makes it impossible to determine whether these once continued to the full height of the room or not. Various solutions to this problem have been suggested. The drawings of the Anonymous Destailleur show them with flat coffered ceilings, annotated "couperto di lignamo or bronzo", while most other Renaissance artists indicate cross-vaults on their plans.[91] Blouet, followed by Iwanoff, believed that these areas were unroofed, although Hülsen preferred to accept the wooden roofs shown by the Anonymous Destailleur.[92] Brödner believed that it was no longer possible to determine the

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[89] Thatcher 1956.

[90] Broise 1991.

[91] Anon. Dest.: Bl.27 recto, P 106; Palladio: Zorzi 1959, fig.112; Battista da Sangallo: Uffizi Arch.1381 recto; Abaco: Uffizi Arch.1545 recto.

[92] Blouet 1828: Pl. VII, XI; Iwanoff-Hülsen 1898: 42-43, Taf.XVIII.

roofing of Rms 20-22, but Rm 19 certainly had no vault; nevertheless her plan has a cross-vault over the centre of Rm 20.[93]

Fortunately, the recent discovery in the service passages of a vertical drain from the outer corner pier of Rm 19W has confirmed that this room was roofed in some way.[94] It seems reasonable, therefore, to assume that Rm 20 was also roofed, and the fragments of a terrace paved in black mosaic over the apses of Rm 20 encourage this view. On the other hand, heated rooms with wooden roofs in bath buildings of this sophistication run counter to the usual beliefs that vaulted concrete is particularly suited to the needs of baths, not in the least for its heat resisting capacities. One possibility is that both areas had flat concrete roofs. While it is often stated that the curved vaulted form was essential in Roman concrete construction to cover most spaces, there is in fact a small amount of evidence to the contrary. Middleton recorded unsupported hypocaust floors in the Severan constructions on the Palatine and, with a span of up to 6 m, in the House of the Vestal Virgins. It also appears that the hall between the "Garden Stadium" and the "Casino of the Semi-circular Arcades" in Hadrian's Villa had a flat concrete ceiling.[95] In the latter case, several large pieces of concrete with the preparation layers for a mosaic floor on the upper side, and marks of boards on the underside, still survive. The room is approximately 10 x 16 m, and the relatively thin walls rise to a height of about 10 m without any signs of normal vaulting. By comparison, the clear spaces roofed in Rms 19 and 20 were 16 and 18 m square respectively. I have thus restored these rooms with a nominal flat concrete roof.

2.5.7 "cella solearis", "basilica thermarum" and Rms 12

So far we have looked only at some of the subsidiary points covered by Krencker and Brödner.

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[93] Brödner 1951: 19, Taf.1.

[94] Unpublished. I am grateful to Dr Angelo Corazzo for this information.

[95] Middleton 1892 (II): 70-72; Blake-Bishop 1973: 244-45; Salza Prini Ricotta 1988.

It is, however, the whole concept of the "basilica thermarum" which is most important for any reconstruction of the Baths. The radical theory that the porticoed areas previously believed by all to be open courts were in fact covered basilicas with wooden roofs aroused adverse criticism - most of it, I believe, thoroughly justified - when proposed first by Krencker, and later more fully by Brödner.[96] In the previous two sections I have already argued the fallacy of her assertions about the access to the portico terraces and the extent of the hypocausts, while I have argued in detail elsewhere that the "cella solearis" is to be identified with the caldarium rather than the "basilica thermarum" or the natatio (see Appendix 3).

The broader arguments on which the "basilica thermarum" theory were based have been convincingly refuted by both Von Gerkan and Tschira, and need only be looked at briefly here. The insistence on a closed bathing circuit with a large covered area for sports and social activities was based on parallels from buildings mainly in North Africa and the eastern provinces, where quite different climatic or cultural conditions prevailed, and on buildings of a much smaller scale. Given the poor state of preservation or the total disappearance of the other imperial thermae, the arguments from within this cohesive group rely very heavily on the Baths of Caracalla. The suggested formal development of the basilica as a whole (from a broad to a long shape), into which the "basilicae thermarum" of the various imperial thermae are supposed to fit, is easily refuted by reference to early "long", and late "broad", basilicas. Indeed, the validity of the use of the term "basilica thermarum" is doubtful, given its rarity in even very late classical sources.

There remain some arguments specific to the Baths of Caracalla to deal with. Both Brödner and Krencker made much of the apparent lack of a difference in level between the supposed court and its portico, the problem of its drainage, and of the fact that the court was paved with mosaic. As

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[96] See the review of Krencker by Von Gerkan (Gnomon 1932: 31-46), and those of Brödner by Von Gerkan (BJ 1951: 132-35), Crema (Palladio 1952: 94), Ward-Perkins (JRS 1953: 210-12)), Tschira (Gnomon 1956: 628-30) and Lezine (RA 1957: 98-99).

all the reviewers pointed out, the area has suffered both too much subsidence and too much restoration for the original levels to be recovered. Lezine notes that in the Antonine Baths at Carthage, the plan of which has many parallels with that of the Baths of Caracalla, there is a step, but of less than 0.2 m, between portico and court. On the other hand, the courtyard of the Insula of the Muses and, as far as can be ascertained in the present state, the palaestra of the Forum Baths at Ostia, both of which have mosaic floors, have no step between portico and court. The court of the Insula of the Muses slopes in towards a central drain; although the mosaic has been relaid, the drain at least appears to be original. There are also central vertical drains in the open areas of Rms 12 in the Baths of Caracalla, as well as longitudinal drains along the outer face of Rms 8/9/10. These latter do not seem to have taken the water from the terraces over these rooms, which were served by the vertical drains in the outer face of the building, but were connected to other drains coming from the centres of the individual rooms; in addition, there was at least one sump which could have served the open court. Given that these courts received no rainwater from the terraces, if they also sloped from the colonnade towards Rms 8/9/10 the drain in the centre and along that edge would have been sufficient to carry away the excess water without the necessity of a step, and any excess would have simply run away into the drains within the three rooms.

Finally, there are structural considerations. Von Gerkan, supported by Ward-Perkins and Tschira, argued that the columns are too slender to support the massive superstructure suggested by Brödner, pointing out that the corresponding columns in the Basilica Ulpia, and in Christian basilicas of a similar span, are all thicker. Crema also noted that the system of iron ties and anchorages identified by Brödner would be more necessary to resist the outward thrust of the barrel-vaults of the portico if there was not a stabilizing mass of masonry above the colonnade, although the identification of a similar system in the aisles of the Basilica Ulpia does leave the question open.[97] Perhaps a more telling problem created by Brödner's reconstruction of the basilical hall concerns the face giving on to Rms 8/9/10. Not only is it difficult to imagine how this wall, and particularly the junction between this and the colonnades, was treated, but no restoration would solve the problem of lighting these rooms since the roof of the basilica must have been at least as high as that of Rms 8/9/10. As Brödner herself points out with respect to the natatio, there can be no structural or functional reasons for the absence of windows in the outer wall, so that the light for these rooms must have been designed to come from elsewhere; in this case the only possibility is the open court of the palaestra.

[97] For the Basilica Ulpia see Amici 1982. I have discussed the structural implications of this type of construction elsewhere (DeLaine 1990: 417-21).

CHAPTER THREE: DESIGN

INTRODUCTION

This chapter attempts a reconstruction of the design process used by the unknown architect of the Baths of Caracalla, both as the first step in understanding how the complex was created, but also as a means of elucidating more general principles of Roman architectural design. Because of the limitations of the survey, this can only be done in detail for the central block, but enough can be deduced about the outer precinct to show that the same kind of approach was followed. On the other hand, it has been possible to extend the analysis to most aspects of the elevations, which allows a far better appreciation of design methods than could be achieved by consideration of the plan alone. Throughout the chapter I have tried to bring out the practical implications of the design process for the task of generating the plan on the ground and the elevations, in the hope of throwing light on the relationship between design and construction.

3.1 THE PROBLEM OF DESIGN

3.1.1 The nature of the problem

> "...to recreate the architecture of a particular period, as a necessary preliminary to understanding it, the historian must recreate the architects' thought processes."[1]

The only literary descriptions of the mechanics of design which have come down to us from the Roman period are those in the de architectura of Vitruvius. Although Vitruvius describes the actual design process only for the basilica at Fanum (de arch., V.i.6), he does give a variety of general rules and precepts (including specific proportions) for designing temples, the orders, public

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[1] Boyle 1981: 5.

buildings, and houses. Thus he provides evidence for the use of arithmetic (V.i.6) and geometric (I.vi.6-7, IX.vii.2-6, V.vi.1-6) methods of design, simple measure (V.i.6), commensurable proportions (III.i.2 and v.8, IV.vii.1-2, V.i.2-5 and ii.1, VI.iii.3-8), incommensurable proportion (VI.iii.3-4), and module (IV.iii), as well as general statements, difficult to translate and therefore open to widely differing interpretations, about symmetria, proportio, quantitas, dispositio, decor, eurythmia and ratio (I.ii, III.i, VI.ii). Even deviations from a strict arithmetic or geometric scheme can be accomodated under Vitruvius' prescriptions for adjusting a given symmetria for specific site conditions (VI.ii).

These elements and their combinations provide a wide range of possible interpretations of the ancient design process which are often difficult to choose between. An example will suffice to show the nature of the difficulties involved. Among the various buildings which make up Hadrian's Villa at Tivoli are several with complex curvilinear ground plans. Since 1960 three different attempts have been made to recreate the design process for one of these - the Piazza d'Oro - with three quite different results (Fig. 33).[2] All start from the building in its present state, and all have a geometric basis. Hansen, working from an earlier published plan, develops an abstract geometric scheme based on the golden section, which he then scales to fit the actual building. Rakob, using his own very detailed survey, starts by determining the modules, in round numbers of Roman feet, on which the scheme is based; he then sets up a grid using two of the modules with the third as the radius generating the curved walls of the building. Jacobson, using Rakob's survey, returns to the abstract geometric approach but employs a grid of close-packed circles based on one fixed length, the radius of the circle, which he equates with Rakob's third module. Needless to say, each author criticises his predecessor's results,[3] but how are we to choose between the various possible schemes?

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[2] Hansen 1960; Rakob 1967; Jacobson 1986.

[3] Rakob 1961: 243-50 on Hansen; Jacobson 1986: 76-78 on Rakob.

All these attempts to discover the design process assume first of all that there is a rational process to discover. The fact that a logical and internally cohesive design process produces a high degree of fit with the structure as built is taken as confirmation.[4] It is the fit that is the touchstone, and this raises an important question. How do we decide what lines of the building as it stands were critical for the original design? This not only affects where we draw the lines in analysis but also where we take the measurements in our surveys. The alternatives are defined by Rakob in his latest article on the curvilinear Hadrianic buildings, and can be summed up as follows:[5] do we measure from the face of the decoration, the line of the bare wall, or the projection of the foundation, and do we take as the basis for analysis the clear width between the walls, the distance between the axes of the walls, or the width of the room plus the wall thickness? Or, we might add, some combination of these?[6]

3.1.2 Accuracy and the Roman foot

In essence the answer is that one chooses the line which gives critical dimensions in whole numbers of Roman feet, and for large units preferably those which are multiples or fractions of 10 or 12.[7] This, of course, presupposes that a modern metric survey can be converted accurately into dimensions in Roman feet, which in turn involves finding the "right" value for the foot and deciding on a suitable degree of precision. Various attempts have been made to determine the "standard" Roman foot, working from the few existing ancient measures and from buildings of "known" dimension. The latest, by Bauer,[8] is worked out to the unlikely six figure decimal of

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[4] This is, however, only expressly stated by Geertman 1984a: 31, in his discussion of Peterse 1984.

[5] Rakob 1984.

[6] Cf the debate over the design diameter of the Pantheon. Davies et al. (1987, cf. Wilson-Jones 1989a: 129-31) favour 150 ft, De Fine Licht (1968: 194-98) and Geertman (1980: 203-29) 148 ft.

[7] Stated most firmly by Rakob 1967, and assumed as a first principle by, for example, Rasch 1984a and Gawlikowski 1985. For the latest and most detailed arguments see Wilson-Jones 1989a.

[8] Bauer 1983: 136, and contrast the sensible comments by Wilson-Jones 1989a: 108, note 8, and Rakob 1984: 220 and note 3.

0.294715 metres, although he allows that this is only valid for the city of Rome! The important recent monograph by Hecht dealing with this problem has shown the invalidity of this kind of approach.[9] The range of values now commonly accepted is between 0.294 and 0.297 metres, while the actual figures used tend to be stated to four decimal places, e.g. 0.2957 metres by Hecht, 0.2942 metres by Rasch in his analysis of the Mausoleum of Maxentius, with Jacobson accepting three different values - 0.2942, 0.2956 and 0.2958 metres - for different buildings within his survey, despite the fact that most of them are part of the same complex.[10]

This concern with millimetric accuracy in defining the Roman foot is, to quote Ernest Will, "...une preoccupation plus moderne qu'antique...".[11] Certainly under the Roman empire some attempts were made to standardize the foot measure in use in different places, although even there different foot standards existed side by side. This does not mean, however, that there was any attempt to copy an existing standard to that degree of precision recognised in the modern scientific world, nor in practical terms would it have been feasible; in fact it is highly unlikely that the problem was even recognised. It is worth remembering that even today, despite the existence of an absolute standard and the technology to reproduce it accurately, it is not unusual to find differences of several millimetres in a selection of non-scientific 300 mm measures such as school rulers; yet no-one denies that these represent a "standard" 300 mm. The use of values in metres to four decimal places for the Roman foot, although necessary to the scholar in manipulating figures converted from metric surveys, nevertheless gives a misleading impression of intended precision, as the figure is after all only an average value.

This concern with accuracy in respect to the value used for the Roman foot is in strange contrast

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9 Hecht 1979.

10 Rasch 1984b: 69; Hecht 1979; Jacobson 1986: 84.

11 Will 1985b: 328. On this problem in general see Fernie 1978.

with a universal willingness to accept a surprisingly wide range of values for a particular dimension in order to achieve a close fit between reconstructed design scheme and measured plan. For example, to return to the Piazza d'Oro, Rakob accepted the values of 4.36, 4.51, 4.42 and 4.32 metres as representing 15 Roman feet of 0.2942 metres, i.e. allowing a variation of up to $\pm 2\%$ from the ideal value of 4.41 metres,[12] and there are other examples. This variation is in fact much greater than the percentage error which would have been generated by using a different value for the foot. Paradoxically it was Rakob's strict adherence to the primacy of "klare und runde Fussmasse",[13] which led him to base his design scheme for the Piazza d'Oro on the three distinct modules of 15, 12½, and 12 Roman feet. His concern with "precise" dimensions has been criticized on several occasions for being too rigid, and other scholars have accepted even wider ranges of values as representing a particular design dimension. Jacobson, by treating the measurements which Rakob interpreted as two modules of 12 and 12½ Roman feet as all representing 12½ Roman feet, was able to produce a much simpler - and much more believable - design scheme for the same building.

3.1.3 Practical considerations

The lack of fit is explained by Jacobson as a product of the inaccuracies inherent in ancient surveying techniques and instruments,[14] and this introduces the third factor which we must take into account in trying to assess the validity of a given scheme. For there to be a perfect fit between the reconstructed design and the survey plan used as the basis of analysis, the structure as built must have corresponded exactly with the original design, which was not necessarily, and I suspect not even usually, the case. While Jacobson is no doubt right in seeing the source of minor dimensional inaccuracies in the surveying methods used, not all techniques were open to the

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[12] Rakob 1967: 120, note 156.

[13] ibid, 76-7.

[14] Jacobson 1986: 84.

same kind or the same degree of error.

Let us assume, for example, that a line 100 Roman feet long has to be set out. This could be done using a single cord, the length of which is determined by measuring against a "standard" foot rule, or more likely a ten-foot rod.[15] The cord then measures 100 or 10 times the length of the standard used, but any error in that standard will be increased 100 or 10 times. In addition, cords would be prone both to stretching and to sagging, adding an extra source of error. The line could also be set out using one or more ten-foot rods marked or laid out on the ground. If the rods were not exactly the same length, or not laid out exactly in a straight line with their ends just touching, the line would be shorter or even longer than 10 times the initial standard. With both the cord and the rods, errors may be self-compensating, so that the line would end up exactly 100 feet long, or 98.9 feet, or 101 feet, or any other figure within the range of, say, $100 \pm 1\%$. Subdividing the line into half and half again could then produce four equal segments which were accurate with respect to the original line but not with respect to the initial standard. Similarly, error could be introduced in laying out a circle or a segment of a circle either in the initial measurement of the cord for the radius, or by not maintaining the same tension on the cord when fixing points on the circumference. If too few points are used, a polygon rather than a circle is produced. Fixing a dimension by intersecting circles, as must have been the case for some of the curvilinear Hadrianic buildings, compounds the possible errors.

In all cases, however, the degree of accuracy obtained will to a great extent be proportional to the degree of care exercised by the surveyors. When necessary, as in the laying out of tunnels and aqueducts, Roman surveyors could and often did achieve degrees of precision commendable even

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[15] See Zimmer 1984 for Roman measuring rods.

by modern standards,[16] but such precision needs time and care, and it seems that the results were often not deemed to warrant the effort involved. In his investigation into the design of the Baths at Argos, Aupert has postulated that the building was set out on the ground using angular measurements taken with a dioptra rather than by direct measurement, a rapid method but one prone to error if the resulting dimensions were not checked.[17] Here, clearly, a high degree of accuracy was not felt to be required, and the resultant irregularities would not have been noticed by the normal observer, however obvious they might appear from the archaeologist's survey.

So far we have been talking only about dimensional inaccuracies resulting from careless surveying or the use of an inaccurate standard, producing errors which can be absorbed in the process of reconstructing a design scheme by accepting a range of values to represent a specific dimension within a tolerance of one or two percent. There are, however, ways in which the structure as built may come to differ more substantially from the original design; these include straightforward mistakes in setting out, deviations from the original plan made necessary by specific site conditions, or changes introduced for structural, aesthetic or purely external reasons such as the whim of the client. Examples of most of these can be found in published surveys, and, although it must be admitted that none of them can be proved, most of them are convincingly argued.[18]

3.1.4 Recreating the design process

In trying to recreate the design process for any Roman building, therefore, we need to take into consideration a large number of variables. Most are interrelated, forming as it were a set of simultaneous equations which can only be solved by a process of iterative induction, i.e. by alloting

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[16] This is mosty commonly stated with reference to the building of the aqueducts. See, for example, Ashby 1935 passim. For recent experiments with reconstructions of Roman surveying instruments which confirm the precision with which they could be used, see Adam 1982.

[17] Aupert 1985: 266-67.

[18] e.g. simple errors - Boyle 1981: 186, 179; site conditions - Gawlikowski 1985: 283-90, Rasch 1984b: 60, Taf. 79; alterations during construction - Nohlen 1985: 269-76.

fixed values to some of the variables in order to solve the equations and then testing the solution against the given conditions. If the conditions are not met, the amount of divergence is used to suggest a new set of values and the process continues in this way until a set of values for all the variables has been worked out to fit the given conditions. Much depends on the original choice of values, and the fact that a solution can be found does not necessarily mean that it is the only possible one. The variables can be divided into five classes, each of which have different conditions attached to them. The first class consists of the elements of the design process, such as proportion, module, etc., where the number of the individual units is limited but the possible combinations many. The second class consists of the main dimensions of the original design, which should be in whole numbers of feet or simple fractions, with the further condition that the larger dimensions should be in multiples of 5 or 6 feet. The dimensions of the structure as built make up the third class of variables, and although these are the only ones which can be measured directly the measurements can be taken from a number of different positions. The value of the fourth variable, the length of the Roman foot, is set within the narrow range of 0.294 to 0.297 metres. The final factor is the error in the structure as built which can be given an acceptable value, say at the outside $\pm 1\%$ of any given dimension.

This is, of course, just a formal statement of what is usually done by "intuition", or educated trial-and-error. It is, nevertheless, a statement that is worth making, as it helps clarify the assumptions made in reaching a particular solution. The most important of these is the identification of the type of process used, since on it depends the other variables; an appropriate initial choice is made through a familiarity with the likely shapes and proportions of Roman buildings. It is possible to work out the design process in relative terms first from the geometry of the structure as built, which reduces the number of variables in the early stages of analysis. This is the approach favoured by Geertman, an approach which stems from the author's exceptional awareness of the problems involved in the interpretation of ancient methods of design.[19] The problem with this method is that there are fewer internal cross-checks until the value of the foot and thus the design dimensions are worked out. This could easily lead, for example, to a mistaken choice of significant dimensions if there is no check on the actual figures in Roman feet. Working from the pure geometry of the built design also does not easily allow for the recognition of large errors or adjustments to the original design scheme. Whatever the approach, there always remains the danger that by adjusting the parameters, and particularly the degree and nature of the variation between ideal and realised plan, quite a wide range of possible processes can be made to fit any given structure.

3.1.5 Critieria for choosing possible design processes

Thus we come back to the same question - how do we choose between different interpretations of the design process for a single building? Clearly, while the test of "best fit" is an important factor, it is not a sufficient one. Nor is the criterion of a logical and internally consistent process much help, as this is met by all versions of the Piazza d'Oro designs. As I see it, the critical factor is simplicity. Not only is a simple design much more likely to be thought of in the first place, but it is also much easier to lay out on the ground with a minimum of error. It is, in essence, a question of practicality. This is the approach favoured by Coulton in his analysis of Greek temple design, but most of his ideas are also valid for Roman architecture.[20] Simple proportions based on straight-forward round numbers are obviously preferable to complex geometries effected by arithmetical approximations to irrational proportions. That is not to say that geometric solutions per se should never be considered; it is impossible to imagine the curvilinear Hadrianic buildings discussed by Rakob and Jacobson in any other way. As Jacobson points out, the development of mathematical skills and the architectural use of them were features of the Hellenistic age taken over

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[19] Geertman 1984a: 31-32, following Peterse 1984.

[20] Coulton 1975: 64-65.

by the Romans for their practical value.[21] In addition the flexibility of concrete construction was particularly suitable to curvilinear designs, which were necessarily of geometric origin. Proportional or geometric, it is essential that at the heart of any scheme lies a conceivable round number.[22]

To sum up our conclusions so far:

1 The design process should be logical, internally consistent, as simple as possible and capable of being laid out easily on the ground.

2 The design should be based on one or two primary dimensions which can be expressed in conceivable round numbers of Roman feet.

3 Errors should always be definable and explicable, and an acceptable range of percentage variation should be decided for dimensional inaccuracies.

4 The value of the Roman foot should lie within the range of 0.294 to 0.297 m, unless there are strong arguments to the contrary, but the actual value chosen as a starting point is not important.

3.2 DESIGNING THE BATHS OF CARACALLA

A number of features of the Baths of Caracalla make them an appropriate subject for a full design analysis. As has been argued in Chapter 2, the state of preservation is such that both plan and elevation of the central block can be reconstructed to an acceptable degree of accuracy for all areas except the tepidarium, although there are some details in other rooms which are doubtful. In addition, the nature of the building makes it clear that the architect had to meet certain functional requirements in the size and arrangement of the rooms and the provision of services, which would

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[21] Jacobson 1986: 69-72.

[22] i.e. numbers which are easy to subdivide or multiply in either the decimal or duodecimal systems. Cf. Wilson-Jones 1989a: 121.

have formed the basis for the preliminary stages of design. The major axes of the building and thus the starting point for the formal process of design are immediately apparent from the ground plan, while the symmetry of the design about one of these axes provides the means of cross-checking any hypothesis about the design and detecting any major errors in setting out. The complexity of the scheme in plan and elevation strongly suggests that both must have been the result of a detailed design process, leaving only the degree of detail left to the builders to be determined.

3.2.1 The rough outline

The decision to build a bath complex to serve several thousand people had a number of repercussions, since it was not possible simply to enlarge the plan of a small establishment catering for, say, 100 people. Entrances and exits, doors and passageways, form valves and controls, so that it is more practical to increase their number rather than their size; the Roman architect's appreciation of this point is obvious from the design of their theatres and amphitheatres. In the changing rooms there was need for more wall space to provide storage for the clients' clothes rather than for more floor space, and this again is best met by increasing the number rather than the size of the units. The dry sweating rooms depended for their proper functioning on the radiant heat transmitted by the tubuli lining the walls, helped by the rays of the afternoon sun.[23] This must have determined not only their location but also their size, since there would be a maximum distance which a bather could be from a heating surface and still maintain the required elevated body temperature. Once again the solution is in increasing the number rather than the size of the units. A similar argument can be applied to the heated pools of the caldarium; indeed, the sizes of caldaria pools are only a little larger in the Imperial thermae than in the small Republican type

[23] Thatcher 1956.

baths such as the Forum or Stabian Baths at Pompeii.[24]

On the other hand, the caldarium itself is much larger than what seems to have been the maximum size for dry hot rooms. Since the main functional element in a caldarium is the hot water, the need to maintain a high body temperature in the bather is less important. Besides, the relative humidity in caldaria is much higher than in dry heated rooms, so that the actual temperature required to produce perspiration is less. The size of the tepidarium in the Imperial baths seems to be controlled more by its function as a passage than by any purely technical requirements. There are, of course, no practical limitations on the size of the open natatio and palaestrae, while the only one on the covered frigidarium is structural. In fact the latter may have been the deciding factor in determining the scale of the whole complex; the only clear spaces covered by Romans architects which are known to have been larger than those of the cross-vaulted halls of the Imperial thermae are those of the Basilica Ulpia, itself one of the wonders of Rome, and the Basilica of Maxentius.[25] Finally, allowance had to be made for the provision of services. The rationalization of water supply and drainage sanctions the traditional linear sequence of natatio, frigidarium, tepidarium and caldarium, the only rooms requiring large amounts of water. The problems of lighting perhaps dictate the location of the palaestrae, while service courts need to be sited between tepidarium and caldarium to provide heat to these.

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[24] Measurements of caldaria pools in round figures: Pompeii, Stabian Baths, 6 x 2.5 m; Pompeii, Central Baths, 8 x 2.5 m; Ostia, Baths of Neptune, 7 x 3 m; Tivoli, Hadrian's Villa, 6.5 x 2.5 m; Rome, Baths of Caracalla, 7 x 4 m.

[25] Clear dimensions and areas in round figures: Baths of Caracalla, frigidarium 24 x 55 m, 1,320 m^2; Baths of Diocletian, frigidarium 23 x 59 m, 1,360 m^2; Kaiserthermen, Trier, frigidarium 22 x 57 m, 1,250 m^2; Basilica Ulpia 25 x 87 m, 2175 m^2; Basilica of Maxentius 25 x 80 m, 2,000 m^2. The area of the Pantheon, diameter 43 m, at 1,470 m^2 is only slightly larger than that of the frigidaria of the Imperial baths.

It seems that a basic scheme to cope with many of these needs had been created much earlier, possibly for the Baths of Nero, but certainly for the Baths of Trajan.[26] A comparison with the plan of the latter (Fig. 34) shows that the architect of the Baths of Caracalla was following an established pattern with regard to the overall size and layout, but still had abundant scope to exercise his creative faculties. He had to decide the overall shape of the building, and the size, form and distribution of many of the elements within the given scheme. One of the difficulties must have been integrating all the necessary elements into a cohesive whole.

If the plan of the Baths of Caracalla is reduced to a bare framework, it falls neatly into a series of blocks; the architect might have produced a similar kind of sketch in the early stages of the design process (Fig. 35). Certain basic decisions have already been taken at this stage. The overall shape of the block is roughly a double square with the circle of the caldarium projecting from the centre of one long side. Longitudinally the block is divided into five parts, the central one defining the series natatio/frigidarium/tepidarium/caldarium, and the end ones the palaestrae, with the remaining two being given over to dressing rooms, passages and services, lying between the main functional areas of the baths. The palaestrae are bounded on the north by entrance halls and on the south by the hot rooms. Other important decisions were to make the natatio roughly the same size and shape as the frigidarium and to extend the long sides of the frigidarium to define the passages between it and the palaestrae.

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[26] The plan of the Baths of Trajan has been reconstructed on the basis of the Severan marble plan, the drawings of the Anonymous Destailleur, Palladio and Canina, and the recent survey of the surviving parts by De Fine Licht 1974, but it should be noted that there are several discrepancies between these sources. The most accessible plan is MacDonald 1982: Fig. 73 which fits with De Fine Licht's survey within the limits of the small scale adopted. The plan in LSA 6.2, Fig. 3 also fits with De Fine Licht, but some of the other relationships are different to those given by MacDonald.

3.2.2 The scheme for the ground plan

Starting from this basic outline the architect then had to fill out the details of his plan; this is the critical formal process of design in which are decided the proportions of the rooms and the relationship between the parts and the whole and between one part and another - the things, that is, which determine the aesthetics of the design.

The obvious starting point for analysis is to look at the dimensions and proportions of the major spaces and of the overall plan to see if any simple relationships emerge. The outside dimensions of the central block excluding the projection of the caldarium and the apses in Rooms 9 are 218.07 x 111.88 (av.) m, i.e. 739.2 x 379.3 Roman feet.[27] Even if we take this as representing 740(-0.1%) x 380(-0.2%) feet,[28] giving a ratio of length:breadth of 1:0.513, this seems an unlikley starting point for a design. If the architect had started his design from the overall shape of the block, we would have expected perhaps 700 x 350, or 750 x 375 feet. The search for simple dimensions in the major rooms or internal divisions is more rewarding. The clear internal width of the palaestrae averages 29.52 m on the east and 29.35 m on the west, i.e. 100.1 and 99.5 Roman feet respectively. The average length of the frigidarium measured between the centre-lines of the columns which divide it from Rms 14 is 58.83 m or 199.6 Roman feet,[29] while the distance between the outer face of the south wall and the longitudinal axis of the frigidarium is almost exactly the same, 58.88 m or 199.6 Roman feet. There can be no doubt that these were intended to be 100 and 200 feet respectively. A shorter foot of 0.2944 m gives even closer values, 100.3 and 99.7 feet for the average width of the palaestrae and 199.8 and 200.0 feet for the rest, and

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[27] Using initially an average value of 0.295 m for the Roman foot.

[28] Blouet 1828, Pl. IV, gives the measurements as 112.015 x 218.491 m. See Section 2.2.2 for the weaknesses of Blouet's survey.

[29] Alternatives are: inner faces of the end piers - 189.3 Roman feet; inner faces of projecting spurs - 196.8 feet; inner walls of Rooms 14 - 204.3 feet.

would also be more suitable for converting the overall dimensions of the block into round figures, giving 380.0 x 740.7 Roman feet. A foot of 0.2944 m will thus be used from here forth.

The next step is to determine the proportion or construction which controls the design, starting from those spaces which have simple round measurements as one of their dimensions - the frigidarium and the palaestrae. The average width of the frigidarium is 23.89 m, giving a proportion of 1:0.406, while the average internal length of the palaestrae is 66.81 m on the east, and 67.22 m on the west, giving proportions of 1:0.442 and 1:0.437 respectively. Although the frigidarium proportions could easily represent 1:0.4, i.e. 2:5, this is no help with the palaestrae, and the absence of any round dimensions is equally disheartening. Taking the distance between the outer walls of the palaestrae, however, produces proportions of 1:0.415 and 1:0.411 for the east and west respectively. Both of these can be regarded as approximations to the incommeasurable ratio $1:\sqrt{2}-1$, as in fact could the proportion of the frigidarium with an error of 2%, or less than 2 feet in the total width. This proportion appears again in the natatio if measured between the outer walls. In addition, the average value calculated for the radius of the caldarium to the outer face of the wall is 24.53 m or 83.3 feet, a reasonably close approximation to $200(\sqrt{2}-1) = 82.8$ feet. Furthermore, the distance from the inner face of the outer walls of Rooms 8/9/10 to the inner face of the palaestrae is 12.14 m or 41.2 feet, which is very close to $100(\sqrt{2}-1)$ or 41.4 feet.

The recurrence of $\sqrt{2}-1$ can hardly be coincidence. Nor is it an unlikely value, as it is easily constructed from a unit square, here of either 100 or 200 Roman feet. The use of the proportion $1:\sqrt{2}$, to which $1:\sqrt{2}-1$ is geometrically related, is attested in Vitruvius (de arch. VI.iii.3-4), and was fundamental to the design of the Pantheon.[30] Starting from a basic dimension of 100 Roman

[30] Geertman 1980.

feet and using the $\sqrt{2}$-1 construction, it is in fact possible to reconstruct the main outlines of the ground plan using a sequential process in which each length is determined from a previously determined dimension. The process can be illustrated in a series of simple steps (Fig. 36):

1 Lay out the perpendicular axes XX' and YY' intersecting at O, the centre of the frigidarium. Define the length of the frigidarium by laying out two lines aa' and bb' 100 feet either side of and parallel to YY'. Similarly lay out cc' and dd' either side of and parallel to XX'; cc' forms the south wall of the natatio and dd' the centreline of the tepidarium (Fig. 36a).

2 Lay out ee' parallel to and 100 feet from dd', forming the south boundary of the block. Take the diagonal of the central square defined in step (1) and lay out the north boundary ff' that distance from and parallel to dd' in the direction OY' (Fig. 36b).

3 Lay out the east and west boundaries gg' and hh' parallel to and a distance equal to twice O/ff' either side of YY' (Fig. 36c).

4 Lay out the north and south walls of the frigidarium within the central 200 ft square, starting from the corners of the square and using the diagonal from the corner to O to set out ii' and jj' parallel to XX' (Fig. 36d).

5 Lay out the circular caldarium by defining the outer limit 100 ft from the south boundary along YY', and the radius equal to the width of the natatio (Fig. 36e).

6 The south wall of the tepidarium is marked by the intersection of the circle of the caldarium along YY', and the north wall is set out symmetrical to this about the centreline dd'. The width of the tepidarium is made 100 ft, set out symmetrically about the axis YY' (Fig. 36f).

7 Lay out the inner long walls of the palaestrae kk' and ll' parallel to the east and west boundaries of the block respectively, and a distance equal to the diagonal from one corner of the central 200 ft square to O from them. The width of the palaestrae is then set at 100 ft. The length is made equal to the distance between the south boundary of the block and the north wall of the frigidarium, set out symmetrically about the axis XX'(Fig. 36g).[31]

8 Define the zones 1/2/3, 13/14, and 15-18 by extending the lines of the north and south boundaries of the frigidarium to intersect with the inner walls of the palaestrae. The groups of rooms 4/5/6 and 7-11 are already defined in the setting out of the palaestrae (Fig. 36h).

The major lines of the ground plan have thus been established by means of a relatively simple design process which relates all the major spaces by the use of either the proportion $1:\sqrt{2}-1$ (frigidarium, natatio, palaestrae), and/or the dimension $200(\sqrt{2}-1)$ ft (width of frigidarium, width of natatio, radius of the caldarium) derived from that relationship. The only other dimension used is $100\sqrt{2}$ ft, which again is related to the original proportion. The tripartite division of the area between the main longitudinal axis XX' and the south boundary of the block created by the south boundary of the frigidarium and the centreline of the tepidarium is in the ratio of $(\sqrt{2}-1):(2-\sqrt{2}):1$, as is the division between the centreline of the tepidarium and the north boundary of the block, created by the north and south boundaries of the frigidarium. The length $100(2-\sqrt{2})$ ft also occurs in the distance between the natatio and the frigidarium, and as the generating dimension of the arrangement of hot rooms; it is of course a natural result of the combination of 100 and $100(\sqrt{2}-1)$ (Fig. 37). These relationships arise from the geometrical process used for laying out the scheme, based on a square and its diagonal, but they also suggest a specific concept behind the design. The

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[31] Simple algebra shows that this produces the required proportion of $1:\sqrt{2}-1$.

ratio $(\sqrt{2}-1):(2-\sqrt{2}):1$ is the solution for a unit square of the Pythagorean harmonic mean, which in the general case can be stated as $c/a=(c-b)/(b-a)$, where $a<b<c$.[32]

3.2.3 Completing the plan

To complete the general outline of the plan it is now only necessary to subdivide the blocks between frigidarium and palaestrae and those flanking the palaestrae. This was done by division in simple ratios, rather than by dimension, an approach consistent with that used in the main stages of the design process. Simple ratios no doubt were preferred because of the difficulty of dividing a given line in an irrational ratio. The dominant ratio used here is 2:3, which interestingly is reasonably close to the ratio $1:\sqrt{2} = (\sqrt{2}-1):(2-\sqrt{2})$ at the heart of the design. Thus the division between Rms 1/2 and 3 is in the ratio 2:3, that between Rms 4, 5 and 6 is in the ratio 2:3:2, and that between Rms 7,8,9, 10, and 11 in the ratio 2:3:4:3:2. The division between Rms 1 and 2 was created by making Rm 2 approximately square, the dividing line giving the centres of the columnar screen between the two rooms, while the central space of the group of Rms 3 was given the proportion of 2:3 and set symmetrically in the centre of the block.

The area of Rooms 15-18 was divided up very simply. The distance between the end of the frigidarium and the inner boundary of the palaestra was divided into halves, the line marking the inner face of the walls of Rms 17 and 18; this length was then set off from the south boundary of Rm 14 to create the division between Rms 15/17 and 16/18. Rooms 13 and 14 are also divided roughly in the ratio 1:1. In its final form, however, Rm 14 has the proportion 3:4 measured between the internal walls, rather than between wall and column screen, and this probably determined the exact location of division between Rms 13 and 14, while the general location was

[32] See Heath 1921, 85-86. For the use of harmonic ratios in bath design see now Heinz 1991.

decided at the outline stage by the ratio 1:1. The diameter of the semicircular Rm 13 was made equal to the width of the natatio, also used in determining the caldarium.

The only part of the block where the rationale for dividing up the spaces is difficult to determine is the range of hot rooms 19-22. The outer face of Rms 21 divides the group of rooms into two (Rms 19/20 and 21/22) roughly in the proportion 4:3, measuring to the intersection of the centreline with the caldarium ring, or roughly in the proportion 3:2 measuring along the facade. Rms 21 are 60 feet wide internally, while Rms 19 are 61 feet wide. If, however, we take the width of Rms 19 from the outer lines of the block established in the basic design process, this also becomes 60 feet. Thus it may be that these rooms form an anomalous case, where a simple measure unrelated to the rest of the design process was used following an initial division into one of the standard ratios.

The general outline of the building has therefore been achieved using only a single measurement of 100 Roman feet, the remaining dimensions being derived from this geometrically using irrational proportions to obtain the outline, which was then subdivided using rational proportions (Fig. 38). The only possible exception to this is in the setting out of Rms 19 and 21. There are several advantages in this method. For the architect it is a relatively simple way of creating a complex plan which is consistent and harmonious. It is also reasonably simple to lay out on the ground compared with a design given entirely by measurement, especially where the dimensions are large and the plan complex.

3.2.4 Designing the outer precinct

Given the nature of the available evidence (Section 1.2.3) it is not possible to examine the design of the outer precinct in the same detail as used for the central block. The published plans are unfortunately without exception on a scale of 1:1000 or smaller and include few if any dimensions.[33] Thus, although the major lines of the scheme are fairly clear, the analysis presented here must be considered provisional only, and many problems remain.

The general shape of the precinct, bounded by the outer face of the portico to the north, the inner face of the libraries and "stadium" to the south, and the outer main boundary walls (excluding the exhedrae) to the east and west, is a square 323.0 m NS by 323.3 m EW, or 1097 x 1098 Roman feet (Fig. 39).[34] In addition, the distance between the south boundary and the start of the north terrace/portico block is 294.75 m or 1001 Roman feet, while the EW distance between the lateral porticos is 297.37 m or 1010 feet. This suggests an ideal scheme of a 1000 ft square set symmetrically EW within a 1100 ft square and with a common south border, with an error in the EW dimension of the smaller square of 1% (Fig. 40). This does, however, leave the problem of locating the central block within its precinct.

In fact, the simplest way to generate the design while obviating this problem is by a successive process which starts from the width of the central block and generates the main lines of the outer precinct using $\sqrt{2}$ constructions and the absolute dimension of 1000 Roman feet (Fig. 41). The relation between the width of the central block excluding the projection of the caldarium (AOA'), the distance between the north edge of the central block and the south edge of the terrace/portico (BB'), and the outer edge of the north portico (CC') is very close to $4{:}\sqrt{2}{:}1$, or if we take half the width of the block, $2{:}\sqrt{2}{:}1$. This ratio can be set out easily from the original dimension by setting up a square with sides equal to half the width of the block (AO), drawing the diagonals, and making AB equal to the length between one corner of the square and the intersection of the

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[33] The most useful are those of Blouet 1828: Pl.III, which includes major dimensions; and Iwanoff and Hülsen 1898: Tav. A..

[34] Using a foot of 0.2944 m as established for the central block.

diagonals, while BC is equal to both half AO and the result of repeating the above process using BB' as the side of the original square (Fig. 41a). In numerical terms, for a width of 380 ft AB should be 134.4 ft (Blouet's dimensions work out at 134.7 ft), and BC 95 ft (cf. Blouet's 95.8 ft). The inner pair of east and west boundaries are then set out using AB, which results in a figure of 1010 ft rather than 1000 ft. The south boundary, however, is set out 1000 ft (actually 1001 ft) from the edge of the terrace/portico, and this produces the overall NS length of roughly 1097 ft (Fig. 41b). This dimension, rather than a set number of feet, seems then to have been used to define the outer east and west boundaries.

Two other details of the design reveal different sides of the same of approach. Firstly, the division of the north block into terrace and portico alond DD' is in the ratio of $1:\sqrt{2}-1$, which can be created using the same construction outlined above from a square of sides BC. The length BD is then used to establish the projection of the small rectangular exhedrae from the inner east and west boundaries. The location of the centreline of the major segmental exhedrae, however, seems to have been fixed by taking the length of the central block AA' and setting it off from the outer north boundary (Fig. 41b). The size and shape of these exhedrae, on the other hand, were defined according to measure; the centres were set 100 ft in from the outer E and W boundaries, while a 200 ft radius defined the curve of the inner wall and a 250 ft radius the inner face of the outer wall (Fig. 39).[35] The opening of the "stadium" along the portico is, predictably, very close to 600 ft (one stade) long. Beyond this it is impossible to go without a more detailed survey.

3.2.5 A "blueprint" for the imperial thermae

In Section 3.2.2 it has already been suggested that a basic general scheme for the imperial thermae had been determined at least as early as the Baths of Trajan. Now that we have established the

[35] This is admittedly merely a high probability as only the west exhedra survives and none of the survey exactly agree on its dimensions.

precise nature of the design process for the Baths of Caracalla it is possible to go further and identify a "blueprint" for designing these thermae. Even within the limitations of the existing plans of the Baths of Trajan (Fig. 34) and the Baths of Diocletian (Fig. 42) a common basic design process emerges for the central block, based on an initial 200 ft square and $\sqrt{2}$ constructions.[36] The basic steps for the two outline schemes are illustrated in Figs 43 and 44. Certain features which occur also in the Baths of Caracalla stand out. First is the definition of the frigidarium at the centre of the initial 200 ft square using the diagonals of opposing 100 ft squares, creating a width of $200(\sqrt{2}-1)$. This distance and its multiples are then used to generate many of the other dimensions of the design, in conjunction with units of 100 and 200 ft, and their diagonals $100\sqrt{2}$ and $200\sqrt{2}$. Irrational units are used to define the east and west boundaries and either the north or the south one, the other being set out 100 or 200 ft from the initial square.

There are more obvious parallels between the design for the Baths of Diocletian and the Baths of Caracalla than can be found with the Baths of Trajan. These include fixing the south boundary 100 ft beyond the central square, and assigning a strip $100(\sqrt{2}-1)$ for the outer east and west ranges and dividing the rooms flanking the palaestrae in the ratio of 2:3:4:3:2, but on the whole the plan of the Baths of Diocletian is much simplified and requires fewer steps to complete than that of the Baths of Caracalla. The caldarium, however, seems to be borrowed almost exactly in terms of the outline design from the Baths of Trajan. Should we perhaps recognise in the Baths of Diocletian an architect's hasty pastiche based on earlier surviving drawings and/or commentaries?

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[36] For the Baths of Trajan see note 26; MacDonald's plan gives consist results using a Roman foot of roughly 0.295 m. The plan of the Baths of Diocletian is based on Paulin 1890, from which is derived MacDonald 1986: Fig. 170. The two give a reasonable correspondence for the central block, and produce a satisfactory scheme provided that a foot measure of roughly 0.32 m is used.

3.3 DESIGN DETAILING

3.3.1 Principles and problems

So far we have been discussing only one part of the total design process. Once the basic linear scheme has been worked out, details such as wall thicknesses have to be added, and the elevations decided. These in turn allow the depth of the foundations to be established. In a complex structure it is impossible to deal with the detailing of the plan of a single room in isolation. Wall thicknesses and openings, unless on the periphery of the building, are shared by two (or occasionally more) rooms, and must function with respect to both of them. The choice of a column of any given diameter determines within a small range of values the height of the column and the approximate height of the whole order, and sets limits on the spacing of the columns if used structurally;[37] the detailing of a columnar screen, therefore, affects both plan and elevation. The overall height of a room is determined by its size and proportions in plan, although it can also be affected by the heights of the surrounding rooms. Purely decorative details such as niches and non-structural columnar orders have their own grammar, and are dependent on the size and shape of the individual room rather than affecting these in any way.

These are topics which are all too often ignored.[38] Analysis of the detailing has gone little further than, for example, the banal observation that minor features such as doors were in multiples of the foot or half foot, which we might have expected anyway.[39] The exception is, as usual, the Pantheon where there can be no excuse that the elevation is incomplete; Geertman in particular presents a geometric analysis of the elevation of both portico and interior and exterior of the rotunda which is satisfyingly consistent with his interpretation of the plan.[40] Davies in turn has

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[37] Wilson-Jones 1989b.

[38] Cf. the comments by Will 1985b: 325-31, and esp. 330. A welcome attempt to give a full design analysis is made by Rasch 1984b: 59-68.

[39] Boyle 1981: 173, etc; and see Finsen 1962.

[40] Geertman 1980: 207-209.

demonstrated that the portico of the Pantheon was not built to the original design but used instead a smaller columnar order for the portico, validating the hypothesis by showing that the larger order would have removed the inconsistencies of elevation and plan, making the proportions and dimensions of the building coherently related in numerical terms.[41]

There is some information on detailing and elevations in Vitruvius apart from that dealing with the orders. His comments on windows and openings (VI.iii.11 and vi.6) suggest that rules did exist, although they could be adjusted on site in difficult situations.[42] For elevations he gives a number of specific rules for working out the height of a room with respect to its plan. For oblong rooms this is height = (length + breadth)/2, and for a square room height = 1½ x width (V.ii.1, VI.iii.8); for an atrium, height = 3/4 length (VI.iii.3-4); the more complex prescription height = width + 1/3 is given for tablina (VI.iii.6). It should be noted, however, that these are rules for rooms with timber ceilings, and should be used with caution for vaulted concrete roofs where the distinction between wall and ceiling is rarely so easy to define.[43] The rule for determining the height of a circular laconicum as equal to the diameter of the room (V.x.5) is of course an exception, and the use of this in the more general context of domed buildings finds its most popular exemplar once more in the Pantheon.[44] Although these prescripions give some idea of the general type of rules in operation, they do not help with the details, and these must again be worked out from the existing structure.

As discussed in Chapter 2, reconstructing the design process for the elevations of the Baths of Caracalla is hampered by the incomplete evidence. We shall therefore examine the general

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[41] Davies et al. 1987.

[42] See the discussion by Gros 1985: 247-48.

[43] Rakob 1984: 220-21.

[44] De Fine Licht 1968: 194-98.

principles used in designing the details and elevations of the whole block, using examples from various rooms, rather than trying to analyse the process for each individual room. The exception to this will be the group frigidarium/ natatio, which is the most complex area in both detail and elevation and where there are specific problems, caused in part at least by errors in laying out the plan at the foundation level.

3.3.2 Wall thicknesses

The thicknesses of the walls of most of the smaller barrel- and cross- vaulted spaces seem to have been worked out using a rough rule-of-thumb which set them at 1/10 of the span, shared walls obviously taking their thickness from the wider span. The span appears to have been calculated from the general outline, with the resultant wall thickness added on either side of the line. Thus the north and south walls of Rm 14 are both about 8 ft thick for an internal span of 81 ft; the walls between Rms 7 and 8 and between Rms 10 and 11 are 5.2 ft thick for a design dimension of 51.7 ft, measured between the centreline of Rms 8/9 and 9/10 and the inner face of the walls of Rms 8 and 10; and the north wall of Rm 4/5/6 is about 6.4 ft thick for a total span of 65 ft between the outer faces.

For some walls, however, this rule seems only to provide a guide to the minimum thickness of the wall. The perimeter wall on the north, east, and west sides has a more-or-less uniform width, where it can be measured, of 6.4 ft. As we have seen, this fits the rule for the north wall of Rms 4/5/6, but is wider than necessary on the east and west flanks where the spans are roughly 40 ft, and narrower than expected at the north end of Rms 1, which have a longitudinal design span of about 91 ft. The short spur walls forming the division between this latter room and the natatio are, on the other hand, exceptionally thick, considering that the natatio was unroofed, and this may have been to compensate for the rather thin north wall - the thrust of a cross-vault is, of course, carried mainly at the corners. In Rms 3 and 3a-d, the walls 3/3ab and 3/3cd are 6.5 ft wide for a design span of 48.5 ft, while the span including the two wall thicknesses is 61.6ft. In addition the walls between the barrel-vaulted Rms 3a/3b and 3c/3d are 4.4 ft thick for an internal span of 27 ft and an external width of 38.2 ft. The use of the design dimensions for determining the thickness of the walls would be easier than having to calculate the actual external span, which would in itself require setting an interim value for the wall thickness; but clearly the result was not always thought adequate and could be adjusted.

Similar proportional rules seem also to have applied to the larger domed spaces. The thickness of the caldarium piers is 1/8 of the outer design diameter, while the minimum thickness of the wall between the semicircular Rm 13 and Rm 14 is close to 1/8 of the inner i.e. design diameter. It is interesting to note that at the foundation level the wall of Rm 13 is exactly 1/8 of the diameter, but in building the superstructure the diameter was enlarged while thus reducing the wall thickness. Originally, in the foundation layout, the diameter wall facing the palaestra was also made 10 ft or 1/8 of the diameter thick, but this was reduced in construction to 7 ft, the width of the rest of the palaestra wall.

3.3.3 Room heights

Simple but flexible rules seem to have existed for determining the heights of rooms. These can best be seen from Table 1, which includes all the simple square or rectangular rooms except for the frigidarium. Relationships which appear to result in simple ratios are in bold type. The proportions for rectangular and square rooms given by Vitruvius are (length + breadth)/2, or 1.5 x length (de arch. VI.iii.8). While it is clear from Table 1 that this does not work for any of the rooms, what does appear on several occasions is the relationship H_r=1.5xB (Rms 1, 3, 3a-b, 4, 6). For a barrel-vaulted room, B is usually the dimension across the vault, which is the only dimension visible in relation to the total height; for a rectangular cross-vaulted room B is often the side where the arch of the vault is the full width of the room, the 'perfect' shape for a cross-vaulted room being square (Fig. 45). In other words, this is an extension of Vitruvius' rule for a square room, rather than a rectangular room as might have been expected. It also means that the wall up to the springing of the vault is a square, and this was emphasised in the finished building by decorating the part of the wall above the springing of the vault in the same way as the vault itself.

Table 1: Proportions of Rooms

Room	L	B	L+B/2	H_r	H_r/L	H_r/B	H_v	H_v/L	H_v/B
1	80.5	47.1	63.8	73	0.91	1.55	45	0.56	0.96
2	47.1	36.3	41.7	76	1.61	2.1	54	1.15	1.30
14	81.2	61.0	71.1	76	0.94	1.25	45	0.56	0.75
3	61.1	49.1	55.1	73	1.20	1.49	49	0.74	1.0
3a,b	30.2	27.6	28.9	41	1.35	1.49	27	0.9	0.98
3d	32.8	27.6	30.2	41	1.24	1.49	27	0.83	0.98
4,6	52.2	40.6	46.4	60	1.15	1.48	42	0.81	1.03
5	59.9	52.2	56.1	60	1.0	1.15	40	0.67	0.77
7/11	35.6	24.0	29.9	41	1.15	1.66	27	0.76	1.13
7/11*	35.6	26.7	31.2	41	1.15	1.54	27	0.76	1.02
8,10	49.3	35.0	42.2	63	1.28	1.81	42	0.85	1.21
9	68.6	35.0	53.3	63	0.92	1.81	42	0.61	1.21
8,10*	46.2	35.0	40.6	63	1.37	1.81	42	0.91	1.21
9*	63.4	35.0	49.2	63	1.0	1.81	42	0.66	1.21
17	56.5	47.6	52.1	68	1.21	1.43	47	0.83	0.99
17*	46.5	37.4	42.0	68	1.46	1.8	47	1.01	1.26
19	76.1	64.1	70.1	74?	0.97	1.13			
21	64.9	60.4	62.7	78	1.22	1.20	45	0.49	0.75

H_v - height of wall to springing of vault; 7/11* measured to centreline of wall; 8,10*, 9* measured inside the walls; 17* measured within the piers.

Two other groups of rooms show similar patterns in the relationship between height of room, height of vault, and breadth or length. In Rms 5 and 9, this takes the form $H_r=L$, $H_v=2/3.L$, while in 14 and 21 $H_r=5/4.B$, $H_v=3/4.B$; in other words the proportions used are 1:2, 2:3 and 3:4, just those used in dividing up the minor spaces in plan. The correspondence between the proportions of the plan and of the elevation results in the satisfying relationship between the height of the group 4/5/6 and the widths of the rooms in the EW direction of B4:L5:B6 = $3/4.H_v:H_v:3/4.H_v$. Room 19, which probably had a flat concrete ceiling (see Section 2.5.6) also has $H_r=L$.

This leaves only Rms 7 and 11 to fit into the scheme. It will be noticed from Table 1 that the height is the standard proportion of 1.5 times the breadth, if this is measured to the centreline of the walls 7/8, 10/11. This breadth is, of course, the width of the palaestra portico, and the height of Rms 7 and 11 is determined by the height of the portico since there is a continuous terrace above them. The design of the portico seems to follow another Vitruvian rule, that the height of the columns of a peristyle are equal to its width (de arch. VI.iii.7). Here the width of the colonnade to its centreline is 26 ft, and the height of the columns the standard 24 ft, leaving a clear width of 23.8 ft. The total height of the order is thus about 29 ft, and a semi-circular barrel-vault set on top of this takes the total height to 40.9 ft, the height of Rms 7 and 11.

3.3.4 Columnar screens

If we now turn to consider the openings with columnar screens, the picture is far less clear. The width of the openings and the number and sizes of the columns are known for almost all rooms, but the spacing of the columns is uncertain. Fortunately, the surviving cuttings usually give us approximately the height of the column and the total height of the order while recent work by Wilson-Jones allows us to reconstruct a standard order from various fragments of base, column or capital, even when many of the pieces are missing (see Section 2.5.4 and Appendix 1). The structural columns used are of three standard sizes - 36, 30 and 24 ft; their distribution, however, is related less to the size of the opening than to the elevation of the rooms. For the moment let us look at the size and spacing of the columns in relation to the width of the opening. Two sets of values are important here. We know from Vitruvius that the normal way of establishing the distance between columns was in relation to the lower diameter of the column. For temples (de arch. III.iii.1-7) the intercolumnation can be 1.5, 2, 2.25, 3 or 4 times, for theatre colonnades (V.ix.3-4) 2.75 times, and for peristyles (VI.iii.7) 3-4 times the lower diameter. These are all relative values. In a building such as a bath building, with openings which must function as passages for large numbers of people, the absolute clear space between the column bases must also have been important. The relationships between opening, order and spacing are given in Table 2.

Table 2: Column Spacings

Location	Width of opening	No. cols	Lower diam.	Inter-col.	I/LD	Width of base	Dist. between bases
1/N	59.0	4	3.6	9.2	2.6	5	7.8
F/14*	57.6	4	3.6	10.9	3.0	5	9.5
F/N	42.8	2	3.6	12.3	3.4	5	10.9
19E,W21	51.3	4	3.0	8.1	2.7	4.2	6.9
8,10/9	32.0	2	3.0	9.0	3.0	4.2	7.8
9/12	55.5	4	3.0	8.9	3.0	4.2	7.7
F pool	32.6	2	3.0	9.3	3.1	4.2	8.1
20	58.6	4	3.0	9.6	3.2	4.2	8.4
8,10/12	36.4	2	3.0	10.5	3.5	4.2	9.3
1/2	36.8	2	3.0	10.7	3.6	4.2	9.5
4/5/6	38.5	2	3.0	11.2	3.7	4.2	10.0
22	39.8	2	3.0	11.7	3.9	4.2	10.5
19S(W)	50.3	4	3.0	7.9	2.6	4.2	6.7
19S(E)	52.0	4	3.0	8.2	2.8	4.2	7.0
12/13	72.8	6	2.4	8.5	3.5	3.4	7.5
12 portico	10.8 inter ax	n.a.	2.4	8.4	3.5	3.4	7.4
Domus Flavia Triclinium	83.5	6	3.6	9.0	2.5	5	7.6
Bas. Ulpia lower order	18.0 inter ax	n.a.	3.8	14.2	3.7	5	12.8
Domus Flavia peristyle	12.2 inter ax	n.a.	2.4	9.8	4.1	3.4	8.8

Some interesting relationships emerge from Table 2. In general the intercolumnations are between 2.5 and 4 times the lower diameter of the columns, while the minimum distance between bases is 6.7 ft. The 36-ft column screen of Rms 1/N and that of the Triclinium of the Domus Flavia on the Palatine have intercolumnations of roughly 2.5 lower diameters and spacings between bases of 7.6 to 7.8 ft, while the other two 36-ft screens of Rms 14/F and F/N have intercolumnations of 3 to 3.4 lower diameters and spacings of 9.5 to 10.9 ft. The 36-ft columns in the Basilica Ulpia have a spacing of 3.7 lower diameters, i.e. within Vitruvius' range for a peristyle, as are nearly all the other examples in the Table. On the other hand, a spacing of about 7.5 to 8ft is found also with 30-ft and 24-ft columns, the intercolumnations being roughly 3 and 3.5 lower diameters respectively. All this points to the existence of flexibile rules-of-thumb, which allow a balance between aesthetic rules and practical considerations.

Let us now see how the proportioning of columnar screens fits into the general scheme for the elevations. The clearest relationship which appears in Table 3 below is that the height of the room is always roughly either twice the height of the order or twice the height of the columns. Thus the height of any room will always be divided into two by the dominant horizontals - upper or lower - of the entablature. It is much more difficult to determine a set of rules for the width of the openings. Some do emerge, and these are related to the height of the order, even when the height of the room is related to the height of the column. For the openings between Rms 4/5/6, Rms 8 and 10/12, and Rm 2/1, the width of the opening is equal to the height of the order; for Rms 1/N, 14/F, 19EW and 21 it is approximately 4/3 times the height of the order; and for Rms 9/12 it is 3/2 times the height of the order.

Table 3: Relation between Heights of Columnar Orders and Rooms

Room	H_r	H_v	H_o	H_r/H_o	H_c	H_r/H_c	W_o	H_o/W_o	H_c/W_o
1/N	73	45	44.5	1.64	36	2.0	59.0	0.75	0.61
14	76	45	44.5	1.7	36	2.1	57.6	0.77	0.63
4,6	60	42	37	1.62	30	2.0	38.5	0.96	0.78
5	60	42	37	1.62	30	2.0	38.5	0.96	0.78
8,10/9	63	42	37	1.7	30	2.1	32.0	1.16	0.94
8,10/12		42	37	1.7	30	2.1	36.4	1.0	0.82
9/8,10	63	42	37	1.7	30	2.1	32.0	1.16	0.94
9/12		42	37	1.7	30	2.1	55.5	0.67	0.54
2/1	76	54	37	2.1	30	2.53	36.8	1.0	0.82
19EW	74?	na	37	2.0	30	2.47	51.3	0.72	0.59
19S (W)	74?	na	37	2.0	30	2.47	50.3	0.73	0.60
19S (E)	74?	na	37	2.0	30	2.47	52.0	0.71	0.58
21	78	45	37	2.1	30	2.60	51.2	0.72	0.59

These are the kinds of proportions we have come to expect. Such approximations as there are in the ratios are often due to the fact that the piers framing the opening are usually made whole numbers of feet long, e.g. 7 ft in Rms 4/5/6, 5 ft in Rms 8/10, 4 ft in Rm 9, etc. The openings between Rms 8, 9, and 10 are made 4/5 of the height of the order, the closest simple proportion to 1:1 which would fit in the space available. In 14/F and 1/N the width of the opening can also be expressed in terms of the length of the wall in which the opening is set; this returns us unexpectedly but not unpredictably to the original design proportions - the width of the opening is $1/\sqrt{2}$ times the length of the wall. Such interrelationships are comforting evidence of a cohesive and rational design process which included both plan and elevations.

3.3.5 Designing the frigidarium

To create the three bays of the frigidarium, the total design length of 200 ft was first divided into three equal parts, each 66.7 ft wide. The piers of the crossvaults were made one fifth of this (13.3 ft), the kind of rough rule we have previously seen for determining the thickness of walls. The inner piers were set symmetrically about the dividing lines, leaving the opening of the central bay 53.4 ft wide. The location of the inner walls of Rms 2, 14 and 15, however, was determined by the columnar screen between the frigidarium and Rm 14, the outer face of the pier forming the wall face of Rm 14 being set half the width of the column bases of the screen beyond the line marking the end of the frigidarium to allow a continuous foundation to be built under wall and columns; this in turn produced the thicker end piers of the frigidarium. The placement of the piers also determines the length of the frigidarium pools.

The next step is the locating of the giant order columns. The order used had 50-ft columns, the total height of the order being 61.7 ft. Ideally, the two inner columns were sited on the same centrelines as the inner piers, while the end columns sit with their bases aligned with the inner edge of the outer piers, in order to distribute the thrust of the crossvaults most efficiently. This would give an interaxial column spacing of 57.0/66.7/57.0 ft, and an intercolumnation of 52/61.7/52 ft. Not only is this 50-ft order the tallest order commonly used in Rome,[45] but it also gives the central bay the 1:1 proportion which is common in columnar openings.

The total height of the frigidarium is, as might be expected, derived from the breadth rather than the length of the room. The springing of the great crossvaults starts not immediately above the order but at about 82 ft, or roughly the breadth of the room, producing the usual square. The radius of the vault, however, is not 41 ft but about 34 ft i.e. half the distance between the bases of opposite columns. This gives a total height of 116 ft, and an overall proportion for the hall of $H_r/B=1.414$ - and we are back to the dominating ratio of the whole design.

The design of the rest of the frigidarium was relatively simple. The backs of opposite pools were set out as segments of the same circle, centred on the intersection of the longitudinal axis of the frigidarium and the line joining the mid-point of the pools between the piers.[46] The radius is set at the distance from the longitudinal axis of the frigidarium to the mid-point of the block between that and the natatio. The openings to the pools were defined by adding spur walls 7 ft long to the sides of the piers, giving a width of 32.5 ft; this was screened by two 30-ft columns, the total height of the order being about 37 ft. The openings thus have similar proportions to those between Rms 8, 9 and 10.

3.3.6 Foundations

Once the overall elevations had been established, the architect could turn his attention to the foundations. Although Vitruvius gives no rules for determining these (except that they should be

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[45] Cf. Davies et al. 1987: 141.

[46] This is the same arrangement as is found in the fountain courts of the Domus Flavia triclinium. See Finsen 1969.

proportionate to the size of the work), Palladius (I, 8, 2), writing in the fourth century, is more specific. Foundations dug into rock need only be one to two feet deep, those in solid clay $^1/_5$ to $^1/_6$ of the height of the building, while those in loose earth need to be dug until solid clay is found or to a total of ¼ the height of the building. Schwarz, however, argues that Palladius was concerned only with minor wooden-roofed structures, and points to the rather different rule given for vaulted structures in the 8th century Mappae Claviculae - that depth of the foundations should equal the height of the walls to the springing of the vault - as indicative of earlier Roman practice.[47]

It is interesting to see how the foundations of the central block of the Baths of Caracalla might fit in with these rules. If we take the foundations proper and the free-standing part of the superstructure, but ignoring the built substructures, the ratio of foundation depth to height of structure in the tallest parts of the building is roughly 1:6.5 and 1:7 for the frigidarium and caldarium respectively; for the rest of the central block it is roughly 1:4. If we include the substructures as part of the foundation, the three ratios are 1:3, 1:3 and 1:1.5; the foundations are then also roughly equal in depth to the springing of the vaults of the tallest rooms with the exception of the frigidarium and caldarium.

None of this is conclusive, but I believe it is significant that the permutations considered give a result within the limits suggested by the late sources.[48] The same kind of simple rule-of-thumb proportions which have already been discussed for the thickness of the walls no doubt applied also to the depth of foundations and substructures. It is also not surprising to find that the depth of the

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[47] Schwarz 1968: 448-53. He supports this thesis with some examples from Switzerland.

[48] Unfortunately very little detailed research seems to have been done on the foundations of buildings in Rome, and it is difficult to obtain figures. The foundations of the Pantheon are often stated to be 4.5 m deep, but De Fine Licht (1965: 92, note 5) is doubtful about the evidence. The foundations of the Domitianic Triclinium on the Palatine are 6m deep, giving a ratio of roughly 1:6 with the probable height of the building, but this I believe had a wooden not a vaulted roof.

subwalls is roughly 27 ft and that of the foundations 22.5 ft, as these represent respectively 6 and 5 work-stage heights of 4.5 ft, the distance between bonding courses in the superstructure and a module used very frequently for door and window heights and vault springings (see Section 6.3.3).

3.3.7 Doors

Despite the fact that most of the doorways in the surviving structure either are damaged or have been rebuilt at various times, it is still possible to detect a range of standard sizes in operation. Because many are lacking their original segmental lintel arches, I have taken the height at the jambs, although it is possible that the design height was in fact the crown of the arch. I have thus given measurements in Roman feet only to one decimal place, and where a dimension is within 1% of a whole or half a foot I rounded it off. For the sake of comparison I have used the height to the springing for the door between Rms 13 and 14 which has a semi-circular rather than a flat segmental arch. The sizes are given in Table 4 below. The doors excluded from Table 4 either are incomplete or are service doors or doors to stairs and are much smaller e.g. Rm 2/stair is 2.5 feet wide and 6.75 feet high, as is that of the staircase in the west caldarium pier.

With a few exceptions, which never occur on both sides of the building and could thus be mistakes, the doors fall into a remarkably limited range of basic sizes, some of which also give neat proportions: 17 x 18 and 17 x 17 (1:1); 14 x 18 and 14 x 17; 12 x 17 (1:$\sqrt{2}$); 10 x 12.5 (4:5); 9 x 12.5 and 9 x 13; 8 x 12 (2:3); 7 x 12.5; 6 x 10 (3:5). It may be that in most cases the intended proportion - if there was one - was based on the crown rather than the springing height. In the few cases where both heights are preserved the crown seems to be roughly a foot above the springing; this would then give us 14 x 19 and 14 x 18 (both close approximations to 3:4), 12 x 18 (2:3), and 9 x 13.5 (2:3). The openings to Rms 3a-d are all approximately 18 foot square. In most cases, the springing of the lintel arches is just below or on one of the bonding courses, usually either the third at 13.5 feet or the fourth at 18 feet, and this would have presumably facilitated construction;

alternatively it may have been intended that the tops of the lintel arches were set at the appropriate bonding course. This is the kind of standardization that one would expect from Roman builders.[49]

Table 4: Doorway Sizes

Doorway	Width (ft)	Height (ft)
13/14 W	17.1	18
13/14 E	16.9	17.9
1/entrance W	17	17
1/entrance E	17.5	17
5/entrance W	16.9	16.7
5/entrance E	17	17
5/12 W	17.1	17
5/12 E	17.2	17.1
1/3 W	13.9	17.9
1/3 E	14	17.1
2/14 W	14.1	17.9
2/14 E	14	17.5
4/12 E	14.2	17.1
7/12 W	14.5	17
7/12 E	14.1	17
11/12 W	14	17.1
11/12 E	13.9	17.1
3/12 W and E	12	17
4/12 W	12	17
12/19 W	10	12.5
12/19 E	10.4	12.5
20/21 W	10	12.5
F/T	10	12.5
12/17 W	9	12.5
12/17 E	9.1	12.5
19/20 W	8.9	12.4
19/20 E	9.7	12.5
20/21 E	9	13
21/22 W	9.7	13.0
22/C W and E	9	13.0
12/18 tce	9.2	13.0
7/8 W and E	8.1	12
10/11 W	8	12
10/11 E	8.2	12
12/18 W	7	12.5
12/18 E	6.9	12.5
18/17 E	7	12.5
18/20 W	7	11.5
3a/3b tce	7.1	?
3b/12 tce	6	10
11 tce/19	6	10

The sizes and shapes of the doorways, therefore, belong to a standard range of values from which the architect could choose depending on the nature and function of the door. The 17-ft wide doors are all entrances (Rms 1, 5) or major connections (entrance Rm 5/12, Rm 13/14 on the main axis); the 12 and 14-ft doors are minor entrances (Rms 7, 11) or connections between important spaces which may need to be closed off (Rms 3/1, 3/12, 4/12, 2/14). All the doors in this first group are 18 ft high, with the exception of the arched Rm 13/14; all connect unheated spaces. Most of the next group, 13.5 ft high, connect heated spaces, the wider 10 ft doors being between cold and warmed rooms (Rms 12/19, F/T), and the narrower 9 ft doors between two heated rooms (Rms 19/20, 20/21, 21/22, 22/C). The exception is Rm 12/17, which has only a 9 ft door although Rm

[49] See MacDonald 1982, 140 and 145-53.

12 is unheated. This must be to conserve heat. The remaining doorways in this group are secondary passages, either 9 or 8 ft wide (Rm 12 terrace/Rm 18 stair and Rms 7/8, 10/11 respectively). The 7 and 6-ft doors, 11.5 and 10 ft high respectively, are all either entrances into the narrow stair/passage Rm 18, or belong to various terraces (over Rms 3a, 3b, 12, 11).

The location of the doors is on the whole predictable. Many are set in the middle of the wall of one of the rooms which they serve, or as close as possible given the arrangement of rooms. It is worthwhile examining the choices made by the architect in two particular examples. The door between Rms 2 and 14 is on the axis of one of the main entrances into the Baths, and thus leads the eye into Rm 14 and the fountain lying on the main longitudinal axis of the complex. The bather is forced to move around this fountain, and is thus directed along this axis to either the frigidarium or the palaestra, two of the major spaces. The asymmetry of the door with respect to Rm 14 is of little importance as from that direction it can never be viewed as part of a controlling axis. The placing of the door between Rms 1 and 3 follows similar rules; with respect to Rm 1 the door is irrelevant to the major axis of the group Rms 1/2/14, and is scarcely visible from the natatio, its place on the longitudinal axis of this being taken by a niche. On the other hand, the function of Rm 3 as an apodyterium requires that those entering are distributed evenly to the subsidiary rooms opening off each side, which is more easily accomplished if the door is halfway between them. The door between Rms 3/12, however, is placed with respect to the palaestra portico, on the axis which continues through the entrance Rm 7. If we consider it from the point of view of the entrance, we have the same situation as we had with Rms 1/2/14.

3.3.7 Niches

The sizes of niches appear to bear some relationship to door sizes, as might be expected. The values for the niches are set out in Table 5 below; as was the case with doors, the edges of the niches were usually damaged so that the widths must be taken as approximate only. As we saw with the doors, there is a limited number of niche heights and widths, while the relationship between them is frequently a simple ratio, indicated in Table 5 by bold type. The most common ratio is 3:2, but 5:3 and $\sqrt{2}$:1 also occur. Some of the niches which do not appear to fall into this pattern may have been intended to, as the equivalent niches in the corresponding places on the other side of the building are regular (e.g. Rms 4, 5, and 6 E, 14 E). The reasons for some of the irregularities in niches of the natatio facade wall will be discussed below.

Table 5: Niche Sizes

RECTANGULAR			
Location	Height	Width	H/W
F, N pool	17.9	10	1.79
F/N	16.5	10	1.65
14 (W)	14.9	10.1	**1.48**
14 (E)	15.1	9.4	1.61
1	14.9	10.0	1.49
F, S pool (side)	14.6	10	1.46
F, S pool (rear)	11.4	6.9	**1.66**
13	11.4	6.9av.	**1.66**
8 EW, 10W	10.4	6.9av.	1.51
10 (E)	10.0	6.7av.	1.49
N lower,ac	10.4	5.6	1.86
N lower,b	10.4	6.8	1.53
4, 6 (E)	10.1	7.0av.	1.44
4,6 (W)	10.5	7.1av.	**1.50**
5 (E)	10	6.9av.	1.45
5 (W)	10.5	7.0av.	**1.50**
N upper,bc	7.0	5.5av.	1.27
N upper,ab	7.0	5 av.	**1.40**
N upper,a	7.0	3.8av.	1.84

SEGMENTAL			
Location	Height	Width	H/W
17 N	13.5	9	**1.50**
17 S	11.5	7.4	**1.55**
13	11.3	6.8	**1.66**
N facade	11.3	6.9av.	**1.64**
Natatio S	11	7.8	**1.41**
F, S pool	10.4	7.0	**1.49**
4, 6	10.4	7.0	**1.49**
8, 10	10.4	7.0	**1.49**
N lower,bc	10.4	7.0	**1.49**
N lower,c	10.4	7.4	**1.41**
N lower,a	10.4	5.6av.	**1.86**
F, N pool	10.0	6.0	**1.67**

Over 50% of niches fall into the range 11.4 to 10.0 by 6.8 to 7.4 ft, with 11.4 x 6.9 ft and 10.4 x 7 ft being the most common combinations. These perhaps represent the ideal dimensions for a standard life-sized statue. Many common statue types based on the single standing figure fit within a rectangle the sides of which are roughly in the proportion 2.2 to 2.8:1, with some as narrow as 3:1 and a few particularly wide compositions as low as 1.41:1. If we take the frequently recurring figure of 2.4:1, or 5:12, then a life-sized statue 6 ft tall would be 2.5 ft wide. Allowing 3 ft for the space above and 1.5 ft on both sides of the statue would require a niche 9 x 5.5 ft; allowing

4 and 2 ft would give a niche 10 x 6.5 ft, while allowing 4.4 and 2.2 ft would give a niche 10.4 x 6.9 ft.

Similarly, a 7 ft statue 2.9 ft wide would require a niche 11 x 6.9 ft if 4 ft was allowed at the top and 2 ft at each side, or if the proportion was 2.8:1 it would be 2.5 ft wide and would require a niche 11.4 x 6.9 ft allowing 4.4 ft at the top and 2.2 at each side. Any further development of this idea would require a more detailed study of both statue and niche sizes than can be pursued at present, but it would be very much in keeping with other aspects of design examined here if such a rationale existed. The few extra large niches would then be designed to hold over-lifesized statues, such as the 18 x 10 ft niches between the frigidarium and the natatio which would fit twice lifesized statues of standard proportions with a border of 5 to 6 ft.

3.4 THE RELATION BETWEEN DESIGN AND CONSTRUCTION

3.4.1 The nature of the problem

It is not always easy to determine the exact role of the architect in some areas of the design process. The survival of several examples of dimensioned ground plans in stone or mosaic[50] leaves it beyond much doubt that plans could be worked out by the architect and transmitted to the builders in visual form. On the other hand, details such as openings and wall thicknesses are shown but not dimensioned, despite the fact that these plans do not seem to be to any obvious scale. On the other hand, none of the surviving are actual working drawings but rather commemorative records of designs, so that they would not necessarily include all the details which were shown on the originals. Not even this much evidence survives for elevations, and this has led some scholars to suggest that section drawings or elevations were not used, the necessary

[50] See von Hesberg 1984.

information being transmitted verbally to the builders or worked out from traditional practice, while any difficulties could be resolved by the architect on site.[51]

What do survive are several full or half scale engravings on site of details (e.g architectural mouldings) and models, the most interesting of which is that of the adyton of Temple A at Niha, since it can be compared with the actual building it represents. According to Will, the engravings are instructions from architects to builders and presuppose an original design on a smaller scale, while the models represent a starting point for discussion between architect and client, as is indicated by the alterations scratched onto the Niha model itself.[52] Both of these imply that the architect must have worked out his design in three dimensions at least in its major outlines, although he did not necessarily decide on all the minor details. While for a simple structure verbal or written instructions for elevations and details would have sufficed, the same information might be transferred more easily by a visual image with added measurements, and for a complex or unusual structure, such as the curvilinear buildings in Hadrian's Villa discussed above, this would, I feel, have been essential. This does not, of course, preclude adjustments having been made on site while the work was in progress.[53]

This problem draws our attention once again to the connection between design and construction. On the one hand, we have seen that an analysis of the design process must start from a consideration of the structure as built, and thus the exigencies and limitations of the construction process must be taken into account in any interpretation of the design methods. On the other hand, the architect himself needed to be aware of the constraints of the construction process. It is interesting in this context to remember that some of the most important structures in the

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[51] Gros 1985: 247-50.

[52] Will 1985a, and citations.

[53] Nohlen 1985.

development of the "new" architecture - the Octagonal room of the Domus Aurea and the curvilinear buildings in Hadrian's Villa - had no obvious direct successors; not, I suspect, because they were considered failures aesthetically, but because the realisation of the buildings in elevation was found to be too difficult to be worth repeating.[54] Both were built as parts of what were essentially private villas for emperors with a strong interest in architecture, which may explain how, in the face of the natural conservatism of ancient builders, they managed to be built at all. The problem of the transmission of information from architect to builder discussed above must also have been an important consideration for the architect in preparing his designs. Finally, the solution of any problems which occurred during construction, whether practical or aesthetic, and the correction of any mistakes, must have required consultation and cooperation between architect and builder. Although pure design, design for its own sake, may have existed in antiquity, we are constrained to work only with projects which were realised, and thus to consider design always in the context of construction.

In evaluating the design principles and processes used in the Baths, I have so far omitted any treatment of the degree of fit between the ideal design and the built structure. In fact there are a number of errors, which can be easily detected as differences between the two halves of what is clearly intended to be a symmetrical building. While some of these can be attributed simply to dimensional inaccuracy and are within the accepted 1% error rate, others are more substantial and the need to account for them also reveals something of the relationship between design and construction. Some allow us to identify the order of setting out details, some hint at the nature and degree of the instructions given to the builders, while others highlight the aspects of the design which the architect thought important.

[54] Cf. MacDonald 1982: 38-40 on the Domus Aurea octogon, and for the Hadrianic buildings, see the comments by Rakob 1984: 221.

3.4.2 Errors in the basic outline

When the design scheme is superimposed on the on the survey plan, some obvious discrepancies appear which are too large to be just the result of dimensional inaccuracy in the original building or the modern survey (Fig. 46), and these are confirmed by the measurements. Most of the differences are to be found in the central section in the division between natatio, frigidarium, tepidarium, and caldarium - for example the natatio being about 2 ft wider than expected and the frigidarium 2.7 ft narrower. A careful consideration of just where these errors lie suggests that they may all be due to a single initial mistake in laying the building out on the ground.

In the original 200 ft square the actual distance between the axis of the tepidarium and the south wall of the natatio is only 57.91 m or 196.7 ft, while the centre of this does not correspond with the longitudinal axis of the frigidarium. On the other hand, the distance from the centreline of the tepidarium to that of the frigidarium is 29.51 m or just over 100 ft. It is possible, therefore, that while the 100 ft lengths defining the centreline of the tepidarium, the southern boundary of the block, and the outer point of the caldarium, were all set out correctly, a mistake was made with the south boundary of the natatio, which was placed only 96.7 ft rather than 100 ft from the central axis. The diagonal of the rectangle so produced, with sides 200 x 196.7 ft, is 280.6 ft which is precisely the actual distance from the centreline of the tepidarium to the north boundary of the block. This would make the width of the natatio (280.6 - 196.7) = 83.9 ft, which is the width as measured. The same length also seems to have been used to set out the caldarium; the intersection of the outer circle with the axis YY' is only 132.2 ft rather than the ideal 134.3 ft from the main longitudinal axis, which is the result of setting out two lengths of 83.9 ft from the outer point of the circle, placed accurately 300 ft from the centre.

The frigidarium on the other hand seems to have been set out from the central square. The southern boundary was set out from the diagonal of the square between the longitudinal axis and the south boundary of the natatio, i.e. using the short dimension of 96.7 ft. This results in a half-width of only 39.1 ft rather than the ideal 41.4 ft. The north boundary was then set out from the diagonal of the true 100 ft square, giving a total width for the frigidarium of 80.5 ft. While this does not agree with the average width as measured of 81.0 ft, it does closely correspond to the clear width between the foundations as shown on De Angelis' plan (Fig. 13).[55] In a building of this type, the major errors in laying out the plan are naturally errors in laying out the foundations, which may or may not be able to be corrected in the finished building. Here it seems that an attempt was made to compensate for the unwanted narrowness of the frigidarium by setting the walls as far back from the face of the foundations as was compatible with the required width of the column screens separating the hall from the plunge pools.

The error in setting out the natatio and the north boundary was also carried over, at least in part, to the laying out of the east and west boundaries. The building as a whole is not symmetrical about the transverse axis of the frigidarium, the east part being some 3 ft longer than the west. In addition the total length between the inner faces of the walls is only 214.53 m or 728.7 ft instead of the ideal 731.2 ft. The distance from the centreline of the frigidarium to the inner face of the west boundary wall is 362.8 ft, but the foundation plan shows that this dimension as set out initially was about 2 ft shorter, say 360 ft, which is close to twice the distance from the longitudinal axis of the frigidarium to the north boundary. This would be the natural consequence of laying out the building on the ground by following the same series of steps as suggested above for the design process. On the other hand, the distance from the transverse axis of the frigidarium to the inner face of the east wall is 365.8 ft, or 2 x 182.9 ft, which is very close to the ideal value of 365.6 = 2 x 182.8 ft. This suggest that the original error had already been noticed by the time the east boundary was being laid out, or at least before the foundations were built. It would also

[55] De Angelis 1903, 108-12, Tav. 1.

have been feasible to calculate the correct length and lay out the boundary using that length;[56] but this would also have had to be an approximation. The fact that the original error was carried over into the setting out of the north and west boundaries and the frigidarium is further confirmation that the building was set out initially using a geometric process rather than by measure alone.

3.4.3 Inaccuracies in the minor subdivisions

There are in fact some minor inaccuracies in the divisions of the ranges Rms 4/5/6 and 7/8/9/10/11. The way in which these errors are distributed gives us some idea of how the division was made. The group of rooms 4/5/6, for example, are split up along the centrelines of the column screens, giving on the east the ratio 0.65:1:0.68 and on the west 0.68:1:0.68. In fact, on the west the length has been divided into seven rather longer parts than is strictly accurate (an easy enough error if working this out on the ground), but then the lengths of Rms 4 and 6 have both been set out using two of these parts, leaving a rather shorter Rm 5 in the centre. On the east side, however, Rm 6 is longer than Rm 4, while the central Rm 5 is exactly 3/7 of the total length. It is rather more difficult to determine how a distribution like this could have come about, but it is worth noting that Rm 6 is the same width as the range 7-11 and could have been set up on this line by mistake, or to save time. If then the length of Rm 5 was set out by subdividing the whole length of the room and then laying out 3 parts along from Rm 6, this would leave Rm 4 shorter than required.

The subdivision of the area of Rms 1/2 from Rm 3, on the other hand, was carried out reasonably accurately, producing the proportions 1:1.48 on the west and 1:1.47 on the east. The resulting lengths, however, differ by over 1% between west and east, because, as we have already seen, the east and west boundaries were not laid out symmetrically, although the frigidarium and palaestrae

[56] See Geertman 1984a for ancient approximations for irrational numbers.

were. This difference in length is therefore another verification of the progressive methods of both the design and the setting out of the building. When Rms 1 and 2 were then subdivided by making Rm 2 square, and the central block of Rm 3 defined, the widths used were, however, those of the **west** block, although in the transverse divisions the west and east blocks had been treated separately. This makes sense considering that the blocks were the same length but different widths; the difference in width was best concealed by distributing the original error over the two rooms, but then to use the different widths to determine the division over equal lengths would have introduced further distortions. This again confirms our previous suggestion that the original mistake in laying out the central square, which was carried over into the placing of the west boundary, was noticed and deliberately corrected in laying out the east; the correction, however, introduced an asymmetry which led to new problems in fixing the boundaries of the rooms in the blocks between frigidarium and palaestrae.

Again this works very well on the west side of the building, but the division on the east is unequal, producing a ratio of widths for Rms 17/18:15/16 of 1.02:1. Rms 13 and 14 are also divided roughly in the ratio 1:1, but both Rms 14 have virtually the same width - 63.4 and 63.8 Roman feet on the west and east respectively, while the difference in the widths of the blocks between frigidarium and palaestrae is absorbed in the wall thickness and the radius of Rm 13. As built the radii of Rms 13 were 83.9 Roman feet on the east and 84.1 Roman feet on the west, clearly derived from the actual width of the natatio. At foundation level, however, the diameter is only about 80 Roman feet, the result of continuing the line of the frigidarium walls (see Fig. 13).

3.4.4 Errors and order in setting out doors and niches

An error seem to have occurred in siting one of the doorways between Rms 4 and 12, since not only are their positions different on east and west but so are their sizes. On the east the door is 14 ft wide and located with its east jamb 25 ft from the edge of Rm 12 i.e. aligned with the centreline of the palaestra portico. On the west side the door is only 12 ft wide, set with its west jamb 20 ft from the edge of the palaestra; the centreline of the doorway, however, is more-or-less aligned with the centre of the portico. If we then consider the location of the door in relation to Rm 4, we notice that in the first case the door is not quite in the centre of the wall; if this had been a 12 ft door it would have been exactly in the middle. In the second case the door is considerably closer to one end of the wall. It is difficult from all of this to decide what the architect had intended, but what is clear is that the nature of the communication between architect and builder was such as to allow for confusion. My suspicion is that the door was originally intended to be aligned with the centre of the palaestra portico and 12 ft wide, the nearest "standard" door size to half the portico width; this would give it the same arrangement and size as the door 3/12.

The location of niches also requires a few words. Single niches, or pairs of niches framing doors (e.g. Rms 5, 14) are always roughly in the centre of the wall or the section of wall. Usually they have been measured out a whole number of feet from one end of the wall, rather than being set symmetrically about its real centre; thus the niche in Rm 1 is 35 ft from south end of the room but 35.3 ft from the north end, while the niches in Rm 5 are set 5.5 ft from the doorway but 5.7 and 5.9 ft from the ends of the wall. Similarly for the group of niches in Rms 4 and 6: the outer ones are set 8 ft from the ends of the walls, the distances between the outer and central ones being 7.8 or 7.6 ft. In Rms 8 and 10, however, the niches have clearly been set out from one end of the wall only. Nearly all the niches start at the second bonding course, 9 ft above the main floor level, and their exact location must have been fixed only at this point, rather than set out with the doors at ground level. This no doubt explains why they were laid out by measure rather than by division of the length of the wall.

3.4.5 Problems with the frigidarium and natatio

The most complex area of the Baths in terms of design which we can still analyse in some detail is that covering the frigidarium and the natatio. It is also one where a number of errors and adjustments, while making it difficult to deduce some of the architect's original intentions, allow us an insight into some of his priorities.

There was a fairly major adjustment to the siting of the east pier between frigidarium and natatio after the foundations had been built up to ground level. This can be detected because the natatio floor is, of course, below this level. In the original setting out of the natatio/frigidarium at foundation level a mistake was apparently made which set the line of either the west or the east columns 3.5 ft - or half the width of a column base - out from its proper position. The foundations for the other set of columns were placed the right distance from these, the error being carried across unnoticed to the final bay since its outer limit was fixed by the overall width of the natatio/ frigidarium. The mistake was probably made in the setting out of the natatio apses, the only major elements of the natatio or frigidarium which were defined in the foundations.[57] Here the east semicircular apse is wider than the west one, the plan being otherwise symmetrical at foundation level, and the columns of the north wall are in fact on the centrelines of the piers of the south wall, as originally laid out.

The error must have been detected when the superstructure was being laid out at the ground level since most of the details were constructed on continuous foundations. The travertine sub-bases for the columns on the north wall of the natatio had, however, already been set in place as part of a continuous ledge, and could not be altered without demolishing the ledge and starting again. Since

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[57] See the sections in De Angelis 1903: Tav.II. Unfortunately the foundation plan is misleading in this case as he has 'corrected' the mistakes in the foundations and the subsequent alterations to produce a regular arrangement, while still showing the shift of the superstructure of the east apse.

these columns had no structural function, and the wall itself formed an independent unit, this asymmetry mattered only with respect to the finished appearance, and was masked by using the same pattern but different widths for the groups of niches framed by the columns (Sheet 3, Section EE). The frigidarium piers, and therefore the pools, were set out as in the original design, but to achieve the right relationship between the pools and the natatio apses, the east apse was shifted as far to the east as the foundations would allow and the east wall of the central bay was cut back to produce a pier face of about the right width. The columns on the south side of the natatio were also moved off the line of their counterparts on the north wall, the east one being set on the design centreline and the west one in the centre of the pier (Fig. 47).

In the frigidarium, however, the east pair of columns was left in the position of the foundation, which meant that the inner edge of the column base was more-or-less aligned with the inner face of the pier, while the western columns were moved to match this. This has the affect of making the interaxial spacing of the frigidarium columns slightly closer to equal, 58.7/63.1/59.0 ft rather than 57.0/66.7/57.0 ft. Comparison with the location of the equivalent columns in, for example, the Baths of Diocletian or the Basilica of Maxentius, shows that the normal placing was in the centre of the piers. It does mean, however, that the length of the frigidarium to the top of the order was formed roughly by three squares (Fig. 48), and this no doubt affected the architect's decision to move the columns to the inner rather than outer positions when the occasion arose.

3.4.6 Other asymmetries

In terms of contemporary architectural practice, we might imagine that the design and location of the staircases which give access to the terraces as part of the architect's brief. The stairs to terraces over Rms 3c/3d and 4/5/6 are particularly interesting in this context. Although those on the east and on the west lead to the same levels, their internal arrangements are rather different[58] (see Sheet 4, Section JJ), which suggests that the extent of the architect's design was simply to indicate the location and functional requirements of the stair, the actual detailing of it being left to the builders. The are also differences in detail between other relatively unimportant features, such as the windows in the north walls of Rms 3d (Sheet 2, Section AA), and the openings into Rms 19 from the terraces over Rms 11 (see Sheet 3, Section FF).

A more surprising apparent asymmetry is the presence of a large window between Rms 2 and 14E, which does not exist on the west side of the building (Sheet 4, Section GG). While there are two vertical discontinuities in the wall on the west side, these appear never to have formed a window since they continue almost to the top of the wall and lack the lintel and relieving arches seen in the east wall. It is not impossible, however, that the east window was at one time filled in, thus representing a change in plan during construction as already argued for the south wall of Rm 17 (see Section 2.3.4), and the difference in appearance is due to the stage of construction reached when the decision was made to do away with the window. On the other hand, the window in the east may have been added by the architect to give extra light to Rm 2E when the sun was in the west during the afternoon hours when the Baths were open, since the only other window to this room is from the terrace above Rm 3a on the east side. In this case a similar but unnecessary window may have been begun in the corresponding place on the west only to be filled in when the mistake was discovered. Either explanation requires the effective interaction between architect and builder during the course of construction.

Perhaps more obviously within the ambit of the builders are the differences in the arrangement of the down-drains between the east and west halves. These involve both differences in number and

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[58] Cf. Brödner 1951: 19-21 and Abb.2.

distribution in certain areas (e.g. on the south sides of the palaestrae), which must have been introduced at the level of the horizontal drains, and differences in the areas which these drains are meant to serve (e.g. those flanking Rms 7 and 11 on the east facade drain the terraces of those rooms, while those on the west do not). Unfortunately it is not always clear whether the "missing" drains were compensated for by pipes in the thickness of the walls, such as survives in the wall between Rm 1W and the natatio, and must have been used to drains the roofs of those rooms without an exterior face such as Rms 2, 14, etc. Similarly there are differences in the location of the inspection passages/flues between Rms 20 and 12/18, where again the function must have been specified but the manner of achieving it not. Other differences are purely matters of construction and will be dealt with in Chapter 6.

3.5 CONCLUSIONS

The designing of the Baths of Caracalla was, after all, a relatively simple process. The relationships between rooms, the proportions of the rooms themselves, and of individual features within them, are governed by a surprising small range of figures and ratios: the square (including the ratio $1:\sqrt{2}$ and its derivatives); the circle; and simple rectangles in the ratios of 1:2, 2:3, 3:4, and 3:5. Columnar orders were selected from a range of standard sizes, the choice often being determined by factors such as the relationship between the height of the room and the width of the opening. At the same time, there were flexible rules which set at least the minimum and maximum column spacings in a given situation. Features such as doors and niches also fall into a series of standard sizes and proportions. Certain elements, for example the detailing of the staircases, appear to have been left to the builders. On the whole, the rules and proportions used are not very different to those given by Vitruvius, and they are certainly the same type of rules, showing a strong conservatism in architectural approach, even if the end result was one that Vitruvius himself could hardly have imagined.

The other aspect which Vitruvius would have appreciated is the ability of the architect of the Baths of Caracalla to be flexible in his application of the rules, and to adjust where necessary to actual site conditions - here the inability of some of the surveyors and builders to get anything quite right. Where it would not be apparent to the normal observer, the architect left well alone or adapted the design to mask the error, as in the detailing of the natatio north facade. The moving of the east natatio apse and the rearrangement of the columns was, I feel, both structurally and visually advisable, if not strictly necessary, as it affected the symmetry not only of what is clearly the most important space in the complex, but also of the thrust of the massive cross-vault which covered it.

This brings us to the question of the nature of the transmission of the design from architect to builders. As we have already seen, the use of the columnar orders implies that the elevations of the building must be fixed to some degree at least before all the details of the ground plan can be worked out. In terms of construction, however, this decision is only important once the building has reached ground level, since columnar screens on the whole sit on continuous foundations up to the locating of their travertine sub-bases. This is not true, however, of the location of the vertical drainage channels, which were built as part of the walls beginning at the level of the horizontal drains. This meant that the drainage pattern of the roofs must have already been decided by the time the foundations reached that level. On the whole it seems almost certain that the architect had designed the elevations in detail before building began.

This is, of course, what we might have expected. It does not necessarily imply, however, that the architect had a set of measured and dimensioned detail drawings for the builders to work from. As we have seen, the ground plan was designed in the way it was to be laid out, and all that the surveyors would have required for laying out the foundations was a drawing of the general scheme, and a set of instructions on how to achieve this. On the other hand, dimensions were required for wall and hence foundations thicknesses, and a dimensioned plan would have provided a welcome check. The corrections and adjustments made both at foundation level and in laying out the superstructure argue in favour of a dimensioned plan. It is harder to show the need for a detailed set of dimensioned drawings of the elevations. The very simple rules governing the heights of the rooms and the manner of vaulting, and the use of standard-sized features, would have made these unnecessary, although again the builders would have been helped by at least a sketch of what the finished product should look like, perhaps room by room rather than in long sections. As will be argued later (Chapter 6), the fixing of many features such as door and window heights or vault springings at the level of the bonding courses would have made it easy to keep a check on the vertical progress of the work without the need for absolute vertical dimensions.

The architect's achievement lies mainly in the coordination of spaces and details, both in plan and elevation. The stark ruins of the surviving monument give us an appreciation of the scale of the building, but not of the subtleties of the design where the use of the columnar orders and the articulation of the wall surfaces emphasised the inter-relationships of plan and elevation not only within a given room but also between rooms. It comes as no surprise to realise that the main columnar orders used have a total height roughly equal to the height of the columns of the next larger size, making the harmonious use of two or more of these within a single space a natural process (cf. Fig. 48). Vistas and axes too were planned with care; we have already noted the use of the fountains in Rms 14 to divert the visitor from the main entrance axis towards the most important spaces, but we could also cite the size and location of the apses in Rms 9, which from the centre of the frigidarium are exactly framed by the columns between Rm 14 and the frigidarium, the doors of Rm 14, and the centre pair of columns between Rms 9 and 12. Vitruvius would certainly have approved.

CHAPTER FOUR: MATERIALS - STONE AND TIMBER

INTRODUCTION

The supply of materials is a critical factor in the success of any building project - laying the first stone assumes that stone, mortar and trowel are all to hand. This becomes even more important as the size of the site increases or the construction time decreases. Fitchen has summarised the essential considerations affecting a builder's choice of material:

> "...the location of its source, the reliability and sufficiency of its supply, the feasibility of its procurement, the methods and routes of its transportation to the building site, its quality, and its cost."[1]

All these factors are relevant to the Roman building industry in general, and to large-scale projects like the Baths of Caracalla in particular, not just for the materials which form a permanent part of the structure but also those which are essential to the **process** of construction; timber for scaffolding and formwork is as necessary for the building of a concrete vault as are lime, pozzolana and caementa.

The study of this aspect of the building industry in Rome has been piecemeal, and very much conditioned by the literary and epigraphical sources, or lack of them (see Section 1.1). In general the sources of most quarried materials - marble, pozzolana, tufa - are known, as are the locations of the major brickfields, but methods of production, problems of transport, and manpower figures are less well investigated. Most surprising is the lack of attention given to the production of lime, which must have been a major concern throughout the late Republic and the whole of the empire.

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[1] Fitchen 1986: 49.

There was certainly a collegium calcariense in Rome,[2] but little is known even about the most common sources of limestone or the centres of production. Still less is known about the supply of iron, scaffolding timbers, ropes, baskets/buckets, spades, trowels, etc., since even the nature and sources of the raw materials is in doubt for some of these items.

While this and the next chapter will be concerned specifically with the supply of both structural and constructional materials to the Baths of Caracalla, they will also help to throw light on the supply of building materials to the city of Rome in general. The site specific approach has particular advantages for locally quarried materials since it allows the most probable sources and the respective transport routes to be identified. This is an important point, since transport contributes a large proportion to the total cost of materials, as is discussed in detail below. In more general terms, the site specific approach focuses attention on all the different material requirements rather than on any single one, and therefore on the total demands in terms of labour and transport over a given period of time. The calculation of total quantities, however, has been left until Chapter 8 when the whole question of the logistics of the building operation will be examined.

These chapters aim to identify the sources of supply and methods of extraction or production for each material, and to estimate the man-power requirements and cost per unit, including transport to the site. As explained in Chapter 1, the calculation of man-power figures will be based on ethnographic evidence from a wide variety of sources, while the calculation of costs will be based primarily on the Prices Edict of Diocletian. Wherever possible, the Prices Edict has been used to supply the labour and transport unit-costs, while the unit cost of the materials is determined from the manpower figures plus the cost of transport by appropriate means from the production centre to the construction site. In a number of cases, particularly for marble and timber, this has not been

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[2] CIL VI 9223, 9224.

possible, and the costs here are taken straight from the Edict. This approach presents its own problems, which differ according to the material concerned, and these will be discussed in the appropriate place below.

The materials have been divided into two groups, those that occur naturally and undergo no secondary processing other than reducing them to the required size; and those which do require secondary processing which we might term manufactured materials. In the first group, which forms the subject of this chapter, are all the quarried materials including pozzolana and marble as well as tufa, selce and pumice, and timber; in the second are lime, brick and tile, iron and other metals, and ropes and baskets. This group is dealt with in Chapter 5.

4.1 TRANSPORT

One of the major factors affecting the cost and availability of commodities - and particularly bulky and heavy commodities - in the ancient world was transport. The importance of the large cost differentials between sea, river and land transport have been much discussed with respect to the movement of grain and other foodstuffs, but are equally relevant to any discussion of the supply of building materials. Questions of transport also affect the logistics of the construction process, since delays in supplies of materials or problems in removing waste from the site can seriously affect the scheduling of building operations.

4.1.1 Land transport

The movement of goods by land could be achieved by several means, from human porterage, through donkeys or mules (or camels in the eastern empire) bearing loads directly, to any of these plus oxen drawing carts.[3] All have different requirements and limitations. A man is adaptable to all terrain, needs no attendant or extra manpower for loading and unloading, and can manoeuvre

[3] Much of the information for this section is from Landels 1978: 170-85, and White 1984:127-40.

easily in difficult circumstances, such as up and down ladders and in narrow places; he can carry a maximum load of about 50 kg (see above). Donkeys and mules are sure-footed and adaptable to most terrains, travel at about the same speed as a laden man (roughly 5 km/hr), and can carry loads ranging from about 55 kg for a small donkey to 120-135 kg for a large mule. If carried in panniers the load must be divisible into two balancing halves, so that even the largest mule could not, for example, carry any single piece of granite or basalt larger than one by one by three-quarters of a foot; and there are volume limitations as well.[4] Each two or three animals need a man to manage them, and more manpower is required in loading and unloading.

Carts were required for larger and heavier loads, normally drawn by a pair of oxen or mules using a yoke and pole. Burford[5] has long since shown that the ox-cart was the normal heavy transport in antiquity in the Mediterranean, and that the type of harnessing used not only was perfectly adequate for this function but could be and was adapted to multiple yoking in series. Oxen are sure-footed, but wheeled vehicles normally need some kind of track or road unless over reasonably flat terrain, and are of no use without one in very hilly country, while the evidence for any kind of braking system is limited.[6] The rate of travel is slow, as little as 1.67 km/hr if heavily laden. The loading limit for an ox-cart (presumably with a single yoke) given in the Theodosian Code (8.5.30) is 1500 librae or not quite 500 kg, while the standard load for a cart (animal not specified) in the Prices Edict (DPE 17.3, cf. 14.8) is 1200 librae or almost 400 kg; the 25 talents given by Xenophon (Cyr. VI.i.52) as the carrying capacity of a yoke works out at roughly 640 kg.[7] There seems always to be a loss of efficiency due to multiple yoking; Xenophon records 15 talents (c.

[4] Length is probably more restricting than height, e.g. in carrying timber or firewood.

[5] Burford 1960.

[6] Molin 1984 thinks he can identify a braking system in the Langres relief. Contra, White 1984: 136-37, 209 on evidence from the Digest.

[7] Meiggs (1982: 479), however, doubts the value normally given to the talent in this instance.

380 kg) per yoke over 8 yoke, while Meiggs adduces a modern parallel of 340 kg/yoke over 9 yoke.[8] There were probably no manpower advantages to be gained by multiple yoking, since it is clear from numerous Renaissance and later illustrations that virtually each pair of oxen needed its own attendant.[9]

4.1.2 Water transport

There is no doubt that water transport, both sea and river, was preferred to land transport in antiquity. Provinces were praised for their river systems, cities for their harbours, access to regular river transport recommended for the siting of agricultural estates. The advantages are obvious. Much larger loads could be carried with far fewer men and in favourable conditions much faster than was possible by land. The size of sea going vessels varied, but the smallest ships considered suitable for long distance transport seem to have been of the order of 70-80 tonnes burden, while ships of 300-400 tonnes were not uncommon, and the largest "supercargoes" like the Isis described by Lucian (Navig. 5) were probably of the order of 1000 to 1200 tonnes.[10] The sizes of ships crews have been estimate at between 4 and 10 men for the small to medium vessels, and the larger ones rather more.[11] The average speed has been calculated as 3-4 knots/hour, or 75-95 miles/day,[12] but much depended on the season of sailing and on weather conditions. Long voyages across open seas, where navigation was by the stars, were restricted by the weather; according to Vegetius (4.39), the seas were closed from early November to early March and considered dangerous to shipping from late September to late May, and there is no reason to doubt

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[8] Meiggs 1982: 340, note 59.

[9] See, for example, Tomassetti 1979: 102, 278.

[10] Landels 1978: 160-164; Pomey and Tchernia 1978; Rickman 1980: 123-124; Rougé 1981: 74-8.

[11] Throckmorton 1972: 77; Parker 1990: 341-42. Cf. the crew of 13 on the ship taken by the 4th century bishop Synesius (Letters, 4).

[12] Yeo 1946: 232.

his dates.

River boats were smaller, perhaps in the order of 150-200 tonnes burden maximum on a large river and no more than 70 tonnes on the Tiber up to Rome;[13] these could be sailed, rowed, or punted, towed upstream by men or oxen and left to drift down it. Rafts, and timber logs, could also travel downstream under their own power. Two main types of river boat have been identified for the Tiber, the lenunculi or flat-bottomed barges, to which belong the larger boats found in the excavations of Claudius' harbour, and the rounder naves codicariae which could bear sail as well as a towing mast and do coastal as well as river work.[14] Ellmers suggests that three-man crews were standard on river boats, although larger ones must be supposed for the bigger vessels, and these might be sufficient to tow the boat upstream where necessary.[15] There is no direct evidence to show to what extent oxen rather than men were used for towing, but they might have been preferred against strong currents like the Tiber and/or for larger vessels. Later figures cited by Casson give 4 pair of oxen for 38 tonnes, 5 for 95 tonnes, and 6 for 140 tonnes; these figures are not particularly consistent, although the last two do suggest that a figure of 20 tonnes/pair might give the right order of magnitude.

4.1.3 Cost of transport

The only evidence for the cost of land transport is the Prices Edict. The carriage cost of a waggon-load of 1200 librae (388 kg) is 20 denarii/mile, of a camel-load of 600 librae (194 kg) 8 denarii/mile, and for a donkey-load 4 denarii/mile (DPE 17.3-5). In the section dealing with loads of wood, however, a camel-load is only 400 librae (129 kg), while a mule-load is 300 librae (97 kg) and a donkey-load 200 librae (65 kg). The loads for donkeys and mules are very much

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[13] Casson 1965: 32, note 10; Pomey and Tschernia 1978: 240; Rickman 1980: 19.

[14] Casson 1965: 35-38.

[15] Ellmers 1978: 11.

towards the low end of the range of maximum possible loads for these animals, but still within it, and it is likely that the same applied to the waggon-load, for which, as we have seen, a higher figure is given in the Theodosian Code. In the absence of other figures I propose to take the values in the Prices Edict as they stand, despite the fact that this goes rather against the general attempt to opt for the minimum case. In the few cases where the loads clearly required multiple yokes, it seems reasonable to use Xenophon's ratio and assume that the rate was 20 denarii/mile for each 720 librae, or three-fifths of the full load.

One interesting point to consider is the relative cost of transport between waggon, camel and donkey. For a load of 1200 librae, a cart costs 20 denarii/mile, a pair of camels 16 denarii/mile (or possibly 3 camels 24 denarii if the load is 400 librae), and 6 donkeys 24 denarii/mile if carrying 200 librae each (or 16 if carrying 300 librae). Since there is thus little to choose in terms of cost between these types of transport, other factors - speed, terrain, availability - would have affected the choice more.[16] In addition, most of the materials used in the construction either were required in small discrete units (caementa, bricks, baskets, planks, short poles, etc) or were infinitely divisible (lime, pozzolana), making them suitable for carrying either in panniers or on single carts. Only the marble architectural elements, and the largest timbers and longest poles for scaffolding and formwork, could not have been taken on pack animals and many would have needed multiple yoking. To simplify calculations I have assumed that all land transport was by ox-cart.

Rates for sea travel are given in Section 35 of the Prices Edict, which is sadly incomplete. Travel from Alexandria to Rome costs 16 denarii/KM (DPE 35.1a), which works out at about 0.013 denarii/KM/mile, compared with 0.56 denarii/KM/mile for an ox-cart; other sea voyages in the Edict where both ports are given suggest a range of 0.01-0.024 denarii/KM/mile (Nicomedia to

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[16] Cf. Yeo 1946: 224-25.

Salona and Nicomedia to Thessalonike). There are also several references to "onera fiscalia" having their own special rates, most of which come immediately after items which have Rome as their destination (DPE 35.75, 80, 87, 89). While these special rates certainly applied to corn, they may also have applied to the products of the imperial quarries and mines such as marble. Nevertheless, since we have no actual figures for these rates, I propose to use a value of 0.013 denarii/KM/mile, where the kastrensis modius represents a corn-based weight measure (see Appendix 4).

Only two passages in the edict clearly refer to river transport, although it is possible that two others may do so as well. In the new edition of the Aezani fragments, DPE 35.51 appears to give the rate for men and animals on river boats as one denarius plus food for each modius over 20 miles.[17] On the other hand, DPE 35.105-107, known only from one of the Aphrodisias fragments and missing an unknown amount from the left-hand side,[18] provides the following figures: travel downstream at a rate of one denarius/modius, which must be river transport; some kind of unspecified transport at two denarii/modius over 20 miles; and similarly from Ravenna to Aquileia at 7500 denarii for 1000 modii. If, as Lauffer suggests,[19] the Ravenna-Aquileia price is for inland waterways, presumably with no strong directional flow, this would be for a journey of roughly 150 Roman miles, giving a cost per modius per mile of 0.05 denarii, comparable to the 0.05 denarii/modius/mile of DPE 35.51. This suggests that DPE 35.105 is also for twenty miles downstream, and that DPE 35.106 may be for travel upstream, since towing a ship or barge against the current of a fast-flowing river even with the help of sail must have been more time- and labour-consuming than letting it float downstream.

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[17] Crawford and Reynolds 1979: 186 "35.51 Item in navibus amnicis per sing v. ulos modios per mille passus viginti denarium unum et victus", where "Item" refers to the "hominibus et pecoribus" of 35.50 and "mille" is presumably for "milia".

[18] Aphrodisias Frag. III. See Giacchero 1974: 45 for details and bibliography.

[19] Lauffer 1971: 293, entry for 37.74, 75.

It is interesting to see how these figures fit with the other transport costs from the Edict. If we assume that the modius is the kastrensis modius used in the sea-freight rates, then the ratio sea:downstream or inland waterway:upstream:ox-cart becomes 1:3.9:7.7:42. Duncan-Jones, writing at the time when there was no clear value available for transport on inland waterways, used the cost of transport down the Nile to produce a ratio of 1:4.9:42 (for ox-cart), roughly comparable with figures from England in the early 18th century[20] and not incompatible with the figures suggested above. Until the difficulties with the Edict are resolved, it is perhaps preferable to use Duncan-Jones' ratio, with the addition of a value for river transport upstream of twice the downstream value. Thus the transport rates adopted will be 0.2 KM/tonne/Roman mile for ox-carts, 0.046 KM/tonne/Roman mile upstream, 0.023 KM/tonne/Roman mile downstream, and 0.0048 KM/tonne/Roman mile by sea.

4.2 LOCALLY QUARRIED MATERIALS

The selce, tufa and pumice which form the caementa of the foundations, most of the walls and vaults, and the upper parts of the vaults respectively, and the pozzolana of the mortar, are all to be found in Rome and its vicinity (Fig. 49). All were produced by a series of volcanic eruptions of the Quaternary period emanating from the Latial volcanoes.[21]

4.2.1 Pozzolana

The pozzolana used in the superstructure (Fig. 50b) is the red pozzolana ("inferiore" or "di San Paolo"), which was both the earliest formation of importance, and the most extensive; being the deepest layer, it is most easily accessible where river erosion has cut through the overlying strata. Although ancient, medieval and later quarries are to be found throughout the city, the most

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[20] Duncan-Jones 1982: 366-69.

[21] For discussions of Roman building materials see Blake 1947: 21-44. Technical data is derived from Ventriglia 1971.

important which were certainly worked by the Romans are those near San Paolo fuori le Mura, close to the bend in the Tiber (Fig. 49).[22] This is as likely a source as any for the pozzolana used in the Baths of Caracalla, and a very suitable one in terms of transport; the pozzolana could have been taken by road along the Via Ostiensis and around the foot of the little Aventine, a distance of roughly 2 Roman miles (c. 3 km). Alternative suitable sources are the ancient quarries of the Fosse Ardeatine, the valleys of Grotta Perfetta and Tre Fontane, and the Marrana della Caffarella, using the Via Ardeatina (c. 3 km ≈ 2 miles), the Via Laurentina (c. 6km ≈ 4 miles), or the Via Appia (c. 4 km ≈ 2.7 miles) respectively as transport routes (Fig. 49).

The mortar of the foundations and substructures is grey to purplish-grey in colour.[23] This suggests that either the black pozzolana ("media" or "delle Tre Fontane"), which occurs in layers less than one metre thick except in the area around Tre Fontane,[24] or the grey pozzolana ("superiore" or "pozzolanelle") produced by the last eruption of the Alban volcanoes were used. Although the latter is found in abundance, it has reduced pozzolanic properties when compared with the black and red varieties. It is therefore assumed that the black pozzolana from the Tre Fontane quarries was used in these substructures.

There is little doubt that the pozzolanas of Rome and the vicinity are the harenae fossicae of Vitruvius,[25] and this gives our only clue from antiquity about their methods of extraction: the pozzolana was dug (fodiatur) from special quarries (harenaria). Rather more is known about the later extraction of the material, which has been mined as a component of mortar at least since the

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[22] Blake 1947: 44; Lugli 1957: 400-401; Ventriglia 1971: 28-30.

[23] Petrassi 1985: 602-603.

[24] Ventriglia 1971: 206-208, 216-19.

[25] Vitruvius, de arch., ii.4.1, and cf. Faventinus 8, and Palladius i, 10. For the controversy over this point see the discussion in Lugli 1957: 396-99.

Renaissance, although details of man-power requirements are scarce.[26] Pozzolana in its natural state has the consistency of gravel mixed with earth, and is sufficiently tenacious to be mined by tunnels, leaving piers of the material to support the strata above. In the 17th and 18th centuries various types of pozzolana quarries were operated, both open-cut and galleried. Taxes paid for the former were higher, since carts could be brought directly to the face and thus operating costs were lower, while lower ones were paid for the galleries where the material had to be raised to the road level, and even less where the galleries were too narrow to allow for a cart.

Using the 17th-18th century situation as a model, a range of values representing man-days/unit volume for the Roman period can be calculated. Assuming that quarrying pozzolana is equivalent to "excavating earth mixed with coarse gravel", then from Hurst's constants this requires 0.20 man-day/m^3.[27] Pozzolana increases in bulk by about one twelfth of its original volume when excavated and thrown into a loose heap,[28] i.e. the cubic metre becomes 1.1 m^3, and 0.18 man-days are required to produce a cubic metre of loose pozzolana. This material then had to be moved away from the quarry face. Where a cart could be drawn up nearly at the face, Hurst's constants suggest a figure of 0.068 man-days/m^3 for shovelling the loose pozzolana directly into it,[29] producing a total for each cubic metre of loose pozzolana of 0.25 man-days/m^3.

Alternatively, the pozzolana had to be transported to the carts at a maximum distance of, say, 100 m from the face. It is assumed that the loose material is carried by men in baskets, a practice

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[26] For the 17th and 18th centuries, see Scavizzi 1983: 30-31, and Demarchi 1894 for later periods.

[27] Hurst 1865: 212 (0.18 day/cubic yard, for a 10-hour day).

[28] Rea 1902: 35.

[29] Hurst 1865: 212 - "Throwing with a shovel to a height of 5 feet, or filling trucks, per cubic yard: hard earth, clay, etc - 0.062 days"

represented several times on Trajan's Column and in other ancient illustrations;[30] there is no evidence that the Romans ever used wheelbarrows.[31] If the capacity of the baskets is one cubic Roman foot (equivalent to two modii, see Section 5.6.1) or 0.026 m^3, the filling time for the baskets works out at 0.063 days/m^3.[32] Pozzolana in its natural state weighs on average 1700 kg/m^3, although this varies greatly depending on the amount of moisture it contains, and excavated pozzolana rather less, about 1600 kg/m^3.[33] A basket of pozzolana will therefore weigh about 40 kg, which is less than the maximum load a man can lift and carry (50 kg of contents, see Section 1.3.2), and one cubic metre of pozzolana will require, in round figures, 38 trips. Hurst's constant for "removing with wheelbarrows/m^3 over 25 yds and return" converts to 0.0031 days/basket-load over 25 m, or 0.118 day/m^3 over 25 m, and roughly 0.47 day/m^3 over 100 m.[34] Thus each cubic metre of pozzolana would need 0.65 man-days/m^3.

It is clear that the most significant element in the total cost at the quarry is also the most difficult one to determine - the distance the pozzolana has to be carried by manpower. Since a single value is needed for the purposes of later calculations, I shall take this to be 0.45 man-days/m^3 although it must be recognised that this could vary by as much as 50% either way.

4.2.2 Tufa

The eruption which produced the red pozzolana was followed by three minor, localised emissions,

[30] Trajan's Column: Scenes XI, XII, XX, LII, and LX, in Cichorius' numbering (= Lepper-Frere 1988: Pl. XI, XII, XV, XXXVII, XLII). Cf. the construction scene from the tomb of Trebius Justus on the Via Latina (Fig. 69).

[31] White 1984: 127.

[32] Hurst 1865: 213 - "Filling barrows, per cubic yard: clay, stony earth, etc - 0.058 days"

[33] Ventriglia 1971: 210-13, Tav. XXVII, XXVIII.

[34] Hurst 1865: 213, using figure of 0.036 days/yd^3 over 25 yards for clay, stony earth, etc. A wheelbarrow holds roughly twice as much as a basket (Rea 1902: 51).

the first of lapilli ("conglomerato giallo"), the second the black pozzolana, and the third a tufa of little strength. It was the next major eruption that produced a lightweight but reasonably resistant lithoidal tufa ("tufo lionato"), suitable for use in construction although not for cutting into large squared blocks. The most characteristic colour of this strata is tawny, tending both to yellow and to red; various other shades from greyish-yellow to reddish-brown are found, sometimes in the same quarries, a dark brown being the most common colour in many areas on the east of the city.[35] It is this stone, in a mixture of mainly tawny-yellow and tawny-red (Fig. 50), rather than any of the more famous varieties of tufa - Grotta Oscura, Anio, Monteverde - which forms the caementa for most of the walls and vaults of the Baths of Caracalla.

This material is virtually ignored by Blake and Lugli, but Lanciani records his exploration of ancient quarry galleries on the Little Aventine near San Saba which produced a yellowish, soft tufa which should be identified with the "tufo lionato" (Fig. 49).[36] It is not impossible that these quarries produced the material for the Baths of Caracalla, and their closeness to the site (600 m) would have recommended their use. Other galleries of uncertain age but certainly pre 19th-century, which may have supplied tufa or pozzolana, exist behind the Baths of Caracalla and on the Aventine itself,[37] but it is safer to assume that the materials came from quarries which are known to have been in use in antiquity. On the other hand, the tufa may have come from the more distant quarries, say of the Fosse Ardeatine. Given the natural variation in colour of this deposit, it is possible that both the reddish and yellowish tufas of the caementa came from the same quarry; alternatively, since Lanciani does distinguish the yellow tufa of the Aventine from other red tufas, they may come from different quarries. We shall assume that half the tufa comes from the Aventine quarries, and half from the Fosse Ardeatine.

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[35] Ventriglia 1971: 208.

[36] Lanciani 1897: 32-33; cf. Blake 1947: 39, and Ventriglia 1971: 32.

[37] See Ventriglia 1971: 314, and Carta: Cavità Sotterranee, Nos D5: 4, 9, 11.

The quarrying of this relatively friable tufa must have been scarcely more difficult than that of pozzolana.[38] Since large squared blocks were not required the tufa could have been cut roughly from the face using a pick and broken into pieces small enough to be moved by hand. It is reasonable to assume that the further breaking of the stone into small caementa also took place at the quarry; this would certainly save space on the construction site.

In calculating the man-hours involved in producing a cubic metre of tufa caementa, it has been assumed that the tufa can be equated with English chalk. Hurst's constants produce a figure of 0.218 days/m^3 solid; the increase in volume on quarrying would be about 33%.[39] The weight of natural tufa is on average the same as that of pozzolana, 1700 kg/m^3, so that 1.33 m^3 of quarried material weighs 1700 kg, requiring 51 trips in a two-modius basket, each containing 33 kg. Filling the baskets requires 0.065 days/m^3 of rubble stone, and each basket trip over 25 m takes 0.0034 days. Assuming that the average trip is 50 m, then filling and carrying the equivalent of one cubic metre of solid tufa over an average distance of 50 m requires 0.43 days. The time taken to break this material into caementa is more difficult to determine. Rea's figures for breaking various materials into a 2" gauge range from 4 yd^3/day for used bricks to 0.5 yd^3/day for granite.[40] Since the tufa is both soft and already partly broken up, a figure of 5 yd^3/day should not be far wrong. This works out at 0.22 days/m^3 of finished volume (the same as the original quarrying), or, allowing a total increase in volume over solid of 60%, at 0.35 days for the original one cubic metre of solid tufa.[41] These caementa need then to be loaded into carts, perhaps involving another round of filling baskets and carrying, say, 25 m to the carts. The increased volume means

[38] Cf. Scavizzi 1983: 42 on this point with respect to the 17th and 18th centuries.

[39] Hurst 1865: 212 gives 0.2 days/yd^3 for chalk, and see Rea 1902: 35 for the volume increase.

[40] Rea 1902: 44-45.

[41] For typical increases in volume for gravels at different gauges, see Hurst 1865: 202. The average size of the caementa is 0.03 x 0.03 x 0.075 m.

more trips, but the trip time over 25 m is the same as before; the time taken will be 0.25 days for the original cubic metre of tufa.

Thus in order to produce 1.6 m^3 of caementa from one cubic metre of solid tufa requires 0.22 days quarrying, 0.35 days breaking, and a total of 0.68 days carrying, making 1.25 days in all.

4.2.3 Selce

The final volcanic event was a lava flow extending from the Alban Hills in the south-east to the Tomb of Caecilia Metella on the Via Appia to the north-west (Fig. 49). This produced the layer of leuctite ("selce" or "lava di Capo di Bove") quarried by the Romans mainly for paving their roads, but also used as a heavy aggregate in foundations including those of the Baths of Caracalla.[42] Ancient selce quarries are known from the area of Tor Carbone, between the fourth and fifth milestones of the Via Appia,[43] and it is assumed that the material for the foundations came from there.

The surviving evidence from ancient selce quarries suggests that only open cut methods were used, as might have been expected from the position of the deposit. Selce shows a tendency to split naturally along concave planes, allowing simpler quarrying methods than other hard stones such as granite. There is no evidence to show whether or not the selce caementa were a by-product of quarrying for paving stones; this would of course be the most economic use of the material. Nevertheless, even a by product requires some labour, and we have already seen for pozzolana and tufa that much of the total labour in quarrying is involved in moving material from the face rather than in the actual quarrying. Thus assuming that the selce was quarried specifically for the purpose would not overly inflate the resultant manpower figures or cost. I shall also assume that, as for

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[42] Petrassi 1985: 602-603.

[43] Ashby 1907: Map I.

tufa, the breaking of the quarried blocks into caementa took place at the quarry.

According to Rea, a quarryman will turn out ½-1 tonne of granite or other hard stone per day.[44] With the natural weight of selce at 2.92 tonne/m^3, and assuming that on average one tonne is produced in a 12-hour day, then 2.92 days are required to quarry one cubic metre of selce. There is no evidence to indicate the size of the quarried stone. A block weighing 50 kg, the maximum for a man to lift and carry, would be roughly a cube with sides of 0.26 m, and a total volume of 0.017 m^3. The number of man-trips required to move one cubic metre will thus be roughly 57, and assuming that the blocks are carried, say, 50 m from the quarry face before being broken into caementa, this will require 0.39 man-days.[45] If it takes 4.0 man-days to break one cubic metre of granite or other very hard stone into 2" gauge, then it should take rather less time, say 3 man-days, to break the selce into the larger caementa.[46] The increase in volume is 60%. Assuming, as for tufa, that the finished caementa are then carried 25 m and loaded into carts, this will require 0.065 days/m^3 of rubble for filling baskets, and another 57 basket trips at 0.0034 man-days/trip of 25 m, a total time of roughly 0.3 days for the original cubic metre of selce.

Thus to produce 1.6 m^3 of caementa from one cubic metre of selce requires an average of 2.3 days quarrying, 3 days breaking, and a total of 0.7 days carrying, making 6.0 days altogether.

4.2.4 Pumice

Although Vitruvius knew of pumice only from the region of Vesuvius or from Etna, there is no

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[44] Rea 1902: 44-45.

[45] Using a trip length as before of 0.0034 man-days over 25 m. This should give an answer of the right order of magnitude even if the blocks were too large for one man to carry alone; for example, if the blocks were twice the size, they would require two men for each trip, but the number of trips would be halved.

[46] Rea 1902: 44-45 gives a figure of ½ yd^3 after breaking per 10-hour day for a 2" gauge, where the increase in volume will be 82% (Hurst 1865: 202). The caementa of the foundations are assumed to be the same size as those for the walls (cf. Note 41).

evidence that this was used in vault construction in Rome.[47] Blake was perhaps the first to suggest a local source of pumice, and drew attention to finds of this material on the Janiculum and the Velia.[48] Recent investigations, however, have shown that the pumice for construction came from near the ancient peperino quarries at Marino (Castrimoenium) in the Alban Hills (Fig. 49).[49] The town was linked by two roads to the Via Appia and the Via Latina, the average distance to the site of the Baths of Caracalla being about 30 km or 20 Roman miles.

The pumice in the quarry forms a loosely cohesive deposit, with some of the material already existing in quite small lumps. This should make quarrying relatively easy, and the light weight of the pumice would minimise transport. The figures should be very similar to those for the quarrying and breaking of tufa, and it is safe to assume a total of 1.25 man-day/m^3 to produce 1.6 m^3 of pumice caementa.

4.2.5 Costs

It is now possible to calculate the costs of the various materials using Diocletian's Prices Edict, in equivalents of a castrensis modius (KM) of wheat (see Section 1.3.3). Since the work of quarrying, carting and breaking stone is not particularly skilled, labour has been costed at the rate for an agricultural labourer. It is assumed that ox-carts were used for transport with a maximum load of 1200 librae (see Section 1.6.1). The Lex Iulia Municipalis, which forbade the use of vehicles in the streets for ten hours after sunrise, did not apply to carts supplying public building sites or demolition works. It can thus be assumed that the carts could go directly from the quarries

[47] Vitruvius, de arch., ii.6.2-3, does not in fact infer that pumice was necessarily a building material, and its chief architectural use at that time seems to have been as a decoration for nymphaea, to create the effect of a cave. The pumice used as a depilatory (cf. Juvenal, Sat., viii.16), or for polishing wood (cf. Catullus, Carm., i.2) was clearly more akin to the modern toiletry than to the very coarse black material used in Roman construction.

[48] Blake 1947: 41.

[49] I am grateful to Dott.sse Marina Piramonte and Alessandra Capo di Ferro for this information.

to the site. The results are given in Table 6.

Table 6: Cost of Locally Quarried Materials

Material	ManDays /cu. m	Cost KM/cu.m	Transport by ox-cart				Total cost KM/cu.m
			Dist. Rm.	Trips /cu.m	Days	Cost KM/cu.m	
Pozzolana	0.45	0.16	2.3	4	1.5	1.84	2.0
Selce	6.00	2.20	3.8	7.20	4.6	5.60	7.8
Tufa	1.25	0.45	1.2	4.25	0.85	1.02	1.5
Pumice	1.25	0.45	13.6	2.25	5.1	6.12	6.6

4.3 MARBLE

Marble[50] was used extensively in the Baths, both structurally, e.g. in the palaestrae porticoes, and purely decoratively, as ornamental columnar orders, wall and floor veneer, and as tesserae for floor mosaics. The sources of most of the commonly used decorative stones of the empire are known, and much is understood of the pattern of imperial exploitation of these resources, although new investigations are constantly refining the emerging picture.[51]

4.3.1 Types and sources

The marbles firmly identified as having been used in the Baths belong, with one exception, to a relatively limited and predictable range of types, mainly from well-known quarries (Fig. 51). The columns shafts are of grey-green Carystian (from Euboea), creamy purple-veined Docimian (from

[50] "Marble" will be used in its broadest sense (parallel to the Latin marmor) to refer to any decorative stone capable of taking a polish, whether a true marble in the geological sense or not.

[51] Following the pioneering work by Bruzza (1870) and Dubois (1908) on the organisation of the Roman marble trade, the study of Roman marble quarries was taken up only much later by Röder (1965; 1971; Kraus and Röder 1962; 1967) and Ward-Perkins (1951; 1971; 1980a; 1980b). Research in this field has blossomed recently, and the bibliography is very large. The recent collections of papers edited by Fant (1988a) and Herz and Waelkens (1988) give a good indication of the scope of modern research.

central Asia Minor), yellow Numidian (from Chemtou in Tunisia), a banded grey marble which is probably Proconnesian (from the Sea of Marmara), alabaster (probably Egyptian), and red porphyry, red Assuan and grey Mons Claudianus granites (all from Egypt);[52] the bases, capitals and entablatures are of (?)Luna (Carrara), (?)Proconnesian, or Pentelic marble. Other marbles represented by veneer fragments only include Thessalian green, pink-grey Chian, the red marble of Cape Taenarum, the red/pink/yellow breccia corallina from Bithynia, green- and possibly black-matrixed africano from Teos, a strongly marked black and white granite from Anatolia ("bianco e nero tigrato"), and Lacedaemonian, the green porphyry from near Sparta.[53]

Not all of the white marbles were necessarily used in the original construction. Although the final results are still awaiting publication, it seems clear that, while all the entablature fragments in Pentelic belong stylistically to the Severan period, some of those in (?)Proconnesian belong to a later third century restoration, as may the figured Composite capitals from the frigidarium pools.[54] In addition two column fragments - one of alabaster and the other of Numidian marble - now set up in the Baths are still in their quarry state, and cannot have formed part of the original decoration. If indeed they do belong to the Baths they most probably represent late restorations.

[52] Kraus and Röder 1962: 120 identified the larger grey granite columns from the central block as Mons Claudianus. Some smaller columns in the garden area of the Baths come from three separate sources in addition to Mons Claudianus, one of which is probably the Troad (supplying the granito violetto). The identifications are based on portable gamma ray analysis. My thanks are due to Dr O. Williams Thorpe and the late Dr R. Thorpe of the Dept of Earth Sciences, The Open University for making this information available at such an early stage of their project. Some fragments of columns of porfidio bigio from near Fréjus were found in the late 19th century excavations (Gnoli 1971: 114-15) together with an Ionic capital with a bust of Harpocrates. As this certainly came from one of the libraries of the outer precinct (Kinney 1986), and no fragments of this marble have to my knowledge been found in the central block, it is reasonably safe to assume that the columns of this stone also come from the libraries.

[53] Some small fragments of veneer still exist in situ, while many were recorded in the Pellegrini's weekly excavation reports of 1873-4 (Biblioteca della Storia Dell'Arte e dell'Architettura, Mss Lanciani 37: Pellegrini Codice Scavi; Archivio Statale, Ministero della Istruzione Pubblica, Direzione Generale, Antichità e Belli Arti: Busta 101/102, Fasc. 134). See also Iwanoff-Hülsen 1898: 25-36; Gnoli 1971: 170, 204.

[54] Jenewein 1983, and for the Composite capitals see Mercklin 1962: 58-60. The identification of white marbles is problematic; see Waelkens etal. 1988a: 83-85 for a recent summary with extensive bibliography.

By the start of the third century most of these quarries were in imperial hands. Imperial ownership is most clearly indicated by the inscriptions cut on quarry state blocks as part of the accounting system.[55] The following marbles have produced quarry marks: Carystian, Docimian, Numidian, Proconnesian, alabaster, the Egyptian granites and porphyries, Chian, africano, Parian and Luna. Quarry marks are relatively rare on white marbles, but the recent publication of blocks from the Fiumicino canal near Portus has added a further 24, including several identified as Parian.[56] There is most debate about the Pentelic quarries, which have been thought to have belonged to Herodes Atticus in the mid-second century on the strength of a single inscription on a block from the Marmorata in Rome.[57] The form of this inscription, however, has parallels in the imperially owned Docimium quarries of the later second century, and according to Fant should argue for imperial ownership rather than against it.[58] In addition, the extensive use of Pentelic marble by the Severan emperors, both at Lepcis Magna and in the Baths of Caracalla, does strongly suggest that at least by the end of the second century these quarries were under imperial control.

Until recently it was thought that much of the marble used at Rome from the later part of the second century onwards came from stockpiles of material quarried at an earlier date.[59] This theory was based on the dearth of quarry marks after the mid-second century and the presence of unworked blocks dating from the first century in various sites at Rome, Portus and Ostia.[60] It

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[55] See Dodge 1988: 59-70 for a convenient summary of the evidence.

[56] Baccini Leotardi 1989: nos 92-106, 112-114, 118-123.

[57] Bruzza 1870: no. 291. For the arguments see Ward-Perkins 1951: 92. Contra, the brief note by Pensabene 1972a: 352, n.109.

[58] Fant 1988b: 152 and n.26.

[59] Largely formulated by Ward-Perkins in a series of articles (1951; 1971; 1980a; 1980b), and followed by Pensabene 1972a; 1978; 1989, and most recently by Dodge 1988; Waelkens etal. 1988a: 108-10.

[60] Ward-Perkins 1971: 147-48 and 1980b: 26; Pensabene 1982: 21.

is now clear, however, that the imperial quarries were flourishing in the Severan period[61] and continued to operate well into the third century, some being active also in the late empire.[62] Fant has explained the change in the form of the quarry inscriptions and the cessation of regular inventories at the time of Hadrian as reflecting the commercialisation of the marble industry for the benefit of the imperial pocket.[63] Implicit in this suggestion is a belief in a continuing demand for the products of the marble quarries, and in a continuing high level of production at the quarries. This latter point fits well with the exploitation of the imperial quarries into the third century.

In addition it can be shown that the importation of marble into Rome continued into the third century. The latest surviving quarry inscription recorded from Rome is AD 206 on a block of statuary marble from the Baths of Caracalla, while an africano block from the Campus Martius bears a mark of AD 190;[64] with these exceptions, however, the series ends at both Rome and Ostia in the 170's.[65] Lead seals found in Rome, mainly from the bases of columns, however, continue into the reign of Gallienus.[66] Several shipwrecks with marble cargoes from the coast of Italy and Sicily which may have been destined for Rome also date to the first third of the third

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[61] Docimium - latest quarry inscription AD 236 (Fant 1989: 10), and cf. arguments by Waelkens 1982: 37-38; Assuan - new quarries under Septimius Severus (Bruzza 1870: 169); Carrara - relief from Fantiscritti quarry under Caracalla (Dolci 1980: 36; 1985-87: 425).

[62] Assuan, Mons Claudianus and Mons Porphyrites were all operational at the time of Diocletian (Ward-Perkins 1980b: 38; Kraus et al. 1967: 119). Numidian quarries were abandoned in early 4th century (Rakob et al. 1979: 55-57). Quarries at Proconnesus and Carystos still functioned in Byzantine period.

[63] Fant 1989: 151-52.

[64] NSc 1883: 14.

[65] Bruzza 1870: No. 279 for the block from the Baths. The fragmentary inscription No. 325 from the unworked part of a ?Luna marble pedestal in the Palatine stadium giving *Tertullo cos* may in fact refer to the consul of 195 rather than that of 158, which would fit very well with Severan restorations in this area.

[66] Bruzza 1870: 116-17.

century.[67]

The supply of marble for the Baths of Caracalla must be viewed in the light of this evidence for a continuing production of marble at all the major quarries and for its import to Rome into the third century. The Baths required not only exceptional quantities of material (e.g. 60 matching grey granite shafts for the palaestrae porticos) but also exceptionally large columns (e.g. the 45 foot shafts for the frigidarium columns) and individual blocks (e.g. the cornice blocks for the frigidarium, measuring roughly 5.4 x 4.7 x 1.7 m each). These are unlikely to have been furnished from a stockpile created some 50 years previously at Rome and drawn on constantly for imperial constructions since. It is thus safe to assume that at least all the major structural elements were quarried specifically for the Baths or were selected from recently produced stock at the quarries.

4.3.2 Quarrying and production

The extraction methods used at any given marble quarry are largely conditioned by the geology of the deposits and the specific site conditions. Different problems must have been created, for example, by the fractured irregular beds at Docimium in comparison with the massive and consistent ones at Proconnesus, or by the strongly bedded Carystian or Thasian compared with the fine uniform grain of Luna marble. While red porphyry and the Egyptian granites were obtained from extensive deposits, the green porphyry of Sparta was dug from pits in small lumps. These various factors make it difficult to generalise about marble production, and dangerous to extrapolate from information relating to a single type of marble.

Nevertheless, it is possible to discern a basic set of common techniques of extraction and

[67] e.g. Punta Scifo wreck (Docimian and Proconnesian blocks, columns and other items) of AD 200 (Pensabene 1978); Marzamemi I (blocks and columns of Attic marble), first third of the third century (Kapitän 1961: 290-300; Panella 1972: 93 for dating).

production which, although differing in detail, were applied at most of the Roman marble quarries.[68] Normally, a block was defined at the quarry face by cutting trenches along the back and sides with a pick, and then split from the bedrock using iron wedges, or by applying levers to a continuous groove made with a point. For the harder granites and porphyries, wedges were also used vertically to split the sides of the block from the bedrock. There is very little evidence that saws were used directly at the quarry face.[69] Individual quarry sites seem generally to have been small but numerous, and modern parallels suggest that on average 3 or 4 men could have worked together to free each block from the face,[70] although more might have been employed on the larger columns.[71]

Once the rough block had been freed, it was first moved a short distance from the quarry face, and then shaped; the exceptions seem to have been columns which were shaped while still attached to the parent rock, usually singly but also as paired, triplet and quadruplet columns joined along the long axis.[72] Veneer blocks were trimmed first into regular rectangular solids, after which any defective areas were removed, usually as rectangular steps although a number of surviving blocks have trapezoidal sides. The process is well demonstrated at Docimium.[73] Marble for architectural elements other than columns would normally have been left as rectangular blocks,

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[68] See Kozelj 1988, and Waelkens et al. 1988a: 95-107, but emphasising the differences, with a discussion of earlier theories.

[69] Dolci 1980: 201. The only positive evidence comes from Docimium, where there is one saw-cut face high on the south rim of the Bacakale quarry. I am grateful to Clayton Fant for this information.

[70] Compare e.g. the quarries at Mons Claudianus (Kraus-Röder 1962: 109-110; Kraus et al. 1967: 146) with those at Carystos (Lambraki 1980). For the size of recent quarry teams see Fant 1989: 3; Dolci 1980: 203-205.

[71] This can tentatively be inferred from the much-quoted passage from the Passio sanctorum quattuor coronatorum auctore Porphyrio, Acta SS, nov. VIII, 4.

[72] There are numerous examples from the quarries of Chemtou, Chios, Docimium, Carystos, Cararra and Mons Claudianus. Pairs - Gatti 1907: 207; Baccini Leotardi 1989: no. 129. Triplet - Fant 1984. Fours - Gatti 1907: 207; Baccini Leotardi 1989: no. 46.

[73] Fant 1989: 35-36.

possibly trimmed to a predetermined size (standardised or to fill a specific order).[74] In this case the discovery of faults in a block would have been more serious, unless the block was told over for veneer. The importance of this second stage of working has confirmation from Fant's recent analysis of the quarry marks from Docimium,[75] and there is a parallel at the Carrara quarries during the 15th and 16th centuries, where the rough stone was worth less than one third of the value of the dressed block at the quarry.[76]

Architectural elements could be either transported as rough blocks or taken a stage further and given their preliminary shaping at the quarry. Evidence for the former comes from shipwrecks off the coast of Sicily, which include large, plain, rectangular blocks suitable for entablatures, and some smaller ones suitable for capitals and bases.[77] On the other hand, roughed out capitals, bases and entablatures have been found at both the Carrara and Proconnesian quarries, mostly left behind because of some flaw or error,[78] and other shipwrecks have produced roughed out capitals and bases.[79] Nevertheless, examples of partly worked elements in the marble collections of Rome and Ostia are rare before the late empire.[80] The prefabrication of architectural elements such as capitals and bases, however, suggests a standardisation of these elements of the orders which is not in fact apparent in the major buildings of imperial Rome, as Mark Wilson-Jones' recent work on

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[74] Waelkens 1982: 35 argues that Docimian was quarried in modular sizes, although the blocks of Asiatic marble from the Isola delle Correnti wreck (Kapitän 1961: 282-84) show only a moderate tendency (about 10%) towards dimensions in whole or half feet.

[75] Fant 1989: 35-36.

[76] Klapish-Zuber 1969: 146

[77] Kapitän 1961: 282-300, and cf. Pensabene 1972: 321-23.

[78] Carrara - Dolci 1980: 200-201; Proconnesos - Asgari 1978: 476-78.

[79] See Asgari 1978: 479, and 1988; Beykan 1988; Pensabene 1978: 108.

[80] According to Pensabene 1972b the capitals Nos 186-197 and 545-549 from the Tempio dei Fabri Navales are all later 4th century. The Ionic capital in Proconnesian from the Fiumicino Canal (Baccini Leotardi 1989: no. 115) should also be 4th century (cf. Giuliano 1982: No.I.38).

the Corinthian order has clearly shown.[81] This is in contrast to the standardisation in the heights of column shafts, which were determined at the quarry. More work is required both at the white marble quarries and with the architectural ornament of the capital before this dichotomy can be resolved, although the most likely solution is that all three possible systems - general prefabrication of standard elements at the quarry, prefabrication to specific orders at the quarry, and fabrication only at the building site - were in operation at some or all of the white marble quarries.

Other large items such as fountain basins, labra, and sarcophagi were certainly shaped at the quarry. Fifteenth-sixteenth century Carrara again may provide an insight; there the shaping and finishing of objects such as capitals and mortaria were often done by the quarrymen when work at the face was not possible, due to bad weather or illness.[82] There is evidence from the Roman period of a break in quarry operations at the Saint Beat quarries in the Pyrenees between the Ides of November and the Ides of March;[83] the shaping of articles would then have provided work for the quarrymen throughout the year. On the other hand, excavations at the Chemtou quarries have provided evidence for large-scale serial production of objects such as labra, and this suggests a permanent operation independent of the quarry teams.[84]

4.3.3 Transport

The problems relating to the transport of marble from the quarry to the Baths of Caracalla are of quite a different order than those relating to the locally quarried materials discussed above. The transport of large monolithic blocks and columns must have always created problems for the imperial administration where any distance over land or sea was concerned, but our only direct

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[81] Wilson-Jones 1989b: 37-53.

[82] Klapish-Zuber 1969: 142-43.

[83] Bedon 1984: 98-99. The same is true today at Docimium.

[84] Rakob et al. 1979: 55-57.

evidence comes from several papyri relating to the Egyptian quarries.[85] In all three examples the requisitioning of extra transport or supplies for draught animals suggests that these were special cases which could not be met through the normal operation of the transport system. The urgency behind the requests also points to the same conclusion, that these are special orders for particular buildings. The relatively short construction periods for many imperial buildings, the restrictions on the sailing season in the Mediterranean, and the limitations of movement down the Nile to the period of flood,[86] must all have contributed to the difficulties faced by the administration in these examples.

Not all quarries presented the same problems, and the methods of transport used no doubt differed according to the different physical locations.[87] One main consideration was the size and weight of the blocks involved. Even for the 24 foot columns of the palaestra portico, one of the smaller orders used, untrimmed the capital blocks weighed roughly 2.2 tonnes, the architrave and frieze 7 tonnes, and the column shafts 10.2 tonnes. The largest blocks were the frigidarium columns and cornice blocks, weighing about 90 and 60 tonnes respectively in the rough state. None of these could be pushed or lifted without some device to improve the mechanical advantage, and all are beyond the strength of a single yoke of oxen pulling a waggon.

Within the quarry it is likely that the blocks were moved on sleds drawn by men, using capstans for the larger blocks. Various attempts have been made to estimate the manpower required under these circumstances, the major factor being the nature of the surface over which the sled was

[85] e.g. Syene - P.BeattyPanop. 2.44-6 (Ward-Perkins 1980b: 38); Mons Claudianus - P.Giss.69 (Peña 1989); porphyry - P.Lond.II 328, BGU 762.

[86] Cf. the difficulties faced by the French in transporting the Luxor obelisk down the Nile; after waiting from 31 October 1831 to 24 August 1832 for the Nile to rise again, it took nearly five months from Luxor to Alexandria, including a long wait stranded on the Rosetta sandbank (Adam 1977: 17).

[87] For an overview of methods of transporting marble from quarries see Wurch-Kozelj 1988.

dragged and the amount of lubrication. Bedon estimates that a man can push or pull up to 0.1 tonne over a smooth flat surface using rollers,[88] while Cotterell and Kamminga suggest 0.15 to 0.25 tonnes with lubrication depending on the conditions but only 0.06 tonne over grass.[89] Thus under good conditions it would take several men pushing or pulling to move even the smallest blocks on the flat, and over 500 men to move the largest column shafts, although this number could be reduced by the use of capstans. In terms of manpower calculations, however, we need to know not only the number of men but the rate at at which they move the blocks across the ground. If the average power output for a man in pushing or pulling is about 30 Watt and the maximum force exerted by a man pulling a sled is 300 Newtons, then the maximum speed should be 0.1 m/sec., compared with an average walking speed of a lightly burdened man of 0.75 m/sec.[90] and the speed of 0.17 m/sec. for a man carrying a 50 kg load derived from the 19th century sources (cf. section 4.2.2).

All the blocks of the 24 foot order could be manoeuvred down steep slopes on a sled over a paved road, with ropes operated by capstans attached to bollards on either side of the road for braking,[91] although handling the <u>frigidarium</u> blocks would have been a difficult undertaking. Waggon loads of 10-15 tonnes of marble drawn by 12-18 pair of oxen were common in 15th-18th century Italy,[92] but the problems of loss of efficiency and coordination of the draught animals increases enormously as their number increases. Here again attempts must have been made to lower the coefficient of friction at all stages, by moving the blocks on rollers or sleds over a smooth surface,

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[88] Bedon 1984: 132-37.

[89] Cotterell and Kamminga 1990: 217-23.

[90] See Cotterell and Kamminga 1990: 18-43, 194-96 for the data and theoretical basis of this.

[91] Where sleds were used until recently at Carrara the maximum load was normally 20-24 tonnes (Dolci 1980: 203-205).

[92] Bedon 1984: 138; Mannoni 1978: 103.

possibly using clay as a lubricant. A very gentle incline would also have been beneficial; in this way it was possible to move Mussolini's obelisk, weighing some 560 tonnes, with only 60 pair of oxen.[93]

Once at the water, the marble had to lifted onto a boat using pulleys in combination with man-operated capstans or treadmills to multiply the mechanical advantage. One man can raise 0.14 tonne using block and tackle, four men operating a capstan on a derrick can raise about two tonnes, while loads over 6 tonnes require the use of a treadmill and four men operating a large wheel can raise over 10 tonnes.[94] Thus while all the blocks for the 24 foot order could be managed easily by a double treadmill,[95] the largest blocks again must have created problems. It would have been easier to drag these blocks and columns up a gentle incline and then swing them over and lower into the waiting ship than to lift them from the quay. The chances of damage or loss at every transfer as well as during transport must have always been high, but particularly so for outsized blocks and columns. Here too we can make an estimate of the kind of manhours required for these operations. Records from 19th-century Australia where treadmills were used in prisons suggest that a man could generate about 70 Watt of power over a 12 hour day. Using a five-sheave pulley and a reduction drum system and assuming 100% efficiency it should be possible to raise 26 tonnes through one metre in an hour. In reality, however, the pulley alone loses over 20% efficiency, and the total loss may have been as much as 50%.[96]

Although it is clear from the various shipwrecks that small and medium sized blocks and columns

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[93] See Adam 1977 for this and other ways of moving very large blocks.

[94] Adam 1977: 36, 38-40.

[95] As on Thasos, see Sodini et al. 1980: 119-22.

[96] Cotterell and Kamminga 1990: 41 for the power output for the treadmill, and cf. Landels 1978: 87-89 where he suggests a rate of roughly 12 tonnes/m/manhour which is half the maximum possible rate.

were carried in the holds of ships, presumably at the lowest level and even as paying ballast, this is not feasible for the large columns. We know from Pliny (HN XXXVI.2) that special ships were built for transporting marble, the most famous of which was that built by Caligula for the Vatican obelisk (Pliny, HN XVI.lxxvi.201-201; XXXVI.xiv.70). The fact that this ship was roughly four times the length of the obelisk and needed 800 tonnes of lentils as ballast suggests that the obelisk was carried on deck, so that the apparently excessive dimensions and the load of ballast were needed to ensure the stability of the vessel.[97] This presumably was the normal way of carrying all large columns.

Once the ships reached Portus, any marble not for immediate use was stored at a site on the Fossa Traiana immediately above the canal which linked it to the hexagonal basin itself.[98] Since large ships could not be hauled up the Tiber to Rome, some of the marble, particularly the large blocks and columns, must have been transferred to river boats, with further risk of damage. Marble was landed at the Marmorata area below the Aventine, from where it was moved presumably by cart to the site; an alternative route used for moving the Lateran obelisk to the Circus Maximus in the time of Constantius II (Ammianus Marcellinus XVII.iv.14) was to land at the Vicus Alexandri three miles south of the city and continue by road. Both Tibullus (II.iii.43-44) and Juvenal (III.257-61) convey the disruption created by these heavy waggons moving through the streets of Rome. The necessity for multiple yoking to pull even the smaller architectural blocks must have added to the difficulties, and the movement of the largest columns must have amounted virtually to a public spectacle, even if Tibullus' "thousand yoke" must owe something to poetic licence. Nevertheless, on the paved streets of Rome the largest blocks would have needed some 300 pair

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[97] See Testaguzza 1970: 109-111 for the ship which was later sunk to form the mole of Claudius' harbour at Ostia.

[98] Testaguzza 1970: 189.

of oxen, unless special surfaces were prepared and/or rollers used under sleds instead of carts.[99] Alternatively some of the traction could have been provided by men, hauling directly on the ropes or operating capstans from fixed locations on the ground.[100]

4.3.4 Manpower Requirements

As will by now be obvious, estimating the manpower requirements for marble production is far more difficult than for other materials already discussed. The specific geology of the quarry and the site conditions affect not only the tools and techniques of extraction but also the manhours required to achieve a given product. The location of the quarry, the distance and transport route to its port, and the distance from the port to Rome also strongly influenced the total manpower requirements.

Our only ancient source is the Passio sanctorum quattuor coronatorum, set in the porphyry quarries of Pannonia during the reign of Diocletian.[101] According to the account it took an unrecorded number of men working every day for 3 months to turn out a porphyry column of unspecified size, but the saints (helped by God!) only 26 days. This perhaps gives us a rough order of magnitude of, say, 6-12 man-months for a reasonable sized porphyry column. These figures can be tested against 19th century English constants for quarrying granite. Using the higher values for quarrying and rough dressing of local granite supplied by Rea and Hurst, a 20 Roman foot shaft would take about 50 days to produce, a 30 foot shaft about 130 days, and a 40 foot shaft about 260 days.[102]

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[99] As was the case with the Lateran obelisk, weighing about 500 tonnes.

[100] Cf. the moving of the 500 tonne Vatican obelisk under the direction of Domenico Fontana in the 18th century which required 800 men and 120 horses. For this and other examples of moving large obelisks see Dibner 1979.

[101] Delehaye 1910: 766-67 for the Pannonian quarries. Gnoli 1971: 102 relates this account to the Egyptian quarries at Mons Porphyrites.

[102] Rea 1902: 88; Hurst 1865: 219.

Unfortunately these tables give no figures for quarrying marble. In a recent experiment, it took Kozelj 22.5 hours of effective work to quarry a block of Thasian 1 x 0.5 x 0.25 m (weighing roughly 340 kg),[103] without further dressing. This figure is, of course, likely to be rather high due to Kozelj's lack of experience. There is still scope for observing traditional quarry methods in operation at several sites in Turkey, and Fant records from Docimium that it "takes a skilled man only a few days" to dress a block (of unspecified size); it is a pity that his observation was not more precise.[104] This data can be set against the information existing from the Carrara quarries, although here too it is not possible to produce a neat set of figures. In the 15-16th century the cost of a "carrata" (roughly 850 kg) of squared marble at the quarry was the equivalent of 8 to 9 man-days of skilled labour,[105] while the value of the material before shaping was more like 2½-3 man-days. On the other hand, some of the labour would have been contributed by apprentices, who were given board and lodging and provided with tools and clothes, but not otherwise paid. Costs other than the labour of the quarrymen had to be taken into account; rents were paid on the quarries, tools had to be maintained, waste had to be removed from the working area, etc. Not all the marble quarried was usable, and for specific requirements such as statuary or particularly large blocks, a large amount of material might have to be quarried before a suitable block was found.[106] Nevertheless, it is reassuring to note that these figures are of the same order of magnitude as those already obtained. Assuming that the work of quarrying a block is relative to its surface area rather than its volume, it would have taken Kozelj about 38 hours, or 3-4 days to quarry a "carrata" of marble, to which must be added another, say, 2-3 days to square the

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[103] Kozelj 1988: 36-39.

[104] Fant 1989: 3.

[105] Klapish-Zuber 1969: 147. Bedon 1984: 98 interprets this to mean that it takes one mason 8-9 days to produce 850 kg of marble, but this is taking the evidence beyond its limitations.

[106] Klapish-Zuber 1969: 62 cites a 16th century sculptor who complained that "A Carrara cavano ale volte dua mesi prima che possano avere un pezzo di marmo statuale". Lambertie 1962: 58 estimates that the percentage of blocks obtained from a quantity of quarried marble rarely exceeds 25%.

block.

Transport figures within the quarry and from the quarry to the port are much more difficult to calculate. In the 15 and 16th centuries, the cost of the squared blocks from Carrara was roughly doubled by the time they were loaded on board ship at the port. While customs dues and taxes account for some of this, about two thirds was the cost of moving the material from the quarry to the port, a distance of between 9 and 12½ km;[107] this gives an equivalent of 5 man-days for the trip. Relatively higher prices per "carrata" were paid for larger blocks, reflecting here the increased difficulties of moving the blocks at every stage; it is the chance of breakage, and thus loss of income for labour expended, which must be taken into account, as much as a relatively higher manpower requirement.

4.3.5 Costs

Section 31 of the Prices Edict gives a list of maximum prices for a range of marbles, including many of those used in the Baths of Caracalla. The prices range from 250 denarii for Lacedaemonian and probably red porphyry (the second digit being uncertain), to 200 denarii for Docimian and Numidian, 150 for africano and Thessalian, 100 for Assuan (Pyrrhopoicili), Claudianus and Carystian, 75 for alabaster, and 40 or 50 for the white marbles of Lesbos, Thasos and Proconnesus. Important omissions for our purposes are the white Luna and Pentelic marbles, and, to a lesser extent, Chian and rosso antico.

The cost in the Prices Edict is almost certainly for a square foot of veneer (see Appendix 5). This leaves the problem of objects shaped in some way. Was a column, for example, priced in the same way as veneer, or a roughed-out capital the same as a squared architrave block? Given how little we know about the marketing process, it is not even certain that columns and other architectural

[107] Klapisch-Zuber 1969: 147; Dolci 1980: 34.

elements - the use of which, after all, was restricted to public buildings or the residences of the elite - were in fact available on some kind of open market. The fact that marbles were included in the Edict at all is in itself a curious phenomenon. Fant has pointed out that long distance trade in stone is unlikely in the first place, and that the administrative changes in the operation of the imperial quarries in the mid second century, as revealed by the quarry marks, suggest a commercialisation of the marble quarries which makes sense only as a lucrative economic venture to the benefit of the imperial pocket.[108] In addition, the high prestige value of marble is attested by the prominence given to notable donations of columns by various emperors to individual communities.[109] The means by which marble from imperially owned quarries found its way onto the market are not clearly understood, although negotiatores and redemptores marmorarii are attested in the epigraphic record.[110]

Such considerations must affect our understanding of what the marble prices in the Edict really represent.[111] If our interpretation of the Edict is right (see Section 1.4), they should be the market prices in the eastern empire, most probably at Nicomedia. The price differentials should then reflect variations both in difficulty of working and in transport to Nicomedia. While there is some correlation with these factors for many of the marbles, there are also many difficulties. There seems to be no immediately obvious explanation for the higher cost of the africano from Teos or for Thessalian compared with Carystian, as all three are roughly the same distance from Nicomedia, and none are difficult to quarry. On the other hand, the Carystian quarries seem to have produced consistently larger and more numerous blocks and columns than the other two, so

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[108] Fant 1988b.

[109] e.g. 100 columns of Numidian given to Athens (Paus. I, 18, 9) and 20 to Smyrna (IGRR IV, 1431) by Hadrian; 100 of Numidian given to Ostia by Tacitus (SHA, Tac. 10, 5).

[110] CIL VI, 33873, 33886. See Pensabene 1989: 43-45 for a recent resumé of the problem.

[111] This part of the discussion has benefitted greatly from a paper presented by Dr H. Dodge to the Oxford Ancient Architecture Discussion Group in May 1990.

that the unit cost of production was lower.

More puzzling is the 100 denarii for Mons Claudianus granite compared with the 250 for porphyry from the nearby quarries of Mons Porphyrites, both of which required an overland haul of some 150 km before reaching the Nile.[112] On the other hand, while at first glance it seems that the cost of Assuan granite, where the quarries are on the Nile, should be less than that for Mons Claudianus because of the difference in transport, calculations show that this may not be the case. Using Duncan-Jones' figure of 0.064 denarii/KM/mile for transport down the Nile and assuming that the cost of sea transport given in the Edict from Nicomedia to Alexandria was the same in the opposite direction, the cost to transport one cubic foot of Assuan granite to Nicomedia works out at roughly 480 denarii. The cost of transporting Mons Claudianus granite comes to 670 denarii if we assume that the overland costs are the same as those given for ox-carts in the Prices Edict and the maximum load is 1200 Roman pounds or 388 kg. If, on the other hand, we assume that the basic load is the Italian "carrata" of 850 kg - well within the limits for a pair of oxen on level ground - then we could reduce the cost of the overland component from 360 to 160 denarii, and the total cost to 470 denarii. The figure would not be much lower if camels rather than oxen were used.

It is possible to make very rough calculations on the likely cost of the marbles based on the manpower figures determined above and the cost of labour and transport in the Prices Edict. The equivalent cost of Luna marble at the quarry works out at an average of 43 denarii per foot cubed (P^3), and from Kozelj's experiment with 2-3 days added for squaring Thasian would cost on average 35 denarii/P^3. This latter figure, however, makes no allowance for tools and their maintenance, movement of blocks within the quarry (e.g. from place of extraction to working

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112 This now seems the generally accepted route for the products of Mons Claudianus and Mons Porphyrites, rather than by way of Myos Hormos and the Red Sea. See Klein 1988: 54.

stage), wastage of blocks, removal of quarry debris, administration, leases, etc,[113] so that it would be reasonable to use the higher figure obtained for Carrara. Added to this must be some factor for the cost of moving the blocks to their nearest port, another 70% in the case of Carrara marble, considerably less - say 30% - in the case of Thasian.[114] In other words, the unit cost of production is likely to be in the order of 55 to 75 denarii, or 7 to 10 denarii per square foot of veneer. If the cost of transport by sea is added, the most direct voyage from Thasos would add at least about 32 denarii/P^3, that from Lesbos about 29 denarii.[115] This gives a cost in the region of 11 to 13 denarii per square foot of veneer, even with no allowances made for loading and unloading along the way or for profit, compared with the 40 to 50 denarii in the Prices Edict. On the other hand, the transport costs from quarry to port for Carystian and Thessalian should not have been much different from those from the Carrara quarries to the sea, and the cost of sea transport roughly 40 denarii/P^3 in both cases, giving a total of 15 denarii/P^3, compared with the 100 and 150 denarii for Carystian and Thessalian respectively. Clearly other factors are operating here, relating to the difficulty of working or of obtaining the requisite size of blocks, of particular transport problems, and the intangible operation of fashion and taste.

The problem with understanding the prices of marbles in the Edict becomes even greater if we look at the more expensive types. Even assuming that the cost of quarrying the granites and porphyry are no greater than for marble, the transport costs of the Egyptian stones calculated above would appear to be very high indeed. Similar calculations give the cost of transport for Docimium as 940

[113] See Fant 1988b: 153 and Pensabene 1989: 46 for an idea of the administration of the quarries and their possible cost.

[114] For the Thasos quarries see Sodini et al. 1980: 81-145.

[115] Since one KM of wheat weighs roughly 10 kg (based on Duncan-Jones 1982: 370), and one P^3 of marble weighs roughly 70 kg (assuming an average weight for marble of 2.7 tonnes/m^3), then one P^3 of marble should cost on average 0.091 denarii/Roman mile (cf. Section 4.1.3 and Appendix 5).

denarii/P^3 (440 using the "carrata") following the Maeander route,[116] and 680 (360) denarii for Numidian, equivalent to 117 (55) and 85 (45) denarii per square foot of veneer. These figures are account for much of the Edict prices of 100 to 250 denarii even without adding any figures for production.

These difficulties are without immediate solution. For the purposes of this study I am constrained to use the Edict as the basis of the cost of marble. In order to allow columns to be costed as well as the raw blocks for capitals, architraves, etc, I shall use a figure for architectural elements per cubic foot which is eight times that given in the Prices Edict. For veneer I shall use the value given in the Edict, in square feet.

4.4 WOOD

Although no major roofing timbers were needed for the substructures and central block of the Baths, large quantities of wood were required during construction, for shuttering, scaffolding, centering and formwork.[117] These items naturally leave no remains and are not mentioned in the literary sources, which concentrate on decorative and structural timbers or props for viticulture. The ancient evidence for the supply of timber to the city of Rome has recently been discussed by Meiggs,[118] but he does not consider the problem of construction timbers in any detail. Nevertheless, it is possible to identify likely sources of the necessary material from the physical requirements for the different constructional purposes.

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[116] Now generally accepted. See Waelkens 1982: 51.

[117] The only rooms with timber roofs were the libraries and the central halls of the segmental exhedrae of the outer precinct.

[118] Meiggs 1982, especially Chap 8.

4.4.1 Types and sources

Large squared timbers were needed for the supports and framework of the vault centerings, the frames of the lifting devices, and the posts and shores of the foundations. Those for the centerings and machines needed to be both strong and stiff (i.e. resistant to deflection under load), while those forming the major chords of the frigidarium and caldarium centerings had to be long as well. Secondly, boards and planks were required for the foundation shuttering, the formwork of the vaults, and the working platforms of the scaffolding.[119] Here strength is not as important, while ease of working and a certain degree of flexibility for the vault formwork over curved surfaces would be an advantage. Finally there are the timbers needed for scaffolding and ladders. Later building practice was to use sapling or coppiced poles rather than sawn or split squared timbers, and the roughly rounded shape of the putlog holes in the Baths of Caracalla (see Section 6.3.4) suggests that this was Roman practice as well. The poles for the standards need to be at least 30 ft, for the ledgers 10 to 15 ft, and for putlogs about 6 ft.

The first two categories of constructional timbers presumably came from the same basic sources as structural building timbers. Vitruvius provides us with a list of the timbers in use in his day (de arch. II.ix.5-17): fir, three kinds of oak (quercus, aesculus, and cerrus),[120] beech, black and white poplar, willow, lime, agnus castus, elm (Ulmus glabra), ash, alder, hornbeam, cypress, pine[121] and larch. Only in Palladius (XII. 15) do we find chestnut added to the list as a building

[119] It is possible that in some cases wickerwork hurdles were used as scaffolding platforms. They were certainly used in the medieval period (see Fitchen 1961: 16), but have the disadvantage of being unable to support heavy loads of materials. Since Roman concrete construction demanded a ready supply of brick, rubble and mortar, wooden planking would have been more suitable.

[120] See Meiggs 1982: 45-46 on the difficulties of identifying the deciduous oak species referred to in the ancient texts. The recent Atlas of European Flora shows Quercus robur, Quercus petraea, and Quercus cerrus as the common central Italian species, and these are probably to be identified with Vitruvius' quercus, aesculus, and cerris respectively.

[121] The species of pine is not indicated, and there are problems of identification similar to those of the oaks. The most likely species are Pinus pinaster and Pinus halepensis from coastal regions and in particular Pinus larico from mountain regions. See Meiggs 1982: 43-44.

timber, but it was clearly used much earlier to provide strong stakes and props by coppicing, and it would be surprising if it were not also used for building. Columella's figures for dressing timber suggest that fir, oak, poplar, elm, ash, cypress, and pine were the major ones (Rust. XI.ii.13), while the Prices Edict (DPE 12, 1-14) for large timbers lists fir, oak, beech, ash, cypress, pine and sappinus.

The properties of these various timbers seem to have been well appreciated in the Roman period. Most of them have also been in commercial use this century, and the data on their natural properties (durability, stability, strength, ease of working) and common uses in the latest handbooks[122] accord reasonably well with the comments of Vitruvius, Faventinus, and Palladius. The dense hardwoods furnish the strongest timber, although all but Quercus robur, Quercus petraea and chestnut are short-lived while elm and ash are resilient but flexible and inclined to bend under load. In ancient Rome, oak seems to have been preferred for its durability, with some distinction being made between robur and aesculus.[123] The lighter hardwoods - the poplars, lime, willow and alder - are all short-lived, soft, and except for poplar not particularly strong even for their weight. Among the softwoods, fir is strong for its weight but perishable, the pines are heavier and slightly longer lasting, while larch is heavier again and moderately durable. One advantage of the softwoods, apart from their greater ease of working, is of course the longer straight pieces which can be obtained compared with the hardwoods; fir and larch give lengths of up to 100 ft, pine 60 ft and over, while oak rarely produces lengths over 30 ft, with 20 ft being more common. Elm and poplar produce longer straight lengths than oak and other hardwoods, and it is not surprising to find that Vitruvius recommends using these, along with cypress and pine, as a substitute for fir (de. arch. I.ii.8).

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[122] See for example Patterson 1988. For a discussion of the passages on timber in the ancient authors see Plommer 1973: 3-7.

[123] Vitruvius de arch. II.ix.8-9; Palladius XII.15. Cf. Puteoli building inscription (CIL I, 577 = ILS 5317) with robur for door-jambs, aesculus for the lintel and beams for the porch.

The most likely material for the heavy duty timbers in the centering would have thus been oak (robur or aesculus), with fir or perhaps larch used for the long chords in the major rooms.[124] The specifications for centering for the nave of St Peter's in Rome, which is approximately the same span as the frigidarium of the Baths stipulate chestnut or oak (probably Q. robur) for all the major timbers, including the 25 m (c. 84 Roman ft) long main chords; that timbers of this length were exceptional was, however, recognised, and the chords were allowed to be made up of two pieces if necessary.[125] This may have also been the solution adopted by the Roman builders, although in large span timber roofs they seem to have preferred single beams. The same document also helps to throw some light on the timbers used for boards and planks. Here we find "ischio" (Q. petraea) and "cerro" (Q. cerris) specified for reinforcing the vaults (whatever that means), with elm and alder used generally in the centering and for the coffer shapes. Despite Vitruvius' dismissal of it as decaying quickly, cerrus was in fact used in the Roman period, e.g. in the palisade of Lake Nemi,[126] and could also have been adopted in construction. In the foundation shuttering, where the boards and posts were used once and not recovered, a mixture of perishable woods - cerrus for the posts and the softer alder, beech, willow or poplar for the planks - would have been quite acceptable.

Most of the scaffolding timbers have similar physical requirements to agricultural props and poles and could have been furnished by coppicing. Columella recommends chestnut (Rust. IV.xxxiii.1-5), and this was still used for scaffolding in southern Italy into the 20th century.[127] Other species

[124] In order to produce a beam of the same strength in fir and oak, the fir would need a larger cross-section. The use of larch in two of the boats from Claudius' harbour at Ostia suggests that despite the distance it had to travel it continued to be used in Rome after the time of Tiberius. See Meiggs 1982: 248-50 and note 98 for discussion.

[125] Published in Scavizzi 1983: Appendix VI, 107-108.

[126] Ucelli 1956: 138, 147.

[127] Douglas 1915: 298.

were coppiced (IV.xxxi.2), while juniper, cypress, pine, poplar and elder are mentioned as supplying round props, presumably from branches (Columella, Rust. IV.xxvi and Pliny, HN XVI.lx.141). The long poles needed for the standards are more likely to have been saplings of fir or pine, while ash (which is still used for ladders) or elm are also possibilities.

One of the factors which must have affected the choice of constructional timber was availability. Oak (Q. robur and Q. petraea) is native and dominant in the woods of central western Italy to an altitude of 1200 m, along with the evergreen holm-oak (Q. ilex), which is also a strong timber, and beech on well-drained soils. The cerrus oak is also fairly common. Fir occurs naturally in the mountains above 1200 m, and seems to have been far more common in antiquity than it is today. It is clear from Strabo (222, 228, 235) that in the Augustan period Rome was supplied mainly from the Sabina ("rich in oaks"), Etruria and Umbria through the Tiber and its tributaries, and there is no real evidence that this had changed by the early third century. Pine and fir, however, could have come from the natural forests above Pisa (Strabo 223), and possibly from Liguria, the Sila forest in Calabria, or Corsica, while the larch had to come from the Alps via the Adriatic.[128] There is no way of knowing to what extent the Romans used these obviously more expensive timbers for constructional purposes, but they may have been the only possible source for the largest beams used in the centering.

Some of the wood and all of the poles and posts, on the other hand, probably came from agricultural estates. Elm, poplar, willow, pine, cypress, chestnut and aesculus oak are all recommended for planting by the agricultural writers,[129] although these would have also occurred naturally. While there is plenty of evidence that coppice was considered a sound investment, there is none to suggest that trees were planted on a large scale specifically to produce large timbers for

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[128] See Meiggs 1982: 247-48.

[129] e.g. Varro, Rust., I.xv.1; Columella, Rust., IV.xxx.2.

the building industry rather than just the needs of the estate.[130] Nevertheless, the fact that Columella, in discussing the squaring of timbers, says that the amounts that a man can square in a day for different timbers are all called a "vehis" or (waggon) load strongly suggests that he has an outside market in mind and not just the needs of the estate.[131]

4.4.2 Production and transport

We know virtually nothing about the management of public forests, and our only information about the felling and preparing of timber comes again from the agricultural writers. Great importance was attached to felling timber at the right time of the year, generally the autumn and winter.[132] Columella gives January as the month for cutting coppice and making vine props and stakes as well as for felling and dressing building timber (XI.ii.11-13). He is the only author to supply any kind of manpower figures for these tasks. In a nine-hour day[133] a man can cut down, strip and sharpen 100 stakes or split and smooth and sharpen 60 oak or olive props, while a further 10 stakes or 5 props can be finished by artificial light in the evening and the same before dawn.

Columella's account of the dressing of timber is rather less straight-forward. He gives no figure for felling per se, but for the different timbers he gives the amount that a workman should be able to square perfectly with an axe in a day: 20 foot of oak, 25 ft of pine, 30 ft of elm or ash, 40 ft of cypress, and 60 ft of fir or poplar.[134] This has usually been interpreted as a square foot but

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130 The sources are discussed in Meiggs 1982: 266-70.

131 Columella, Rust., XI.ii.13. The term load for a given quantity of timber is also common in later periods; in 18th century London (Salmon 1736: 26) the standard load was 50 ft of squared timber, cf. Columella's figures of between 20 and 60 ft.

132 See for example, Vitruvius II.ix.1.

133 Columella (XI.ii.90-91) notes that the winter day has 9 hours of light and 15 of darkness, which suggests an otherwise rare use of a day split into 24 equal hours rather than the variable hour normally used by the Romans.

134 Columella, Rust., XI.ii.13: "ab un fabro dolari ad unguem per quadrata pedum XX", etc.

the fact that all these measures are also know as "vehes" or waggon loads makes this unlikely.[135] If the resultant piece of squared oak had a girth of 3 ft, the same as that given in the Prices Edict (DPE 12.10), then 20 ft^2 represents a piece 6.67 ft long, containing 3.75 ft^3 and weighing in the order of 220 to 230 librae, while the largest load, assuming a log of the same girth would be 420 librae for fir. If, however, the rates were for a set length of a piece of the same 3 ft girth, then the load for oak would be in the order of 650 to 710 librae and for fir 1270 librae, or just over the maximum load for an ox-cart given in the Prices Edict (see above Section 4.1.1).[136]

The passage cited above from Columella is also of interest from the point of view of transport, since it assumes that timber was commonly moved by cart. In mountainous country, however, the logs would first have to be dragged or carried by oxen, mules or men from the hillside; a 20 ft oak log weighing about 250 kg could be carried easily by six or eight men using ropes or on their shoulders, and Ammianus Marcellinus (XVIII.ii.5) records soldiers carrying timbers of fifty feet or more. At some point they could be loaded onto carts, or taken straight to a waterway. As for other materials, transport by water was always to be preferred where possible. Timber has the special advantage that it can easily be floated down river as separate logs or tied together into rafts, although on the open sea it probably had to be carried by ship. Most of the timber for Rome no doubt came down the Tiber and its tributaries in this way. Pliny (HN III.53), however, makes it clear that for the upper reaches of the river and the tributaries even rafting was a seasonal business, and that the streams were dammed for nine days when the rain came in order to supply a sufficient flow to carry the timbers.

Once in the city, the timber had to be transferred to the building site. We either have to assume

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135 Cf. Burford 1960: 10 for the existence of a classical Greek concept of a "waggon-load" (hamaxa).

136 Based on the weight of seasoned timber. The need for seasoning is recognised in the sources, and various methods for achieving it mentioned. See Vitruvius (II.ix.2-3, 11) and Columella Rust., I.vi.19, and Meiggs 1982: 351 note 88 for discussion.

that this was carried as roughly squared timber - presumably where possible cut into suitable lengths like the 12 ft which seems to have been standard for much formwork - and sawn as required on site, or worked into planks etc at timber yards near the river. As we have seen, a reasonable amount of timber could be carried by a cart drawn by a single pair of oxen, but the tall pines and firs would be more difficult to move; the largest timbers in the Prices Edict would have weighed roughly 2.6 tonnes and needed as many as 10 pair of oxen. One of the difficulties of moving the larger timbers through the city must have been the sheer length of the carts plus oxen; the description of this type of transport in the well-known passage from Juvenal's Third Satire (254-6), speaks of the "shaking" and "nodding" of the trees, and from this I imagine the timbers propped up at one end to reduce the overall length of the vehicle as far as possible, surely a necessity in the narrow and twisting streets of ancient Rome. The routes for long timbers must have been carefully planned to avoid sharp bends and tight corners. This would not have been difficult for the Baths of Caracalla, since the carts could have travelled alongside the river to the Forum Boarium, used the open space of the Forum for turning, passed alongside (?or through) the Circus Maximus, and straight along the Via Nova to the site of the Baths.

4.4.3 Cost

The difficulties in identifying precisely the types and sources of wood used in construction, and in calculating the manpower required for cutting and transporting the timbers, make it impossible to estimate the costs using the methodology for the locally quarried materials. As was the case with marble, we are forced to return to the Prices Edict to gain some idea of relative costs, although of course we have no idea of how much transport affected the values given. Section 12 of the Prices Edict relates to large timbers. The size of the timbers concerned is given by length (in cubits) by girth (in cubits or digits), which presumably applies to a roughly squared log. Table 7 gives these measurements converted into feet, followed by a calculated volume, the price given in the Edict, and a price per cubic foot.[137]

Table 7: Timber in the Prices Edict

DPE 12.	Species	Leng. ft.	Girth ft.	Volume cu. ft	Price den.	Price/ft³ den.
1.	Fir	75	6	169	50,000	296
2.	Fir	67.5	6	152	40,000	263
3.	Fir	60	6	135	30,000	222
4.	Fir	52.5	5	82	12,000	146
5.*	Fir	42	6	95	10,000	106
6.	Fir	45	4.5	57	8,000	140
7.	Fir	42	4	42	6,000	143
8.	Fir	37.5	4	38	5,000	133
9.	Pine as for fir.					
10.	Oak	21	3	12	250	21
11.	Ash	21	3	12	250	21
12.	Beech	21	3	12	250	21
13.	Cypress	18	3	10	300	30
14.	Sappinus	18	3	10	250	25

The only anomaly is item 5, which may of course represent a mistake in the original compilation; a girth of 5 ft would give a more appropriate value. Except for items 5 and 7, both for 42 ft timbers, the lengths for fir rise in steps of 7.5 ft which may thus represent some kind of standard timber measure. The lengths given are quite appropriate if we assume that they are for roughly squared whole logs, which would then be cut to required size on the job.[138] More difficult is the small girth of the shorter timbers, although this may reflect the fact that younger trees are being used than we might expect.

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[137] This table supersedes those in Meiggs (1982: 366-68), which contain several mistakes and lead him into some false deductions. The main error comes from using a rate of 12 rather than 16 digits to the foot when converting the girth of those trees into feet, so that, for example, 72 digits becomes 6 rather than 4.5 ft. The surviving fragments of the Greek texts use dactyls as the measure. Nor are his conversions coherent; in Section 12.7, 64 digits becomes 5.333 ft while in Section 12.8 it is 5½, while items 10-14 which are all 48 digits in the best texts become 5.667 (perhaps based on the old readings), 4 and 3 ft. These affect his attempts to convert the prices into a cost/ft³ (labelled square foot in the table), and his subsequent discussion of the differentials. The effect of the recalculated values is to reduce the differentials between the longer and shorter fir and pine timbers, between the fir/pine values and the other timbers, and between oak and the other common hardwoods, to more acceptable levels. The cost of transport of the fir and pine as well as the relative rarity of the longer timbers would account for much of the main differences.

[138] Meiggs (1982: 368) expresses surprise at the absence of shorter timbers from the list, but he is perhaps unduly influenced by modern retail timber yards.

For the cost of scaffolding timbers and ladders we turn to Sections 12 and 14 of the Edict.[139] Various prices are given for stakes, props, and poles. At Section 12.27 a "palopedica sine ferro" is 10 denarii, while "rediges sive pali" at 14.1a are probably to be taken at 40 denarii for two. Longer poles (Section 14.5) cost 50 denarii each, ladders of 30 rungs (Section 14.6) 150 denarii. A welcome confirmation that these are at least the right orders of magnitude comes from Pliny (HN XIV.lx.141), who tells us that a 12 year old branch of cypress, which would make a reasonable sized pole, sold for 1 denarius, roughly equivalent to 44 denarii in the Prices Edict.[140] The long scaffolding standards presumably were rather more expensive.

In assessing the cost of construction timbers, some allowance must be made for the possibility of reuse. The foundations shuttering was left in place, but all other construction timbers are recoverable. Any wood in contact with lime or mortar - here the putlogs and the boarding of the formwork - has a short life, particularly if of a non-durable type, and perhaps could not be used more than three or four times. The normal softwood scaffolding poles used until early this century had a life expectancy of 5 to 6 years; if the butt end of the standards rotted before this, they could simply be shortened or used as ledgers. The heavy timbers for the centering supports and frames, however, would have had a much longer life, although the possibilities for reuse would have been limited by the size and form of the shaped timbers. Any timber past its useful life could, of course, be used as firewood.

4.5 CONCLUSIONS

This chapter has concentrated on the simply produced materials required for the Baths in their raw state or with very little secondary working. By following the steps required to produce the

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[139] In addition to Giacchero 1974 see Reynolds and Crawford 1977.

[140] This is taking a value for grain at rome of HS6/modius in the 1st century AD and assuming a kastrensis modius of 1.5 times the Italian modius.

materials ready for use on site, both qualitatively and where possible quantitatively, it has been possible to identify the amount and nature of the labour required. The production of the locally quarried materials needed relatively little and relatively unskilled labour at the face, and most of the workers were involved in either moving the material from the quarry face or reducing the raw material to the appropriate size, neither of which required any specific skills. Although the calculations are far from precise for the marble, it is clear that more skilled labour was needed at the face here, without, however, lessening the need for a large body of general labourers involved in moving the material around. Rather different skills were required for cutting and dressing the timber and scaffolding poles, and unlike the quarrying operations this can be seen as basically agricultural work.

The production of materials is of course only part of the process, since they also have to be delivered to the site. The importance of transport has been highlighted throughout the chapter. For the locally quarried materials - which after all account for the bulk of the finished structure - the cost of transport has been shown to be from three to twelve times that of production (Table 6), and it must also have contributed a great part of the cost of marble and timber. For the marble there is the added difficulty of moving very large and very heavy items, which required a high level of organisation as well as large numbers of men and beasts. Vitruvius had good reason to define distributio in terms of adapting to the availability of materials to avoid difficult and expensive transport problems (de arch. I.ii.8), and to regard it as one of the major components of architecture.

CHAPTER FIVE: MANUFACTURED MATERIALS

INTRODUCTION

This chapter deals with those building materials which undergo two or more main stages of production, including lime, brick, metals and ropes and baskets. The first three items require the quarrying of the raw material -limestone, clay, or mineral ore - and its alteration under heat. Compared with the simple quarried materials discussed in Section 4.2, the second stage in these manufactured materials means an increase in labour, some of it highly specialized, and a ready supply of fuel, the gathering of which is in itself a labour-intensive activity. For ropes and baskets the raw materials have to be harvested and processed before the items can be manufactured. It is assumed that the processing and manufacture of all these materials takes place away from the building site, with the exception of the slaking of lime.

5.1 GENERAL CONSIDERATIONS

On a small scale, the production of lime, brick, and ropes and baskets was a normal adjunct to an agricultural estate, often but not always to serve a specific building or agricultural need.[1] In some parts of the Roman world, but probably not in Italy where mining was banned, iron too could be produced in small quantities for local consumption. The large quantities demanded by the building industry of the city of Rome, however, presumably led to more intensive modes of production. The legionary lime kilns at Iversheim in Lower Germany, the brickworks of the Twentieth Legion at Holt Denbigshire and the Wealden ironworks in Britain, all throw some light on the organization

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[1] Cf. Cato, Agr., XXXVIII.4, where the implication is that lime-burning is a normal occupation if the stone is available. Lime production is also seen as a function of landed estates in Cod. Theod. 14.6.1 and 3, but the scale of production on each estate is not indicated.

of such large-scale production.[2] In each case, a number of kilns or furnaces were arranged in banks, presumably to facilitate loading and firing, and to minimise labour; in addition these were all permanent installations, with associated living quarters, close to supplies of both raw material and fuel.

The examination of remains from excavated lime and brick kiln sites has shown that a variety of material was used as fuel. The nature of the fuel varied with the locality, and it is a mistake to imagine that only logs and heartwood were employed. The Iversheim kilns burnt willow and poplar, while both lime and brick kilns in Britain used mainly oak, with some brushwood of field maple, hazel, hawthorn, beech, poplar and willow, and possibly cherry and gorse;[3] at Weekley, for example, none of the remains came from wood with an original diameter of over 40 mm. At Poetovio, in Upper Pannonia, it was mainly beech, with some oak, maple and fir.[4] Cato advises the planting of elm, poplar, willow and cypress and mentions the making of faggots and the collecting of firewood, sometimes of vine cuttings and tree prunings, including olive;[5] any of these could have been used to fire the lime kiln he describes. A comparison with the fuels used in later pre-industrial lime and brick kilns is instructive. Gorse was used with some coppiced wood in the Surrey lime kilns, while in Italy during the 16th and 17th centuries brushwood, oak trimmings and olive husks were burnt.[6] Traditional pottery and brick kilns still in operation in southern Italy and Sicily in the 1950's and '60's used all kinds of wood - branches, roots and trimmings - but also

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[2] Iversheim - Sölter 1970; Holt - Grimes 1930; Wealden - Cleere 1976.

[3] Sölter 1970: 19; Grimes 1930: 10; Jackson 1973: 136; Rahtz and Greenfield 1977: 46-8, 364.

[4] Subic 1968: 472.

[5] Cato, Agr., VI.3-4, XXXVII.5, LV, CXXX, CXLIV.3, CLI.1-2.

[6] Surrey - Robinson and Cooke 1962: 21-2; Florence - Goldthwaite 1980: 199; Rome - Scavizzi 1983: 30, 104.

straw, olive husks, shavings and sawdust.[7]

The volume of material required necessarily depends on the species of tree and type of material - brush or heartwood - and this will also to some extent affect the length of firing. The amount of labour required will in turn be influenced by the volume of material, although the accessibility of the various fuels will also be an important factor. Fortunately, all wood and brush in a dry state has the same calorific value of 4.5 Kcal/gm, which decreases with the increase in moisture content, being about 3.5 Kcal/gm in green timber.[8] Thus the weight of dry material required will remain constant, and it is possible to compare the different volumes of fuel used in different situations for firing kilns by converting the figures as far as possible into weights. In addition, fuel costs in the Prices Edict of Diocletian are expressed as loads of a given weight, so that it should be possible to establish the approximate cost of fuel.

The smelting of metal ores, however, requires the use of charcoal rather than wood to attain the necessary temperatures, and this involves yet another stage in production. Almost any type of wood can be made into charcoal, although the yields differ according to the weight and moisture content of the original timber, and the ancient sources recommend different varieties and ages of wood for different purposes.[9] In the Wealden ironworks oak and birch of 30 mm diameter was employed, probably from the natural forest, although Rackham has suggested that oak coppice was used instead.[10] The method of burning charcoal described by Theophrastus and Pliny (HN XVI.viii.23) seems to have been of the traditional heap type, still in use early this century in the

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[7] Hampe-Winter 1965: 196.

[8] Information kindly supplied by Dr H.C. Dawkins of St John's College, Oxford, formerly of the Oxford Forestry Institute.

[9] e.g. Theophr., Hist. Pl. V.ix.1-4.

[10] Cleere 1971: 207; Rackham 1980: 108-109.

Weald, so that some idea of the manpower requirements can be obtained from historical material.[11]

5.2 LIME

5.2.1 Sources

Identifying the sources of the stone burnt for lime to supply the city of Rome is not an easy task, since the material is only found as the lime component of mortar. Nevertheless, some reasonable hypotheses can be made based on the small amount of information in the literary sources considered in the light of the geology and topography of the area. According to Vitruvius, lime was made "de albo saxo aut silice" (de arch. II.5.1), the harder stone being better for construction, the more porous for plastering. Cato urged that the stone for the lime kiln should be "candidissimum" (Agr. XXXVIII.2). To the advice of Cato and Vitruvius, Pliny adds that lime made from "silex" is not recommended for either purpose, and that it is better if made from quarried stone than from that gathered from the banks of rivers (HN XXXVI.53). Faventinus (IX), writing probably in the 3rd century AD, gives a longer list of suitable materials: album saxum, travertine, dove-grey river stone, rubrum, and spongia, to which Palladius (I.10), a century or so later, adds marble.

In a general sense, I believe that all these can be identified as they apply to the area of Rome (Fig. 52). The album saxum must be the ordinary limestone of the Apennine chain, the lower outcroppings of which ring the Roman Campagna east of the Tiber, from the Monti Sabini to the Monti Lepini, and include the isolated peaks of the Monti Cornicolani and, west of the Tiber, Monte Soratte.[12] The "silex" for lime refers to the very hard types of limestone and marble, as

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[11] For traditional charcoal burning techniques in Britain see Armstrong 1978.

[12] Here I must disagree with Lugli (1957: 393-94), who equates the album saxum with marble and travertine, and the silex with limestone; there is no specific evidence that marble was burnt for lime until the 4th century (Palladius I, 10), and in any case it is quite clear from Vitruvius (de arch II.7.1) that "silex",

can be deduced from Vitruvius (de arch. II.7.2) where the building stone from Soratte and travertine are classed as medium (temperatae), while others (unspecified) are "durae, uti siliceae".[13] The limestone pebbles from the Tiber valley, and the travertine from below Tivoli need not detain us. Given that Faventinus is the first to mention both travertine and spongia in his list, the latter can probably be identified with the porous upper layer of travertine, which had to be cleared before the good building stone was reached and which supplied much of the lime for Rome during the 16 to 18th centuries.[14] Finally, the rubrum is perhaps the red limestone which forms the central layer of the Monti Cornicolani, which Lanciani believed were the source of some of the lime used at Rome.[15]

Given the first place given to "saxum album" in all the lists, the limestones from the mountains on the edge of the Campagna are the most likely source of the lime used in the Baths of Caracalla, although the lime for plaster and stucco work may have come from Tivoli. These areas had the added advantage of being naturally rich in fuel, either from olive plantations and vineyards on the lower slopes, or natural oak forest on the higher land. Closer identification can perhaps be made by considering the available transport routes. In the 4th century AD at least, some of Rome's lime - and, significantly, some of its firewood - came from Terracina.[16] Transport by sea was much cheaper than by land (see Section 1.6.3), and Terracina lies at the base of the Monti Ausoni, at the one point where the limestone mountains come down to the sea. Likewise, lime from the Sabina and Monte Soratte had a relatively short trip overland before reaching the major waterway of the

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not "saxum album", is the harder stone.

[13] Cf. Pliny "Luniensem silicem" for Carrara marble at HN XXXVI.29.135

[14] Scavizzi 1983: 29.

[15] Lanciani 1897: 5.

[16] Symmachus Relat. 40, where the lime is used for repairing the city walls, and cf. Cod. Theod. 14.6.3, where the lime is assigned to the Pharos and the port "according to ancient usage".

Tiber,[17] while all the products of the travertine quarries used the Aniene, as would have any limestone from the Monti Tiburtini. There is an exonerator calcararius (CIL VI 9384) recorded at Rome, and his collegium may have been involved in unloading lime from river boats.

In contrast, lime from the Monti Cornicolani, Prenestini, and the northern part of the Monti Lepini, would have had to travel overland much if not all of the way to Rome.[18] These cannot be entirely excluded from consideration since the Theodosian Code (14.6.1, 3) seems to assume that transport of lime is by a standard ox-cart "load", which suggests that land transport of lime was common if not usual at that period.

5.2.2 Kiln types and sizes

From Cato's description of a lime kiln (Agr. XXXVIII), and a number of excavated Roman kilns, a clear picture of the method of lime burning emerges. The material has recently been studied by Dix (1982), so that only a summary is necessary here. All the kilns are periodic rather than continuous firing, i.e. the kiln is loaded, fired, cooled and unloaded, after which the cycle starts again. In the permanent structures found at Iversheim, a projection separates the kiln into two, the limestone being built up immediately above the ledge as a vault which supports the rest of the load, with the fire in the lower part (Fig. 53b). This separates the fuel from the limestone, ensuring evenly burnt and clean lime. The kilns are often built into the side of a hill, or in a pit, so that they can be loaded and unloaded from the top, but fired from the bottom, again ensuring the minimum of contamination of the clean lime.

The size of kilns varied. Cato's kiln, ten feet wide in diameter at the base tapering to three feet

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[17] See Quilici 1986: 211 with references for the possibility of a lime industry in the Sabina.

[18] The possible lime industry identified by Quilici at Artena (1982: 124-25, 149-50, 168, 181) is, I believe, more likely to have served the nearby Alban hills than the city of Rome itself.

at the top, and twenty feet high, would have had a capacity of about 27 m^3.[19] At Iversheim (Fig. 53a) there were six kilns each with a capacity of about 15 m^3, while the smaller kilns at Tipasa were about the same size;[20] the large kiln at Tipasa, however, would have produced 65 m^3 of lime, and was thus the equivalent of the original four kilns at Iversheim. Larger kilns of the Roman type are possible, such as the lime kilns of 16th- to 18th-century Italy capable of producing up to 180 m^3 of lime, at each firing,[21] but there is no evidence that such large kilns were in fact used in the Roman period. The use of banks of smaller paired kilns, with a staggered operative cycle of filling, firing and unloading, as suggested by Sölter for the Iversheim kilns, may have seemed more efficient, and would certainly have been more flexible, than single large kilns. In calculating the manpower requirements, I shall examine two possible cases, a single large kiln of 60 m^3, and four smaller kilns operating in pairs with the same total capacity.

5.2.3 Production

The Apennine limestones although hard are strongly bedded and easily fractured, so that quarrying and breaking into pieces suitable for the kiln could be done in the same operation. Nineteenth-century labour constants suggest that a quarryman can turn out 5 to 8 tons of limestone each 10-hour day, or 2½ to 3½ m^3/12-hour day.[22] Taking an average to include the breaking gives a figure of 0.33 days/m^3. It is assumed that the stone is quarried close to the kilns, so that material can be carried in baskets from quarry face to the kilns and loaded directly. The time taken for filling baskets with rubble has already been calculated for tufa (Section 4.1.2) at 0.065 days/m^3, and each trip of, say, 100 m takes 0.014 day. Limestone weighs an average of 2,560 kg/m^3, so

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[19] This is assuming that the kiln is roughly circular and that the taper reduces the volume by one third. Adam (1984: 73-4) obtains a figure of about 50 m^3, but this is assuming a rectangular kiln with vertical sides.

[20] Sölter 1970: 14; Baradez 1957: 293.

[21] See Scavizzi 1983: 29; Goldthwaite 1980: 183-84. 1 moggia of lime is approx. 8 bushels or 0.29 m^3.

[22] Rea 1902: 88.

that 51 trips of 50 kg will be required. Since limestone loses about 10% of its bulk when converted to lime, 66 m^3 of stone are need to produce the 60 m^3 of lime from our imagined kilns. This 66 m^3 of solid limestone requires 22 man-days quarrying, 4.3 man-days filling, and 47 man-days carrying, a total of 73 man-days.

The manpower requirements for the firing cycle are more difficult to determine. The time taken for filling and emptying should be roughly proportional to the size of the kiln, with a single large kiln being somewhat faster than a number of smaller ones of equivalent volume. A number of sources give a figure of 1½ to 2 days for filling a kiln of 12 to 15 m^3 capacity; two men would be needed, one inside the kiln setting the stones and another selecting and handing down the pieces, giving a total of 3 to 4 man-days.[23] Thus it might take 12 man-days to fill a 60 m^3 kiln, which could be divided between 2 men working 6 days, or, given the greater working space within the kiln, 4 men working 3 days. I assume that unloading takes the same time as filling.

Recorded firing times range from 1 to 7 days,[24] and do not seem to be necessarily related directly to the size of the kiln; other factors are the type of stone and the size of the pieces, the design, location, and efficiency of the kilns, and the type of fuel used. The experimental firing at Iversheim took 6 days, but, given the inexperience of both the builders and the firemen, this should perhaps be taken as an upper limit for a small kiln. On the other hand, firings lasting 3 to 4 days seem to be common, and the higher of these two values would seem a sensible figure to adopt for the smaller kilns, with perhaps 5 days for the large kiln. In all cases the kilns must be operated

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[23] Iversheim - 3 days for filling and unloading (Sölter 1970: 30); Tipasa - 2 days filling, 2 days unloading (Baradez 1957: 293); Surrey (18-19th century) - more than 1 day filling for 1 man and 1 boy (Robinson/Cooke 1962: 24-5).

[24] Iversheim - 6 days for 15 m^3; Tipasa - 3 days, 12-15 m^3 and/or 65 m^3; Florence (16th century) - 6 days, 26 m^3 + 10,000 bricks (Goldthwaite 1980: 197-8); Rome (16-18th century) - 3-4 days, 65-180 m^3 (Scavizzi 1983: 29); Surrey (18-19th century) - 1-1.5 days, 12 m^3; England (19th century) - 3 days, no size given (Burnell 1850: 36-7); traditional contemporary kilns - 3-4 days, 25-30 m^3 and 7 days, 120 m^3 (Adam 1984: 72-3).

continuously, and a careful eye kept on them to ensure correct burning; the fireman was a skilled worker. At least two men must have been on hand at all times, one to watch the kiln and feed the fire, the other to ensure a continual supply of fuel, and it is assumed that there were two twelve-hour shifts in each full day. The large kiln may have required an extra man on each shift. Cooling times are also variable, but should certainly be longer for the larger kilns. Fortunately this figure does not affect the manpower requirements, although it is useful when comparing the operation of multiple small kilns with a single equivalent large one. For the sake of argument I have assumed that it takes 3 days for the small kilns to cool, and 5 days for the large.[25]

We are now in a position to determine the firing cycle and calculate the man-power requirements needed to produce 60 m^3 of lime using two different systems. If the four small kilns are operated in two pairs, with two men firing each pair of kilns without extra assistance, and the second set of kilns being fired immediately after the first set, it would be possible for two pair of firemen working alternate shifts to complete the two sets of firings in 15 days with 64 man-days labour. With the addition of an extra day, this would create an indefinitely repeatable cycle. By comparison, the single large kiln will require 54 man-days over a cycle of 16 to 19 days. There thus seems to be little difference in either time taken or man-days required by the two systems, and an average figure can be adopted for all lime production. Thus each cubic metre of lime requires roughly 1.2 man-days quarrying, and between 0.9 and 1.1 man-days firing. For the purposes of later calculations I shall assume a figure of 2.2 man-days total.

This figure does not, of course, include a component for fuel. The experimental firing at Iversheim used 60 m^3 of beech to produce 15 m^3 of lime. If the dry weight of beech is taken as 0.82 tonnes/m^3, then 3.3 tonnes are required to produce each cubic metre of lime. Given the

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[25] Cf. 4 days suggested for Tipasa, 6 inferred by Dix for Iversheim (1982: 336), but only 1 day given by Burnell.

experimental nature of the firing, this is likely to represent a high value. Burnell in the 19th century gives 1.7 m^3 of oak or 3.3 m^3 of pine as needed for each cubic metre of lime;[26] assuming that this is partially dry but not seasoned wood, and given the range of densities cited for these two materials, Burnell's figures suggest that between 1.6 and 2.7 tonnes of wood are needed for each cubic metre of lime, which is reasonably consistent with 3.3 tonnes used in the experimental firing. I shall thus assume an average value of 2.5 tonnes/m^3.

5.2.4 Lime slaking

The product of the operations discussed above was of course quicklime, calcium oxide (CaO), whereas the lime used in mortar is slaked (or hydrated) lime, calcium hydroxide ($CaO(OH)_2$). The ancient preference for white limestone - i.e. relatively free from the impurities which give other stones their colour - as the basic raw material meant that the resultant lime was predominantly non-hydraulic in nature, as has been confirmed by recent analyses.[27] Slaked lime is produced by the addition of water to quicklime, resulting in a highly exothermic reaction. Non-hydraulic limes absorb two and a half to three times their own weight of water, and increase greatly in bulk during the process. Documented figures for volumetric increase vary widely, from as little as 20% for chalk lime in 18th-century London, to 40 or 70% in 17- and 18th-century Rome, and over 100% in later manuals.[28] The amount of increase depends on the purity of the lime, the thoroughness of the slaking, and the stiffness of the resultant paste. In order to ensure that all the quicklime is thoroughly slaked, and that a uniform lime putty results, the mixture needs to be worked over several times at intervals with a hoe to break up any lumps and bring all the quicklime into contact with the water.

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[26] Burnell 1850: 36-37.

[27] Frizot 1975: 280-83.

[28] London - Langley 1749: 30; Rome - Scavizzi 1983: 30. Building Trades Handbook 1925: 150 gives an increase of 125%.

The need for thorough slaking of lime over a long period was well-known to the Romans, at least where the lime was to be used for plaster.[29] The amount of time that lime was normally left before use is uncertain. According to Pliny (HN XXXVI, lv), old building regulations forbade the use of slaked lime less than three years old, but the context strongly suggests that this was no longer the case in his day. In 17th-century Rome the minimum time permissable for slaking was only 15 days, while modern regulations suggest 20 to 90 days depending on the intended use.[30] Slaked lime forms a thin skin of calcium carbonate on contact with air which prevents the rest of the material deteriorating, and for greater protection the limepit could be covered with sand or earth.[31] Recent analyses show that part of the success of Roman mortars is due to the use of well-slaked and matured lime,[32] so that we should assume a longer rather than a shorter period, say at least 90 days, for this stage. This also suggests that the volumetric increase should be higher rather than lower, and I shall adopt a figure of 60% as a reasonable estimate.

The lime could be slaked and stored either at the production site, or at the building site. There are arguments for and against both options, since quicklime is lighter and less bulky than slaked lime, and thus cheaper to transport, but is also caustic and prone to air-slaking in humid climates. A fragment of Theophrastus (de lapid., frag. 2, 49, 69) demonstrates the transport by sea of quicklime in the 3rd and 4th centuries BC, and also some of the dangers attached to it, but there is no specific evidence that this still occurred in the Roman period. Dix suggests that lime was slaked immediately after production and stored, but also notes scenes of lime slaking in Roman

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29 Vitruvius, de arch., VII, ii, 1 and cf. Faventinus 20.

30 Scavizzi 1983: 29-30.

31 Cf. Adam 1984: 76, note 107.

32 Malinowski et al. 1982; Biernacka-Lubanska 1970: 111.

depictions of building operations and the presence of mixing troughs and pits at ancient sites.[33] These may, however, be related more to the mixing of mortar than to lime slaking. On the other hand, it was just as common in later periods to sell and transport quicklime as it was slaked lime, the slaked lime being obviously the more expensive.[34]

The deciding factors may well have been the degree of maturation of the lime required, the size and duration of the project, and the amount of space available on site. Conditions at the Baths of Caracalla were such that, despite the large quantities of lime required, space for the installation of permanent lime slaking pits would have been available, probably at the rear of the terrace platform. If the pits were created at the very start of the building programme, the first loads of quick lime would have had time to mature while the construction terraces were being levelled and the foundation trenches dug. Since this would probably also have been the cheaper option, I feel that it is safe to assume that the slaking was carried out on site.

5.3 BRICK

Subsumed under the general heading of brick I shall, in fact, be discussing a number of items. Firstly, there are the various sizes of flat bricks, used for facing concrete walls, bonding courses, arches and barrel vaults, lining vaults, and as the floors and pilae of the hypocausts. Three different sizes were employed - bipedales, sesquipedales, and bessales - and there are two distinct ranges of thickness.[35] In addition, rectangular tubuli for heated walls were required.

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[33] Dix 1982: 338-9. Adam 1984: 75-76 thinks the quicklime easier to transport, but suggests that shortage of space on the building site may have led some Roman builders to buy their lime already slaked.

[34] By 10 to 25% in 16th- and 17th-century Rome, see Scavizzi 1983: 29.

[35] The wide variety in the facing makes it difficult to be certain about the type of brick used. There are five possible ways the facing bricks could have been formed from these three types of brick as shown in Fig. 54. The fact that the pieces are trapezoidal rather than triangular in shape would normally mean that the face dimension would be rather less than expected, although for pieces cut from the larger bricks this would not necessarily be the case; it would, however, be the most economical way of using the brick to avoid numerous small fragments. The length of the bricks varies widely in the range 50-365mm, with peaks at 280-295 and

5.3.1 Sources

Clay is abundant in the subsoil of Rome, as tertiary alluvial deposits, often alternating with sands and gravels, which underlie the younger volcanic formations of tufa and pozzolanas (Fig. 55). During the Roman period, the clays in the area between the Janiculum and the Vatican hills on the west bank of the Tiber were certainly worked, and continued to be so to the end of the 19th century.[36] Other suburban areas seem also to have supplied brickworks, e.g. the Esquiline, Caelian, and at the start of the Via Appia.[37] The clay was also accessible in the Colli di Aquatraversa along the Via Cassia. The mixture of calcareous clay and pozzolana of the Tiber alluvium and its tributaries also made good bricks, and possible sites for various figlinae such as the Salarese along the Via Salaria and extending as far north as Orte and the river Nera have been identified (Fig. 55).[38]

Many of the brickfields supplying Rome during the empire appear to have been in this latter area, where fuel was more readily available and the river could be used to transport the finished products.[39] This is reflected in the distribution of urban brickstamps found outside of Rome, its immediate suburbs, and Ostia (Fig. 55). These fall into three main groups: sites easily reached by sea from Ostia (Antium, Centumcellae, Pyrgi); the Alban Hills (Tusculum, Albano, Velitrae, etc) and the Ager Tiburtinus (mainly Hadrian's Villa); the western Sabina (Bocchignano, Cures

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310 mm long for the thicker bricks and 220-230, 260-270, and 280-310 mm long for the thinner ones. Thus the thinner bricks are probably a combination of sesquipedales cut mainly into eighths, with a smaller proportion of sixteenths, and either halved bessales or bipedales cut into eighteenths, with possibly some bipedales cut in sixteenths, while the thicker bricks seem to be predominantly bipedales in sixteenths or sesquipedales in eighths.

[36] For the topography of the brickfields see Steinby 1978: cols 1507-9. Lanciani (1897: 41-2) speaks of the clay-pits still being in operation in his day. For finds of kilns and kiln waste in the region of Rome see Petracca and Vigna 1985.

[37] Petracca and Vigna 1985: nos 1, 2, 12; Scrinari 1983.

[38] Cf. Setälä 1977: 19-20; Steinby 1978: cols 1507-1509.

[39] Steinby 1978: col. 1509, based on the work of Huotari.

Sabina, Poggio Mirteto), as far as Otriculum and Narni and including a number of sites on the western bank of the Tiber (Nazzano, Bomarzo).[40] Compared with the almost total absence of urban brickstamps in any other area north of Rome, this latter group is highly significant. In addition, the recent Farfa survey has revealed an increase in the number of villas along the Tiber and the River Farfa in the late first and second centuries, reaching a density in some places of two per square kilometre - a density seemingly in excess of the productive capacity of the area.[41] While these may be explained simply as luxury retreats from Rome, they could also, I would argue, reflect an increasing exploitation of the clay-pits in the valleys below to supply the expanding market for brick products in Rome.

There are strong grounds for arguing that the bricks for the Baths of Caracalla did indeed come from the Sabina. More than 80% of brickstamps which show Caracalla as dominus can be connected with the great tegularium, still operational in the 6th century AD, of the Portus Licini[42] (see Appendix 3). Although the precise site and nature of this are unknown, it is possible to make some deductions about them. On the one hand, the Portus Licini was situated in the praedia Liciniana, where were also the figlinae Veteres, and some bricks are marked PortLic without the name of the figlinae. It seems also to have functioned as a storage and redistribution place for bricks from various other figlinae. This suggests firstly that it was close to Rome, or at least closer to Rome than the other figlinae that it served, and secondly, since brick is both heavy and bulky to transport, and as is indeed suggested by its very name, that it was beside a waterway, obviously the Tiber.[43]

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[40] Cf. Steinby 1981: 238-39.

[41] Moreland 1987: 413.

[42] Cf. Cassiod., Var. I, 25.

[43] Cf. Steinby 1978: col. 1511-1512. Bloch (1959: 200-201) argues convincingly from Ulpian that "portus" in the context of Cassiod. Var. I.26, cited above, means a place where goods are brought together and then redistributed, but this is surely is a secondary meaning, and certainly does not preclude such a place

If the site of the figlinae Vocconianae, which had associations with other of the figlinae served by the Portus Licini, is indeed to be identified in the area of Fidenae and Ficula along the Tiber north of Rome,[44] this perhaps represents the furthest limit for the Portus Licini. Huotari's study of the location of the imperial figlinae, however, used medieval place names recorded in the Farfa register to identify possible sites in the Sabina. This suggests that the figlinae Vocconianae are rather to be associated with the fundus Buccinianus, located close to modern Bocchignano on the north side of the River Farfa just below Poggio Mirteto. Furthermore, according to the Farfa Register Ponticlum, which should be the site of the figlinae Ponticlanae, was situated above the River Farfa, in the vicinity of the castello of Tribucum, the whole area being called the fundus caesarianus.[45] Tribucum has now been identified with a site on the south side of the River Farfa, about 4 km from its confluence with the Tiber. There is reference to a medieval furnace on this site, and the site itself produced large quantities of brick and tile, unfortunately without stamps.[46] If this identification is accepted, then, given the close connections in the later second and early third centuries between the figlinae Ponticlanae and those of the Domitianae maiores, Bucconianae, Oceanae, and Genianae (usually seen in the use of the same officinatores), all of which were on imperial property, it is likely that these were in the same general area along the River Farfa, extending as far perhaps as the Tiber itself.

5.3.2 Nature of production centres

Our understanding of the organisation of the Roman brick industry is greatly hampered by the

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being originally a harbour.

[44] Steinby 1974-5: 29.

[45] Giorgi/Balzani 1879-1914: II.29 (AD 746); III.196 (AD 1013); IV.22 (AD 1012)

[46] Only interim reports of the field survey carried out by Dr J. Moreland of the University of Sheffield have appeared so far (Moreland 1986; 1987). Documentary evidence for land holdings of the Abbey has been studied by Sig. Tersilio Leggio, Honourary Inspector for the Sabina. I am grateful to both of these for information and discussion on this point.

absence of any archaeological remains which can be associated with a known officina which served Rome. There is little doubt that originally the production of tile, and later brick, by dependents of the landowner could be part of the normal functioning of an estate on which suitable clays and fuel supplies existed, very much, as Cato makes clear, as happened with the production of lime.[47] The demands of the city of Rome for tiles and other brick products (e.g. in baths), and in particular the growing use of brick as a facing for concrete in the first century AD, seems to have led to a more complex system where the landowners let contracts for the working of the clay-pits to another individual, the officinator, who provided the requisite workforce, while the landowners remained the owners of the finished product.[48] The existence of several officinatores in any given clay district (figlinae), which might extend over the land of more than one owner, suggests a number of work-units, each with their own kiln and associated area for moulding and drying the bricks, but perhaps with the actual clay pits in common. This type of organisation ("clustered industries") has been identified in Roman Britain by Darvill and McWhirr at Minety (Wiltshire), where possibly 10 kilns and associated clay pits are spread over a very small area.[49]

For Rome, Steinby has emphasised the role of the landowner, rather than the officinator, as the prime-mover in the brick industry, and the evidence for some kind of central control in the uniformity of both the use and the formula of brickstamps, and the omission of the name of the officinator in the Severan period.[50] Her theory is strongly supported by the case of the Baths of Caracalla, where, as we have seen, over 90% of the extant brickstamps from the original building

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[47] Cf. Varro, Rust., I.2.22-3. For a general discussion of estate production see Peacock 1982: 128-35. A possible example of estate production, serving a fairly small local area near Rome (but not apparently extending to it), is that of Q. Sulpicius Sabinus near Eretum (Ogilvie 1965).

[48] This interpretation depends on the work of Setälä 1975 and Helen 1975; for an analysis and summary see the review by Purcell in JRS 1981: 214-15, and for a slightly different interpretation, Steinby 1982.

[49] Darvill/McWhirr 1984: 251-54.

[50] Steinby 1982: 231-34.

have the emperor himself as dominus, and at least 80% of these probably passed through the Portus Licini. Examples of military or municipal brickworks outside of Rome suggest a physical organisation consisting of banks of kilns associated with large workshops/drying sheds, allowing for a more efficient cycle of firing, and a more efficient use of skilled workmen as already postulated in the case of lime production.[51] Thus we might imagine that while the officinae in a given figlinae serving Rome were self-contained and scattered over the district, each officina operated several kilns and had substantial areas for making and drying the products. For the purposes of the man-power analysis, I shall assume that each officina has two kilns, fired as a pair like the lime kilns at Iversheim.[52]

5.3.3 Kiln types and sizes

We have no literary description of a brick kiln to compare with that of Cato's lime kiln, but the archaeological evidence is richer. Although relatively few examples of the imperial period have been excavated in Italy, there is sufficient evidence from the rest of the western provinces (e.g. at Holt, Denbighshire, Fig. 56) to confirm that these are representational.[53] Italian brick kilns are of the updraught type, usually square or rectangular in plan, with a lower combustion chamber separated from the main firing chamber by a perforated floor; the arched supports for the floor, necessary because of the great weight of the unfired bricks, help distinguish brick from pottery kilns. The kilns are often built into the slope of a hill or in pits, as was noted also for the lime kilns, with the stoke holes at the lower level. Although clamp kilns, where the fuel is mixed in

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[51] Darvill/McWhirr 1984: 247-49. The military material is conveniently summarised by Peacock 1982: 136-42, and cf. the bank of kilns in what is believed to be a municipal brick-works at Poetovio (Subic 1968).

[52] Cf. the two kilns side by side in the recent finds at Tor di Quinto (Petracca and Vigna 1985: 134).

[53] For the Italian material, see Cuomo di Caprio 1971-1972 and 1978-1979, and for the few kilns near Rome the brief notes in Petracca and Vigna 1985. A gazetteer of British sites with bibliography is given in McWhirr 1979b; there is a typology for German kilns in Berger 1969, and more recent references in Tomasevic-Buck 1982 (Augst-Kaiseraugst) and Ljamic-Valovic 1986 (Köln-Feldkassel). For kilns in Gaul see Duhamel 1973.

with the bricks, and horizontal through-draught kilns are known from Britain, these are totally absent from the Italian material and it is safe to assume that the kilns supplying Rome were of the updraught type described above.

The sizes of kilns believed to be for brick or tile, rather than for pottery, range from a little less than 2 m square internally to an exceptional example in France which is reported to be 8 m square, although no details are given. The most common size-range seems to be 3 to 5 m internally for the longest side, with the largest examples at Holt, Holdeurn and Köln being closer to 6 m.[54] Unfortunately, there is little evidence for the heights - and thus the capacity - of these kilns, as the upper chambers rarely survive. The largest kiln at Oltina survives to a height of 1.73 m, while the firing chamber of the Lateran kiln appears from the published section to have been at least 3 m high. Kilns in 19th-century England and Holland of similar type and cross-sectional area to the Roman examples had heights of 3 to 3½ m,[55] and this could perhaps be taken as the average height of the Roman kilns.

5.3.4 Production

There are no useful literary sources and very little physical evidence to illustrate the stages of brick production,[56] so that we need to turn to traditional brick-making procedures in more recent times for a general picture of Roman practice, which can in part be checked against the archaeological

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[54] e.g. Lateran - 4.8 x 4.8 m (Scrinari 1983); Serle, Lombardia - 3.5 x 3.4 m (Cuomo di Caprio 1971-2: 436-8); Augst - 4.5 x 4.5 m, 3.4 x 2.96 m (Tomasevic-Buck 1982); Holdeurn - oval kilns 6 x 5 m, 5.8 x 5 m, 6.5 x 6.5 m (Holwerda/Braat 1946); Holt - 5.3 x 4.4 m, 5.3 x 4.1 m, 4.2 x 4.2 m, 5.4 x 5.4 m (Grimes 1930: Fig.15, 19); Köln - 4.6 x 2.8 m, 4.6 x 2.4 m, 5.9 x 5.9 m (Ljamic-Valovic 1986); Oltina: 4.3 x 3.7 m, 3.3 x 3.3 m, 3.7 x 4 m (Irimia 1968); Poetovio - 3.1 x 3 m, 2.3 x 2.5 m (Subic 1968).

[55] Dobson 1850: 50-51, 79.

[56] Vitr., de arch. II.3., refers of course to unbaked, not fired, bricks.

record.[57] As well as identifying the stages of production I shall, as before, try to estimate the manpower requirements at each stage.

Brick-making in Italy has been traditionally a seasonal occupation. The clay is dug in the late summer, autumn or winter, and left to weather until spring, the action of frost and rain serving to break down the clay. The main season for the actual production is from April to September, when, in southern Italy at least, little or no rain is expected.[58] That this was also the practice in the ancient world is suggested by the few graffiti on bricks giving dates mainly between June and October, and is reflected in the footprints of very young sheep and goats found on some tiles.[59]

First the clay had to be dug. The clay pits were most probably open-cast, and situated close to the production yards. From Hurst's constants, a labourer should take 0.13 days/m^3 to dig the clay, 0.063 days/m^3 to fill into baskets, and roughly 1.2 days to carry one cubic metre, in 38 basket loads, over 250 m, the average distance between the clay pits and the work area at Holt.[60] After weathering, the clay had to be further tempered to produce an homogeneous paste, either by treading or hoeing, the larger impurities being removed by hand, and any necessary additions made. The inclusion of a certain amount of stable ballast, usually sharp sand but evidently pozzolana or other fine volcanic material around Rome, was necessary to prevent excess shrinkage and warping of the brick. Chabat records that among 19th-century Walloon brickmakers, two men

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[57] As has been done by McWhirr and Viner (1978: 360-63) and Peacock 1982. The discussion which follows owes much to these and to the treatise by Dobson (1850) on current brick-making practices in Britain and the Low Countries.

[58] e.g Chianti, 16th century (Carnasciali/Roncaglia 1986: 47-48, and p.20, note 45, on the problem caused by unexpected wet weather at the end of June); Rome, 16th to 18th centuries (Scavizzi 1983: 31-32 and esp. note 1); Venice, 14th century (Goldthwaite 1980: 187-88). Goldthwaite also notes that Florence was unusual in having all-year firing.

[59] The dated stamps are collected by Spitzlberger 1968: 102-103, and see also Tomlin 1979: 233. For the animal prints see Cram and Fulford 1979: 206-208.

[60] Hurst 1865: 212-13, and using an average weight/unit volume for clay of 1900 kg/m^3, based on the Table in Ventriglia 1971: 196.

could prepare 2 m^3 of clay in 1½ hours,[61] but this was for small, deep bricks of coarse texture. Since the larger Severan bricks are on the whole noted for their uniformity of texture, and a fine paste must have been needed anyhow for the large, relatively thin, sesquipedales and bipedales, I shall assume that the tempering for these took twice this time, i.e. 0.25 man-days for each cubic metre of clay, although the figure may have been higher.

The prepared clay then had to be moulded into shape. The basic step must have been to make a flat slab within a wetted wooden frame, which was then shaped round a form to make imbrices and tubuli, or cut to shape the tegulae. Recent parallels suggest that this was done at a bench, sanded to prevent the clay from sticking, within a work shed, and a number of structures which could have been used in this way have been found, notably at Itchingfield and on the Lateran site in Rome.[62] The bricks had then to be carried, still in their frames, to the drying floor, where the frame or form was removed; alternatively, the simpler bricks, particularly the bessales, could have be formed directly onto the drying floors, as still happens in modern Tunisia,[63] thus removing a step in the process.

Graffiti from bricks from many areas of the Roman world suggest that the daily output was about 220 bricks/day, and this figure has been widely accepted.[64] This appears, however, to be a surprisingly low figure compared with many recorded in more recent times, where an output of

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[61] Chabat 1886: 213.

[62] Itchingfield - Green 1979, with earlier bibl.; Lateran, Rome - Scrinari 1983. Cf. comments in Broise and Scheid 1987: 131-145 on bessales. For several 19th century descriptions of brick-moulding see Dobson 1850 and Chabat 1886.

[63] See the illustration in Peacock 1982: 44.

[64] Peacock 1982: 143; Spitzlberger 1968: 86-87.

5,000 to 8,000 per day is not uncommon,[65] these being the figures for the moulder alone, and do not include the assistants who supply him with clay, prepare the "clot" for the moulder to throw into the mould, and remove the moulded brick from the table. A more normal range is perhaps 500 to 2,000/day, depending on the number of helpers, two at the most compared with the 6 or 7 employed in the first case. At Ashburnham in the 1840's, a moulder working alone could produce 500 to 600 bricks/day, or 1,000 with an assistant, while in modern Italy 800 to 1,000 curved roof tiles, identical to the Roman imbrex could be produced by a moulder and assistant.[66] Thus a figure of 500 to 600 bricks or 400 to 500 imbrices per man-day could be taken as a reasonable figure, which is still two to three times the assumed Roman output.

The problem can, I believe, be resolved by considering more carefully the type of brick involved. The later figures from north-western europe are all for house-bricks, which are on average 0.23 x 0.11 x 0.076 m, with a total volume of roughly 0.002 m^3. While reports on the Roman graffiti do not always give the size of the brick, the group from Siscia (Pannonia Superior) are all from large, thick "tegulae", although it is not clear if this means tiles or bricks.[67] A bipedalis 0.035 m thick has a volume of roughly 0.01 m^3, or five times that of a house-brick; an average Roman tegula has a volume of about 0.003 m^3, with larger ones up to 0.009 m^3 or very close to the volume of a bipedalis. If, then, we look not at the number of items produced but at the volume of clay worked, the correlation is much closer: 1-1.2 m^3/man-day for house bricks, 0.7-2.2 m^3 for the large Roman bricks or tiles. Naturally, it would have taken less time to make one bipedalis than five house-bricks, since the carrying time would have been less.

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[65] e.g. 6,000/day in Holland (cited by Heres 1983: 30); 7-8,000/day in Holland, Belgium, Britain, northern France, but only 2-3,000 for Bourgogne (Chabat 1886: 218); 5,000/day in London (Dobson 1850 (II): 24).

[66] Ashburnham - Peacock 1982: 47; Italy - Hampe/Winter 1965: 49-50, 119. Cf also 700/day in the Oxfordshire brickworks cited by Bond et al. 1980: 25.

[67] CIL III 11378-11386.

To simplify the subsequent calculations, I shall thus assume that 1,100/man-day were needed for bessales (at half the volume of house-bricks, but assuming a double mould[68]) and 220/man-day for both bipedales. Allowing for 10% shrinkage in the final product, the volume of clay required for each man/day of moulding is 1.2 m^3 for bessales and 2.4 m^3 for bipedales. For sesquipedales, which each have a volume of 0.0058 m^3, a figure of, say, 400/man-day using 2.4 m^3 of clay can be assumed. The tubuli are more difficult. The size varies enormously, but an average example might measure 0.35 x 0.15 x 0.09 m, formed from a slab 0.35 x 0.48 m, and have walls 0.015 m thick, giving a clay volume of 0.0025 m^3. The slab has to be wrapped around a block, sealed, removed from the block, and any vents cut in the side;[69] 300/man-day might be a suitable figure, needing 0.8 m^3 of raw clay.

The wet bricks were laid out in a single layer until they became dry enough to handle, either in the open or under a rough shed; later practice suggests that the they were set on a layer of fine sand, and dusted with more sand to prevent the surface from drying too quickly and cracking. The animal footprints mentioned must have been made during this initial drying, and the discovery at Llafranc in Spain of an area of unbaked tegulae laid out in neat rows has provided unexpected confirmation of this practice.[70] When the bricks were leather-hard, which might take 1 to 6 days depending on the weather, they would then have been stacked in low heaps to continue drying, perhaps for as long as 3 to 4 weeks. This is probably the context of a graffito from Hesse, cited by Peacock, which states that there were "in the third layer large tiles of the number of the 22nd legion";[71] the leather-hard state is, of course, ideal for taking incised marks. We can assume that

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[68] Peacock 1982: Pl. 15 shows such a mould in use in Tunisia.

[69] See Morgan 1979 for the process of making tubuli. He has informed me that an unskilled student working alone can make a tubulus in 5-10 minutes.

[70] Nolla et al. 1982: 152-60. It is unfortunate that the limited excavation made it impossible to determine the size of the tile area and whether it was covered or not.

[71] Peacock 1982: 143, "stratura tertia laterculi capitulares num leg XXII".

the stacks were close to the drying area and the bricks had to be moved no more than 25 m, requiring 0.0035 man-days/trip. At this stage the bricks would still be fairly fragile, so that we might expect no more than one bipedalis, two sesquipedales, four tubuli, or eight bessales in a single trip. Alternatively, the bricks were stacked on hods carried by two or more men; this involves extra labour loading and unloading, so that the saving would probably not be sufficient to affect the final figures in any significant degree. The same kind of value should also apply in moving the bricks from the stacks to the kilns, say 0.0045 man-days/trip, allowing slightly longer for the filling of the kiln.

Figures for firing times and fuel consumption are available from a wide variety of sources, from experimental firings of Romano-British kilns to traditional tile producers in southern Italy in the 1960's. It is rare, however, to be given all three required pieces of data - capacity of the kiln and/or number and size of bricks, firing time, and fuel details - in a useable form. Where figures from 19th-century England relate to coal burning rather than wood, it is possible to calculate the equivalent weight of wood from the respective calorific values.[72] Where the volume of fuel is given but not the weight, the type of fuel must also be indicated to be useful. A number of factors which affect firing times must also be taken into account: the size and thickness of the material to be fired, the dryness of bricks and fuel, the density of material in the kiln, the type and volume of the fuel, and the speed at which it is added.[73] As was the case for lime burning, the resultant figures for firing time and fuel requirements are averaging estimates only, but ought to give at least the correct order of magnitude.

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[72] Wood averages 19 MJ/kg @ 0.9 tonne/m^3, bituminous coal averages 31-35 MJ/kg @ 1.14-1.4 tonnes/m^3. Thus for the same calorific content the weight of wood has to be 1.63-1.84 times the weight of coal. An average value of 1.75 is used in the following calculations.

[73] Cf. Cuomo di Caprio 1971-1972: 403-404.

Table 8 gives firing times and fuel consumption derived from the most complete figures available.[74]

Table 8: Brick-kiln Firings

Place	Date	No.bricks or size of kiln	■ no. bessales	Firing time hours	Wood or wood ■ tonnes	Wood/ 1000 bessales
Stafford	1800s	8,000	16,000	36-38	6.2-7.1	0.39-0.44
Suffolk	1800s	50,000	100,000	60	44.5	0.45
Suffolk	1800s	35,000	70,000	40	21.8	0.31
Barton*	1960s	0.79cu.m	470	?	0.2	0.43
Italy	1960s	5.78cu.m	3,500	12	1-6**	0.29-1.7

* experimental firing in Romano-British circular kiln
** 200 bundles of twigs were used. At the most these would be about 1 m long and 0.33 m in diameter, weighing 30 kg each, at least about 0.4 m long and 0.2 m in diameter, weighing roughly 5 kg, comparable to the bundles of twigs listed in the Prices Edict.

While the firing time seems to be roughly proportional to the size of the kiln and the quantity of material fired, the weight of fuel required seems remarkable consistent. The percentage of water in brush and twigs is much higher than that in cut wood, so we should expect a rather higher figure where faggots are used rather than heartwood. If the fuel is assumed to be at least partly wood, a figure of 0.45 tonnes/1000 bessales (or 100 bipedales) would appear reasonable. The firing time for our standard kiln holding 54,000 bessales can be taken as about 40 hours, a figure confirmed by data from other similar sized kilns.[75] For ease of calculation, a firing time of 48 hours will be assumed.

Firing the kilns requires perhaps four men on duty at all times, two watching the kilns and feeding the fires, the others maintaining the supply of fuel. Altogether, each firing requires 16 man-days.

[74] Stafford, Suffolk - Dobson 1850: 95, 98. Barton-on-Humber - Bryant 1978-79: 21. Italy - Hampe/Winter 1965: 29-30

[75] Minturno - kiln 3.6 x 3.6 x 5.5 m, 40 hrs; Villarosa - large kiln, 48 hrs (Hampe/Winter 1965: 50, 120); Ashburnham - ■ 40,000 bessales, 50 hrs (Peacock 1982: 47).

The cooling period would have to be fairly long in order to prevent the large thin bricks cracking under thermal stress; 3 to 5 days is attested for 19th-century Flemish tile kilns and at Ashburnham, and this seems a reasonable figure to assume in this case. Finally, unloading the kilns would require only about half the labour needed for loading, since the bricks are lighter in weight and less fragile, so that a greater number of items can be handled each time.

If we assume a kiln size of 5 x 5 x 3 m, and allow 40% of the solid volume of all items except for the tubuli to provide space between the bricks for the passage of heat,[76] then the production figures for a kiln load of the various items can be calculated (Table 9, below).

Table 9: Brick Production

Item	no. 000s	Vol. cu. m	Man-days Quarry	Make	Stack	Load	Fire	Total Mdays
bessales	54	59	90	49	24	30	31	224
bipedales	5.4	60	98	25	19	24	28	194
sesquiped.	9	55	90	23	16	20	26	175
tubuli	16	42	69	53	14	18	25	179

As well as calculating the total number of man-days required for production, it should also now be possible to determine a yearly cycle which minimises the labour force and maximises production. The cycle is conditioned by the length of the firing season, which we can assume to run from mid-April to mid-October, say 180 days in all. As well as allowing for the required labour, a certain amount of dead time has to be included while the bricks are drying, an average figure of, say, 28 days. In addition, the firing cycle for each type of brick is fixed by the length of the actual firing - two days - and the cooling time for the kiln (say four days), plus the time taken to load and unload the kiln. For a kiln of the size suggested above, the number of men involved can perhaps be restricted to no more than four. The area of greatest flexibility is in the

[76] Cf. Dobson 1850: 79. It is assumed that the hollow tubuli can be touching.

number of men engaged in actually making the bricks, but this only conditions the cycle at the start, after which it is the firing which is the determining factor.

Let us consider the production of bessales. Exclusive of the making, the first firing requires 28 days drying, which includes the stacking of the bricks, 7.5 days to load the kiln using four men, two days firing, four cooling, and nearly four days to unload the kiln, say 17.5 days. Taking the extreme case, if 49 men were employed for one day making the bricks then the minimum first firing takes 46.5 days, and between further 7 and 8 firings could be fitted into the season; if only one man was employed to make the bricks the first kiln load would be ready in 94.5 days and only five more firings could be done in the year. The most efficient method would seem to be to have four men involved in the making, and to fire eight kiln loads each season; the makers would then work for 98 days. In addition two extra men are required for stacking the drying bricks. The makers and stackers might also quarry and prepare the clay during the rest of the year, creating 220 days work for 6 men over the year. If the firing team also consisted of four men (who would, however, have to work day and night during the firing), these would spend 110 days over the eight firing cycles, while the rest of the year could be used in gathering fuel for the firings. This is of course an ideal pattern which does not allow for any interruption due to bad weather or other causes, but it does show how a small number of men could be organised efficiently for a large output. The figures vary slightly for the different types of brick; bipedales work out at nine firings per year using 11 men, sesquipedales at 10 firings using 11 men.

5.4 COST OF LIME AND BRICK

We are now in a position to calculate the approximate cost of lime and bricks. Unskilled labour is costed at the rate for an agricultural labourer (25 denarii = 0.25 KM/day), skilled (lime burners, brick-makers and firemen) at 50 denarii = 0.5 KM/day, both plus a wheat ration of 0.11 KM/day (see Section 1.3.3). The fuel cost is based on the rate of 150 denarii = 1.5 KM for 1200 librae of wood.

Table 10: Cost of Lime and Brick Production

Material	Unit	ManDays/unit		Cost	Fuel		Total
		Sk.	Unsk.	KM	Qty tons	Cost KM	KM/unit
Lime	cu. m	0.5	1.7	0.92	2.5	4.2	5.1
Bessales	1000	1.02	3.13	1.75	0.45	1.8	3.6
Bipedales	100	0.71	2.88	1.46	0.45	1.8	3.3
Sesquiped.	200	0.77	3.12	1.59	0.54	2.2	3.8
Tubuli	1000	3.00	8.19	4.78	1.52	6.0	10.8

The cost of per 1000 pieces of facing brick generated by these calculations works out at 1.7 KM for halved bessales, 1.8 KM for bipedales cut into 18 pieces, 2 KM for bipedales in 16 pieces, and 2.3 KM for sesquipedales cut into 8 pieces. This at first sight runs counter to the usual idea that bipedales and sesquipedales are considerably more expensive than the smaller bessales and are thus not made specifically to be used in facing, but there are other factors to be taken into consideration. Firstly, there must have been a far higher failure or wastage rate in the production and transport of the larger bricks which would have presumably added to the cost of "firsts". In addition, the extra cutting involved in reducing the large bricks into so many pieces would raise the cost if used for facing; on the other hand, seconds and broken bricks presumably were thus used. None of this, however, necessarily invalidates the basic production figures.

To these production costs must be added a figure for transport. Transport from kiln to port and from dock to site are assumed to be by ox-cart, with a maximum load of 1200 lb. It is quite possible that here baggage animals were used, but it seems simpler to cost everything by the waggon-load since it makes little difference to the overall cost (see Section 4.1.3). The distance Kiln/Port is hypothetical, assuming the shortest distance from probable source of limestone to port. The river boats coming both upstream and downstream are assumed to land at the Emporium, and the distance Dock/Site is thus the most direct route from there to the Baths. A figure has been added to the final cost for loading and unloading at kiln, port, and dock.

Table 11: Total Cost of Lime and Brick

Material	Unit	Source	Distance in miles Kiln/ Port	Sea	River	Dock/ Site	Cost KM	Total KM
Lime	cu. m	Terracina	2.7	78	20↑	1.2	4.9	10
		Soracte	2.0	-	58↓	1.2	4.7	9.8
		M.Tiburt.	3.0	-	37↓	1.2	4.0	9.1
			Via Tiburtina - c. 23 miles				10.0	15
Bessales	1000	R.Farfa	1.0	-	48↓	1.2	9.9	14
Bipedales	100	R.Farfa	1.0	-	48↓	1.2	9.9	13
Sesquip.	200	R.Farfa	1.0	-	48↓	1.2	11.1	15
Tubuli	1000	R.Farfa	1.0	-	48↓	1.2	21.1	32

It is possible to make an independent check, at least in orders of magnitude, on the figures for lime and bricks. For lime this depends on two sections of the Theodosian Code: 14.6.3 which orders a payment of one solidus to the lime makers and carters for each "load" of lime (AD 365); and 14.6.1, dated six years earlier, which stipulates that carters are given an amphora of wine for every 2900 librae of lime. If from this we can assume that a standard "load" is 2900 librae, and there were 72 solidi a pound of gold, then the equivalent cost for one "load" of lime at the time of the Edict would be 10 KM, and one cubic metre of lime would cost 9.1 KM.[77] If, on the other hand, the "load" was the standard ox-cart load from the Prices Edict of 1200 librae, then the cost for one cubic metre would be 21.9 KM. There is, of course, no specific indication of where the lime was to come from, since the only two sources mentioned - Terracina and the Tuscan cities - are specifically excluded, but as we have already seen the possibilities are limited. On the whole the fact that the resultant cost of lime is in both cases close to the hypothetical figures is reassuring.

Testing the price of bricks depends on internal evidence from the Prices Edict itself. Two sections are relevant; DPE 7.15-16 give the piece rate for firing and making bricks respectively, while DPE

[77] In the monetary edict 1 lb gold = 72000 denarii. See Callu 1978: 108.

15.90 gives the price of foot-square bricks. The difficulty in the first instance is in deciding exactly what is being paid for. Since the rates form part of a list of daily rates of pay to individuals, the most likely explanation is that these are for the actual kiln-men and brickmakers (with their assistants) but would not include the supply of the raw materials - the clay and the fuel. If the kiln-men are assumed also to load and unload the kilns, then from the hypothetical figures in Table 9, 104 bipedales could be fired per man-day which would earn 52 denarii/day plus food, which compares well with the 50 denarii/day for lime-burners given at DPE 7.4. Even if half of this labour were unskilled, the hypothetical cost for labour would amount to 37.5 denarii/day. If we turn instead to look at the brickmakers, a rate of production of 220 bipedales/ day as suggested above would earn 55 denarii/day plus food, excluding the time taken to prepare the raw clay. Since we should probably include the time taken to stack the bricks for drying, and assume that half of the labour for the actual brick-making is unskilled, then the hypothetical cost for labour would be 57 denarii/day. Thus both for firing and for making the bricks the hypothetical calculations provide a figure that is satisfyingly consistent with the rates given in the Prices Edict.

It is rather more difficult to make any serious comparison with the price from the Edict for a foot square brick (DPE 15.90), since we have no way of telling what type of transport costs might have been involved. Nevertheless, the order of magnitude is consistent, since the hypothetical calculations produce costs of 1.4 denarii for a bessalis, 7.4 denarii for a sesquipedales, and 13 denarii for bipedales, compared with 4 denarii for a pedalis in the Edict. It is a pity that the price of bipedales is missing from the surviving texts of the Edict, and that there is no way of knowing the size of the tubuli at DPE 15.92.

5.5 METALS

A considerable amount of metal, predominantly iron, formed a permanent part of the structure of the Baths or was used to attach decoration. Iron bars were embedded in the walls to support architectural decoration (e.g. in the palaestrae) or gangways (e.g. Rms 23), and in the vaults to support the tile linings and the decoration of the caldarium (Appendix 4). Other bars, presumably of iron, gave stability to the vaults of the palaestra porticoes (see Section 6.4.5). Architectural members were joined by iron or bronze dowels and cramps set in lead, marble veneer and heating tubuli were held in place with iron or bronze cramps, and iron nails were hammered into the brickwork to give purchase to stucco decoration. Large amounts of lead were required for the water pipes leading from the cisterns to the central block, lead or bronze for the tanks in which the water was heated for the caldarium, and bronze for the heat-exchange tanks in the rear of the caldarium pools. Finally, if my reconstruction of the "cella solearis" is correct, decorative bronzework was used in the ceiling of the caldarium. All the metal used for structural and decorative purposes formed, of course, an integral part of the finished building and therefore a consumption of resources.[78]

5.5.1 Sources

Most standard accounts of Roman mining depend heavily on the written sources, and on a few well-known sites such as the Rio Tinto mines in Spain.[79] Archaeological investigations have been hampered by the destructive nature of mining and the further exploitation of many Roman mines in later periods, combined with the difficulty of dating slag heaps and industrial installations in the absence of ceramic material. Recent archaeological surveys of particular mining districts, in particular the Wealden ironworks and the Huelva silver and copper mines of southern Spain, however, have made an important contribution to understanding the nature and scale of these

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[78] I am ignoring the large quantities of iron tools which were required at all stages of the work, since these items would have had a long life outside this particular project and would have made a negligible contribution to the overall consumption of metal for the Baths.

[79] Davies 1935; Forbes 1950; Healy 1978.

operations.[80] Nevertheless, given both the absence of any surviving remains of the metal from the Baths and our uncertainty over the supply of non-precious metals to the city of Rome, it is impossible to do more here than present the general evidence and suggest a few likely sources.

There can be little doubt that by the mid-empire Spain was the main supplier of non-ferrous metals. While gold and silver were the main metals of economic importance, there was also extensive production of copper, tin and lead workings, the latter generally as a by-product of silver.[81] Lead pigs bearing Spanish stamps have been found in Rome, showing that this at least was sent to supply the capital.[82] Outside of Spain there were extensive lead mines in Britain, and it is possible that from the mid-empire onwards Sardinia also supplied lead.[83] Workable deposits of iron ores are found in many places within the Roman empire, with possible sources of supply for Rome itself in the early third century being Spain, southern Gaul, Elba, Sardinia, and Noricum,[84] although no extensive remains of iron mining and smelting have been found in Spain to match those of the non-ferrous metals, and it has been thought that only finished products were exported. Whatever the case, the iron of Spain - as that of Noricum - was noted for its high quality, and was presumably preferred for weapons and tools. It would not, however, have been necessary for the structural elements used in construction, and sources closer to Rome may have been preferred.

The Romans practised both open-cast and underground mining. Whilst attention in both the ancient sources and modern accounts focuses on the more spectacular operations of the latter, this was only used where necessary in the mining of precious metals as surface deposits gave out and not, it

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[80] Weald - Cleere and Crossley 1986, with earlier refs; Huelva - Rothenberg and Blanco-Freijero 1981.

[81] Davies 1935: 94-139; Rothenberg and Blanco-Freijero 1981: 173-82.

[82] <u>CIL</u> XV.7916

[83] Healy 1978: 61.

[84] Healy 1978: 63-64.

seems, as a general rule for obtaining the more common ores. Iron in particular came almost entirely from opencast mines, such as those in Britain, Gaul and on Elba, unless the deposits were extremely rich.[85] Pliny (HN XXXIV.xlix.164) notes the economic advantages of the surface deposits of lead in Britain which can be worked without the extensive excavation needed in the Spanish and Gallic mines. The initial smelting of ores and further refinement of the various metals - e.g. to produce tin and lead ingots and worked blooms of iron - normally appears to have taken place close to the mines, although the iron ore from Elba was processed on the mainland at Populonia due to the problem of maintaining fuel supplies. It is clear from Pliny (HN XXXIV.xli.144-145), however, that there were centres such as Tarragona in Spain and Como and Sulmona in Italy noted for the further refinement and working of iron but which were not connected with mining districts, just as Campania produced bronze objects despite having no local sources of copper or tin. Ingots of tin, lead and copper found in various shipwrecks, mainly of late Republican and early imperial date, confirm the trade in raw metals.

As far as the construction of the Baths is concerned, only the lead for fixing the dowels and clamps in the architectural ornament must have arrived at the site in ingot form. The iron and bronze pins, clamps, dowels, holdfasts and nails, as well as all the tools, were presumably standard items, while the larger iron bars are more likely to have been made to order; these may have been produced as required on site, elsewhere in Rome and its vicinity, or further afield where supplies of fuel were readily available. The more specialised the application, the more likely that the objects were produced at or near the site, so that the T-shaped bars from the vaults might easily have been produced on site from ready-made straight bars of standard cross-section. The bronze lattice decoration for the caldarium vault could have been prefabricated in part, but in final form must have been put together not merely on site but within the caldarium itself.

[85] Britain - Cleere 1983: 110-13; Gaul - King 1990: 121-22 with further refs; Elba - Davies 1935: 68.

5.5.2 Iron Production

The smelting of iron ores has been the subject of much archaeological experiment in Britain and elsewhere, and the process is now reasonably well understood, despite some uncertainty over the use of fluxes to help separate the metal from the slag.[86] The most useful studies for our purposes are those by Cleere on the Wealden iron, since he has looked at iron production not only from the technological angle but also with a view to establishing some kind of manpower figures.[87] While he gives no justification for his figures on the early stages of production, he does give sufficient information on the techniques used to allow for an independent assessment, which can be combined with the figures he gives for the actual experimental smelting stages. Although the difference in the types of ores used and in the mining techniques needed to obtain them varied considerably from one part of the Roman world to another and must have affected manpower figures, in the absence of any comparable study the Wealden results will at least give an idea of the orders of magnitude.

The iron ore of the Weald exists as carbonate nodules encased in a skin of limonite which lie at the base of a heavy clay layer, and was obtained from open pits dug in the clay, the clay in its turn providing the material for the furnaces. The ore could be separated easily from the limonite casing, leaving a clean ore which had to be crushed and screened for size but not washed. Before smelting the ore was roasted in a shallow pit with charcoal to drive of the moisture and convert the carbonate to oxide. Smelting took place in a conical clay shaft furnace, augmented with bellows, and with a facility for tapping the slag. The furnace was first heated by burning charcoal, and then fed gradually with ore and charcoal over the period of several hours, producing a spongy bloom of iron incorporating a substantial amount of trapped slag.

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[86] e.g. Wynne and Tylecote 1962; Straube et al. 1964; Cleere 1971; Barbré and Thomsen 1983; Pleiner 1983.

[87] Cleere 1976; Cleere and Crossley 1986: 78-79.

From his own experiments and similar ones elsewhere, Cleere has estimated that a single such furnace could produce about 30 kg of iron at each firing, at an ore to metal ratio of 6:1 and an ore to charcoal ratio of 1:1 for the smelting, and more like 1:2 if the charcoal for ore roasting is included. Although he has published various estimates for manning requirements over the years, it is clear that at the very least two men were needed throughout the day to operate the smelting, and another two for ore roasting if this is carried on simultaneously.[88] His total estimate for the whole operation, calculated for the 8 Bardown furnaces and assuming a workforce of 41 men, works out per tonne of iron at 14 to 15 man-days producing 6 tonnes of ore, 70 to 75 man-days cutting timber for and preparing 12 tonnes of charcoal, and 180 to 200 man-days for the ore-roasting and smelting.[89]

The basis for his mining figures is that one man can process 2 tonnes of ore and overburden each day, and it is clear that the actual ore must constitute roughly 22% of this by weight, the remainder being stiff clay. If the manpower required for this is calculated according to Hurst's constants, and it is assumed that both ore and overburden need to be moved 100 to 150 m by hand, then the total obtained for 6 tonnes of ore is 10 to 17 days, very much in keeping with Cleere's figures.[90] As usual, the most significant factor is the distance over which the ore and overburden have to be transported, and it is no surprise that the smelting works in the Weald seem to have moved as the ore in a given area became depleted.[91]

Manpower figures for wood cutting and charcoal burning are more difficult to assess. Payments

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[88] Cleere 1971: 217 (10 man-days for roasting and smelting); 1976: 244 (2-3 man-days for smelting; Cleere and Crossley 1986: 78-79 (3-5 men/furnace).

[89] Cleere and Crossley 1986: 78-79.

[90] Using the figures in Section 5.3.4 for clay, and assuming that the ore nodules weigh approximately 3.5 tonnes/m^3.

[91] Cleere and Crossley 1986: 81-83.

to wood cutters and charcoal burners in the 16th to 18th centuries compared with wages for other workers suggest that to produce one tonne of charcoal would take something in the order of 7 to 8 days cutting for unskilled workers and 3 to 4 days coaling. The latter figure is roughly in accord with 19th- and early 20th-century practice where the charcoal heap needed constant attention for the first day or two but for the remaining three to five days of burning another heap can be built, giving a series of overlapping cycles of building, burning and dismantling, each complete cycle of taking a week.[92] The 12 tonnes of charcoal needed for each tonne of iron would therefore take roughly 120 to 140 man-days to produce, substantially more than the 75 days suggested by Cleere. The 12 tonnes of charcoal might have consumed about 1.4 hectares of coppice to judge from 18th-century figures,[93] or on Healy's reckoning about 0.4 hectare of natural oak forest if completely cleared.[94]

In total therefore, if we allow the minimum figures of three men/day/furnace for smelting plus another two man-days per smelt for ore-roasting, each tonne of ore requires 165 man-days, giving a total of at least 295 to 320 man-days, of which almost half is spent on the production of charcoal. I would thus suggest 300 man-days/tonne of iron as a conservative minimum, which excludes any time taken for crushing and screening the ore. This compares closely with the figures given by Cleere, although the distribution of labour is slightly different. Also excluded in both cases is the amount of time required to free the bloom of its excess slag, which would need both extra time at a forge and extra charcoal. In 19th-century accounts of iron production this phase is reckoned to have added considerably to the cost of wrought iron compared with the industrial processes then in use, but I have not been able to find any precise figures; it may have been as much as half the production time for the bloom again if the requirements for charcoal burning are included.

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[92] Based on the figures in Armstrong 1978: 74-75, cf. 32, 62.

[93] Cited by Armstrong 1978: 75.

[94] Healy 1978: 152.

5.5.3 Costs

The Prices Edict supplies us with a range of prices for bronze, from 75 denarii/librae for Cyprus bronze to 50 denarii/librae for (?) ordinary bronze (DPE 15.68-70). It is much to be regretted that the section on iron (DPE 15.72a-77) is missing all the prices. If we calculate the cost of iron in the unworked bloom using the manpower requirements above, this gives a figure of 140 KM/tonne, or 4.5 denarii/librae. Transport costs are difficult to assess, but from Elba (the minimum case) these would only add at the most 4 KM/tonne. If we also add a factor for working the bloom to a semi-finished product, the price would be perhaps 6 to 7 denarii/librae. This seems surprisingly little compared to the cost of bronze, although there are plenty of other general indications that the price of iron in the Roman world was low.[95] There is some indication that this figure might not be too far out in the relative cost of worked iron and other building materials in 18th-century Rome. The price ratio of a kilogram of worked iron to a cubic metre of unslaked lime at Rome works out at roughly 1:30 in the mid-18th century,[96] and at 1:45-55 according to our estimated figures for unworked iron and using an average value for lime of 10 KM/m^3 (see Table 11). If we add a factor for the working of the iron into simple bars, the correspondence becomes closer. Late 19th-century figures suggest that it takes a blacksmith a day to process one hundredweight (51 kg) of iron, and he would probably need an assistant. Adding a further amount for the cost of the charcoal, the finished bars would cost something in the order of 8 to 10 denarii/librae, and the ratio of lime to worked iron becomes 1: 33-38.

For the price of lead our only indication is that given by Pliny (HN XXXIV.xlviii.161), who fixes it at 7 denarii/librae, which would be the equivalent of roughly 300 to 450 denarii/librae depending on the value used for corn in the 1st century AD. Even given the high cost of lead historically, this seems exceptionally high, particularly if applied to the cost of lead pipes; the materials for a

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[95] Manning 1976: 147.

[96] Based on the figures in Scavizzi 1983: 29, 132.

ten-foot length of the smallest gauge (5-digit) would thus cost at least 17,100 denarii, while each ten-foot of 100-digit mains would cost 351,000 denarii![97] The difficulty with Pliny's figure has already been noted by Boulakia, who compares it to the price of lead in 4th century BC Greece; unfortunately his alternative value would make lead cheaper by weight than iron, which is unlikely.[98] In the late 19th century, the price of unworked wrought iron was roughly one third by weight of unworked lead[99] which would set it at, say, 30 denarii/librae.

5.6 BASKETS AND ROPES

The evidence for the use of baskets for moving loose materials in quarrying and construction has already been discussed (see Section 4.2.1), while ropes were used extensively on the construction site for lashing together the scaffolding and for raising weights, both directly and as stays and guys for the cranes. All these items had a limited life (hemp ropes for example losing about one quarter of their strength in four to six months of use), and baskets are particularly susceptible to decay when in contact with lime and mortar. In the course of a six-year building project it is highly likely that some items would have to be replaced, and we can assume that none of them were fit for reuse.

5.6.1 Types and materials

White identifies the baskets used in construction as a form of cophinus, an item of hard basketry made predominately from willow woven on a rigid framework with a reinforced band at the top.[100] He assumes that these are half rather than whole bushel baskets from the evidence on Trajan's Column, where a bushel is roughly 0.03 m^3 or just over one cubic Roman foot (0.026

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[97] See Landels 1978: 43-44 for the size and weight of Roman water pipes.

[98] Boulakia 1972: 141-42, and now Bruun 1991: 131-32.

[99] cf. Laxton 1880: 194, 230.

[100] White 1975: 73-74.

m^3). If we accept that the baskets represented on the Column are to scale - a reasonable hypothesis given the way in which the soldiers are shown handling them - White's assumption only works in a few cases (Scene XII), while in most of the scenes (LII, LVI,LX, LXV) a rather larger basket (roughly 0.02 m^3) seems to be in use. The basket shown in the scene from the tomb of Trebius Justus appears to be larger again, nearer 0.04 m^3. Builder's baskets in the 19th century usually had a capacity of one bushel, and I have assumed that the Roman equivalent was a two-modius basket with a capacity of roughly one cubic Roman foot.[101] Strong baskets made of esparto with wooden handles and reinforced sides were used in the mines at Aljustrel,[102] and these would also have been suitable for quarrying and construction purposes.

Roman ropes were usually made of hemp, flax, or esparto, with pith, papyrus and grass also recorded in the Prices Edict (DPE 33, 22-5); plaited leather ropes were also used for presses and harnesses and there is record of a stranded bronze rope from Pompeii.[103] Various thicknesses of rope have been found at different sites, ranging from 3 to 25 mm in diameter at Pompeii and up to 35 mm at Xanten, but without any indication of their use. Some idea of the weight and thickness of ropes needed for construction purposes can, however, be deduced from Zabaglia's treatise of 1743, Pl. II. He recommends ropes of 15 mm diameter weighing 0.13 kg/m for scaffolding cords, 19 mm diameter and 0.23 kg/m for raising weights by hand, 26 mm and 0.68 kg/m for windlasses, 0.34 mm and 0.91 kg/m for guy ropes and heavier loads on a windlass, and 37 to 56 mm and 1.14 to 1.82 kg/m for raising weights with pulleys and block and tackle. The largest ropes are for weights up to 2.03 tonnes, and this is in close agreement with the breaking weight given for manilla ropes in the early 20th century, although in this case it is recommended

[101] Thatcher 1904: 95; Rea 1902: 34.

[102] Healy 1978: Pl.32c.

[103] See Gaitzsch 1985 with references for ancient rope-making in general.

that the load should be no more than one sixth of the breaking weight![104] Larger loads require either proportionately thicker and heavier ropes or several strands using multiple pulleys.

Most of the raw materials for baskets and ropes could have been produced on farms in Italy. All the agricultural writers recommend planting osier beds to supply withes for tying up vines, but they could also be used for making baskets, while flax and hemp were common crops.[105]. For stronger baskets and for the framework willows were cut only every second or third year, but the withes were an annual product. Palm leaves and broom (genista spp.) could be used as substitutes. There is some uncertainty whether the true esparto (Stipa tenacissima) was ever grown outside of Spain and North Africa, despite its widespread use for the strong ropes needed in ships and building cranes. The difficulty lies partly in Pliny's passage on esparto in which he says both that it is widely used in all countries for these purposes and that, while enough is grown in a small are around Carthago Nova to supply all needs, the cost of transport prevents it being taken very far,[106] and partly from the tendency among Latin writers to use the word spartum for other rope fibres such as rush and broom. Nevertheless, there is no firm evidence that esparto was ever grown in Italy, and it is probable that it was imported from Spain, possibly from the area around Carthago Nova.

5.6.2 Production and cost

The preparation of the raw materials for baskets and ropes was laborious. Osiers had to be cut, stripped and finished, while flax, hemp and esparto went through a long process of drying, soaking, and beating to release the fibres, which then had to spun into a yarn. Finally the osiers

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[104] Thatcher 1904: 76, where a 2¼ inch or 57 mm rope has a breaking strain of 39 cwt or 2.03 tonnes.

[105] e.g. Columella Rust., IV.xxx.2, XI.ii.90-92; Varro Rust. I,xxiii, 5-6. Pliny HN XIX.ii-iii shows how widely spread was the growing of flax, mostly for sails and clothing.

[106] Pliny (HN XIX.vii-viii).

were woven into baskets and the yarns twisted into ropes. Both techniques already had a long life by the Roman period and remain basically unchanged in pre-industrialised societies. While it is clear that the finished products for agricultural purposes could be produced on the estate, the Prices Edict provides evidence that the materials could be sold at any stage of the process up to and including the finished product.[107] Cato (Rust. CXXXV.2-3) recommends certain towns for different kinds of ropes and baskets, suggesting a degree of specialised production, as does the existence of collegium restionum (CIL VI 9856) at Rome and the inscription of the stuppatores res(tiones) in the "Piazzale delle Corporazioni" at Ostia.

The Prices Edict gives some idea of the cost of these items. A cophinus of unspecified material but of 1 modius capacity, and any basket of palm fibre, cost 4 denarii.[108] Assuming that the modius is a Kastrensis modius, the first should have a capacity of 0.0128 m^3, or half a cubic Roman foot. A two-modius basket would then presumably cost one-and-a-half to two times this, say 6-8 denarii. Hemp, flax, and (probably) esparto ropes all cost 8 denarii/libra. Thus scaffolding cord would cost 0.94 denarii/Roman foot, and the larger pulley rope 8.2 denarii/foot. If scaffolding cords were 15.5-18.5 foot long,[109] they would have cost roughly 15 to 17 denarii each. The relationship between prepared hemp, hemp spun for rope, and finished ropes of 4:6:8 denarii/ libra may also give some idea of the amount of manpower involved. A skilled workman earning 50 denarii/day plus food would have to produce 15 scaffolding cords of average cost 16 denarii from the spun yarn to earn his keep, while a spinner would have to produce enough yarn for 15 cords if classed as skilled, or enough for 9 or 10 cords if unskilled. The remaining 8

107 Section 12.39-42 is for osiers in four stages of preparation from stripped and finished to rough and unfinished, while Section 33.17a-26 includes prepared hemp, hemp spun for ropes, and ropes of hemp, and esparto as bundles and (probably) as rope. (Reynolds and Crawford 1977: 136, 149; Crawford and Reynolds 1979: 180, 202-203).

108 Section 33.29, 27. See Crawford and Reynolds 1979: 180, 202-203.

109 Based on the length of English scaffolding cords, see Thatcher 1904: 77.

denarii must have covered primary production, processing of the hemp, and transport.

5.7 CONCLUSIONS

All the materials discussed in this chapter require far more processing and thus are more labour-intensive to produce than the simple materials covered in Chapter 4. The manufacture of these materials demands a certain amount of highly specialised labour, although, as we found with the simple materials, the requirement for unskilled labour is always higher. In the production of bricks, lime, and metals, much of the latter is expended on fuel gathering, while quarrying and the movement of materials during the production process again account for a substantial proportion. In terms of costs, the supply of fuel has been shown to be a major item in the total cost of manufacture, roughly equal to the other labour costs for brick and iron and four times that for lime. In contrast, the cost of transport for brick and lime forms a smaller proportion of the total compared to the simple materials (half to two-thirds), despite the far greater distances involved. Here the use of water transport is the deciding factor, without which the total cost of these essential bulk materials might have been prohibitive. For both brick and lime, the cost of the labour for the actual production is only 10 to 12 percent of the total, the rest being for fuel and transport.

It has also been possible for brick, lime and iron to establish the size and nature of the basic production units, and in the case of brick to see how these might operate during a yearly cycle. The basic units operating are relatively small, between 8 and 12 men over groups of two to four kilns or furnaces. There is also evidence from the brick stamps that some 20 or so units were operating in the same general area in the valley of the River Farfa. Most if not all of these producers appear to have been fixed in the landscape, moving only within restricted areas as dictated by the supply of raw materials including, presumably, fuel. The centres of production for brick, lime, metals were essentially in rural districts, and the raw materials for ropes and baskets as well as most of their processing took place on agricultural estates. We cannot, however, begin to discuss the importance of these workers in the rural economy without some idea of the total quantities involved, and this will form an important part of Chapter 8.

CHAPTER SIX: CONSTRUCTION

INTRODUCTION

The aim of this chapter is to follow the construction of the Baths from the establishment of the building site to the decentering of the vaults. By focusing attention on the details of construction as part of the process of construction, new light can be thrown on such familiar and oft-debated techniques as bonding courses, relieving arches, brick ribs and tile linings of vaults. At the same time such an approach provides information on the organisation of construction, including the individualisation of work crews. The chapter will also look briefly at elements of the construction programme too often neglected since they leave no permanent record: the setting up of the site; problems of access to the site and moving materials around it; details of scaffolding and formwork. The intention is that this should be a processual, qualitative account, with the calculations of quantities and the details of logistics being left to Chapter 8.

6.1 PRELIMINARIES

6.1.1 The aqueduct and access road

Concomitant upon the decision to build the Baths must have been the decision to restore the Aqua Marcia and build a new branch line (the Aqua Antoniniana) to serve the Baths (see Section 2.3.1). At the same time, since concrete construction requires large quantities of water, it would have been highly advantageous to have had the water available by the start of the building season in AD 213 when the substructures were probably begun. The work on the aqueduct, both main and branch lines, must therefore have been one of the priorities of the construction programme, as must have been the building of at least some of the cisterns on the south edge of the site into which the aqueduct flowed.

The Via Nova, the new road built by Caracalla "sub eius thermis" (SHA, Cara. IX.9), i.e. parallel to the Via Appia on the north side of the Baths, should also be seen as an essential preliminary. The road ran from the south-east end of the Circus Maximus to the east end of the Baths, and to have been considerably wider than the Appia itself. As such it would have formed an ideal access road for all the heavy vehicles - including those carrying the architectural marbles and timbers - coming from the Tiber wharves as well as carts bringing pozzolana from the San Paolo quarries, thereby freeing the important stretch of the Appia outside of the Porta Capena from no doubt unwanted heavy and continuous traffic.

6.1.2 Organising the site

As on any major building site, the first steps must have been to define the site boundaries, establish some kind of administrative centre, set up a depot for equipment and materials, and clear the site as far as necessary of pre-existing structures. Evidence survives only for the last of these activities. The presence of demolition crews has been identified in the Hadrianic house, which was systematically reduced to just above first floor level.[1] The wooden ceilings were knocked in, and the structure filled with the rubble from the upper storey. Although some of the marble veneer from the walls was removed, presumably for reuse in the Baths or for resale, the demolishers appear to have been selective, as other fragments were found stacked up, and several small pieces of sculpture came from the excavations.[2] Some of the brick may have have been reused in the Baths, to judge by the small number of Hadrianic brickstamps from the figlinae Sulpicianae recorded from them (see Appendix 2).

Before work began on cutting the terraces the builders must have set aside areas for the storage

[1] The subrutores of CIL VI, 940 were defined by Mommsen as demolition experts. Contra Kühn 1910: 30, for whom they are tree fellers.

[2] Castagnoli 1949/50: 168-73; Carpano 1972.

and maintenance of tools and equipment. By the time the terracing had been completed, arrangements must have been made for handling, storing, and (where necessary) working the large quantities of materials - pozzolana, lime, brick, tufa, wood - required in construction. While it is not impossible that supplies of locally obtainable materials such as the selce and tufa caementa and the pozzolana were delivered every day, it is more likely that reserves were kept in hand to avoid delays in construction. It has already been suggested that the lime was slaked on site (see Section 5.2.4) and this would require the digging of pits. Materials which came from a distance and were not required continuously during construction, particularly the marble and timber, could have been held in general depots elsewhere until required, but these also had to be worked further on site. A timber saw-pit was no doubt an essential feature of the site, and once vaulting was begun areas would have been given over to the preparation of formwork. Facilities for smithing were probably also required for the maintenance of tools.

The careful positioning of these service areas was important. Problems of access for carts delivering materials had to be taken into account at all stages of construction. In addition, at least while the foundations and substructures were being built these areas must have been located so as not to hinder the gradual rise of the platform. This suggests that the rear of the site in the area of the later "stadium" and libraries, where little excavation and build-up of terraces was required, would have been most suitable for any permanent depots. Since water was readily to hand as soon as the aqueduct was finished, it would also have been appropriate for the slaking of lime and mixing of mortar.

6.2 FOUNDATIONS AND SUBSTRUCTURES

The importance of good site preparation and good foundations for the ultimate stability of a structure was well known to the Romans. Vitruvius discusses foundations in several sections (de arch. I, v, 1; III, iv, 1-2; VI, viii, 1-8). His basic rule is to build "ab solido et in solidum" (de arch. III, iv, 1 and cf. I, v, 1), while at the same time giving instructions for dealing with various types of unstable sites. Pliny's letters to Trajan on the problems of the theatre at Nicaea and the aqueduct of Sinope (Ep. X, 39; 90) show that these were far from academic concerns. The cutting away of the Quirinal spur to create the site for the Forum of Trajan, the transformation of the Palatine hill by cutting and artificial terracing to creat the imperial palace, and the incorporation of the Esquiline wing of the Domus Aurea into the substructures of the Baths of Trajan, all show the extent to which Roman builders were willing and able to invest extensive resources in producing the necessary setting and support for their creations. The Baths of Caracalla are no exception.

As we have seen in Section 2.5.3, the foundations and substructures which support the bulk of the central block and create the platform for the surrounding precinct extend to a maximum total depth of 14.5 m below the platform level, and show three distinct phases of construction (Sheets 8 and 9). Firstly, a series of terraces was cut into the natural clay, after which the foundations were cut into the terraces and filled with selce concrete, and finally the substructures were built up from the foundations in brick-faced concrete. As the substructures rose, the unwanted voids within the substructures and the surrounding platform were filled in with inert material, raising the overall level of the site at a uniform rate. The lowest terrace was just below the previous ground level, as indicated by the Hadrianic house, so that the foundations proper would indeed be laid "ab solido".

6.2.1 Excavating

No particular mystery need be attached to the actual levelling of the terraces and digging of the foundation trenches. The geology of the site - and in fact the geology of Rome itself - is such to make large scale earth moving merely a question of manpower and organisation; matters would have been very different if the city had been founded on an outcrop of granite. The difficulties are primarily logistical, for example the removal of the unwanted spoil from the site, and will be treated in detail in Chapter 8. Since the site is predominantly clay, it could not have been worked with any ease during wet weather, a point of some importance when we come to reconstruct the scheduling of the construction programme.

The work was presumably carried out in two phases, both of which required the frequent presence of surveyors. They were needed not only at the start to fix the shape and location of the terraces, but constantly during the excavation to achieve the required levels. Experiments by Adam using a short form of the Vitruvian chorobates has shown the effectiveness of this simple levelling instrument, while the full-sized device could have been realistically applied on a site the size of the Baths.[3] An alternative device, known to Vitruvius but rejected as too inaccurate, is the dioptra described by Hero of Alexandra[4], which could also replace the groma for establishing the lines of the site. While this does not seem to have been used by the land surveyors, we have no ancient literary evidence for the instruments actually used in building survey, and no way of deciding between the possibilities.

With terraces complete, the next step was to set out the foundations for both the central block and the platform enclosure. This was the most critical stage for the transfer of the architect's design, as only small adjustments within the limits of the foundations could be made at a later stage. The process for setting out the central block has already been discussed in Section 3.4, where it is shown that some small errors were made. As part of this phase the main drain, running below the central block and then in a roughly northerly direction to join the cloaca of the Circus Maximus, was established. This again required careful levelling to ensure a sufficient fall in the right direction.

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[3] Adam 1982: 125-29; 1984: 18-20.

[4] See particularly the discussion in Dilke 1971: 76-79.

6.2.2 Filling the foundations

Although there is no direct evidence for the precise form of the foundations in the Baths of Caracalla, their nature can be inferred from those of other large-scale structures, such as the Flavian palace on the Palatine or the Temple of Venus and Rome. All foundations over a metre or so deep and in unstable earth require shoring to prevent the sides from collapsing. The normal procedure was to line the trench with horizontal planks, kept in place with upright posts at fairly regular intervals on the inside, which were in turn held apart by horizontal cross-pieces (Fig. 57).[5] While the cross-pieces were usually removed as the foundations were filled, the rest of the shoring was left in place; in virtually all cases this has since rotted away, leaving the characteristic toothed effect in plan, and sometimes the marks of the boards on the sides.

The manner in which the mortar and caementa were placed in the foundation trenches is less clear. Large foundations in Rome and the vicinity either have the caementa thrown anyhow into the trench or laid in rough rows alternately with the mortar.[6] Lugli believed that the mortar and caementa were mixed together first, and then thrown into the trenches in layers about 0.3 m deep, while Blake suggested that the caementa were thrown in first and the mortar poured on top afterwards, or that they were thrown in in alternate layers.[7] Given the size and weight of the selce caementa, I am inclined to follow Blake rather than Lugli. In all cases it appears that the layers were rammed down to compact the mass and eliminate air pockets.

6.2.3 Building the substructures

The substructures can be divided into four main functional groups: the sub-floor walls which support the central block; the maintenance passages and drains; the subterranean service galleries;

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[5] See Giuliani 1990: 123; Lugli 1957: 385-86.

[6] See Blake 1959: 160; Giuliani 1990: 127.

[7] Lugli 1957: 385; Blake 1947: 351, 1959: 160.

and the terracing structures, including the cross-vaulted chambers forming the facade on the Via Nova and extending along the east and west flanks, as well as the outer walls of the exhedrae (see Section 2.5.3). There are precedents for all these types of substructures, although it is rare to find them all in use in a single complex or so rationally applied. The technique of building deep sub-floor walls to create a cellular foundation progressively filled in with inert material is found in the Colosseum and the amphitheatre at Nîmes.[8] The use of subterranean vaulted spaces to support a main structure is far more common, and it is unnecessary to cite more than a couple of well-known examples such as the Severan substructures on the Palatine, and of course the substructures on the Baths of Trajan which encapsulate the remains of the Domus Aurea. Equally well-attested is the use of parallel vaulted chambers with arcaded facades to support large earth-filled terraces; the travertine arcades of the platform of the Temple of Deified Claudius is but one familiar example. Finally, Hadrian's Villa provides us with an example of an extensive system of subterranean service galleries, with a comparable single entrance and road system for carts.[9]

The construction of the sub-floor walls has been revealed by the recent excavation in the south-west corner of Rm 2E. The walls are of brick-faced concrete identical to that of the central block but with no put-log holes in the face. This suggests that the work progressed in stages, with the walls being built to the height a man could work from the ground (equivalent to the height of a scaffolding lift) and the voids subsequently filled in to create the next work level.[10] These are defined by thin horizontal layers of trampled mortar and building debris which divide up the loose fill in the voids. The use of bonding courses in these walls thus cannot relate to the use of scaffolding, as is often argued for walls above ground. The maintenance of regular bonding course

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[8] Colosseum - see Cozzo 1928: 204-206, where the subfloor walls are about 6m deep; Nîmes - Bessac et al. 1984.

[9] Salza Prini Ricotta 1973.

[10] See Conforto 1991: 47.

stages would have made it much easier to keep track of the absolute height above foundations, and thus the relative height of one part of the structure to another (see Section 6.3.3 below for further discussion).

The importance of controlling the relative heights of the structure is clear if we examine the relationship between the sub-floor walls and the service galleries, maintenance passages, and drains (Fig. 58). Apart from the emissarium, which has its base at roughly 2 m below the top of the foundations, the floors of the rest of the main drains serving the central block run at roughly three to four metres above foundation level. A metre above these and just above the vaults of the service galleries are the maintenance passages. Minor drains in the palaestrae lie just above the inspection passages, which in turn are connected to their underlying drains by vertical shafts. Horizontal passages connect the major peripheral drains with the subfloor walls of the central block where the vertical downpipes for the superstructure start. The major drains and maintenance passages all have to pass through the subfloor walls, as do the sections of the service galleries under the caldarium and tepidarium.

At first glance, it seems that to establish all of these relationships correctly, and to ensure that, for example, the fall in the horizontal drains was in the right direction, must have required both highly detailed plans and the constant presence of the surveyors. A closer look at the maintenance and drainage passages shows that this was not necessarily the case. Firstly, the locations of the vertical shafts leading to the emissarium, which must have been established at foundation level, could be measured or eyed in roughly from the foundations of the sub-floor walls, as all are either immediately next to a foundation or mid-way between two (Fig. 13). Precision was apparently not expected, the shaft in the east bay of the frigidarium being well off centre, nor is the distribution of shafts in Rms 13 and 14 the same on the two sides. These vertical shafts allow the line of the emissarium to be maintained as the substructures rise, and determine the line of the central maintenance passage.

The construction of this upper passage appears to have been carried out in sections.[11] Breaks in the fabric, mostly identifiable only through a difference in level, coincide with the faces of some of the subfloor walls, and a heavy buildup of scale probably conceals discontinuities at other interfaces. While some of the differences are considerable (a maximum of 0.89 m), in no case is there a large change in level on both sides of a section of wall, and where both discontinuites are visible, it is clear that the difference only occurs on one side. It is thus clear that the passages in the sub-floor walls were built first, with the base supposedly at the appropriate height, while the linking passages were built as the voids were filled in, starting at one side of one wall and working across to the opposite side of the next. The passage is not in fact a straight line (cf. Fig. 13) but is composed of a series of short sections on slightly different alignments, a pattern fully in accord with the construction process suggested above. Problems were obviously encountered in the central bay of the frigidarium, where the maintenance passages bends in a shallow V to the north and also rises either side of the centreline; one of the causes at least was the height of the underlying transverse drain running from the natatio into the shaft leading to the emissarium. Some of these features - the discontinuities and slight changes of alignment - are also seen in the maintenance passage running around the periphery of the central block, although they are by no means as common and there are no marked differences in floor level.

There is no way of telling whether the discontinuities also appear at the lower level, but as the outer walls of the upper and lower passages are continuous, and vertical shafts in the sides of the upper passages connect with the lower drains, it is likely that the alignments of the two are similar. There would have been advantages in working the maintenance passages in sections, since this

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[11] I am grateful to Dott. L. Petrassi and Dott. A. Corazzo for discussing their work on the drainage passage with me.

would allow the vault formwork to be reused; it would also minimise the difficulties of removing the formwork once the passage was completed. This explanation does not, however, hold for the lower drains, since the great advantage of the ubiquitous "a cappuccina" drains closed by a pair of tiles leaning against each other is precisely that they provide a structurally strong covering without the need for inconvenient formwork. Rather the 25 to 50 Roman foot sections may give us an indication of the amount of work undertaken by a single team of builders.

Other details of the upper passages also give an insight into the organisation of the work and the degree of detail indicated by the architect. Firstly, the horizontal connecting channels between the sub-floor walls and the lower drains are located quite accurately on the centrelines of the orthogonal walls dividing, for example, Rms 4/5, 5/6, 1/3. Those that are not (e.g. those serving the natatio and the centres of Rms 1 and 5) come in at a higher level and there are some channels on the east side of the natatio which seem to have no function at all, if they were ever connected. Thus here too it seems that the channels - some of the earliest parts of the system to be built - could have been located according to a simple set of instructions; where this meant "opposite all cross walls" location was easy and accurate, while those that were set mid-way between two fixed points were located much more roughly.

A second notable feature is that different systems are used for the two halves of the central block. On both sides the vertical channels in the sub-floor walls are connected to the lower drain by horizontal channels, but on the eastern half the inspection shafts are set into the side of the upper passages, allowing access either from here or from the ground level outside, while on the western side there are two sets of inspection shafts, those corresponding to the horizontal channels but set close to the subfloor walls and those set in the floor of the maintenance passages in positions which do not correspond to the horizontal channels. It thus appears that two distinct groups of builders (both, as we have seen, composed of several teams) were at work on the two sides of the building, each of whom had a different way of interpreting the architect's instructions concerning the drainage system, and that those instructions were expressed in terms of result (e.g. provide access from maintenance passage and from terrace level to lower drain) rather than as specific construction details. This is a phenomenon which we shall see again in the main structure.

The construction techniques of the rest of the substructures are similar to those used in the main structure and will be discussed in more detail below (Section 6.3). All walls appear to have been built in brick-faced concrete, and where visible they have bonding courses at intervals of roughly 1.32 m or 4.5 Roman feet. Most of the walls also have putlog holes for scaffolding, but some of the lower ones in the galleries south of the central block lack them. In these cases it can be assumed that the upper part of the walls, not much more than half a scaffolding lift high, were worked from free-standing trestles. The concrete vaults were originally lined with a layer of bipedales over a layer of bessales, although now only some of the bessales remain.

6.2.4 Creating the platform

We have already noted that the level of the floor of the central block was raised after the completion of each stage of the walls, and that the drains and maintenance passages were built at the same time. While there is no direct evidence to show that the whole of the platform level was also raised in equal stages concurrently with the central block, this would be a perfectly reasonable assumption to make.[12] In fact, the lack of putlog holes on the outer wall of the peripheral block containing the maintenance passages and drains - visible in the side of the excavation for the Hadrianic house (Fig. 12) - supports this view. This process also has both structural and constructional advantages, since each lift of concrete is given time to develop strength while the voids are being filled and the new work platform established, and the lateral pressures exerted by the loose fill are kept in equilibrium, thus avoiding any danger of the structures shifting from the

[12] Cf. Conforto 1991: 47.

vertical.

The fill exists also under the service galleries to the south of the central block and under the peripheral drains, which would be consistent with gradual raising of the platform.[13] This fill is uniform across the site and consists of a brownish sandy earth containing numerous ceramic fragments (including amphorae, terra sigillata, and coarse wares), plus brick, marble, and mortar. It finishes 0.8 m below the final platform level, which corresponds roughly to the top of vaults of the maintenance passages and service galleries; in both cases the sides of the light wells project beyond the top of the vaults. This is also the level at which the cross walls dividing the terracing south of the eastern octagon stop, to be covered with a thin layer of beaten earth.[14] The fill in these cells was deposited in distinct layers, apparently thrown from the tops of the walls, and differs from one layer to another, while the layer above the beaten earth had a rather different character. All of this suggests that the construction platform for the Baths was not at its final level but 0.8 m below this.

This result should not surprise, since in the central block too the main construction platform must have been lower than the final overall floor level. This is obviously the case for all the rooms with hypocausts (Rms 14, 17-22, C, T), the service courts Rms 15 and 23, and the natatio. In the other rooms the work level must have been below the final mosaic or marble layer, and probably also below the underlying packing and levelling layers. In the large open spaces of the frigidarium, palaestrae, and natatio, a 0.8 m thick bed of selce concrete underlies the final preparation and finishing layers, and the floor of the natatio is further reinforced by six transverse arches.[15] It is likely then that these areas were the main work floors for the construction of the central block,

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[13] Petrassi 1985.

[14] Cecchini 1985: 587.

[15] See Petrassi 1985; De Angelis 1903: Tav. II, Section GH.

where materials, including the large and heavy marble elements, could have been collected, formwork and supporting structures assembled, and treadmill operated cranes erected.

6.3 CENTRAL BLOCK: WALLS

6.3.1 Setting out

The setting out of the superstructure of the central block on the sub-floor walls took place in two main stages. The location of columns had to be established at or below the final working level to enable the travertine blocks on which they rested to be set in place (Fig. 59).[16] Evidence from the openings between Rms 8/9/10E and the east palaestra suggests that the end piers of columnar screens were also set out at the same level and the intervening spaces filled in to floor level later (Fig. 60). Also set out below final ground level must have been the frigidarium pools, between 1 and 1.5 m deep, and the caldarium piers to allow for the installation of the praefurnium arches. The second and major stage occurred at or just below the nominal ground level, where there is evidence for walls being realigned, producing a step back from the face of the sub-floor wall in some places (Figs 16 and 30a) and including the major alteration to the natatio discussed in Section 3.4.5. Doorways would also have been set out at this stage.

6.3.2 Distribution of materials in construction

The most striking feature of use of constructional materials are the existence of two quite different basic regimes for both facing and core, a feature which missed in earlier published studies of the construction.[17] The surviving facing in the interior walls of the hot rooms 19-22 and the caldarium is composed of pale buff to yellow or pale salmon-coloured bricks, 0.038 to 0.047 m thick but with concentrations at 0.04 and 0.045 m (Type A, Fig. 61a). In contrast, the rest of the

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[16] None of the blocks themselves survive intact, but their location is frequently indicated by robber holes. The supposition that the blocks were travertine rather than any other material is based on standard Roman practice.

[17] Van Deman 1912: 423-26; Lugli 1957: 612.

block, including the south facade, has a facing predominently of mid-salmon to light red bricks, 0.03 to 0.035 m thick within the range 0.028 to 0.038 m (Type B, Fig. 61b). The bipedales of the bonding courses tend in both cases to be 0.58 to 0.59 m long and show the same range of thicknesses as the rest of the facing bricks, being frequently slighter thicker - but occasionally also rather thinner - than the surrounding face brick. In addition, the core of the hot rooms has caementa of brick, usually of the same type as the facing but including sporadic pieces of roof tile, while the rest of the block has caementa of yellow and orange tufa of average dimensions 0.03 x 0.03 x 0.075 m.

The distribution of Type A brick plus brick caementa in the hot rooms and Type B brick with tufa caementa in the rest of the block shows signs of being a deliberate feature. There is no indication in the brickstamps that the thicker bricks represent either a different source of supply or the reuse of earlier material.[18] Where the joins are visible, the change from one facing to another is neat and precise; on the window jamb of the east pier of the caldarium (Fig. 62), and on the west jamb of the door between Rms 19 and 12E, the two are keyed together in steps of 5 Type A to 6 or 7 Type B bricks, while in the southeast corners of Rms 19W and 12E the two types of facing abut. In all cases the mortar is continuous across the joints. The core of the south walls above the terraces of Rms 16 and 18 is of tufa while the other side of the walls, in Rms 21 and 22, it is of brick. In the upper part of the walls above the 14th bonding course of Rms 19, both facing and core revert to Type B.

The association between the Type A bricks with brick core and the heated surfaces of the hot rooms is hardly fortuitous. In many baths where the facing is generally reticulate, the hot rooms

[18] See Appendix 2 for the distribution of brickstamps. Lugli (1957: 611) notes a small percentage of thicker, yellower bricks in the Aqua Antoniana and in the Severan baths of the Palatine, but believes these are material from earlier periods.

are faced in brick[19], presumably because brick has much better thermal properties than tufa. I know of no instances where differences in core caementa accompany these changes in facing, although the use of brick caementa in the lower parts of a wall with tufa above is reasonably common; it is, however, easy to envisage how the rationale behind replacing tufa in the facing with brick could be extended to the core. The change in the brick facing is rather harder to explain, since the thicker, lighter coloured bricks, which have weathered more, appear to have been fired at a lower temperature and/or for a shorter period than the thinner, darker bricks, and their thermal properties would thus be less well developed.

In addition to the differences between Type A and Type B brick, it is possible to detect some gradations in the thickness of the Type B brick. Generally speaking, the bricks from the northeast part of the block (Rms 1-10 east, and the north side of Rm 12 east), the north, south and west facades, and the frigidarium average 0.031 to 0.032 m thick, while those in the rest of the block outside the hot rooms average 0.033 to 0.034 m. Unfortunately there are insufficient brickstamps from these areas to decide if this represents a difference in the brick supplied from particular officinae, or the widescale use of earlier material. While a distinction can be made in the bricks, there is no comparable difference in the modulus of five courses of brick and mortar which is frequently used as a standard way of describing - and dating - brick facing.[20] The modulus in fact varies widely throughout the building, from an exceptional 0.196 m where several rows of very thin bricks are included to anywhere between 0.23 and 0.28 m for the Type B bricks, and 0.29 to 0.305 m in the areas using Type A. This clearly points to the dangers of using the brick modulus alone to document brick facings, a message previously brought home by Steinby with

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19 Examples include the Large, Small and Heliocaminus Baths at Hadrian's Villa; the Terme Marittime at Ostia; the baths at Via Terracina and at Carminiello ai Mannesi in Naples.

20 For the use of the modulus see Van Deman 1912; Lugli 1957: 583-84; Heres 1983: 9-11.

respect to a group of buildings in Ostia.[21]

At the same time, however, it is noticeable that some attempt was made to make up for the thinner Type B bricks by increasing the mortar joints, and of course where different thicknesses of brick were used in the same row, the mortar joints were varied to make up the differences. Extra thick, and occasionally extra thin, mortar joints are also found just below the bonding courses. These two points suggest that there is some justification in the basic reasoning behind the use of the modulus - that there is an identifiable relationship between brick thickness and mortar joints - but that the exact relationship is determined by factors which vary according to other circumstances than just time.[22] If we think about the modulus in terms of construction rather than documentation, it is obvious that it should represent some kind of rule about the number of courses of brick over a given vertical measurement, whether expressed as a foot (or more probably some multiple of it), or a stage between two bonding courses. The value of such a rule would be that of accountability, both in checking the amount of work done by the bricklayers and the amount of brick consumed.

6.3.3 Bonding courses

One of the most noticeable features of the central block in its present state is the series of horizontal divisions of the core created by courses of bipedales - the so-called bonding courses - with which are frequently associated rows of small cavities normally identified as putlog holes for scaffolding (Fig. 63).[23] Up the springing of the vaults in most of the block the distance between

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[21] Steinby 1974.

[22] The clearest example of this are the brick-faced mausolea of the mid-second century in the suburbs of Rome, where the exceptionally fine-jointed brickwork (often only a few millimetres) of the facade gives way to a more standard brickwork on the rest of the exterior, and frequently even coarser work on the interior.

[23] Contra, Conforto (1991: 47) who believes that these holes in the central block are related to the decoration.

consecutive bonding courses is regular within the range 1.32 m ±0.05 m (4%), while the average over a number of consecutive bonding courses shows an even smaller deviation - at the seventh bonding course for example all but 3% are within the range 1.32 m ±1.5% - giving a standard of 1.32 m or 4½ feet (3 cubits).[24] Usually, a large deviation from the standard in one bonding course is adjusted in the next. Where bonding courses are omitted, e.g. at the tenth course in Rms 8, 10 and Rm 19E, putlog holes are often found at roughly the position of the missing course (Fig. 63). Where the regular vertical pattern of bonding courses is disrupted over a plain wall, the putlog holes usually maintain the rhythm, although the variation from the standard spacing tends to be greater.

The main interruptions to the pattern of bonding courses and putlog holes coincide with the division of a wall surface by a vault; this can be seen clearly on the west side of Rm 4E, and above the portico terraces of the palaestrae (Fig. 64). Less obviously the presence of a terrace on one side of a wall seems to affect the placing of the bonding courses on the other; the west wall of Rm 4E again provides an illustration (terrace to Rm 3d), as do the missing bonding courses of Rms 8E, 10E and 19E, or the additional course in the north wall of Rm 21E (terrace to Rm 18). Other events on one side of a wall may also cause disturbances to the pattern of bonding courses on the other, most noticeable in the central section of the north facade wall, at the level at which the entablature for the secondary order of the natatio was inserted.

Interpretations of the function of bonding courses in Roman construction have varied, and there is still no consensus of opinion.[25] The earliest regular use is in the Domitianic structures on the Palatine, and they occur thereafter in major constructions in Rome and Ostia under Trajan,

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[24] Not 5 feet as Lugli (1957: 611) would have it.

[25] For discussions see Middleton 1892 (I): 58; Lugli 1957: 570-74; Blake 1959: 102-41 passim, 162-63; MacDonald 1982: 162-63; Ward Perkins 1981: 99; Heres 1983: 47-49.

Hadrian, and then again from Commodus and the Severans through the third century to Constantine. The vertical spacing varies between 3 and 5 feet, and they may or may not correspond to the rows of putlog holes; where they do, the most commonly recorded position for the holes is directly above the bonding course. They clearly have no actual bonding function between the face and core or the two faces of a wall, and they are generally believed to operate only during the construction process, marking the end of a single work-stage and providing firm base for the next by obviating the effects of any uneven settlement. These ideas have been often repeated but without the detailed argument necessary to substantiate them, and they are thus worth closer investigation. The problems fall into two groups, those affecting the nature and function of each individual course, and those relating to the vertical spacing of the courses.

A consideration of the development of the use of through courses of bipedales in brick-faced concrete construction suggests that one of the principle functions of each course was to ensure stability by providing a level bed for the next stage of the work and avoiding undue settlement. In pre-Flavian work, e.g. in the Domus Aurea, courses of large pieces of brick or tile, are found immediately above the foundations and at the springing of the vaults, two places where the need for a firm and level bedding is indisputable. Some continuity of this thinking is still visible in the Baths of Caracalla, where an extra (often short) course bipedales is inserted at the springing of door and niche arches and of vaults where this does not coincide with a regular bonding course (e.g. Rm 4E, Fig. 65; niche of E natatio apse). It is my belief that this principle was soon extended to apply to the wall itself. The creation of level surfaces at regular intervals would have contributed to the stability of the structure by preventing uneven settlement and thus ensuring that the face of the wall was built to a true vertical. It is significant that regular bonding courses start with the building of the Domus Flavia which included in its state rooms (Aula Regia, Triclinium) and in the Forum vestibule some exceptionally tall and slender walls, where any slight deviation from the vertical would have been critical.

This levelling function, however, is far from explaining the appearance of regular intervals between bonding courses, or the particular distances used. We can certainly dispel the notion that each bonding course marks the end of a single day's work. Simple manpower calculations (see Section 8.2.3) show that for the ordinary 2 m thick walls in the Baths of Caracalla, it would take a pair of masons about 9 days to build a section 2 m (7 ft) wide and one bonding course (1.32 m) high without allowing for laying the bonding courses or erecting scaffolding. Even if the masons were squeezed closer - 1.5 m would be the absolute limit - and the wall were thinner, say 0.88 m (3 ft), it would still take over three days to build a section 1.32 m high. It is also unlikely that the bonding course interval represents any other specific unit of work time, since the spacing does not appear to alter with the thickness of the wall, the presence of niches or voids, or any other elements which require more or less work. On the other hand, the correlation between uniform numbers of brick courses and standard bonding course intervals would allow an easy calculation of the amount of face work done by the masons, since this presumably required a higher level of skill and may have been paid at a higher rate.

Viewing the problem from a different angle suggests that each stage represents the maximum height of concrete which could support its own weight, after which the wall had to be left to cure for some specified period before the next stage was added.[26] In this case the layers of bipedales would have the added function of protecting the curing concrete from any excesses of the weather. Another suggestion is that the level courses also formed a stable and horizontal bed to support the scaffolding[27], which would automatically explain the vertical spacing since the height of a scaffolding stage is determined by the height to which a man can work. This cannot have been the origin of the technique, however, since in the Domus Flavia the spacing of the bonding courses is irregular and the putlog holes rarely coincide with them. Indeed, in the Baths of Caracalla the

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[26] Also suggested for the Pantheon by De Fine Licht 1968: 94.

[27] Particularly by Heres 1983: 48.

putlog holes in the lower parts of the walls, usually as far as the tenth bonding course, are in fact just **below**, rather than just above, the bipedales (Fig. 63), and often the two do not coincide at all (Fig. 64). The need to erect scaffolding does, however, constitute a natural break in the rhythm of construction, which could be economically associated with the necessary curing period for the concrete, and it may be that gradually, provided other circumstances did not intervene, this was recognised as the obvious place to create a new level.

None of these explanations account for the tendency to maintain a consistent spacing over a number of bonding courses. The frequency with which sill or lintel heights and the springing of arches or vaults coincide with bonding courses, plus the setting of the interval between them to a precise number of Roman feet or cubits, suggests that bonding courses were assumed to be at a specific distance above a datum. There would be obvious advantages when working high above the floor level in being able to fix vertical distances for individual features without the need to measure them from the ground. A terrace would create a new datum, and it is not surprising to see the bonding courses reassume their regular spacing above terrace height. The corollary to this is the potential from the architect's point of view of being able to keep a check on the progress of construction, particularly in areas such as the complex set of connected terraces over Rms 3, 4/5/6, and 12.[28]

The picture which emerges is of a device initially developed to provide a firm and level base for walls and vaults, but expanded to aid the construction of tall, slender walls by ensuring their trueness and allowing localised curing of the concrete. Other totally unrelated advantages of the system were then perceived, including the combination with the scaffolding stages. On the whole the levelling function seems to have taken precedence over the regular spacing where a clash was

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[28] The painted red line used to pick out the bonding courses in some late 2nd C buildings, where the brick of the courses is virtually indistinguishable from the rest of the facing, may reflect the same concerns. See Lugli 1957: 573.

inevitable, as can be seen from many of the irregularities cited above.

6.3.4 Scaffolding

So far we have discussed the putlog holes for scaffolding only as they relate to the bonding courses, but they also provide information on the nature of the scaffolding itself. Despite the importance of scaffolding in any kind of large-scale construction, it is a topic rarely treated in any detail,[29] and Roman scaffolding for a long time was no exception. Some recent handbooks, however, do illustrate the four basic types of scaffolding presumably used by Roman builders - trestles, free-standing and engaged pole scaffolding, and cantilevered scaffolding - and provide short discussions of their construction and methods of use.[30] What is lacking is any comprehensive study of the falsework of specific buildings, despite the widespread survival of the putlog holes which provide the best evidence for scaffolding techniques.

In the Baths of Caracalla the putlog holes are sufficiently well preserved for some useful observations to be made. In a few places, however, and particularly around the height of the second bonding course, the wall is too ruined to preserve any of the putlog holes. Modern restoration has also concealed some evidence, and the regular but random holes left in some of the new facing to indicate the existence of some kind of cavity beneath are positively misleading.

As a general rule, from the second or third up to the tenth bonding course the putlog holes are roughly circular and about 0.1m in diameter, reflecting the shape and size of the sapling poles

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[29] This omission has been stressed by Fitchen (1961: 241-47) in a survey on the literature of falsework. He himself makes the most valuable modern contributions to the subject both in general (1986: 85-90) and in relation to medieval building (1961: 248-52, 271-79). Thatcher (1904) is the most useful of the 19th-century technical treatises and one of the very few devoted to the study of scaffolding.

[30] Adam 1984: 85-90; Giuliani 1990: 194-99.

from which they were made (Fig. 66, lower).[31] Where they could be measured the holes penetrate roughly 0.5 to 0.6 m into the wall from the face. While the horizontal spacing is far from regular, particularly where some feature such as a niche or window breaks up the wall surface, intervals roughly equivalent to 3 or 4 feet, or multiples of these, are common. Where they coincide with bonding courses, which is the most common case, the putlog holes nearly always lie below them. Above the height of the tenth bonding course, square (or more rarely polygonal) putlog holes topped by a piece of brick or tile are found above the bonding courses, either replacing or in addition to the circular ones (Fig. 66 upper, Fig. 67). These square putlog holes vary in size from 0.1 m to nearer 0.2 m in width; in some walls (Rms 1, 4, 3E, 17E, 14W) there are also several very large sockets up to 0.4 m square. It has not been possible to measure their depth, although in the upper parts of the north facade wall over the terraces to Rms 3c and d they pass all the way through the wall, as they also do at the tenth bonding course of the outer wall of the staircase in Rm 3Ed (Fig. 68). Where there are two sets of putlog holes either side of a bonding course (and occasionally where there is no bonding course) the two are almost always separated both horizontally and vertically by about 0.1 m or more. The horizontal spacing of the square putlog holes, generally 3 to 4 feet, appears more regular than that of the circular ones, although this may simply reflect their better state of preservation.

What do these patterns of holes represent? Firstly, the absence of putlog holes below the second or third bonding courses shows that initially the scaffolding was free-standing, no doubt very similar in appearance to that shown in the painting from the Tomb of Trebius Justus (Fig. 69). Two sets of vertical posts, or standards, are required, one close to the face of the wall and the second 4 to 5 feet away from the first, and the standards are placed at intervals of between 4 and 8 feet depending on the eventual height and the weight of materials the scaffold has to support (Fig. 70). The standards in each set are joined horizontally by long poles, or ledgers, at regular

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[31] Putlogs in 19th-century construction were usually 4" in diameter (Thatcher 1904: 74).

intervals of 3 to 5 feet, and on these are set transverse poles, or putlogs, 3 to 4 feet apart which support the planks or hurdles of the working platform. Although the standards in the painting appear to be about 10 feet high, standards in traditional pole scaffolding were anything up to 50 ft long.[32]

The major problem with free-standing, as with most other forms of scaffolding, is that of ensuring stability. Cross-bracing the external standards will prevent the whole scaffold from tilting sideways, but not from falling away from the face of the wall. Some stability for the vertical poles could be achieved by burying the butt ends in the ground, and vertical props could also be used. In the Baths of Caracalla the problem was solved by building the putlogs into the wall so that friction between the wood and the concrete resisted the outward pull of the scaffolding. It is not entirely clear whether the inner standards were continued once the use of embedded putlogs was commenced, since it is also possible to build scaffolding with only the external set of standards, which is how Roman scaffolding is shown in most reconstructions. The rather wide spacing noted in the lower ranges, and the tendency for that to reduce and there to be more putlog holes as the walls rise, suggests stability rather than support as the main function and to my mind favours the retention of the inner standards. The frequent lack of vertical congruency of the putlog holes shows that the putlogs were normally fastened to the ledgers rather than to the standards. The notable exceptions are at the ends of walls and at the edges of tall windows, for example those in Rms 4 and 6, where the scaffolding was carried round the jambs rather than across the face. Rather than being set vertically in a single line, these putlog holes appear either side of a narrow vertical band representing the standard itself. If we bear this habit in mind, it is possible to identify the probable location of many of the standards by similar patterns of holes, usually at every second or third bonding course, sometimes over almost the whole height of the wall (Fig. 71).

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[32] Thatcher 1904: 19-29, 74.

Between the seventh and tenth bonding courses, that is at a height of between 30 and 45 feet above floor level, a change of regime was gradually instituted, evidenced by the square putlogs holes. The height at which this occurs suggests that the change was associated with the end of the original standards. New standards could be joined by overlapping the old by several feet (Thatcher suggests 10-15 feet), but it is clear that this would compound the problems of instability. Where both types of putlog holes are present, and particularly where they appear in slightly offset pairs, one could imagine a system where only the outer standards are continued, the inner ledgers being supported on the lower putlogs, the upper putlogs being then laid across both sets of ledgers and supporting the actual platform in the normal fashion.

The outer standards were not carried up to the top of the walls in all cases. Terraces could form a new base to support the scaffolding for the upper levels, as could window openings.[33] In those few places where the putlog holes pass through the wall (e.g. in the upper parts of the outer wall above Tces 3c-d) hung scaffolding was presumably used, where the putlogs were supported by the wall itself with the addition of small diagonal braces and horizontal ties to stabilise the outer edge (Fig. 70b). It is probable that such scaffolding was also used in those upper parts of the building where the square putlog holes occur alone (e.g. the piers butressing the frigidarium cross-vaults). The fact that these holes are often built with neat brick sides and tops suggests that the putlogs were wedged into place rather than built in, which would allow the complete triangular trusses to be set in place and removed easily.

Access to the scaffolding would normally have been by wooden ladders, as shown in the painting from the Tomb of Trebius Justus. This appears to be a ten-rung ladder, which would just reach to the second scaffolding stage; the thirty-rung ladders listed in the Prices Edict of Diocletian, which would have reached the sixth scaffolding stage, would have been necessary in large-scale

[33] As happened in the building of medieval cathedrals, see Fitchen 1961: 18-23.

construction. The circulation of workmen and materials would have been aided by leaving in place the planking or hurdles of at least every third or fourth scaffolding stage, these being connected by ladders in a number of places. The staircases within the caldarium piers, the outer frigidarium/natatio piers (reached from Rms 2), and in Rms 3c, would also have provided access during construction. Some of the slit windows in the north facade, from which the Rms 3c stairs were lit, were originally wider than at present, allowing workmen access to the external scaffolding from them as well.

6.3.5 Arches: doors, niches, windows, relieving arches

Perhaps the most striking feature of the central block in its present state is the number of arches which appear in the face of the wall over doorways, windows and niches, giving the impression of a "live" material, as Ward-Perkins has so aptly noted.[34] In addition to those which form the heads of openings, there are the so-called "relieving" arches which appear to distribute the weight of the wall above a vunerable point. This section deals with all arches or short vaults which form to passages through solid walls rather than those which cover spaces, although the distinction in the case of wide and deep openings is not always obvious. On the other hand, I have left discussion of the arches formed by the ends of vaults to Section 6.4.2 below, even though many of them, such as the arches in the north walls of Rms 1 and 5, also form the heads of windows.

The range of forms and techniques used for the wall arches is very limited, and all except the upper niches in the natatio aedicular facade are made of bipedales. Most doors and rectangular niches have a single flat or slightly curved lintel arch and a semi-circular relieving arch;[35] windows and the door between Rms 13 and 14 have a double arch, segmental or semi-circular, while curved niche have a single arch; service passages have a sharply curved arch over a

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[34] Ward-Perkins 1981: 99.

[35] For other possible types of door construction see Packer 1968: 364-67.

triangular opening formed from two bipedales; and small slit windows have a slightly curved lintel arch sometimes with a relieving arch above. Double relieving arches appear over lintel arches (Rms 14 east, 5 west, 1), and double semi-circular arches over small niches (apses of natatio). There are one or two sets of single or double relieving arches over the doors between Rms 13 and 14, Rms 19 and 20, Rms 21 and 20, and Rm 22 and the caldarium, as well as over the remaining apses in Rm 20. There are also three single relieving arches in the fill of the blocked opening between Rms 2W and 14W.

The basic construction technique in most cases is the same. The bipedales are not wedge-shaped, but vary in thickness, the differences being made up by the mortar joints (Fig. 72). Only every second or third bipedalis on the face is a whole tile, the rest being halves with the difference made up by mortar, sometimes including small tufa or brick fragments. The surviving evidence points to this system being repeated for the full thickness of the doors, windows, and flat headed niches.[36] The relieving arches over the lintel arches of the doors also seem to have continued through the full thickness of the wall, as did those higher up in the walls, to judge fron that between Rms 21E and 22E.

Most discussions of these brick arches in concrete architecture assume a rather different construction. Particularly in thick walls, the arches are each supposed to be no more than a skin one bipedalis thick with the rest being of the normal concrete with the caementa laid horizontally, although the presence of complete bipedales every fifth or sixth brick is noted; many examples can be cited to illustrate this type of construction.[37] It is then assumed that the arches rose with the surrounding fabric, and had no function once the concrete of the wall had set into a monolithic

[36] Since the rectangular niches tend to be 0.89 m deep they would require two rows of bipedales, as would the unusual barrel-vaulted niches in the natatio apses, which also have a double rather than a single arch.

[37] e.g. Adam 1984: 194, figs 428, 429; Blake 1959: 162-63.

mass, although some (usually unexplained) value is assigned to them during construction.[38] Clearly, the rather different construction techniques used in the Baths of Caracalla, where the arches do go through the walls - a phenomenon otherwise only recognised in the major arches of the Pantheon - must lead us to look for a rather different interpretation.

In a very recent work Giuliani has produced arguments which may form the key to understanding the situation in the Baths. He suggests that the whole bricks divided the arches into artificial voussoirs, and that the arches were not only imagined as substitute ashlar arches, but did in fact act as such both during and after construction.[39] I have already argued elsewhere that Roman builders continued to be influenced by the ashlar tradition in some of the constructional innovations developed in the context of imperial concrete architecture, leading to mixed constructions of stone, concrete and iron.[40] An apparently increasing understanding by Roman builders of the true lithic qualities of unreinforced concrete - as opposed to the super-strong monolithic qualities assumed by some scholars - and particularly its weakness when used as a flat beam under tension, is also shown, I believe, in other ways. Except over small spans, the simple flat concrete lintel arch which was a feature of first century architecture was virtually abandoned for the slightly curved lintel or depressed segmental arches of the second and third centuries,[41] along with the introduction of wooden or iron supports for the flat arches. The growing predominence of semi-circular or full segmental arches over openings in the third and fourth centuries, and the concurrent disappearance of relieving arches also seems to be part of this same movement.[42]

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[38] e.g. Middleton 1892, I: 58-60; Ward-Perkins 1958: 81 and 1974: 152; MacDonald 1982: 162-63.

[39] Giuliani 1990:78-85. His ideas are presumably inspired by the work of Mark and Hutchinson (1986).

[40] DeLaine 1990: esp. 421-22.

[41] Cf. Blake 1959: 162-63, although she gives no explanation for this.

[42] Cf. Heres 1983: 44-45.

If we accept then that in the Baths of Caracalla the arches were seen by the builders as functioning independently in some way, this leads us to question the order of building. The argument that the arches rose with the surrounding structure implies that, while the arches over openings would take their shape from wooden centering, the relieving arches were formed as part the unset concrete. On the two outer surfaces, the brick facing could be shaped to a template to give the appropriate curve, but through the thickness of the core the mortar and caementa were presumably continuous both above and below the "arch". This cannot have been the case in the Baths, however, if the relieving arches went right through the thickness of the wall; the only sensible alternative, which would also explain the smooth underside of the part of the relieving arch which remains over the door between Rms 21 and 22E, is that the relieving arches were built on centering leaving a hollow in the wall which was filled in once the arch and the wall above it had developed some strength. The difference in appearance between the extrados and intrados of the relieving arch over the doorway between the west palaestra and Rm 7 (Fig. 73) would seem to support this theory; in the former some of the caementa of the core continue between the upper edges of the bipedales of the arch, while the intrados leaves a clean line of demarcation. The continuance of bonding courses and sometimes putlog holes across the fill of relieving arches, and the absence of any visible gap between the fill and the intrados, suggests that the delay in filling the voids was not long; once again we are hampered by an insufficient knowledge of the setting curves for Roman concrete in predicting just what this time lag might have been.

In cases where relieving arches occur well above openings, it is easy to imagine the construction process. Most start at a bonding course, and this level area must have been used to support the centering. This would have been rather less than the full curve and rested on a series of wedges which would eventually be removed in the decentering process; the first few rows of brick in the arch are of course either horizontal or rest on a wedge of wall and can be built without any centering at all. The problem is rather more complex in the case where a relieving arch occurs over a lintel arch, since it is unlikely that the centering for the relieving arch rested on the very lintel arch it was designed to protect. A close examination of the treatment of the two arches at the impost helps point to a solution.

In the Baths the start of the lintel arch was usually flush with the jamb or a few bricks inside it, while the relieving arch started rather further from it, creating a roughly triangular section filled with the normal brick and concrete (Fig. 72). Commonly the two arches share the same impost line, which is sometimes marked with an extra bipedales or formed by a bonding course, and the relieving arch is a full semi-circle. Alternatively, the upper arch begins about 0.3m above the impost of the lintel arch, and in these cases the arch is not a full circle.[43] On the south side of Rm 3 west it seems that a mistake was made at the springing of the lintel and relieving arches. In the final form the wide doorways are covered by two superimposed, fairly flat segmental arches, but at the impost line there are three to five bipedales set almost flat as if for the springing of a normal semi-circular relieving arch, the upper segmental arch starting immediately above these (Fig. 74). While the resultant irregular spaces are filled in with brick in the normal manner, there is a clear vertical or slightly curving line of discontinuity between the inner edge of the abandoned semi-circular arch and the upper edge of the lintel arch proper.

The obvious solution is that the relieving arch was built first, with the centering supported by wedges resting on the projecting jambs. In some cases the arch was started from the level of the wedges, as suggested above for the other relieving arches, while in others it started from the centering a foot or so above this. The lintel arch and the fill above it were added only after the relieving arch had been decentered and was supporting the wall above. The centering for the lintel

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[43] In Rm 5 east and on the south side of Rm 5 west wher space was restricted because of the closeness of niche and door, the smaller niche arches are cut short where they meet the relieving arches of the doors, while on the south side of Rm 5 west, where a double relieving arch over the door exacerbates the problem, the relieving arch sits on top of the lintel arch.

arch, which must have been supported on posts from the ground, could thus have been very light, since it only needed to support the weight of the lintel arch and the small amount of fill above.

6.2.6 Down-drains, passages and voids

As well as the major openings for doors and windows, which formed part of the obvious architecture of the building, the structure of the central block also contains a number of vertical drains, passages and other voids which were never meant to be visible but which were generally related to the operation of the Baths. While it is no longer possible to identify the function of every one of these, it is worth looking at the two main groups as far as they relate to the construction of the central block.

The building of the down-drains, as has already been noted (Section 6.2.3), begins below the pavement at the level of the horizontal drains. In the superstructure, these appear in two forms. The most obvious ones appear as long vertical slots, usually 290 to 300 mm square and with brick-faced sides and large bricks for the backs, on external faces such as the walls of the palaestra (Sheet 3, Section DD; Sheet 5, Section MM) and the service courts (Rms 15, 23). The fourth side of the slot was presumably also a large brick and would have been added later. The slots themselves were easy to build as part of the rising wall, and the technique is relatively common in both large-scale public and private building from the Flavian period onwards.[44] The horizontal inlets at the top of the drains are usually marked by a small relieving arch on the face of the wall, and the relieving arches seen occasionally in the back of the drains are related to subsidiary inlets (Fig. 75). In the long walls of the palaestrae the upper sections of the slots have been displaced sideways to avoid interfering with the great double arches marking the face of the semi-domes of Rms 13 in the plane of the wall, indicating clearly the heirarchy of construction (Figs 75, 76). The same type of construction was also used in the frigidarium pools, where the vertical and

[44] e.g. in the Domus Flavia and Domus Augustana, and in numerous Hadrianic buildings in Ostia.

horizontal channels served to house the lead water pipes which fed the pools.

Less frequently observable are the interlocking terracotta pipes set in the thickness of the walls. These must have formed the down-drains in those parts of the building where there was no external wall (e.g. the internal parts of Rms 1-3 and 14), and were also used in place of the built vertical slots, e.g. visible in the thickness of the pier between Rm 1W and the natatio (Fig. 77).[45] The same construction seems also to have been used for some of the hypocaust flues. As usual, the point where the flue pipes emerge at the wall face is marked by a small relieving arch, and many otherwise isolated relieving arches at the base of walls in Rms 20-22 and the caldarium can be linked to the presence of vertical pipes higher up. Terracotta pipes are also to be found in a few places in the thickness of the palaestrae vaults, as in the north-east corner of Rm 12 W, where the opening into the vertical slot has been blocked and its function taken over by the pipe, which presumably joins the slot further down. This adaptation was necessary because the original inlet of the drain was set too high to function with respect to the terrace, which was added at a later stage of construction (see Section 6.5.1).

In addition to the down-drains, a series of horizontal passages and vertical stairways were built into the thickness of the walls, giving access to the upper parts of the building for the maintenance personnel. As well as their function with respect to the finished building, these had two distinct advantages during construction. Firstly, as has been suggested above for the staircases in Rms 3c, they provided access to the upper part of the building during construction, and in particular during the building of the high vaults. Even the passages in the north walls of Rms 21-22 could have been used to advantage, allowing access to the upper parts of these areas from the terraces of Rms 16 and 18. Of further interest in terms of construction are those that were inserted into the thickest parts of the structure: the staircases in Rms 2, 23, and the outer caldarium piers, and the

[45] See Blouet 1828: Pl. IV and XIII; Middleton 1892 (II): Fig. 65.

high passages through the vaults of Rms 20 and the surviving caldarium piers. These together with the otherwise unexplained voids in the wedge-shaped areas between Rms 13 and 14 would have helped speed the curing of the concrete, in a similar way as has been suggested for the key-shaped chambers in Pantheon.[46]

6.3.7 Building in the columnar orders

Although most of the columnar orders in the central block have a principally decorative function,[47] they were not generally added as a skin after the basic construction had been completed but were incorporated into the concrete structure to a greater or lesser degree. Only two recognisable fragments remain in situ, the corbels for the columns framing the niche on the south wall of the frigidarium, and a projecting architrave block on the north facade above the door to Rm 5W (Fig. 78). Otherwise the evidence is reduced to the sockets left where blocks have been removed (Fig. 79), more often than not by enlarging the holes and thus destroying whatever details they might have supplied. Further evidence has been lost by over-zealous restoration, as can be seen clearly in two near contemporary photographs of the frigidarium taken in the late 19th century (Figs 80 and 81). In addition precise measurement of the cuttings has proved impossible due to problems of access, nor has it been possible to match any of the cuttings with surviving pieces of architectural ornament.

The fragmentary evidence which does remain presents a varied picture, reflecting at least in part the differences in size, location and structural function of the orders. The corbels which supported the columns framing the various niches were all deeply embedded to resist the downward thrust

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[46] Originally by Cozzo 1928: 276, and taken up by Ward-Perkins 1981: 114.

[47] The palaestrae porticos, where the columns support the vault, are the exception and will be discussed in Section 6.4.5 below.

of the loads they supported.[48] The columns used as dividing screens (e.g. between Rms 4/6 and 5, between 8/10 and 9, south walls of Rms 19-22, etc) supported continuous entablatures and sometimes a screen wall above, and it is not surprising to find that the solid entablature blocks extended well into the flanking walls or piers (Fig. 79). For further support, the pilaster capitals at the ends of the screens also appear to have been solid blocks set into the walls rather than merely applied veneer. The entablature blocks of the two-storey order framing the aedicules of the natatio north facade also needed to be fixed firmly into the wall behind as the lower members had to support the upper ones.

In contrast, where two columns stood close to the wall face and supported a continuous entablature, the whole aedicule could be built as a separate unit and there is no structural reason for the entablature to be engaged at all; thus in the aedicules framing the niches in the bays of the south natatio facade the sockets for the entablature over the columns penetrated no further than the depth of the brick facing (Fig. 82). While this could have been done even where columns carried a short section of entablature projecting from the wall, as with the orders framing the doors in the north facade or the giant columns of the natatio and frigidarium, the ends of the entablatures here were also embedded in the wall, presumably to ensure lateral stability. In the natatio north facade the entablature sockets for the lower level niches have bricks sides and back, as may have had the much restored upper ones, although the corbels supporting the upper columns were built into the core (Fig. 83). This would have enabled the orders framing the niches to be added at a later stage of construction, surely an advantage in terms both of access to the rising wall face and of protection for the marble during the erection of the rest of the wall and of the larger framing orders.

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[48] For the structural behaviour of corbels and their role in concrete construction see DeLaine 1990: 407-10.

The unexpected depth to which the projecting entablatures of the frigidarium main order were embedded may also have enabled these columns to be added at a later stage of construction (Fig. 84). In this case the entablature blocks had to be in place before the construction of the triple cross-vault since they carry the corners of the vaults and serve to reduce the overall span. As the surviving section of entablature in the Basilica of Maxentius shows clearly (Fig. 85), these blocks were set into the surrounding wall far enough to act as corbels carrying the pier of concrete above without the support of the columns.[49] It would have been perfectly feasible to have added the columns at a later stage, thus minimising the possibility of damaging the capitals and shafts both during the construction of the vault and its decentering.

The building in of the orders, and particularly of the larger blocks, must have created a break in the rhythm of construction.[50] The actual raising of these blocks, most of which weighed in the region of 10-15 tonnes and up to 20 tonnes for the giant orders, required the use of large cranes operated by treadmills and/or a contingent of men working capstans, all of which had to be set up for each block; raising the columns, which for the screens had to be done as part of the same process, required more heavy equipment to cope with weights of up to 35 tonnes for the 36 foot orders. As well as the time required for such operations the supporting wall for the first block - usually the architrave or architrave/frieze but sometimes a pilaster capital - had first to have developed enough strength to support the block without settling. Alternatively, a temporary scaffolding could have been built to support the projecting part of the block until the wall developed sufficient strength.

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[49] Examples of cross-vaults carried on travertine corbels are numerous, e.g. Aula of Trajan's Markets, frigidarium of the Large Baths at Hadrian's Villa.

[50] Such a break in construction has been noted by Hansen 1960: 20-22 for the Piazza d'Oro at Hadrian's Villa.

6.4 CENTRAL BLOCK: VAULTS

Despite the fact that only a handful of the vaults remain intact, it is still possible to restore almost the complete vaulting pattern (Fig. 86), even if the precise profile of the inner surfaces and the treatment of the outer surfaces remain obscure. All the cross-vaults with the exception of the tepidarium survive to their full height at the wall face on at least one side, and have sufficient left at the springing to show the basic construction, while the two remaining caldarium piers survive to about the top of the drum externally and show the start of the upper curve on the intrados. Barrel-vaults were used over the minor spaces (Rms 7, 11, 3a-d), for the palaestra porticos, and on a larger scale for Rm 21, the bays flanking the frigidarium, and over the tepidarium pools; they were also used to link the piers of the caldarium. All the remaining rectangular spaces except Rm 19 were covered with cross-vaults, usually combined with barrel-vaults along the longer dimension of the room so that the cross-vault itself was over a square bay; the frigidarium had a giant triple cross-vault. Semi-domes covered Rm 13 and the natatio apses, while segmental semi-domes were used over the apses of Rms 20. The vaulting of Rm 22 seems to have been a complex combination of cross-vault and segmental semi-dome. The caldarium had a dome only 25 Roman feet smaller in diameter than that of the Pantheon. The main uncertainty is in the roofing of Rm 19 and the central bay of Rm 20, although these may have had a flat concrete ceiling (see Section 2.5.6).

There was, however, nothing particularly innovative or unusual in the form either of the individual vaults or in their combination; here are none of the complex domical vaults to be found in some Hadrianic architecture, for example.[51] On the other hand, the vaults show a range of building techniques which reveal the confidence of a mature technology, ready to apply the appropriate technique to each particular set of statical and constructional requirements.

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[51] e.g. in the Small Baths and the Piazza d'Oro pavilions at Hadrian's Villa. The one possible exception, of which much has been made in the past, is the supposed spherical pendentives in the octagonal rooms of the outer precinct (Rivoira 1925: 169-72); this is fortunately outside the scope of the thesis.

6.4.1 Horizontally laid vaults

As has long been observed, by the mid-imperial period the most common way of creating a vault in the concrete tradition of the capital was to lay the caementa in horizontal rows in the same manner as the walls, a technique that appeared to mark a complete break with the traditions and mentality of ashlar vaulted construction with its discrete radially set wedge-shaped voussoirs. While theories about this inert monlithic or "metal lid" type of vaulting are now giving way to a more reasonable appreciation of the cracked and active nature of such vaults in practice,[52] the distinction between horizontally and radially laid vaults still remains valid in terms of construction technique.

Most of the vaults in the central block of the Baths of Caracalla are of the usual horizontally laid type. The normal fabric of the vaults is a tufa concrete indistinguisable from that of the walls except by the rather larger size of the caementa,[53] and often by a less careful laying of it in horizontal strata (Figs 87, 88). In the upper parts of the larger vaults, where it was important to reduce the weight of the envelope, the tufa is replaced by caementa of porous volcanic scoria similar in size to the tufa but placed more carefully in horizontal layers.[54] This pumice was used systematically in the crown of the frigidarium cross-vaults and for the uppermost layer of the semi-domes of Rms 13, but with less regularity in the upper part of the cross-vaults in Rms 3W, 2E and 14E at least. We would also expect it to have been used for the upper layer in the caldarium dome,

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[52] The "metal lid" idea seems first to have been mooted by Middleton (1892: I.66) and taken up wholeheartedly by Ward-Perkins and others. Attempts have been made to find alternative explanations, e.g. the corbelling action suggested for domes by Pelliccioni (1986), but it is the recent computer modelling of the Pantheon dome by Mark and Hutchinson (1986) stressing the essentially cracked nature of the structure is most convincing.

[53] On a relatively small sample from the fallen vaulting in Rms 4/5/6W these average roughly 0.05 x 0.05 x 0.1 m and go up to 0.1 x 0.1 x 0.2 m, compared with 0.03 x 0.03 x 0.075 m for the walls.

[54] See Mark and Hutchinson 1986: 28-29 for the effectiveness of using lightweight materials in the upper part of vaults to reduce the thrust on the supports.

following the model of the Pantheon.[55] A rather different case is its use in the upper layer in the palaestra porticos, where a lightweight construction was needed for other reasons (see below).

A further distinction in materials, for quite different structural reasons, was made at the springing of some vaults. In the semi-domes of Rm 13, the first 2.5 to 2.6 m above the springing, equivalent to the height of two bonding courses, is built of brick-faced concrete as a continuation of the rising wall surface complete with put-log holes for scaffolding, but with the bricks set at a slight pitch (Fig. 89). Exactly the same technique was used in the lower parts of the cross-vaults of the frigidarium and Rms 3W and 14E, in the latter case to a height of some 3.2 m. This appears again in the caldarium dome, but here whole bipedales were used. The advantage of such construction is that the lower, nearly vertical parts of the vaults can be built in the same way as the walls themselves without formwork, using only a template to achieve the correct shape.

6.4.2 Radial vaults and vault arches

In a number of places parts of the vaults are built of brick set radially on edge rather than laid horizontally. Three separate cases can be identified, and while each has a slightly different structural and constructional logic underlying it, they all reflect a similar way of approaching a problem.

Firstly, brick occurs in the form of a double arch of bipedales at the semi-circular edges of normal barrel-vaults and cross-vaults where there is no supporting wall, or only a screen wall added at a later stage of construction. The most common case is for each arch to form the head of a single window, the sides of which were built up afterwards, e.g. in Rms 1, 5 (Fig. 78), 7 and 11 at the outer walls of the central block, in Rms 4 (Fig. 90), 5, 6, and 17 at the boundary walls of the

[55] For the Pantheon see De Fine Licht 1968: 132-36 with references. The earlier belief that terracotta amphora were used to lighten the caldarium vault cannot be sustained (see Appendix 3).

palaestra, and at the ends of the triple cross-vault of the frigidarium. The ends of the semi-dome of Rm 13 towards the palaestra and the cross-vault of Rm 14 towards Rm 15 are related examples, but with a more complex arrangement of windows. In all cases the arches are the full thickness of the wall and are built in the same way as the usual door and relieving arches discussed above, with whole and half bipedales set radially with much mortar and some tufa or brick caementa in the spaces. In some examples at least the bricks are arranged as an irregular lattice, with three parallel bands of half bricks linked at every fourth or fifth brick by a whole bipedalis (Fig. 91).

Functionally related to these brick end-arches are the arches embedded in the body of the vault, the so-called brick ribs which have attracted so much attention in the literature. Only two examples of this construction occur in the central block. The simplest is the three ribs in the barrel vaults of Rms 21, most clearly visible in Rm 21W (Fig. 92a, b). The other example, which are really half-embedded ribs, divided the vaults of Rms 8, 9, and 10, spanning from the long outer walls to the now vanished piers facing the palaestra. Since these arches lie between two rectangular cross-vaulted bays, in effect they form ribs in short barrel-vaults as in clear in Fig. 93a. The construction is much the same as the usual door and relieving arches, but in both cases the sides of the ribs are not straight; instead every third or fourth brick projects to form a key with the vault (Fig. 93b).

There has long been a debate concerning the function of brick ribs in vaults, and particularly concerning the extent to which these act independently of the rest of the vault envelope. The arguments are similar to those used in the discussion of door and relieving arches in walls, and are based on the extent to which the arches or ribs penetrate into the core or vault and are built concurrently with it; interpretations have ranged from Choisy who thought that the ribs rose first independently of the envelope, to Ward-Perkins who believed that the ribs rose together with the envelope and had no independent function except during construction.[56] Recently Giuliani has struck a more cautious note, suggesting that each case was slightly different and that most explanations, from directing the thrusts of the vault to dividing up and stabilising the weight of the unset concrete, have some validity in some cases.[57]

One theory which Giuliani does reject, however, is just the one most likely to have been the case for the ribs and end vault arches in the Baths, namely that the ribs were built first independently of the vault. This is most clearly seen at the south end of Rm 9W, where the mortar of the vault is clearly not continuous with that of the arch (Fig. 93b). This same kind of keying also occurs on the inside face of the end vault arch in Rm 1W (Fig. 94), and may have been usual in this position throughout the Baths, although the evidence is slight. This technique was certainly used in earlier vaulted construction, and several examples can been seen, albeit much restored, in Ostia.[58] Even in the barrel-vaults of Rm 21 the surviving ribs are clearly distinguished from the rest of the vault and could have had an independent existence. There is of course no greater difficulty in building arches with some of the radial bricks staggered at the outer ends than with them all following a uniform line.

A common explanation for these two related techniques can be given in terms of the process of construction. One of the difficulties of building a horizontally laid vault must have been to contain any "open" end while the concrete was curing, since the mass of mortar and caementa would tend to flow sideways provided the centering is sufficiently rigid to prevent deformation downwards. In building a wall, this sideways flow is contained by the permanent brick facing, which by virtue

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[56] Choisy 1873: 40-60; Ward-Perkins 1981: 433-35.

[57] Giuliani 1990: 94-96.

[58] e.g. in the Insula di Giove e Ganymede. The technique can be seen very clearly in a photograph taken of Thermopolium in the Via di Diana before the reconstruction of the vault (DAI Inst. Neg. 36.443).

of the thin mortar joints and the exposure to the outside air develops strength more quickly than the mass of the core even when built together with it. The great mass of the vault acting horizontally, especially at the crown, would presumably make it advisable to ensure the rigidity of the end supports before laying the rest of the vault against them; the larger the span of the vault in question the more important these considerations would become. The brick construction of the ribs and end-arches would have achieved a balance between economy and speed of setting, and of course is consistent with the general approach for constructing arches in walls. The ribs in the barrel-vaults would then suggest that the vaults were built in stages, while the ribs between the cross-vaulted bays would enable the vault of each bay to be built independent of its neighbour.

These ribs and arches, and particularly the end-vault arches, might also have had a structural effect even after the whole vault had cured. Those who dismiss any possibility of ribs functioning after the concrete has cured argue that the mortar binds the parts into a solid and homogeneous whole. While the mass may be solid, i.e. with no break between the mortar of the rib and the envelope, it is scarecely homogeneous, since there is a difference both in the relative proportion of mortar to caementa and in the nature of the caementa themselves between the arches/ribs and the rest of the vault. The brick arches are thus analogous to the pumice concrete used in the upper part of the vaults, which has different physical characteristics to the tufa concrete below yet is continuous with it. The brick arches and ribs will tend to be stiffer than the rest of the vault even when the whole vault has cured, and will therefore be more capable both of resisting deformation and of transferring thrusts.[59] The arches at the ends of vaults will thus help to transfer any extra horizontal thrusts which may arise from wind loading, for example, to the supporting piers, as well as counteracting any shear stresses which may arise in the unsupported ends.[60]

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[59] For this effect in the vault of the so-called Temple of Minerva Medica, see Mainstone 1975: 116.

[60] In an ideal situation with a monolithic material under uniform dead loading there should be no stresses in the open ends of barrel- and cross-vaults, the main thrusts acting on the supported sides of the barrel-vault and on the groins of the cross-vaults which replace the lateral supports of the barrel-vault (Mainstone 1975:

Finally, we turn to a number of barrel-vaults which are built as two superimposed rings of bipedales set radially, but with the spandrels filled in with normal horizontally laid tufa concrete. Vaults built in this way link the caldarium piers at both levels, the piers of the frigidarium,[61] and the central piers of the south wall of the natatio (Fig. 95), and form the inner part of the vaults over Rms 3a-d. While most of these vaults have been robbed for the bricks they contain, sufficient remains to establish the details of construction. The bricks are mostly whole bipedales set in much mortar and arranged to break joint in an irregular fashion over the length of the vault. The upper ring of bricks is rarely laid as carefully as the lower ring with many bricks far from radial (Fig. 96), and it thus seems certain that the outer ring was added only after the lower was complete. In all cases the vaults appeared at one or both outer edges as a double arch of bipedales.

This is a technique which is normally more closely associated with Roman construction in the eastern empire, as in the late-second century Harbour baths at Ephesos or the baths at Aspendos, where the horizontal fill is also of solid brick.[62] As Ward-Perkins points out, the use of baked brick in Asia Minor was imported from the west, but it is usually assumed that the development of solid brick vaulting took place in the east in the absence of a mortar strong enough to construct concrete vaults in the manner of the capital. The existence of such vaults in the Baths of Caracalla is unexpected, and raises the possibility of direct eastern influence, perhaps by imported workmen as has been suggested for the occasional brick vault in later restorations of the Aurelianic Walls.[63] Examples of similar brick vaults, however, occur sporadically in earlier buildings in Rome,

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82-86, 102-103, and 127-28). But the ideal situation is rarely met with in practice.

[61] Noted by Durm 1905: 256-57.

[62] Ward-Perkins 1981: 275-77.

[63] Cozza 1989: 43.

notably in the Flavian amphitheatre at Pozzuoli[64], in the lower level of the hemicycle in Trajan's Markets, and in the main ramp of the Mausoleum of Hadrian. This raises the alternative of a continuing tradition of brick vault construction in the west which could have been adopted in the east in a far more developed state than has previously been believed.

There can be little doubt that these vaults would have developed their strength far more rapidly than a normal horizontally-laid vault, since the layers of mortar were very thin. In addition, the close radial setting of the bricks would have allowed them to act as voussoirs as soon as the intervening mortar could offer some frictional resistance to the tendency of the bricks to slip down. The process would be aided by building the two rings separately, allowing the first to cure before adding the second, and then filling in the haunches last. Why this was thought to be necessary in these particular cases but not in the other barrel-vaults in the central block (Rms 7, 11 and 21) is another question, which has no easy solution. What can be noted is that, with the sole exception of the vault in the natatio, all the examples occur where the vaults have a definite and similar structural relationship with respect to a larger vault at a higher level. In both the frigidarium and Rm 3 the barrel-vaults link the piers which support the central triple or double cross-vault, while in the caldarium the vaults link the piers supporting the dome. In these cases it would certainly have been advantageous for the construction of the main vaults if the supporting structure developed strength quickly, particularly at the moment of decentering when the forces due to gravity are suddenly "turned on". In the caldarium the barrel-vaults between the piers also serve to transfer the outward thrust of the vault down to the piers themselves.

6.4.3 Tile linings

Most of the surviving vaults and some of the larger arched window heads in the central block had

[64] This reference was kindly supplied by Lynne Lancaster, with whom I have shared many interesting discussions on Roman vaulting during her research into the vaulting of Trajan's Markets (Oxford M.Phil. thesis 1991).

a lining of tiles. Although in most cases only the layer of bessales - or more commonly their imprints - remains in the face of the vault (Fig. 97), there was usually also an outer layer of bipedales which has since disappeared. Only in the natatio apses (where there are clear signs of plaster over the bessales) and possibly in the semi-domes of Rms 13 and the central lower bays of the natatio and frigidarium, are the bipedales absent; even here it is quite possible that the plaster represents a restoration effectuated after the fall of the original outer lining.[65] Many of the tile linings are also associated with a system of iron tie-bars, the chief purpose of which appears to have been to support the tile linings and the decoration later added to their surface (for details see Appendix 3). The bessales linings are far from regular, and include numerous smaller pieces plus, for example in the vaults of the palaestra portico, some pieces of larger bricks (Fig. 98).

Many explanations have been offered for the presence of these tile linings, which are found in many major monuments in Rome from the Flavians onwards, and must represent a sizable expenditure in bricks and manpower. The most widely accepted hypotheses are that they helped in someway to save on the timber required for the formwork, primarily by saving some of the boarding, and/or that they presented a better surface for plaster to adhere to than the raw mortar.[66] These theories have been challenged by Giuliani, who argues that not only were the bricks more expensive than timber boarding, but that plaster did not in fact adhere well to brick, a fact noted by Vitruvius (de arch. VII.4.2-3).[67] In several of the brick vaults in the Baths every second or third brick projects slightly from the surface as if to provide a key for mortar or plaster, which may support this objection. His alternative suggestion is that the tiles, being more rigid than timber, helped to prevent the deformation of the formwork under the pressure of the wet concrete.

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[65] Cozzo 1928: 179-83 was obviously mislead by these examples into believing that a second lining of bipedales was not used in the Baths at all.

[66] See Cozzo 1928: 179-88; MacDonald 1982: 159; Ward-Perkins 1974: 152-53.

[67] Giuliani 1990: 96.

timber, helped to prevent the deformation of the formwork under the pressure of the wet concrete. Only the bipedales, however, have a large enough surface area to have an appreciable counter-effect to the deformability of the centering, and it does not explain the need for the inner lining of bessales, or those examples where bessales appear on their own.

In the Baths the bessales lined the whole of the intrados of the vaults, but in many other cases they merely formed a grid which would have covered the joints between adjacent bipedales. This suggests that one of the functions of the tile linings was to provide a sealed barrier between the concrete of the vault and the wooden formwork which would prevent the mortar coming in contact with the boards. As we have already noted, one of the most critical moments in the life of a vault is the moment of decentering. The difficulty of this process is exacerbated if the formwork adheres to the underside of the vault rather than coming away cleanly when the wedges supporting the centering are gradually removed. This tends to happen if there are gaps between the boards into which the mortar can seep, or the boards themselves to stick to the mortar. While modern practice is to coat the working surface of the formwork with oil[68], the double tile linings of Roman vaults would have answered just as well. Not only are there advantages with respect to the stability of the vault, but the formwork itself can be removed intact allowing it to be reused if necessary.

6.4.4 Centering

Centering is required in vaulted concrete construction to support and give form to the fluid mass until such times as it develops sufficient strength to stand alone. The essential characteristics of centering are its rigidity - that is its resistence to deformation - and its strength, that is its resistance to ultimate collapse. The first is the responsibility of the formwork, both the boards which give the surface shape and the arched forms which support them; the second is the

[68] See, for example, Foster and Harington 1983: 432.

responsibility of the supports which maintain the formwork in the appropriate place. There must also be some way of lowering the formwork from the underside of the vault in a controlled manner, usually by means of wedges interposed between centering and supports. Since the nature of Roman concrete vaults allowed considerable lee-way in the precise geometric form they took (compare the profiles of the edge vault arches over Rms 7 and 11W in Figs 99a and 99b), the degree of local rigidity provided by the boards and tile linings of the formwork did not have to be defined within narrow limits. Nevertheless, the construction of the arched forms for wide spans must have required both large timbers, particularly for the main horizontal chords, and considerable skill.

For vaults of nominally semi-circular profile the vault is almost vertical up to 30° of arc and exerts hardly more inward thrust than the walls themselves, thus requiring little support. In some cases, as we have already noted, the lower third was faced in brick and built as part of the wall, obviating any need at all of formwork. As the vault rises, however, the rate of curvature increases rapidly, and the thrusts exerted on the formwork by the uncured concrete increase with it, the central section being virtually horizontal. Because of the curved shape, these thrusts have a horizontal component as well as a vertical one, and the arched forms must be rigid in the horizontal direction (i.e. across the chords of the semi-circle); the critical point is one third of the way up where the widest span is supported.

In order to produce centering for vaults of large span the Romans almost certainly made use of triangular timber truss construction where the lower horizontal member is kept in tension and therefore rigid. The roof truss appears to have been used by the Romans, if not invented by them, from the mid-Republic onwards for temples and basilicas, and the principle would have been required for many of their more ambitious wooden structures such as Nero's wooden amphitheatre and Apollodorus of Damascus' bridge over the Danube. It has long been recognised that the developments in concrete vaulting, and particularly in wide-span vaulting, would not have been possible without these independent developments in timber construction.

The centering barrel-vaults is the simplest, consisting only of a series of independent semi-circular arched frames joined by straight timbers (purlins) (Fig. 100). For a cross-vault over a rectangular bay or for a series of cross-vaults, the centering is constructed as if for a barrel-vault across the shortest span and then the intersecting sections of formwork are added, either spanning from an outer semi-circular frame directly onto the boarding of the main centering or supported on intermediate frames of segmental form (Fig. 101). The short ends of both barrel- and cross-vaulted rooms therefore play no part in supporting the vault centering or the vault itself while curing. It is thus possible to work out the general pattern of centering frames for all the barrel- and cross-vaulted rooms of the central block, although determining the number and spacing of the frames is more difficult.

The size of the timbers used for the frames and for the connecting purlins depends on the span of the vault, and thus on the weight of the formwork itself, the tile linings, the unset concrete and the live loads of the builders laying the concrete. It also depends on the number of frames over which the load is distributed. There is no way of telling whether Roman builders preferred to use fewer heavier frames, or more lighter ones. The first option reduces the amount of work required to construct the frames and set up lifting devices to raise them, and minimises the difficult job of decentering, while creating problems in the handling of each individual frame and requiring heavy long timbers.

Some indication of possible Roman practice can be gained from the centering for the barrel-vaulted nave of new St Peter's in Rome (Fig. 102) which has a span very similar to that of the frigidarium of the Baths.[69] Here the spacing was roughly 9 metres and each frame would have weighed about 17 tonnes, within the lifting capabilities of two large treadmill operated cranes. If this system is transferred to the frigidarium vault, only seven frames would be required, one at the ends and one intermediary for each bay. If 9 metres is taken as the maximum possible spacing, then most rooms would need only three and the rest at the most four main centering frames, while the short barrel-vaults of the frigidarium and caldarium pools would only need support at the ends. A "minimum case" restoration is given in Figure 103, with a scheme at roughly 3 metres for comparison.

Since most of the vaults in the central block sprang at a considerable distance above ground, and the larger the span the higher the springing, the technical problems of raising and supporting the formwork must have been of paramount importance. While it must always have been possible to support the formwork directly from the ground on a sea of uprights, efforts were presumably made to reduce such supports to a minimum by resting parts of the centering on projections from the surrounding walls. Under these conditions, with a minimum of central supports which could counteract any tendency for the horizontal members to buckle, the use of trussed construction for the centering becomes doubly important.[70] Studies of such suspended centering have concentrated on ashlar constructions where outsized blocks and corbels were left after completion (the Pont du Gard being the favourite example[71]), but the concept is just as valid in concrete construction (Fig. 100).

The most obvious places where such a device could have been used in the Baths are the cross-vaults of the tepidarium and frigidarium, where the heavily embedded projecting cornices over the

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[69] See Scavizzi 1983: 107-108, and Tav. 6N.

[70] Cf. Adam's reconstruction of the centering of the Pantheon (1984: Fig. 443).

[71] e.g. Fitchen 1961: 9-13; Hauck 1988: 127-29.

main columns would have formed ideal supports for the main centering frames.[72] In both cases, and in Rm 3, the long sides are flanked by terraces over secondary spaces, all of which have, as previously noted, brick built barrel vaults. These terraces would have made ideal platforms on which to set the cranes necessary to raise the centering frames and store materials, but could also have supported cantilevered beams bearing the ends of the intermediate centering frames. Such beams could have been braced from the openings in the screens below to give vertical stability, and tied behind the main end-vault arches for horizontal stability, or even over the ends of the terraces. This latter possibility might explain the change in materials in the vaults of Rms 3a-d, the brick-built parts flanking the main vault being built first and the horizontally built rear sections only being completed after the centering of the main vault had been removed. Similarly, the terraces linking the caldarium piers could have served the same dual purpose of bases for cranes and support for centering for the dome.

In Rms 1, 2, 4/5/6, 8/9/10 and 14, on the other hand, it seems likely that it was the continuous cornices of the columnar screens which helped give support to the centering frames. The irregularly placed extra-large sockets which appear in the long walls of Rms 1 and 4 in the lunettes of the vaults may also have contained cantilevered beams, but in this case more likely to be associated with lifting devices than with support for the centering frames themselves. The iron beams which have left a series of sockets at the impost of the barrel-vault in Rm 21 and the shallow segmental apse domes in Rm 20 were probably intended to support a decorative cornice, but could easily have been used to help support the vault centering during construction.

6.5 CENTRAL BLOCK: ORGANISATION OF CONSTRUCTION

So far we have been looking at the individual techniques of construction, albeit as part of the

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72 Cf. the outsized travertine imposts of the cross-vaults in the Aula of Trajan's markets and the frigidarium of the Large Baths in Hadrian's Villa.

construction process. This section will concentrate on the broader picture, by trying to determine the rhythm of construction. While we have already had occasion to note elements of this in the discussions on relieving arches and the columnar orders, both were concerned only with the vertical order of construction. As well as looking at this in more detail here, attention will be focused on the horizontal order of construction, the problems of moving materials in and out, and the evidence for different work crews.

6.5.1 Order of construction

In the discussion on relieving arches, it became clear that the fill under the arch was added after the construction and decentering of the arch itself (see Section 6.3.5). This is but a very minor example of a type of skeletal construction which Cozzo noted in the Colosseum, the advantages of which were to enable the building to be erected more quickly and work to be carried out at variously levels simultaneously.[73] Cozzo was able to identify the Colosseum process because of the changes in materials used, most of the "skeleton" being in travertine, with the curtain walls in tufa and brick-faced concrete, and the vaults in concrete. Such a piece of detection is far more difficult in a stucture such as the Baths of Caracalla which is built almost entirely of concrete.

It is no surprise that the evidence is clearest for the columnar orders, because of the differences in materials. The main example not already discussed in Section 6.3.7, concerns the arrangements for adding the colonnades and vaults of the palaestra porticos at a late stage in construction. Since I have reviewed the evidence for this elsewhere, a brief summary will suffice here.[74] In order to avoid adding the 60 closely spaced columns of the porticos at a very early stage in the overall construction of the central block, the wall faces which were to receive the barrel-vaults of the

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[73] Cozzo 1928: 216-23.

[74] DeLaine 1985: 198-202. For the broader context of this kind of construction see DeLaine 1990: 417-21.

porticos were left rough to act as a key and a travertine anchor block built into the wall corresponding to each column (Fig. 104). The vaults were then added later in a lightweight concrete with pumice caementa, and tied into the main structure with iron bars. In addition, the inner edge of the vault sprang from a heavy marble cornice, itself a later addition supported by large metal bars built into the wall structure. The advantages of this will be discussed further below.

In addition, it is possible to identify a number of walls which were added only after the main structure - including the vaults - of the rooms they serve. All the jambs built into the lunettes of vaults (e.g. Rm 1, north wall; frigidarium main windows; etc.) creating segmental windows, and the south wall of Rm 14, where there are several windows rather than one single one, were built up after the decentering of the vaults, as was the windowed screen under the arch marking the edge of the semi-dome of Rm 13. Screens over entablatures (e.g. between Rms 1 and 2) are also likely to have been added in a later phase of construction. Where these walls survive, however, it often impossible to see the joins, the addition apparently being keyed in to the main structure as happened with the palaestra vaults. De Fine Licht has identified such keying in the inner chambers of the Pantheon,[75] and less careful building joins can be identified in the brick garden facade of the Insula dei Dipinti at Ostia (Fig. 105); it must have been common practice in Roman construction.

Apart from this evidence for a limited amount of skeletal construction, there are a number of discontinuities in the fabric and irregularities in the pattern of bonding courses which also throw light on the organisation of construction.[76] The actual breaks in the fabric are few, and confined

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[75] De Fine Licht 1968: 138-39.

[76] For some evidence of a similar pattern of construction breaks in the Baths of Trajan see De Fine Licht 1974: 42.

to the blocked doors and niches in Rms 9 and 17, and the area around the frigidarium. Here it is clear that the projecting piers which form the ends of the columnar screens between the frigidarium and Rms 14 are added against the main part of the structure, at least in the lower levels (Fig. 106). The irregularities in the lines of bonding courses are far more numerous, although not all are of equal importance for understanding the general order of construction. Two cases are of particular significance. Firstly, for most of the height of the wall, the bonding courses of the central section of the north facade corresponding to the natatio and part of Rms 1E and 1W do not match those of the rest of the facade, the dividing line being generally the windows of Rms 1 (Sheet 2, Section AA). Secondly, there is a clear break above the tenth bonding courses in the north wall between Rms 20 and 21, and in the inner north corner of Rm 19, thus isolating the stretch of wall which forms the south boundary of the palaestra (Sheet 3, Section DD). In addition, there are breaks at the SE and NW corners of Rm 17E above the sixth bonding course, and in Rms 22 south of the door to the caldarium.

If I am right about the nature of the bonding courses, and about the difficulties of detecting joins in concrete structures, then these identified breaks in the fabric should only represent a minimum number of actual joins and others very likely exist for which there is now no visible evidence. It is also possible that the junctions between the two types of brick fabric noted above also represent breaks in construction. Thus we can provisionally divide the central block into units; the (minimum) likely divisions are shown in Figure 107. The main frigidarium and caldarium piers form obvious entities, and were presumably started first, as these would take the longest to build and needed to develop full strength before the great vaults were laid. The south walls of the palaestrae clearly belong with the inner walls and Rms 13, while the rest of Rms 19-22 including the north walls of Rms 21 and 22 appear to have been built later, as could be the rest of the walls of Rms 15-17 and 23. Another possible unit is formed by Rms 7-11 which are independent of the rest of the structure apart from the palaestra porticos, themselves only added at a late stage in construction; I have argued elsewhere that the blocking of the outer doorways in Rms 9 was probably the last thing to have been done.[77] Finally, it is clear the the natatio north wall was an independent unit, which may have also included Rm 1.

6.5.2 Movement of materials

The pattern of construction units outlined above would have had logistical advantages for the movement of materials in and out of the construction site as the building rose. While most of the materials came in small discrete or infinitely sub-divisable units, the columnar orders and the centering for the vaults both required large and bulky items. With the exception of the south range of rooms including the caldarium, which had wide openings to the outer precinct until the columnar screens were set in place, the remaining perimeter wall has only a few relatively small openings and the completed vault centerings were far too large to pass through them. These must almost all therefore have been assembled within the building, and there are internal rooms and groups of rooms which it would have been hard to supply with even the materials for this if the building was erected all as one piece. In fact the whole area of Rms 15 to 18, 23, tepidarium and south frigidarium block would be a logistical nightmare if built in a single operation; the manoeuvring of the 30 foot, 34 tonne tepidarium columns through the small doors between the frigidarium and tepidarium is only the most obvious of the difficulties. Even in terms of the materials which can be carried by individual men, the small number of entrances and exits would have created serious bottlenecks if the whole of the fabric had risen together and the materials been supplied only as necessary.

These difficulties would have been greatly mitigated by building in sections and using the main interior spaces - the natatio, frigidarium, and palaestrae as temporary depots. The breaks in construction suggest that the site was initially divided into five main operative zones (the two

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[77] DeLaine 1985: 202.

frigidarium blocks, the caldarium, and the blocks surrounding the two palaestrae including Rms 3-6 and 17-18) each with ample access and storage areas, and then fill in the remaining three major zones (Rms 7-11 with the palaestra porticos, the north wall of the natatio with Rms 1, 2, and 14-16, and the hot rooms) plus the tepidarium and the final parts of the frigidarium later. If we remember also that the screen walls between the frigidarium and Rms 14 belongs to a later phase of the building programme, then access on a broad front would be available for all areas of the first proposed stage. The walls with large windows in the tepidarium and Rms 17 would also facilitate the movement of materials in areas otherwise difficult of access. This may apply also to the large exterior windows in Rms 4 and 6, where the sills were raised only at a secondary stage of construction. The blocked window between Rms 17 and 18 may again be a means of improving supply of materials and avoiding problems in the removal of the vault centering in Rm 18. Indeed, the potential problems of erecting and decentering the vaults must have been taken into account even at the design stages, and the order of constructing columnar screens and curtain walls worked out very carefully to allow for this. It is noticeable that in the Baths of Diocletian, the plan of the central block (Fig. 42) has been simplified in such a way as to make the construction units even clearer, the distinction between main skeleton and curtain walls being particularly obvious in the zones flanking the frigidarium and natatio.

Once the first-stage units were well under way, the materials for the second stage could be assembled within what would then become enclosed spaces. Thus the elements of the columnar orders for the natatio and Rm 1 would be stored on the floor of the natatio before the building of the last section of the north facade wall, and all the materials including columnar orders and centering timbers for Rms 7-11 and the palaestra porticos assembled in the two palaestrae before the closing ranges were constructed. The frigidarium would have taken the longest to build, but was also self-contained, so that the materials required to complete this could have be brought in before the outer zones were begun. Such organisation of course depended on the availability of materials and has implications for the supply of them which will be considered in Chapter 8.

6.5.3 Work groups

In Section 3.4.6 we looked at some differences in detail between the two supposedly identical halves of the central block in order to illustrate the extent to which the builders appear to have determined the actual details of construction in response to the architect's indication of specific functional requirements. This argument presupposes that the differences in details reflect the existence of at least two sets of builders each with their own "house style", and such a division has already been noted for the construction of the drainage system (Section 6.2.3). Some of the examples cited in Section 3.4.6 - the staircases in Rms 3d and the arrangement of vertical drainpipes and flues - are clearly the result of single major decisions, and the same must have been true for the use of travertine corbels to form the base for a decorative cornice on the west but not the east half of the north facade. Such decisions are not likely to have been in the hands of any individual bricklayer, but at a higher level in the construction hierarchy. The irregularities in the pattern of bonding courses in the central section of the north facade wall also suggests that this section of wall (one of the last to have been built if my interpretation is correct) was built by two teams working under different commands, starting from the ends and working towards the centre. All this points to the existence of two "master builders" each with responsibility for one half of the building, divided along its major axis. Our understanding of the organisation of the Roman building trade is sadly limited, and there is no way of knowing if the existence of two master builders reflects merely the necessities of such a large project or the use of two (or two groups of) contractors for the construction each choosing his (their) own master builder.[78]

In addition to these major differences between the two halves of the central block, there a very few

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[78] The competition instigated by Nonius Datus between the two groups of workmen to complete the aqueduct tunnel for Lambaesis (CIL VIII 2728) makes one wonder whether a similar sense of friendly (or otherwise) rivalry might not have operated in building the Baths as well.

minor differences in construction technique which perhaps take us closer to the individual bricklayers. The most noticeable relate to the construction of lintel and relieving arches. In terms of the general number and pattern of arches over any opening there are differences not only between one side of the building and the other, but also between parallel examples on the same side of the building. For example, there is a relieving arch in the lunette over the door between Rms 12 and 7 but not Rms 12W and 11W, while the upper arches over the external windows in Rms 7 and 11 are different lengths (Fig. 99). Three out of the four doors in the north facade have double relieving arches while the other, to Rm 5W, has only a single one (Sheet 2, Section AA). The windows in Rms 3c and the doors from the terraces over Rms 11 to Rms 19 follow no regular pattern either. These are hardly important details but ones which require the involvement of more than a single bricklayer and thus are possibly indications of a supervisory level of builders. The mark of the individual bricklayers is more to be seen in the details of the setting of the arches, and particularly the way in which the relation between lintel and relieving arch is handled. While the most common combination is to start the lintel arch just beyond the jamb and to have the relieving and the lintel arches starting at the same horizontal level (Fig. 72), there are other possibiliites. The lintel arch may start further beyond the line of the door jamb, the relieving arch may start above the lintel arch, and this line may be marked by a single bipedalis. Occasionally the relieving arch begins at the upper edge of the lintel arch. The distribution of these variant forms follows no determinable pattern and in a very few cases they even differ from one side of a door or niche to another.

On the whole, however, the hand of the individual builder is hard to find. The absence of the brick facing in many parts and the deterioration of the remaining surface has deprived us of possible distinguishing features such as the treatment of the mortar joints.[79] The variations in the thickness of brick and mortar joints in the facing have already been noted (see above Section

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[79] See Heres 1983: 49-51 for possible types of mortar joints used by Roman builders.

6.3.2), but these seem to reflect the supply of materials or the need to achieve a given level for the bonding courses rather than the idiosyncrasies of any individual bricklayer. The fact that particular hands are so difficult to identify is in itself significant. The uniformity and regularity of good Roman construction even at the level of individual actions is generally taken for granted, but in fact is indicative of a high degree of skill among the bricklayers and some kind of operative standards, as already suggested in the discussion of the implications of the brick modulus (Section 6.3.2).[80] If standards existed, they had to be set, but at what level - client, contractor, or master builder - it is impossible to determine. There may even have been a role here for the fabri tignuarii. The wider implications of this particular problem, and the whole question of the organisation of the building trade, will be considered in more detail in Chapter 9.

6.6 CONCLUSIONS

Throughout this chapter the benefits of a close scrutiny of construction details in the light of the construction process have been made clear, as they affect both the building of the Bath of Caracalla themselves, and our understanding of Roman building practice in general. By elucidating the steps necessary to build the Baths from the initial organisation of the site to the decentering of the great vaults, the ground has been laid for quantifying these actions in Chpater 8. The identification of breaks in construction and differences in technique have brought an understanding of the scheduling of construction and the working of different teams of builders. In addition, new insights have been gained into the nature and function of common building techniques such as bonding courses and relieving arches, which are seen to have an important role to play in the process of construction.

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[80] There is enough bad Roman and particularly late Roman construction to show that this uniformity is not "natural".

CHAPTER SEVEN: DECORATION

INTRODUCTION

Even with construction complete and the great vaults decentered the baths were far from finished. With the exception of the mosaic floors, little now survives in situ of the lavish decoration which once clothed the stark concrete shell, yet it was the decoration which brought to fruition the architect's design, had most impact on the sensory experiences of the visitor, and best expressed the power and munificence of the emperor. Enough evidence survives, however, to reconstruct in essence the types of decoration used for floors, walls and vaults in every room, as well as at least part of the sculptural programme. Since the decoration is not shown on the reconstruction drawings, some space must be devoted to the description and discussion of wall, vault and floor treatments. The distribution of the columnar orders have already discussed with respect to the design and construction, but more can be said about their forms, ornaments, and role in the overall decorative scheme. Although the evidence is much slighter, useful comments can also be made about furnishings and fittings such as windows and doors. The free-standing and architectural sculpture, as well as forming part of the architect's intent on a purely decorative level, when taken together suggest an iconographical programme for the Baths which can be put in the wider context of bath sculpture. By considering the decoration as a whole we can then examine the way it was used to articulate the structure and establish a hierarchy of spaces.

7.1 FLOORS

One of the things that most strikes the modern visitor to the Baths is the expanse of well-preserved (and extensively restored) mosaic floors in the central block. Allowing for areas such as Rms 13 and 17 where none are visible today, mosaics accounted for over two-thirds of the floors, including the terraces and the flat roofs of most of the secondary rooms. Only the rooms on the main axis - the natatio, frigidarium, tepidarium, and caldarium - had marble opus sectile floors, but all traces of these have long since disappeared.

7.1.1 Mosaic floors

The mosaic floors can be divided into four main groups: plain black for most of the roof terraces including those over Rms 3a-d; geometric mosaics in either black-and-white or coloured marble (Rms 2-12, 17); the black-and-white figured mosaics of the terraces of the palaestrae and Rms 4-6; and the coloured figural mosaics of Rms 13. The coarse green porphyry mosaics in Rms 1 and 19 are later (see Section 2.3.3), and there is no indication of what the originals were like, although in Rm 1 at least a coloured geometric mosaic is most probable. There is no evidence for the nature of the mosaics in Rms 14.[1]

The plain black mosaics need little comment. The material used is selce, and the tesserae are rather larger (20 mm) than those of the decorative floors. The use of selce mosaics as an alternative to opus signinum or opus spicatum in service areas is fairly common in Ostia and Rome especially from the second century onwards, but rarely considered worth documenting. They are found in the Markets of Trajan, for example, on the terraces around the base of the semi-domes, apparently replacing an earlier floor of herringbone brick,[2] a use which clearly parallels that in the Baths of Caracalla. For areas exposed to the elements and intended to be accessible, the mosaic floors would give a better foothold than opus signinum, while the material itself presumably originates in the waste from the selce quarries and would be cheaper than the specially made bricks used in the opus spicatum floors. The waterproofing of the roof below was, of course, achieved by the thick bed of opus signinum in which the tesserae were set.

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[1] No longer extant but traces recorded by Blouet (1828: 18).

[2] Blake and Bishop 1973: 23-24.

The geometric floors (Fig. 108) can be divided into two classes according to their materials, selce and white limestone for the black-and-white and porphyries and marble for the coloured mosaics.[3] In both cases the tesserae average 10 to 12 mm, the coloured ones being noticeably irregular in size and shape. The black-and-white mosaics individually present no features that cannot be paralleled in other contemporary mosaics, and belong to a well-established tradition within Italy.[4] Apart from Rms 7 and 11 which show a simple pattern of large and small white squares separated by black rectangles, the black-and-white mosaics all use curvilinear motifs. The main fields of Rms 3 (Fig. 109) and 17 (Fig. 108, Fouille H) share the same basic motif of overlapping scales in alternate colours, but set obliquely in alternating rows in Rm 3 and with wide patterned borders which are different in Rms 3W and 3E. The eight small side rooms 3a-d show six different patterns between them, all with a predominantly black ground (Fig. 110). While the laying out of the actual geometric motifs is accurate in all cases, the positioning of the pattern is surprisingly careless and rarely centred in the available field. This is particularly noticeable in Rm 3Ea, set out from the north-west corner, and Rm 3Wc, set out from the south-west corner (Fig. 109, rear). The main fields are surrounded by a broad black border, usually wider at the rear of the room.

The coloured geometric mosaics in Rms 2, 4, 6, 8-10 and the palaestrae also depend on contrast between dark and light and the motifs would not be out of place among black-and-white mosaics.[5] The range of both light and dark colours, however, allows for more subtle effects. The dark areas are predominantly red and green porphyry although a dark grey marble is also used in Rm 2, while the light areas are pink, yellow and grey/white marble. Rms 2, 4, and 6 have rectilinear, light-

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[3] For the key to the mosaics in Fig. 108 see Blouet 1828: Pl. IV. For the mosaics themselves see Blake 1940: 88-89 and Pl. 34, a,b,e,f.

[4] See Blake 1936: 195-200; 1940: 82-93.

[5] The surviving fragments of mosaic in Rms 5 are plain white with a black border. Blake 1940: 90 believes these are later replacements, but the small size of the tesserae should argue against this. Since the floors survive only at the edges of the rooms, it is possible that the mosaics originally had either an opus sectile or a figured mosaic emblema in the centre.

ground designs, with the pattern picked out in dark tesserae. In Rm 2 the central square is defined by concentric alternating isodomic courses with squares forming the diagonal, and framed by a band of square and rectangular panels with inset roundels of porphyry on the two long sides. In Rms 4 and 6, green porphyry tesserae define rows of elongated hexagons filled with alternately pink, yellow and grey, while blocks of the same pale colours divide the rows (Fig. 108. Fouille S).

Although the mosaics in the portico and central space of the palaestrae use the same basic colours, the effect is quite different. Here the light and dark shades are equally distributed over two colour-ways: red porphyry with grey/white marble, and green porphyry with yellow/pink marble. In the portico there is yet another of these alternating scale patterns (Fig. 110bis), this one with a strong directional effect along the length of the portico; the turning of the corner at the angle of the portico is achieved with masterly effect (Fig. 111). A broad band of pink/grey tesserae followed by a narrower band of yellow and a checkerboard strip of alternately green porphyry and grey tesserae, of total width 0.45 m, separates the scale pattern from the wall. The open area of the palaestra has a more sober pattern of roundels set within squares in alternate pairs of contrasting colours (Fig. 112). A border of green porphyry rinceaux on a white ground in front of Rms 8-10 adds a new note. A small area of mosaic uncovered recently in Rm 10E has revealed a green porphyry roundel within a yellow square, itself framed by a broad green band, suggesting that the mosaics of these ranges were closely related to those of the palaestra itself.

Geometric mosaics in coloured marbles and porphyry are not common in Rome and Ostia before the third century, and there are none for which an earlier date has been securely established.[6] While none of the motifs would be exceptional in normal black-and-white mosaics, Guidobaldi has noted that the pattern of roundels set in contrasting squares and the extensive use of the porphyries

[6] Blake 1940: 98; Guidobaldi and Guidobaldi 1983: 491.

is closer to true opus sectile floors such as that of the Pantheon. Nor would the lighter coloured floors look odd if translated into opus sectile, and in fact the treatment of the bands separating the hexagons in Rms 4 and 6 would be more understandable in this context.[7] The extensive marble veneer with which the Baths were decorated must have resulted in a large quantity of waste fragments which could be used up in these floors, creating the appearance of opus sectile but without incurring the expense of it.

The black-and-white mosaics of the terraces of the palaestra portico and Rms 4-6 belong to a different tradition, but one perfectly at home in bath buildings of the imperial period at Rome and Ostia.[8] In the remaining sections in situ of the palaestra mosaic over Rms 11E and 11W, a deep border of heraldic dolphins, oars and tridents in white on a black background frames a marine scene in black silhouette technique against a white background of aquatic beasts with fish tails driven by Erotes together with a Triton, ichthyocentaur, and Nereid riding a sea-monster, with the water indicated by short horizontal black lines (Fig. 113). The scenes face the outer edge of the terrace. Other fragments now lying against the walls of the palaestrae include a Nereid riding a sea-monster in conjunction with a grape vine (implying perhaps that here we have a marine thiasos) and a striding male figure. Only a few fragments survive on the fallen vaulting of Rms 4-6W, just enough to show a border of regular rinceaux in white on a black background springing probably from acanthus clumps at the corners (Fig. 114), and part of a sea creature with a staff decorated with (?) fillets also in white, against a black background with white water lines; this latter piece is sadly on the under side of a piece of fallen vaulting and can only be made out with great difficulty. Also in this area is a piece of mosaic showing part of a fish tail in the more usual black on white technique, but since it is not attached to any fallen vaulting it may have come from the

[7] See Guidobaldi and Guidobaldi 1983: 69-72, Fig. 17 for opus sectile floors of this type.

[8] For the mosaics see Blake 1940: 90; Brödner 1951: 22, Taf. 27-31; Clarke 1979: 88-89, 96-97; Fabbrini 1983.

palaestra. If the reverse silhouette technique was indeed used on the whole field it would be unusual among this class of mosaics; on the other hand, this was an open roof terrace, and the general use of plain black mosaic in this type of situation may have influenced the choice.

Among the fragments of the palaestra mosaics, Clarke has identified not merely two different hands, but two different schools of mosaicists which can also be detected in contemporary mosaics at Ostia.[9] Two different hands or schools can also be seen in the green porphyry rinceaux of the main palaestra mosaics (Figs 112, 115).[10] At the same time the porphyry rinceaux in the west palaestra are virtually identical to the white ones from the terrace of Rms 4-6W. If all the rinceaux were done by the same mosaicists as the figured scenes, as seems reasonable to assume, then so far we have at least three main groups at work, two on the figured scenes and one on the purely geometric work, coloured and black-and-white. It is also possible to suppose some degree of specialisation within the latter group, again according to pattern rather than materials. I would be inclined to put all the scale patterns together (Rms 3, 17 and palaestra portico), then the simple geometric and curvilinear mosaics of Rms 3a-d, 7 and 11, and lastly the opus sectile type patterns.

Finally we need to consider the famous athlete mosaics from the semi-circular Rms 13, now in the Lateran collection of the Vatican Museum (Fig. 116).[11] At the time of excavation that in Rm 13W was best preserved, but enough remained to show that the two were identical in arrangement.[12] The floor was divided into 17 vertical strips, each composed of several panels containing alternately busts and full length figures of athletes and their trainers, with objects

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[9] Clarke 1979: 96-97.

[10] Guidobaldi 1983: 499.

[11] For the mosaics see Secchi 1843; Iwanoff-Hülsen 1898: 73-75; Nogara 1910: 1-3, Pls i-iv; Ippel 1930: 108; Blake 1940: 111-12.

[12] Blouet 1828: Pl. IV.

relating to athletic contests in the triangular panels around the circumference of the room. Each panel is framed by a dentilated patterned, and the panels divided by four-strand guilloches. The figures are clearly the work of several hands, and the whole mosaic is said to have been made in sections.[13]

The dating of these is notoriously difficult, and any period from the time of Caracalla well into the fourth century has been suggested.[14] Since the mosaics were removed following the 1824 excavations and have been restored and re-arranged several times since, the dating cannot be helped by either archaeological data or technical criteria. Coloured figural floor mosaics begin to take over from black-and-white silhouette mosaics in Rome and Ostia sometime in the third century, but there are no clearly dated examples until the fourth century. The nearest parallels to the athlete mosaics are from Tunisia and date to the third and early fourth centuries;[15] the athletes have also been compared with the Giants from Piazza Armerina.[16] Given that there is good evidence from both the coloured geometric mosaics and the colossal sculptures apparently commissioned for the baths (see below) that new ground was being broken in the decoration of the central block, it would not be surprising if the athlete mosaics were also trend setters, and influenced the subsequent move to polychrome mosaics.[17] The source of the new technique must be North Africa, not surprisingly for this dynasty from Lepcis Magna.

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[13] Ippel 1930: 108.

[14] Caracalla - Secchi 1843; Blake 1940: 112; Levi 1949: 58. Later third or early fourth - Iwanoff-Hülsen 1898: 75; Ippel 1930: 108; Dorigo 1971: 145-47.

[15] Cf. mosaics from the Baths at Gigithis (Gauckler 1910: A 300-301bis, Pl. XIX, 1 and 2), and baths at Thaenae (Yacoub 1966: Pl. XV, 1.).

[16] Dorigo 1971: 146-47 (later 3rd century).

[17] Blake 1940: 112 notes the similarity with the athlete mosaics found near the Porta Maggiore and now in the Antiquarium Comunale at Rome.

7.1.2 Opus sectile floors

No trace whatever survives today of the marble floors which once decorated the natatio, frigidarium, tepidarium, and caldarium, although a few small fragments of white marble remain in the frigidarium pools (Fig. 117). Gnoli records finding fragments of Egyptian onyx from the floors of some rooms in the baths, but these are no longer visible.[18] Large areas with granite roundels were found in situ when the caldarium was excavated in the 1870's (Fig. 11), but even this represents a late, possibly fifth century repair or replacement (see Section 2.3.2). Other survivals include fragments of the steps to one of the frigidarium pools and between frigidarium and natatio, and a white marble threshold between Rms 13 and 14W. Given the otherwise total absence of thresholds combined with the clear break between mosaic pavements at doorways, there can be little doubt that once all the thresholds were of marble. Apart from the obvious suggestion that the floors are most likely to have been decorated with large-scale patterns such as those known from the Pantheon and the Palatine triclinium,[19] we can go no further.

7.2 WALL AND VAULT TREATMENTS

As far as can be determined from the surviving evidence, all the walls and vaults were decorated with marble and either painted stucco or glass mosaic. Since the upper part of the walls appears to have been given the same treatment as the vaults, I have taken walls and vaults together. In all cases, while the nature of the surface treatment and the demarcation between marble and stucco or mosaic are easy to establish, hardly any of the detail survives. Thus, although it is a reasonable assumption that both the painted stucco and mosaic included some figured scenes, there is no evidence at all of their nature and discussion is limited to identifying the survivals and plotting the distribution. We are better off with the marble veneer, since the rows of holes for the cramps

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[18] Gnoli 1971: 186-87.

[19] See Guidobaldi 1985 for a classification and chronology of opus sectile floors, especially pp. 176-80 and 226 for this type ("a grande modulo").

which once supported the veneer survive in places even where the marble itself is long gone, and in places it is possible to reconstruct the outlines of the design.

7.2.1 Marble veneer

With the exception of a single piece of fluted Numidian marble high in the NW corner of Rm 14W (Fig. 118), the only fragments of wall veneer in situ are several pieces of a low dado in Rm 3 (grey/white marble, Chian, africano), Rms 4/5/6E (green africano and Thessalian green), Rm 13 (grey/white and Numidian), and Rm 17E (green africano). As well as the fragments still in situ, excavation records help identify the types of marble used in the veneer decoration. Blouet records red, green, and black porphyry, Numidian, Chian, Docimian, Thessalian green, green and black africano, alabaster and white marble, to which can be added breccia corallina, rosso antico, and granite from the 1870's excavations.[20] Gnoli also records fragments of 'bianco e nero tigrato', a relatively rare marble probably from Anatolia which was not apparently used before the Severan period.[21]

The porphyries were most often used as shaped panels set into a frame of light-coloured marble, as in the Pantheon, and this style of decoration presumably accounts for the large number of porphyry fragments found here; the fragments from the frigidarium excavations included a small rectangle of red porphyry 0.12 x 0.23 m, which must have been an inset. Many of the narrow dividing strips and cornices were also of porphyry, Numidian being the next most common material with white marble for several decorated cornices, although these may have come from the architectural orders.

[20] Blouet 1828: xiii; Archivio dello Stato, Ministero della Istruzione Pubblica, Direzione Generale per Antichità e Belle Arti, Antichità e scavi, Buste 100-102, Fas. 133-134.

[21] Gnoli 1971: 170.

As a general rule, the extent of the marble was related architectonically to the space it decorated, coinciding with either half the height of the room (Rms 1, 2, 3) or the springing of the vault (Rms 13, 14, 17, natatio south), or running to the top (Rms 4/5/6, 8/9/10) or bottom (Rm 12 portico) of the entablature of the main columnar order. In Rms 2 and 14 this coincides with both the vault springing and the top of the main order. As already suggested in Section 3.3.3, the effect would have been to clarify the design of the elevations. In the light of this, and given the clear evidence for a cornice at the tenth bonding course in most of Rms 19-22, it seems likely that this marked the extent of the marble veneer in these rooms. The wall behind the aedicular facade in the natatio was sheathed in marble to the top of the tallest order. Not all areas show such extensive use of marble. Although the evidence is slight, it seems that in the minor rooms 3a-d, 7 and 11 a simple sockle sufficed, while on the north, west and east facades and possibly also on the south only the bottom four metres were sheathed in marble. There was a band of marble veneer roughly 2.2 m high above the terraces of the palaestra portico.

It has been possible to reconstruct much of the veneer pattern for some walls of Rms 3, 13, and 14 (Fig. 119), and the fragmentary remains in other rooms show that all followed a similar type of pattern. A low sockle, usually roughly 0.6 or 0.74 m high (2 or 2.5 feet) but up to 3.5 feet, is followed by a row of orthostates 5 to 6.5 feet high capped by a thin cornice moulding. These are usually divided into alternately wide and narrow panels, the most common pattern consisting of panels 3.5 to 4 feet wide divided by strips 1 to 1.5 feet wide. A series of one or two narrower bands follow, 3.5 to 4 feet in height, on top of which is a further set of rather taller orthostates up to 8 feet in height. Next comes a zone made up of several much thinner bands, some only 1 to 1.5 ft high, and including one or more cornice strips, after which there is one or in the taller rooms two further zones of tall panels, again usually divided vertically into alternately narrow and wide strips, finished by a single band and final cornice strip. The internal divisions of the narrower bands have left no trace, the clamps on the upper and lower edges presumably sufficing without the need for any on the vertical edges.

The pattern of low sockle and tall orthostates in alternately wide and narrow panels is well-attested among the surviving marble veneer decoration, such as the Schola of the Augustales or the aula in the palaestra of the Forum Baths at Ostia, and the whole pattern is very similar to the interior of the cella of Maxentius' Temple of Venus and Rome. The use of a second row of orthostates above the first in the lower register is not particularly common, but evidence for marble veneer patterns above the first few zones is anyhow scare. This type of decoration has its origins in the Hellenistic period, as witnessed by the Masonry Style wall paintings from Delos and elsewhere, and the related First Style wall painting from Pompeii and elsewhere in Italy.[22] The division of the upper part of the walls into a series of low bands followed by further vertical panels can also be seen to conform to the basic Hellenistic distribution of a series of string courses followed by isodomic course and at the top some form of miniature decorative order, here equated with the final zone of orthostates. The surviving fragment of veneer from this zone in Rm 14W is fluted (Fig. 118), suggesting that this was in fact treated as a decorative order; the effect must have been something like the original upper zone of the Pantheon.[23]

The pattern of cramp holes and gaps in the plaster backing for the dado either side of most doorways reveal the use of marble frames, usually about 0.44 m (one and a half feet) wide. Some of them (e.g. Rm 3W) appear to have an extra wide band for the lintel which cuts across the horizontal courses of the wall veneer; this was presumably treated as a full entablature in the manner of the Pantheon portal, the narrower uniform frames having just the architrave mouldings all round as in the restored caldarium doorway in the Baths of Buticosus at Ostia. Similar but slightly narrower (c. 0.3 m or 1 foot) frames surrounded the niches (Fig. 120). The evidence for

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[22] See Bruno 1969 for the Hellenistic material, and Laidlaw 1985: 25-37 for the Pompeii.

[23] De Fine Licht 1968: 114-26.

the windows is less clear. In Rms 3, the openings above the broad doorways into the subsidiary rooms appear to have had a narrower frame than the doorways themselves, and the faces of the jambs show the distinctive veneer holes. Unfortunately, only the inner faces of the jambs of the external windows still have their brick facing, and these invariably show a central vertical row of small holes fairly close together, with a few horizontal rows either side at intervals of 1.5 to 2 m. These, I believe, are for fixing the glazing frames rather than for veneer (see below). The exception is the windows at the rear of the south frigidarium pools, which certainly had frames around the opening and possibly veneer on the thick inner jambs as well (Fig. 121).

7.2.2 Stucco and glass mosaic

Most of what survives are the preparatory layers of plaster above the marble veneer which can be seen in Rms 1, 2, 3, 4-6, 8-10, 13, 14, the frigidarium, and on all four facades. Only two small fragments of stucco decoration remain, both high in the lunette of the vault. In Rm 8E the outline of an egg-and-tongue against a blue background, followed by a well-preserved bead-and-reel follow the curve of the vault (Fig. 122), while in Rm 4W traces of another bead-and-reel can be made out. Even less survives of the mosaic pattern, although some coloured tesserae remain in situ in Rm 1W (blue, green), Rm 14W (yellow, green, ochre, blue), and the frigidarium (turquoise, blue, green), and Sear believes that the border pattern in Rm 14 might be made out from scaffolding.[24] In a few places where no plaster survives but the brick facing does, the surface of the brick is lightly picked to provide a key for plaster (Fig. 123), while on the face of the wall at the south end of the east palaestra portico iron pins follow the curve of the vault at 0.4 to 0.6 m centres and are set alternately at 0.8 to 0.9 m centres in every third row of brick, again to provide a key for the plaster.

Provided the final layer of the plaster survives, it is possible to distinguish between the areas with

[24] Sear 1977: 127.

mosaic and those with plaster decoration since the imprint of the tesserae will remain. Thus it is clear that Rms 1, 2, 14, the frigidarium, and the bays of the south facade of the natatio, plus the heads of the semi-circular niches in these last two areas, were all decorated with mosaic, while Rms 3, 4-6, and 8-10 had stucco. In addition, Blouet recorded that the upper part of the south facade, the upper walls and vaults of Rm 17, and the vaults of the palaestra porticos were also decorated with mosaic.[25] In the clearing and restoration of the area between Rms 8-10E and the east palaestra, numerous glass mosaic tesserae came to light in all the usual shades of blue to green plus red and clear glass which was presumably once gold or silver leaf. This suggests that the facade of Rms 8-10 on the palaestra might also have been decorated with glass mosaic. Although it is not usual to associate glass mosaic with large-scale facade decoration, there are a few surviving examples going back to the mosaic pediment on the garden facade of the Casa dei Cervi at Herculaneum.[26]

7.2.3 The caldarium ceiling

On the basis of the famous passage from the Historia Augusta concerning the "cella solearis" of the Baths of Caracalla (Cara. IX, 4-5), a case can be made for the dome of the caldarium being decorated neither with stucco not glass mosaic but with some kind of (possibly gilded) bronze lattice. I have already discussed this passage in some detail elsewhere (see Appendix 3), and only a few comments need to be added here.

The only physical evidence for the bronze lattice mentioned in the text is the robber holes resulting from the removal of large metal (probably iron) bars from the window arches of the remaining caldarium piers, and photographic documentation that similar holes once existed in the inner face

[25] Blouet 1828: xiii, 18. The glass mosaic in the vaults of the palaestra porticos was also noted in the 16th century, see Lanciani 1902-1904 (II): 183.

[26] Sear 1977: 27, 96 (no. 72).

of the dome itself. The form of the proposed lattice can therefore no longer be determined, but I would like to suggest one possibility, that it was designed to reflect the coffering more usually found in both flat timber and vaulted concrete ceilings. In his discussion of the decoration of the Pantheon dome, De Fine Licht points to the existence of hooks in the centres of the coffers and cramp holes below each coffer and along the ribs.[27] This evidence together with the remains of the bronze sheathing of the oculus leads him to suggest that the whole interior of the dome, which bears no other evidence of decoration, might have been sheathed in bronze. It would be a relatively straightforward step to move from decorating coffers cast in the concrete of a dome with bronze, to creating a separate bronze lattice with decorative panels attached to the inner surface of the dome with large iron ties.

7.3 ARCHITECTURAL ORDERS

We have already had occasion to discuss the architectural orders used in the central block, both in terms of the problems of their reconstruction (Section 2.5.4), and as an integral part of the construction process (Section 6.3.7). The evidence is given in Appendix 1. Here I intend to concentrate on the details of the individual orders and their decorative aspects, and on the natatio facade.

7.3.1 Nature of the orders

The decorative effects of the orders depended largely on the colour and surface treatment of their shafts, on the nature of the decorated mouldings, and on their power to articulate a structure by introducing strong vertical and horizontal rhythms. A predictable range of stones was used for the column shafts, but a rather restricted one compared with the marbles so far identified in the veneer. Over 50% by volume of the shafts were of grey granite, including all those of the giant orders and the largest single numerical group, the columns of the palaestra porticos. A further 20% by

[27] De Fine Licht 1968: 142-46.

volume were of red granite from Syene, made up largely of the only other large group, the columns from the facade of the hot rooms. The remaining columns were, in descending order of quantity, of alabaster, Numidian, Docimian, red porphyry, Carystian, and grey/white marble. The relative absence of Carystian is surprising, given the amount used in the Severan building programme at Lepcis Magna, while in such a high status building we might perhaps have expected more of the prestigious Numidian and Docimian. Furthermore, the preponderance of grey granite is unexpected since, even with the shafts polished to a high degree, the overall effect would have been more sober than colourful.

A number of factors can be suggested to account for this predominance of granite. This is a phenomenon not restricted to the Baths of Caracalla, since in Rome at least granite was a common choice in public buildings where either a large number of or very large individual columns were required, as in the Basilica Ulpia, the Temple of Deified Trajan, the Temple of Venus and Rome, etc. According to the Prices Edict of Diocletian, the porphyries (at 250 denarii/P^2) along with Numidian and Docimian (at 200 denarii/P^2) were the most expensive marbles, followed by the granites and Carystian (100 denarii/P^2), then alabaster (75 denarii/P^2), so that it might at first sight be thought an economic choice.[28] As has already been argued, however, these figures represent only some kind of "market values", and not the real cost to the emperor even in relative terms (see Section 4.3.5). The distribution may rather reflect the pattern of production and supply, since very few quarries could produce the giant monoliths (Carystos being the only other source of columns over 40 foot among the coloured stones) or be sure of producing a large number of matching columns at short notice. The use of red granite in the Baths of Caracalla may well reflect the particular circumstance of the opening of new quarries near Syene under Septimius Severus.

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[28] It should be noted that a single 25 foot column shaft contains enough marble to provide all the veneer for Rm 1 or Rm 2, while the Numidian, Docimian, Carystian and alabaster columns, which form barely 20% by volume of the total, could have provided the veneer for all of Rms 1-14.

In the remaining individual elements of the orders rich decorative effects are the rule. The surviving capitals are all Corinthian or Composite with figured varieties included in both types, while decorated Tuscan capitals were probably used for the external screens for the hot rooms (see Section 2.5.4). The few remaining bases are of the plain standard imperial Attic or double-scotia types, although Kinney has tentatively identified some decorated bases in Sta Maria in Trastevere as coming from the Baths.[29] All the mouldings on the surviving fragments of entablature and those recorded in the Renaissance and later periods are decorated, with frequent use of acanthus and scroll motifs (Fig. 124). Without exception these belong to that strand of the Severan tradition in architectural ornament which von Blanckenhagen dubbed the "Flavian revival", although some of the individual motifs (such as the continuous bead used in the architrave of the palaestra porticos) did not form part of the Flavian repertoire.[30] The carving is of variable quality, but in common with much Severan ornament shows a predilection for strong chiaroscuro effects. Such ornament is highly suited to internal use, where there is no strong directional light to give relief to the plain mouldings or pick out the more subtle forms of plastically treated details. There is no evidence to show whether such heavily drilled ornament was also painted or even gilded, but it is a possibility worth bearing in mind when considering the overall effect of the architectural decoration.

Some of the large-scale effects of the columnar orders have already been discussed in the chapter on design (Section 3.3.5) and only need reiterating here. Firstly, the dominant horizontals (top or bottom) of the entablature in any columnar screen divide the height of the room into two equal halves and/or correspond with the springing of the vault, thus functioning visually in much the same way as the division between the marble wall veneer and the stucco or mosaic decoration on

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[29] Kinney 1986: 387.

[30] For the Flavian revival see Von Blanckenhagen 1940: 90-99, and cf. Neu 1972: 53-58 on the Baths of Caracalla.

the wall and vault above. In contrast, the repeated verticals of the (structurally unnecessary) columnar screens create an ambivalent element which both defines the line of a wall and allows passage through it, emphasising the shape and proportions of the individual areas while at the same time creating both physical and - more importantly - visual links between one area and another. Much of the sense of vast space which is today one of the most striking features of the central block is due to the large openings which once held columnar screens, and these would not have substantially altered this perception. If anything, the screens would have increased the sense of space, since they provided a scaled frame against which the distance to the next plane could be read. This can be seen most clearly along the major transverse axis. The perspective effects of a vista successively through columnar screen (F/14), arched opening (14/13), double columnar screen (13/12 and 12 portico), bright open space (palaestra), and columnar screen (12/9), ending in a massive sculpture set in a shallow apse, must have been much stronger than the present one where the scale is defined only by the arched opening between Rms 14 and 13.

7.3.2 The aedicular facade of the natatio

As well as their use in such columnar screens, the orders were employed purely for emphasis and decorative effect. The simplest example of this is the aedicular framing of some niches and the external face of the main entrances on the north facade; the most complex, the north wall of the natatio itself (Sheet 4, Section JJ). Five different sizes of columns in two registers were used in this elaborate decorative scheme, which owes much to imperial traditions of theatre stage decoration and in particular those monumental civic nymphaea which we usually associate with the eastern empire.[31] There is, however, an almost contemporary example at Rome itself, the Septizonium built by Septimius Severus at the foot of the Palatine. Such an elaborate facade was missing from the Baths of Trajan, and it may be that this element was introduced into the scheme of the thermae only with the Baths of Caracalla, possibly under the influence of the Septizonium

[31] See Neuerberg 1965: 84-85, 228.

itself. Such columnar decoration was relatively common in the large baths of the eastern empire, but usually adorning halls associated with the imperial cult and outside of the main bathing sequence.[32] The fountains in the natatio facade, however, make this a less likely source of inspiration than the nymphaea.

None of the decoration remains in situ today, but a certain amount survived into the 16th century and was drawn by various artists of the time. Sketches by Palladio, Antonio Abaco, and Giovanni Battista da Sangallo (Fig. 125) give the basic organisation of the facade, and this is followed by Blouet (Fig. 126). The wall is divided into three bays by a giant order of granite columns. Each bay contains six niches, three in each of two levels, divided by two superimposed columnar orders, the lower with shafts of Carystian marble and the upper of Numidian. So far all versions of the facade agree, and this is supported by the cuttings and robber holes in the actual wall (Fig. 83). Most of the reconstructions show minor orders forming columnar aedicules around all the niches, but the semi-circular niches in the outer bays at the lower level in fact show no signs of such framing and should be restored without it. There is a lack of consensus also in these drawings over the relative heights of the main and the combined superimposed orders, but it is clear from the restored heights of the individual orders and the cuttings that Palladio was correct in showing that these coincided.

This use of both a giant order and two superimposed orders in conjunction with two levels of framed niches is very unusual. Most examples of the scaenae frons type of facade have only the two or three superimposed levels of columns dividing the aedicules, without the giant orders. Alternatively, an engaged giant order can be used in the same manner to divide up superimposed rows of niches (framed by aedicules or not) as in the interior of the temples of Bacchus and Jupiter at Baalbek. The only other example of this combination that I am aware of is in the apses of the

[32] Yegül 1982.

Severan basilica at Lepcis Magna, where it is considered by Ward-Perkins to be an afterthought.[33] It is not impossible, then, that this concatenation of usually alternative schemes was a Severan development. Such a combination of different sized columns is as contrary to the logical of the orders as a broken pediment, and owes much to the so-called "baroque" usage of the orders which became increasingly common during the first three centuries of the empire;[34] it is also, given the use of a truly giant order of the size normally reserved for imperial temples, a clear case of "conspicuous consumption" or, as I would prefer to put it, of conspicuous power.

7.4 FURNISHINGS AND FITTINGS

When we turn to consider the furnishings and fittings which must have once given the final touches to the central block, the evidence is all too fragmentary. Except for those pools which form an integral part of the fabric, nothing remains in situ and we have to rely on records of earlier explorations and excavations which do not always indicate the precise findspots of the objects concerned. The reconstruction of some elements indeed has to be based purely on analogy with other buildings.

This is certainly the case with the window fittings. There is now ample evidence for the widespread use of glazed windows in baths,[35] and there can be little doubt that all of the windows in the central block were glazed. Nevertheless, although Blouet recorded evidence of bronze frames presumably for glazing in the large windows of Rms 17, no such clear traces remain today.[36] Most of the window openings in which the brick facing of the jambs is still intact,

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[33] Ward-Perkins 1981: 386-88.

[34] See Lyttleton 1974 for ancient "baroque" in general, and MacDonald 1986: 183-207, 221-37.

[35] Recent examples include Samos (Martini 1984: 199-200), Corinth (Biers 1984: 95-105 passim), Caerleon (Zienkiewicz 1986: I.32, 337; II.116), Bosra (Broise 1991: 74). The latter includes both cylinder and crown glass.

[36] Blouet 1828: 18.

however, show a vertical line of fairly closely spaced cramp holes, usually but not always roughly in the centre of the jamb. Further holes are placed horizontally either side of this central line, with usually two holes in each set and the sets at roughly two metre vertical intervals, but offset by about 0.4 m vertically either side of the central line (Fig. 127). While it is possible that these are simply for the marble veneer, they could also represent the fixing points for metal window frames braced laterally at regular intervals, surely a necessity given the large size of the openings. Recent work by Broise on window fittings from bath buildings shows how slight can be the evidence for such frames.[37] What is impossible to recover is any idea of the form of the frames, except that they must have been subdivided in some way, the largest window panes being no more than about a metre in their longest dimension.

Not even this much evidence survives for the doors of the central block, although these must have existed at the external openings on the north, east and west facades, between the unheated and heated spaces (frigidarium and tepidarium, palaestra and Rms 17-19), and between the various heated rooms.[38] There were also barriers closing off at least some of the columnar screens. While no trace remains of the "bronze gates" noted by Piranesi between the natatio and frigidarium, fragments still remain of the low marble barriers between Rms 1 and the natatio found in the Conte di Velo's excavations and recorded by Blouet.[39] These latter are of the familiar Roman type, consisting of uprights into which are slotted panels carved to imitate a wood or metal fence with vertical, horizontal, and diagonal bars intersecting at circular bosses. On practical grounds it is tempting to restore such barriers between all but the central intercolumniations of the columnar screens flanking the natatio and the frigidarium pools. Some kind of barrier presumably also

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[37] Broise 1991: 70-76.

[38] There is no real evidence of the provenance of the bronze door, reputedly from the Baths of Caracalla, in the 5th century chapel of St John the Baptist forming part of the Lateran baptistery in Rome. Since the door is original, it is unlikely to have come from the Baths which were still operational at the time.

[39] Lanciani 1897: 538; Blouet 1828: Pl. XII, Fouille T.

existed on the edges of the terraces overlooking the palaestra, but no evidence for these survives.

We are slightly better off when it comes to considering the decorative water features of the Baths since it is almost certain that the two "bath-tub" shaped fountain basins in Mons Claudianus granite now in the Piazza Farnese in Rome came from the two rooms (Rms 14) flanking the frigidarium (Fig. 128). A drain probably for the eastern one is shown on De Angelis' plan of the substructures (Fig. 13). Gasparri traces the circular porphyry basin drawn by Palladio, 3.2 m in diameter and decorated with theatrical masks and snakes (Fig. 129), to Naples and notes evidence for the existence of a second.[40] It is tempting to restore these below the niches set back-to-back, one in the central south bay of the frigidarium (Fig. 130) and the other in the tepidarium. The niches show every signs of having been supplied with fountains, but no basins survive. Such a basin in the frigidarium would mirror the shallow circular pool (? a foot bath) built into the floor of the central north bay (Fig. 131). All of these basins, the frigidarium pools, and the fountain inlets in the natatio facade must have been supplied with water spouts of some kind, but none of these or any other part of the plumbing remains.

Finally, mention must be made of the 1600 seats for bathers reported by Olympiodorus in the 5th century AD.[41] The pavonazzetto seat in the British Museum and less certainly the rosso antico armchairs once in the Lateran may have made up some of this number.[42] Such furniture is rare from excavated baths, although there are several marble and bronze benches in the various baths of Pompeii and Herculaneum, and other have been found for example at Timgad and Cyrene. More common are the masonry benches built against the walls in many Ostian baths, particularly in the apodyteria and in the hot rooms. There are numerous possible sites for free-standing seats

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[40] Gasparri 1983-1984: 136 with refs.

[41] ap. Phot. p.63a, lines 23-30 (ed. I. Bekker, Berlin 1824).

[42] See Gasparri 1983-1984: 136.

or benches in the central block of the Baths of Caracalla, including the hot rooms (Rms 19-22), the apodyteria (Rms 3), and all of the remaining secondary unheated halls (Rms 1, 2, 4-6, 8-10, 13, 14). In the apodyteria there should also have been some kind of niches or cupboards for the bathers' clothes, and these were presumably in wood or bronze and attached to the walls. As might be expected, no traces of these remain, but the wide plain borders on the mosaic floors of the subsidiary rooms 3a-d, which must have formed the storage part of the apodyteria, may reflect their presence.

7.5 FREE-STANDING AND ARCHITECTURAL SCULPTURE

A large amount of free-standing sculpture was discovered in the Baths, most of it during the depredations of Pope Paul III (Alessandro Farnese), including the Farnese Hercules and the Farnese Bull both now in the National Museum in Naples.[43] The early 20th century explorations of the maintenance passages of the central block also produced several notable fragments including a colossal head of Aesculapius.[44] To this we can add several fragments of decorated frieze and the figured capitals of the palaestra and - although possibly of a later date - the frigidarium. The large number of niches in the central block strongly suggests that the surviving and recorded fragments of free-standing sculpture represent only a fraction of the total. Altogether there are 106 niches, most of which begin at the second bonding course (9 Roman feet above ground). The exceptions are those in the pools of the natatio, frigidarium and tepidarium which begin at the first bonding course, and the nine niches in the upper register of the natatio north facade. A total of 41 of the niches, comprising those on the north facade, in the lower register of the natatio facade, in the pools and the centre of the south wall of the frigidarium, and in the tepidarium, were supplied with

[43] Lanciani 1901-1903 (II): 179-84.

[44] Savignoni 1901.

water, raising the possibility that they held fountain sculptures.[45] The two colossal statues of Hercules were found in the intercolumniations between the frigidarium and Rm 14,[46] suggesting that there was a corresponding pair of sculptures in the same position on the other side. In addition, it is almost certain that there were large sculptural groups in the apses of Rms 9 forming focal points at the end of the long axes, and probably in the shallow apses in the central bay between frigidarium and natatio.

The free-standing sculpture from the Baths has recently been subject to a thorough re-evaluation by Marvin (1983), with further work by Gasparri (1983-84). Marvin identifies two main groups from the central block: a small number (10 or so) of colossal figures and groups which appear to have been made specifically for the Baths and a larger number of pieces of clearly earlier date reused here, most of which are life-sized or slightly over, with one or two colossal pieces. The majority of the pieces fit into the normal iconography of bath sculptures recently elucidated by Manderscheid (1981), comprising classical deities, personifications and ideal types suggestive of health and pleasure, and honorific statues. Thus we have athletes (copies of Doryphoros and Diskobolos), a colossal Aesculapius, a colossal Athena possibly in the guise of Minerva Medica, three Hercules, and a possible group of Dionysus and satyr. In addition there are several fragments of idealised nude male figures which may be athletes or appropriate young gods such as Hermes, Dionysus or Eros, and nude or partly draped female figures which should be nymphs or Venuses. There was certainly a statue of Caracalla, and at least one earlier imperial portrait. Other types are less expected, including many of the colossal figures Marvin sees as being made specifically for the Baths. These include the group of Dirce and the bull from the apse of Rm 9E,

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[45] One of the fragments found in the 1901 excavations of the drainage passages is listed as "una mano più piccola del vero, forse di ragazzo, che teneva una fistula" (Savignoni 1901: 253), which is most likely a fountain sculpture.

[46] Indicated in a sketch by Antonio Sangallo the Younger made during the excavations of 1545-1546 (Iwanoff-Hülsen 1898: Taf. N.).

a warrior carrying a dead youth (identified by Marvin as Achilles and Troilus), and a basalt Victory which may have been paired with a basalt Maenad. There was probably a second large mythological group, including an island, several figures and a ship, in Rm 9W.[47] As Marvin points out, some of the colossal figures, such as the two weary Hercules and the giant Aesculapius, are unusual just because of their sheer size, no other bath building having produced more than one colossal figure.

This same mixture of the expected and the unexpected is found in what can be reconstructed of the architectural sculpture. Several frieze fragments from the inner wall of the palaestra show a rich acanthus scroll peopled with erotes and animals (Fig. 132), and a similar decoration is shown on a projecting entablature block probably from the natatio north facade in a drawing by the Anonymous Destailleur;[48] the frieze of the order framing the central niche on the south wall of the frigidarium had a marine scene.[49] Cardinal Alessandro is said to have removed from the Baths a relief with figures of two gladiators which Lanciani believed to form part of the frieze of the portico order from the palaestra,[50] although it may have come from a much larger figured frieze which the Anonymous Destailleur depicted facing the open space of the palaestra above this order (Fig. 133). None of this is at all out of keeping in the context of the Baths. Rather more unusual is a fragment of a weapons frieze now in the east palaestra (Fig. 134), which Hülsen believed came from there but which should perhaps rather belong to Rms 8-10 or their facade on the palaestra.[51] Also unexpected are the figured Corinthian capitals of the palaestra porticos,

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[47] Gasparri 1983-1984: 134-35, who believes that the Geneva papyrus published by Nicole (1906) giving a list of sculpture may refer to the Baths of Caracalla, associates with this island group the Scylla mentioned there and would locate the whole in the natatio rather than in Rm 9.

[48] Iwanoff-Hülsen 1898: Taf. Q.

[49] Blouet 1828: Pl. XII, Fouille D.

[50] Lanciani 1897: 538.

[51] Iwanoff-Hülsen 1898: 28-29.

which have eagles for volutes and torches and thunderbolts in place of the central stem and flower (Fig. 135); clearly these are to be associated with Jupiter.[52] A small figured Composite capital, probably from the natatio, has a satyr and a Maenad (Fig. 136).[53]

In addition to these pieces from the original decoration, there are four figured Composite capitals from the frigidarium pools which are thought to be later third-century replacements. Two are particularly interesting:[54] one has a weary Heracles of the Farnese type on one side (Fig. 137), with half-draped female figures holding a large shell in front of them (Nymph, or ?Venus) on two sides and another female figure in chiton and mantel on the third, while the other has figures of Mars (Fig. 138), Dionysus wearing an animal skin and holding a kantharos, Fortuna with cornucopia and rudder, and an Amazon figure identified by von Mercklin with Roma. Since it is reasonable to suppose that the inclusion of the Heracles was a deliberate reference to what must have been one of the most important sculptures in the Baths, can we relate the remaining figures to other possible major sculptural groups? Among the colossal or well over life-sized pieces is a heroic male nude with baldric, which could be a Mars, a colossal hand with a cup from which Marvin reconstructs a possible Dionysus, and an androgynous head which would not be unsuitable for an Amazon. This certainly introduces the possibility that the designer of the capitals chose the figures on these capitals to mirror the major sculptures of the central block. Admittedly, the surviving figures have their closest stylistic parallels in sarcophagi, which provide iconographic parallels as well, but this really only points to the likely source of craftsmen. The choice and combination of figures on each of these two capitals contrasts with the more predictable erotes on the remaining two, strongly suggesting a programmatic approach.

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[52] Von Mercklin 1962: 270, no. 636. The virtually identical capitals now in the Duomo at Pisa (no. 637) surely also come from the Baths of Caracalla, along with several other architectural fragments.

[53] Von Mercklin 1962: 160, no. 386e.

[54] Von Mercklin 1962: 158-60, no. 385a-d. The other two capitals have figures of erotes holding garlands on all sides.

With the help of these figured capitals and the Jupiter capitals from the palaestra it is possible tentatively to identify an iconographic programme for the decoration of the Baths which goes beyond the usual symbols of health, physical activity, and pleasure, and indeed gives further layers of meaning to such traditional bath figures as Hercules and Venus. The key to the programme is the figure of Jupiter, both in his relation to the Roman state in the person of the emperor (eagle capitals, Victory, Fortuna, ?Roma) and as the father of gods (Mars, Athena, Dionysus, Venus) and men (Heracles, Amphion and Zethus of the Dirce group).[55] Not only was Jupiter assimilated generally with the emperor, but Caracalla had a special affinity with Hercules, whose statues feature so highly in the surviving sculptures, and saw himself - like his idol Alexander the Great - as a son of Zeus. Several of the other figures have further significance within the broad range of imperial imagery. Manderscheid has already pointed out the potential significance of Venus as the divine ancestress of the Julian house, and although in most bath complexes this reference would not naturally be foremost, in this particular case it seems legitimate given the desire on the part of the Severan dynasty to trace its origins back to the earliest Caesars.[56] Mars too features in imperial iconography as the father of Romulus and was frequently paired with Venus in this context.[57] Finally Mars can be associated with Victory and Fortuna in his role as the god of war, an unlikely association for a bath were it not for the frieze of arms from the palaestra area and the close relationship between this soldier emperor and the army.

[55] If my reading is right, then the marble island and ship recorded in the 16th century and the difficult figure of the warrior carrying a slain youth should also relate to adventures of the sons of Zeus. In the first case this could be one of several - Dardanus, Danae, Perseus (a Perseus is recorded on the Geneva papyrus, cf above note 47), an episode from the Argonautica (? Scylla, see again note 47) - while in the second it would argue for Hercules slaying his own children, despite Marvin's arguments.

[56] Manderscheid 1981: 29-30.

[57] As in the imperial couple as Mars and Venus now in the Museo delle Terme in Rome. It is tempting, but would be going too far, to postulate a similar colossal group from the now missing female lower limbs reminiscent of the Melian Aphrodite found in the Baths, and the ?Mars.

7.6 HIERARCHY AND DISTRIBUTION OF DECORATION

So far each type of decoration has been allowed to tell its own tale. The visitor to the Baths, however, would have been more constantly aware of the overall effect of the decoration and the general ambience it helped to create than of any specific element in it. The iconographical aspects of the figured decoration, particularly but not exclusively the sculpture, would have attracted the visitor's attention from time to time, as would specific "showpieces" such as the natatio aedicular facade, but it was the varied effects of light and colour which created the general atmosphere.

Not all areas of the central block were treated the same. We have already had cause to note the existence of different types and degrees of richness within any given category - floors, walls, vaults, columns, sculpture - and this impression of a decorational hierarchy is heightened if we consider the overall effect in any area. Not surprisingly, the most important area sculpturally (to judge by the number of niches or known locations), the frigidarium/natatio combination, is also the most lavish and expensive in its decorative schemes - marble opus sectile floors, marble revetment on the walls, an almost excessive use of ornamental columnar orders in the natatio, and glass mosaic on the vaults - as well as being the most imposing architecturally. The only porphyry columns used in the central block come from this area, decorating the frigidarium pools and forming the screen between frigidarium and natatio. In addition to this lavish decoration, we have already seen the pains the architect went to in order to disguise as far as possible any unwanted visual effects caused by the mistakes made in the construction of the natatio (Section 3.4.5). Although there is no evidence of sculpture, the caldarium also had the same opus sectile floors, extensive marble revetment and use of the decorative orders that marked out the frigidarium and natatio, as well as its lavish gilded bronze ceiling. Clearly, then, the natatio with its extraordinary aedicular facade, the frigidarium with its porphyry columns and colossal sculptures, and the caldarium with its unique ceiling were the most important rooms in the complex in terms of decoration, just as they were in terms of size, architectural elaboration, and spatial organization on the all-important axis of symmetry.

Moving out along the longitudinal axis, however, the pattern of decoration changes. The floor treatment moves from opus sectile through (probably coloured) mosaic of some kind in Rm 14 to coloured figural mosaics in Rm 13, geometric coloured mosaic (with the prestigious red and green porphyries predominating) in the palaestrae, and black-and-white figured mosaics on the terraces. The wall and vault treatments, on the other hand, show the same combination of marble veneer and glass mosaic as the frigidarium until the exhedrae (Rms 8-10) on the far side of the palaestrae, where the glass mosaic is replaced by painted stucco, and the emphasis on the columnar orders is maintained through the screens of Rm 14 and 13, the palaestra portico, and Rms 8-10. The rooms flanking the natatio show the same distribution as Rm 14, as do the halls (Rms 4-6) leading to the palaestra except that they have stucco and not glass mosaic on the vaults. The columns themselves are worth noting, for it is in the internal divisions of these spaces that we find the fluted Numidian and Docimian columns, and the alabaster. The only other marble as opposed to granite columns are in the natatio aedicular facade. All these rooms show by the number of their niches that they were also rich in sculpture.

This is in marked contrast to the apodyteria (Rms 3a-d), which have the simplest decoration of all the major spaces. Black-and-white geometric mosaic floors combine with marble veneer and stucco vault decoration, and no columnar orders are used, while in the subsidiary rooms (Rms 3a-d) and in the secondary entrances Rms 7 and 11, even the marble is restricted to a simple low sockle and the rest is in stucco. Clearly these are intended to be secondary spaces of a functional nature, and not places where the bathers were expected to linger although the slaves in charge of the bathers' clothes must have done. Similarly, the figured mosaic and marble veneer of the palaestra terrace, and the comparable floor of the terrace over Rms 4-6, define these as more public and prestigious areas than the small terraces over Rms 3a-d, which have only plain black mosaic floors.

Even the exterior decoration of the central block shows this hierarchical differentiation. The east and west sides were the plainest, almost blank walls with a relatively low band of marble at the base, and presumably stucco in imitation of ashlar masonry above. The north facade, the main entrance and first view of the central block for those entering the baths from the Via Nova and the Via Appia, was more elaborate. The marble dado was continued, and each entrance portal was framed by a pair of red granite columns which may have carried a pediment above the projecting entablatures. The doors themselves were flanked by niches which may have contained fountains as well as sculpture, and the large windows enliven the large expanse of wall at the upper levels. Some kind of cornice at the height of the order flanking the doors, now only indicated by the broken ends of travertine consoles, once decorated the central blank section of the wall corresponding to the natatio facade, and this is a likely position for the fragmentary (? dedicatory) inscription recorded from the exterior.[58] All this is relatively sober, but the south facade was boldly treated with its large openings screened by red granite columns, the projecting mass of the caldarium, and the whole upper part covered in glass mosaic. To anyone entering the Baths from the Aventine or strolling in the gardens the sight of this facade glistening in the afternoon sun must have been quite breath-taking.

7.7 CONCLUSIONS

Fragmentary as the decoration of the central block is, sufficient still remains to reconstruct at least its main lines. As pure decoration, it shows signs of being very carefully planned as an integral part of the design, both to enhance the proportions of the rooms and emphasise the major axes and vistas. By reinforcing the hierarchy of spaces already created by the shapes and volumes of the individual rooms, the decoration also served to orchestrate the visitor's path through the bathing routine. The sculpture contributed to the decorative effect, while on the whole the representations chosen represented the traditional bath topoi of the health and pleasures of the body, and the gift

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[58] See Platner/Ashby 1929: 520 for this.

of water. In addition to this, there are several works which seem out of place in the Baths due to their warlike or violent nature, and which provide evidence, however slender, of a more specific iconographical programme relating the emperor himself through his identification with Jupiter and his divine and heroic offspring. Above all, the decoration was designed to emphasise the palatial and almost heavenly splendour of the Baths and allow the ordinary mortal to experience however fleetingly and vicariously the life of the rich and powerful.

CHAPTER EIGHT: QUANTITIES, LOGISTICS AND COSTS

INTRODUCTION

In this chapter we turn finally to the calculation of quantities of materials and manpower, of the logistics of the operation, and of the final costs for building the Baths of Caracalla. The basis for the quantitative analysis is the calculation of quantities of materials, derived from the reconstruction of the building outlined in Chapter 2 and illustrated in Sheets 1-9. The quantity of manpower needed both to produce and transport the materials arises naturally from the quantities of the materials themselves, using the figures for the individual items worked out in Chapters 4 and 5, while the manpower for construction is related both to the quantities of materials and to the nature of the construction as discussed in Chapter 6.

Once the total quantities have been calculated, the problem arises of their spread over time, that is of the scheduling of both the construction and the production of materials. The two elements are inextricably linked, since any shortfall in materials necessarily delays construction. The overall schedule including both construction and decoration is governed by the maximum building period of six years as established in Chapter 2; by maximising the use of labour and distributing the supply of materials advantageously over the building period we achieve the "critical path" for the construction programme. This exercise in logistics is essential in determining the absolute numbers of individuals involved in the project over the six years, as opposed to the total number of man-days required.

Finally, from the total amount of materials and labour the total cost of the project can be calculated, expressed in kastrenses modii of wheat. These will necessarily only be minimum figures, since there are several aspects for which it is difficult or impossible to provide a value. We can have no idea, for example, of the cost - if any - of the land, or of the resources and time required in the very early stages of clearing and establishing the site. The construction of the access road and the aqueduct are also problematic, but a very rough costing will be attempted. Figures have to be added for supervision, administration, maintenance of tools, surveying, etc, and this can only be done as a rough percentage of the total. Nor is any allowance made for any profit accruing to contractors or middlemen along the way.

Since the analysis which follows is strictly hypothetical in nature (however much it is based in real quantities), it ought to be full of conditionals - assumes, coulds, shoulds, mays, mights, possibles and probables. As far as possible I have avoided such tedious repetition, on the understanding that all which follows will in fact be read as a hypothesis. Most of the uncertainties and reservations have already been dealt with in the preceding chapters.

8.1 MATERIALS AND MANPOWER CALCULATIONS

8.1.1 Excavation for the terraces

The excavation for the first terrace (A), 8 m below the platform level, begins on a line with the north facade of the central block, and extends over a front of 420 m (Sheet 8). The second terrace, 6 m below platform level, continues at this breadth for a further 26 m to the south side of the peripheral Rms IV, after which it reduces to 330 m, plus the triangles representing the remainder of the lateral exhedrae. In the minimum case, this terrace level finishes at the start of the rear peripheral structures. The area under the "stadium" and cisterns is assumed to have been reduced to the level of the platform. For the slope of 1 in 27 determined in Section 2.5.1, and rounding off to two significant figures, this gives a total of 370,000 m^3 of clay to be removed.

A figure can be obtained using 19th-century labour constants for the manpower required to level the terraces. At a rate of 5.5 m^3/day for digging and throwing behind, this alone needed 67,000 man-days.[1] The loose clay was then filled into baskets and carried to the outer edges of the site to be dumped into carts and removed. If the average distance over which the fill had to be carried was 105 m (a quarter of the total width of the site), then the filling would take 24,000 man-days and the carrying 197,000 man-days.[2] The total for this phase would thus be 288,000 man-days, and all of the labour could have been unskilled.

8.1.2 The Foundations

The assumptions about the nature and depth of foundations are set out in Section 2.5.3. Those under the central block are 6.5 m deep, those under the peripheral structures 4.5 m deep; the exceptions are the inner wall of the "stadium" and the rear portico, which are one metre deep. The floor of the cisterns is of solid selce concrete for a depth of one metre. This results in a total volume of excavation for the foundations of about 150,000 m^3, roughly half that of the terracing.

The restricted space makes digging in trenches rather slower than it is over an open area. Once beyond the first metre and a half, the depth of the trenches also creates problems of access and spoil removal; these required the use of ladders and winches respectively, again requiring extra time. Since most of the trenches are 4 to 6 metres deep, the sides had to be shored as the trenches were dug. Rea gives figures equivalent to 4.8 m^3/12 hr day for digging the first 1.8 m, including levelling the bottom and shoring, with a further 0.77 hours/m^3 to be added for each additional 1.8 m in depth.[3] This results in a total of 41,000 man-days for the digging and removal of fill from the trenches. In addition 9,600 man-days were needed for filling baskets and 80,000 for removing the spoil.

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[1] Rea 1902: 47-48 gives 6 yds^3/10 hr day for clay.

[2] For the use of baskets see Sections 4.2.1 and 5.6.1.

[3] Rea 1902: 48-49.

We can also calculate the amount of wood required for shoring. The total surface area to be covered is roughly 85,000 m². For this, 405,000 m of boards 0.21 m wide by 0.03 m thick, plus 57,000 m of upright posts 0.11 m square and set at 1.5 m intervals were needed.[4] It is not possible to calculate the length and number of horizontal props required, but an equivalent length to that of the uprights would produce the right order of magnitude. If all the shoring was cut from the cheapest timbers given in the Prices Edict (6.2 x 0.22 m square),[5] roughly 2400 such logs would be needed for the planking, 570 for the uprights and the same for the horizontals. The sawing of these elements from the timbers required about 3400 man-days for a pair of sawyers,[6] with an extra 150 man-days employed in moving the timbers to the appropriate positions.

The 150,000 m³ of the trenches were then filled with selce caementa in an abundant grey pozzolanic mortar.[7] Given that the slaked lime in the concrete fills the interstices between the grains of pozzolana, and the resultant mortar fills the spaces between the selce caementa, the total volume of the component parts of the concrete needed to be considerably more than the volume of trenches filled. To calculate the raw materials required we thus need to know: the proportion of caementa to mortar; the proportion of lime to pozzolana in the mortar; the volume loss for this proportion of materials; and any further possible loss of volume due to consolidation.

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[4] Lugli 1957: 386 gives 0.9 - 1.2 m clear spacing (1-1.3 centres), while those of the Palatine Triclinium are more like 1.2 - 1.6 m centres.

[5] See Section 4.4.3. The value for oak has been used because this is the cheapest timber in the Prices Edict, but it is more than possible that other timbers such as poplar or alder were used for the boarding.

[6] Hurst 1865: 222 gives figures for the sawing of oak between 0.0045 and 0.0038 10-hr days/superficial foot, which works out on average at 0.04 days/m² for a pair of sawyers, or 0.08 man-days/m² total. While this is consistent with other 19th-century figures (e.g. Laxton 1880: 161), it is considerably less than the 0.26 man-days/m² suggested by the Prices Edict (Section 12.17) according to Meiggs' interpretation (1982: 368 and note 145). There is no obvious way of resolving this difference, although it may depend on the degree of seasoning of the timber and on changes in the quality and type of saws used. In the interest of producing the lower estimate, and given the difficulties which do exist in the text, I have preferred to use the modern figure while admitting that the real figure could be up to three times higher.

[7] Petrassi 1985: 603.

We have already noted (Sections 4.2.3) that the increase in volume for caementa of average size 0.035 x 0.035 x 0.075 m over solid selce is 60%, which means that 37.5% of a given volume of selce caementa are voids. This is the minimum space which must be filled with mortar. In a sample from the Baths of Caracalla the proportion of lime to ballast was 1:2.[8] We can be less sure about the volume loss, but most building manuals which give figures for mortar made with slaked (rather than quick or hydrated) lime agree on a figure between 20 and 33%[9]; 25% seems a reasonable average to take. Finally, a further loss of 10% is possible in concrete during ramming, and this must be taken up in the mortar.

We can thus calculate the volume of materials in each cubic metre of finished foundations. For each cubic metre of selce caementa, representing 0.625 m^3 solid selce, 0.36 m^3 of pozzolana and 0.18 m^3 of slaked lime are required. For an increase in volume of slaked lime over quicklime of 60% (see Section 5.2.4), this represents 0.113 m^3 of quicklime. Thus the total material requirements for the foundations are: 150,000 m^3 of selce caementa, equal to 94,000 m^3 solid selce; 54,000 m^3 pozzolana; and 27,000 m^3 of slaked lime representing 17,000 m^3 of quicklime. Some 22,000 to 25,000 m^3 of water would be required altogether. The volume of mortar which has to be moved after mixing will be 61,500 m^3.

The lime for the mortar would need to have been slaked some three months before (see Section 5.2.4). Independent figures for lime slaking are difficult to find, since 18th- and 19th-century English practice was to make the mortar of unslaked lime. Hurst gives a figure equivalent to 1.2 days/m^3 for the making of lime putty for plastering from quicklime,[10] and this is a reasonable

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[8] Wetter 1979: Table 3. The proportion of lime to ballast in Roman mortars varied considerably. For discussion of the prescriptions of Vitruvius and Pliny (which vary between 1:2 and 1:4), see Adam 1984: 77-79; Blake 1947: 316.

[9] Hurst 1865: 195, 197; Rea 1902: 52-53; Building Trades Handbook 1925: 152.

[10] Hurst 1865: 238 - "Fine stuff or putty, mixing, 0.040 days/ft^3".

figure to assume for the well-slaked building lime used in the Baths. Some confirmation comes from 17th-century figures, which suggest an increase in the cost of lime at the production centre of 9-10% for slaking and maturing;[11] this would add an average of 0.4 KM/m^3 to the cost of lime calculated in Section 5.4, Table 11, equivalent to 1.1 days of an unskilled labourer. Thus the total for lime slaking would be about 20,000 man-days. Most of this labour would be needed well in advance of the actual filling of the foundations.

It is clear that the slaked lime and pozzolana of Roman mortar were mixed together carefully with water to form a relatively uniform slurry just before depositing.[12] It has been suggested that the pozzolana or other aggregate in Roman mortars was sieved or screened for size;[13] visual inspection of the mortar in the superstructure of the Baths supports this view. The largest fragments in the mortar of the facing would pass through a digitus screen, while those in the core would pass through an uncia screen, although most of the fragments are much finer and would pass through a semiuncia screen.

The 18th- and 19th-century manuals give rather different figures for mixing concrete and mixing mortar for brick laying,[14] but since the former is only for turning over the dry materials twice and adding water, the latter would be more appropriate given the nature of Roman mortar. The use of unslaked lime also made a difference, and we have to allow for the sieving of the pozzolana.

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[11] Scavizzi 1983: 29-30.

[12] The hydraulic properties of lime/pozzolana mortars mean that setting begins as soon as the mortar is mixed, and, since this is irreversible, a delay of more than a few hours makes it unusable.

[13] The results of tests on Roman mortars in Britain suggest that screens of semiuncia, digitus, and uncia were used for wall rendering, masonry and foundations respectively (Davey 1974: 195). Cf. Blake 1947: 314.

[14] Concrete, mix and deposit - 0.25 days/yd^3, or 0.5 days/yd^3 (Rea 1902: 54), 0.30 days/yd^3 (Hurst 1865: 214); mortar mixed by hand - 0.72 days/yd^3 (Hurst 1865: 214; Rea 1902: 70). Slake lime and mix with sand for mortar - 0.45 days/yd^3 (Langley 1749: 34).

A figure of 0.7 days/m^3 for mixing and depositing the mortar in baskets and ramming the finished concrete should be acceptable, to which must be added 0.56 days/m^3 for transporting the mortar.[15] In addition, 0.04 days/m^3 are needed for filling baskets with the selce caementa, and another 0.53 days/m^3 for carrying them 105 m and depositing them roughly in the trenches.[16] This gives a total of 43,000 man-days for mixing the mortar, 34,000 man-days for carrying it and throwing in the trenches, plus 6,000 man-days for filling baskets with selce caementa and 80,000 man-days for carrying and depositing.

The total man-power required for construction of the terracing and foundations is summarised in Table 12 below.

Table 12: Manpower for Terraces and Foundations
(000's man-days)

Location	Excavate	Carry	Slake lime	Mixing mortar	Sawing	Total
Terraces	67	220	-	-	-	290
Foundations	41	210	20	43	6	320
Total	110	430	20	43	6	610

8.1.3 Substructures

The calculations involved in estimating material quantities and manpower for the substructures are more complex than those needed for the foundations. As well as calculating the total volume of construction, we need to distinguish in terms of both materials and labour between the brick facing and the tufa core, and between walls and vaults, while further allowances have to be made for bonding courses and arches, for working to curves and creating hollows such as windows and light

[15] If the weight of the wet mortar is roughly 2000 kg/m^3 (cf. the figure for 1:2 lime mortar in Hurst 1865: 197), then 40 trips each weighing 50 kg are needed to move 1 cubic metre. A bricklayer's hod of 2/3 ft^3 would hold about 40 kg of mortar.

[16] For the basis of the calculation see Section 4.2.1.

wells in otherwise solid volumes, and for erecting scaffolding for the walls and formwork for the vaults. In addition we must take into account the division of labour between skilled and unskilled workers.

A number of assumptions have been made in calculating the areas and volumes of the substructures beyond those already mentioned. The substructures of the east exhedra are treated as if they were identical to those of the west, which is not in fact true; unfortunately the east side is not sufficiently well documented to attempt a separate calculation.[17] In addition, no allowance has been made for small openings, since the labour and materials saved on the opening are compensated by the extra needed on forming the jambs. The quantities involved are so large that the final result will not be appreciably affected. The number of bipedales in the bonding courses are calculated from the cross-sectional area of the walls and the number of bonding courses;[18] where there is a facing on only one side of the wall (usually because there is a vault on the other), the bonding course is assumed to be only a single brick deep. In calculating the number of bipedales in the arches it is assumed that each thickness is composed of alternately whole and half bricks, and that the arches extend through the whole thickness of the wall except for niches (see Section 6.3.5).

The first problem is to estimate the quantity of brick in the facing. Measurements of the length and thickness of the brick and mortar show that on average 62% of the facing is brick and the remaining 38% mortar. The bricks in the substructures are made of triangles deriving from a mixture of sesquipedales and either bessales or bipedales. Assuming that these are represented in equal proportions, each square metre of face contains on average 105 pieces of brick, representing roughly 6 whole sesquipedales and either 28 bessales or 3 bipedales. In addition, if the average

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[17] See Iacopi 1985a: Fig.2 for a summary plan of the east exhedra as far as it has been excavated.

[18] A nominal figure of 0.6 m square for a bipedales is used in calculating the bipedales in a bonding course to allow for mortar.

maximum depth of the facing is 0.15 m, the total volume of the facing and the volume of mortar in it can be calculated. In a similar fashion the proportion of tufa in the core and vaults can be calculated at 55% (solid volume), with the mortar forming 45%. If each piece of tufa is roughly 0.035 x 0.035 x 0.075 m, then each cubic metre of core contains 6,000 caementa. We have already discussed the means of calculating the amount of lime and pozzolana required for a given volume of finished mortar, although in this case there is no reduction due to ramming. Altogether, 38% of the core and 58% of the facing is pozzolana, while 19% of the core and 29% of the facing are slaked lime. Finally, the number of bessales and bipedales required for lining the vaults are easily calculated from the surface area.

The quantities of materials in the substructures are set out in Table 13 below. I have divided the data into five zones of operation rather than provide a single set of figures in the interest of giving some sense of the distribution of the workforce when we turn to labour requirements and to scheduling the work.

Table 13: Quantities of Materials in Substructures

Location	Pozz. '000s cu.m	Lime Quick '000s cu.m	Tufa (solid) '000s cu. m	Bricks			
				To face		To arches, etc	
				Bess. '000s	Sesq. '000s	Bess. '000s	Bips '000s
Cisterns	26	8.0	34	720	180	-	35
Facade	14	4.4	16	450	97	270	130
E side	12	3.8	15	280	62	97	53
W side	12	3.8	15	280	62	97	53
Galleries	11	3.4	15	120	27	197	35
Central	35	11	44	700	200	-	160
Total	110	34	139	2550	628	661	466

The next step is to establish constants for building the walls and vaults. There is no shortage of

18th- and 19th-century figures for brick laying, ranging from 500 to 1500 bricks/10-hr day depending on the quality of the surface finish.[19] The rate at which a man can lay bricks does not depend on the shape or size of the brick, provided that it can be held in one hand, so that these figures can be applied readily to the Roman situation. This is a better guide than a rate/unit area, as there is far more work in laying a given area of small bricks than large bricks. A figure of 800 bricks/12-hr day for a bricklayer and labourer (somewhere between that for ordinary and face work) has been chosen given the neatness of the facing in the Baths. Since the core of the walls where visible in the central block is laid in rough rows of caementa alternating with mortar (indicated by the occasional gaps which remain between adjacent caementa), then the rate should be similar to, but probably a little faster than, the rate for rough brickwork; I have therefore adopted a figure of 2000 pieces/12-hr day for a bricklayer and labourer,[20] equivalent to 3 days/m^3. The work of the labourer is to keep the bricklayer supplied with materials, including mixing the mortar and stacking the bricks to hand. Thus we need no extra figure for these items, although something must be added for bringing the materials from the depots on the periphery of the site and for slaking the lime needed for the mortar.

These figures are for building straight walls with no arches, bonding course, or vaults. For the

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[19] Figures for bricklaying are given in different forms. Since these are for walls of solid brick, most of them include a component for the facing and for internal thickness. Rough brickwork has no facing joints, ordinary brickwork is intended to be plastered over, facework includes all kinds of special jointing for brickwork which is meant to be for the final surface. The number of days indicated is for each of a bricklayer and a labourer.

	Rough brickwork	Ordinary brickwork	Facework
Langley 1749:	1500 (p.83)	1000 (p.87)	500 (p.100 f.)
Dobson 1843:		900 (p.31)	
Hurst 1865*:	1300 (p.214)		500-700 (pp.214, 216)
Rea 1902:	1500 (p.72)	1000 (p.75)	500 (p.75)

(* Hurst gives his figures in a different form, but I have recalculated the constants for ease of comparison)

[20] This is roughly the rate given by the 15th century Italian architect Filarete for the masons building the walls of the imaginary city of Sforzinda (IV, 23r), a figure which has been called into question by modern commentators presumably basing their comparison on 20th century figures. See Spencer 1965: 41.

additional work involved in most of these we have to rely on Hurst,[21] although there are difficulties in estimating figures for handling the large bipedales. Working to curves relates only to the outer face of the wall, and this takes roughly half as long again as straight work, or 0.066 days/m² of face[22]. Extra time taken for erecting and dismantling scaffolding is given as the equivalent of 0.025 days/m² of face, and I see no reason to alter this given the similarity between 19th-century pole scaffolding and that used by the Romans (see Section 6.3.4). This figure should apply irrespective of whether the scaffolding is free-standing or engaged. Hurst gives several figures for arches on face, which range from 105-420 bricks/12-hr day of bricklayer and labourer. This is for house bricks, and rather fewer bipedales would be handled in the same time; taking the area rather than number of bricks gives between 40 and 140 bipedales/day. Thus a figure of 100 bipedales/day for bricklayer and labourer should at least produce the right order of magnitude. The same figure is assumed for laying the bonding courses, including levelling[23]. Extra labour is required in laying the vaults, but as the pieces are larger (av. 0.05 x 0.05 x 0.1 m) the same figure of 3 days/m³ calculated for the core can be used. The construction of the centering for the vaults will be dealt with at a later point since there is a problem with the repeated use of formwork which can only be solved in the context of the work schedule.

These figures do not include any item for transporting the materials from the depot to the bricklayers. For our usual trip of 105 m at 0.014 days/ trip, and allowing 40 trips/m³ for mortar, 44 trips/m³ for the tufa caementa, and 27 triangular brick pieces or 15 bessales or 1 bipedalis per trip, 128,000 man-days are required to carry and 18,000 man-days to load the materials into

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[21] Hurst 1865: 214-16.

[22] Hurst 1865: 216, and cf. Langley 1749: 143.

[23] Some figures from Hurst, for laying paving bricks and for tiling, would suggest for an equivalent area 40-70 bipedales/day. In both cases the surface area of the individual elements is smaller, so that despite their size it should be faster to work with bipedales. This is contrast to the arches where the small area of the edge of the bipedalis compared with its depth is in question.

baskets. No element for carrying has been included for the cisterns which are at the south edge of the site by the depots. We must also add a factor for filling the voids to create the platform (see Section 6.2.4). The fill is a mixture of a brown sandy earth and predominantly ceramic material which in modern parlance would be termed "hardcore", in proportions of roughly 3:2. Since the 190,000 m^3 of hardcore is in fairly small pieces, some breaking was necessary, say 0.2 days/m^3, a total of 38,000 man-days. Within the boundaries of the central block 112,000 m^3 is required, and within the terracing structures of the platform a further 365,000 m^3, needing a further 271,000 man-days if all was basketed over our standard 105 m, plus 31,000 man-days for filling the baskets.

We can now calculate the total basic manpower figures for the substructures. These are presented in Table 14 below, the data being again divided into five zones of operation.

Table 14: Manpower for Substructures
('000s man-days)

Location	Slake lime	Walls and Vaults				Carry	Total
		Work to face		Work to core			
		Brick.	Lab.	Brick.	Lab.		
Cisterns	15.3	3.6	3.6	183	183		
Facade	8.3	3.2	3.2	88.4	88.4		
E side	7.2	1.7	1.7	77.4	77.4		
W side	7.2	1.7	1.7	77.4	77.4		
Galleries	6.7	0.7	0.7	84.2	84.2		
Central	20.8	3.5	3.5	236	236		
Total	65.5	14.4	14.4	746	746	486	2,070

8.1.4 Central block: Walls and Vaults

The rules for determining the amount of materials and the labour constants deduced for the substructures can equally be applied to the construction of the central block, with the same reservations. The most important one is the difficulty of estimating the amount of timber required for the centering of the vaults, and the amount of extra manhours required for setting them in place, a matter of particular importance with the large vaults of the frigidarium and caldarium. The building in of the columnar orders and of the iron supports in walls and vaults also present problems without easy solutions.

In calculating the quantities of materials a number of simplifications and assumptions have been made. The only openings which have been ignored are the small service passages in the heated rooms and caldarium, the staircases in the thickness of the walls, and all vertical drain pipes and flues. Since the rate of laying walls and vaults is roughly the same, the calculation of the total volume was made by deducting the volume of the voids from that of the solid block; this avoided the difficulty of dividing a solid volume between vault and wall where the vault existed on one side of the wall only (e.g. between Rms 3a and 2). The volume of walls with brick rather than tufa caementa, and of pumice or solid brick vaults was then calculated separately, as was the volume of brick arches. The area of the walls was calculated for each room, including door and window jambs, and the area of brick arches deducted. Further calculations were made of the area of the bonding courses, the surface of the vaults, and relevant arched window heads with tile linings. The bonding courses are assumed to cover the whole area at each level, with any missing and extra bonding courses cancelling each other out.

The amounts of materials are given in Table 15 below. The figures have been divided into four groups vertically divided by the major breaks in construction. The first of these occurs at the sixth bonding course, where the centering for the vaults of Rms 3a-d, 7, 11 and the barrel-vaulted passages between the natatio and the frigidarium, the first blocks of the columnar screens in Rms 19-22 and all of the 30 ft orders had to be set in place. The second occurs at the tenth bonding course, where most of the major vaults except for the caldarium and frigidarium spring. The third block extends from the tenth bonding course to the top of the walls of the main part of the block at the 18th bonding course, while the casting of the frigidarium high vault and the caldarium dome together with the vaults of the palaestra porticos form the last.

Table 15: Quantities of Materials in Central Block

Location	Pozz. '000s cu. m	Lime Quick '000s cu. m	Tufa '000s cu. m	Pumice '000s cu. m	Brick			
					Face		Arches, etc	
					Bess. '000s	Sesq. '000s	Bess. '000s	Bips '000s
1-6	16.9	5.3	14	-	1140	285	8	129
6-10	13.4	4.2	11	-	653	163	77	246
10-18	30.7	9.6	37	2.2	712	178	523	376
F, C, 12 vaults	13.4	4.2	15	3.7	82	20	167	48
Totals	74.4	3.3	77	5.9	2590	646	775	799

In addition to the quantities in the Table, some 4300 m^3 of brick caementa in the first stage and 2900 m^3 at the second are needed. This material, mainly brick but with some roof tile, is not obviously reused, and does not seem to be general rubbish. The most likely source is the waste from brick and tile production, which might occur at any stage from the unloading of kilns to the building site. While this material is waste in the sense that it would not command the price of sound brick, it still had to be produced and presumably added to the market cost of the rest. There is no evidence for the proportion of waste to sound brick created under normal circumstances, or the period of accumulation which this volume represents. If all the brick caementa were derived from bipedales, the total volume would represent 600,000 whole bipedales. We must further add the iron incorporated into the structure during construction, comprising the bars in the vaults, the supports for entablature veneer, and the tie-bars for the palaestra portico vaults (see Section 6.5.1). Altogether 2.95 m^3 or 23 tonnes are needed between the sixth and the tenth bonding courses, 4.48 m^3 or 35 tonnes between the tenth and the eighteenth, and 5.3 m^3 or 41 tonnes for the high vaults and palaestra porticos. This would take 2100 man-days of a smith and his assistant to convert to the required form, plus the charcoal consumed at this stage.

Finally there are the materials needed for the scaffolding; the formwork and centering requirements will be left until the next section since they involve a certain amount of reuse. Standard rather than suspended scaffolding is assumed throughout, and all the building is taken as covered with scaffolding at the same time. If the average horizontal spacing of the putlogs is four Roman feet (1.18 m) and the average vertical spacing 1.32 m (the standard bonding course height), 85,000 putlogs including the double sets in the upper parts are needed over 100,000 m^2 of face. For an average spacing for the standards of six feet (1.77 m), a total length of 95,000 m of standards plus 152,000 m for the ledgers is required. For the putlogs, 42,500 poles are required at two to each 12-foot pole; the standards and ledgers need 35,300 24-foot poles. In order to tie the members of the scaffolding together some 86,000 cords are needed. The planks on which the builders stand are usually moved up from one stage to the next with a few short sections left at each stage to allow ladders and access to the parts above, needing only 9700 m^2 of planking cut from 370 of the smallest timbers given in the Prices Edict.

We can now calculate the manpower required to build the main structure of the central block, excepting the formwork for the vaults.

Table 16: Manpower for Central Block
('000s man-days)

Location	Slake lime	Face		Core		Arches		Carry
		sk.	unsk.	sk.	unsk.	sk.	unsk.	
1-6	10.2	6.9	6.9	101	101	0.5	0.5	31.3
6-10	8.1	4.1	4.1	78	78	1.8	1.8	27.7
10-18	18.4	4.2	4.2	213	213	2.1	2.1	68.4
F, C, 12 vaults	8.1	0.8	0.8	103	103	0.1	0.1	57.4
Totals	45	16	16	494	494	4.5	4.5	185

The raising of the building materials to the required height on the building is assumed to be by some kind of lifting device, and the figure of 12 tonnes/metre height/hour suggested by Landels[24] used to calculate the extra manpower.

8.1.5 Central Block: Columnar Orders

The calculation of marble quantities and the manpower expended on the columnar orders during the construction stages of the central block requires its own set of assumptions. Firstly, since the columns arrive as rough cylinders and all remaining architectural members as roughly squared blocks, the size of the rough columns, capitals and bases are easily calculated, but the entablature members are more variable. Although the architrave blocks must span from column to column they can be divided into two or more blocks vertically, or into wedge shaped blocks horizontally forming a series of lintel arches. Frieze blocks may follow the pattern of or be combined with the architraves, or be divided into a number of shorter blocks; cornice blocks, which are naturally much wider than the rest of the entablature, are usually also shorter. Projecting corbelled entablature blocks seem on the other hand to be divided horizontally only. The surviving entablature blocks give very few indications of their original size. The amount of material required, however, is virtually the same in each case, the main effective differences being in the number of dressed faces to be worked and the weight of the individual blocks.

It is this last factor which I have used to determine the most likely sizes of the blocks. As we have seen in Section 4.3.3, the largest load which can be lifted using a treadmill operated by four men is about 10 tonnes, and it is interesting to find that none of the architrave blocks for the screens or colonnades would have weighed much more than that when trimmed, nor would any of the capitals except those for those of the two largest orders. Accordingly, all the cornices are divided into blocks weighing no more than 10 tonnes. The only blocks in excess of this amount would then be the engaged architrave, frieze and cornice blocks of the main orders of the frigidarium and

[24] Landels 1978: 87-89, and see discussion Section 4.2.3

natatio, the largest of which would weigh about 27 tonnes when trimmed, plus all the column shafts of 25 ft or over.

The marble requirements for this phase of the work can now be summarised.[25] Altogether, at least 1430 blocks of white marble are required for the bases, capitals, and entablatures, with a total volume of 3,900 m3, plus a further 100 m^3 for the architectural veneers. In addition the 252 column shafts have a total volume of 1660 m^3, divided into the following groups: eight each of $41^2/3$, 40 and 30 ft shafts, 16 x 25 ft shafts and 60 x 20 shafts of grey granite, totalling 930 m^3; 40 x 25 ft and 8 x 20 ft shafts of red Assuan granite, 310 m^3; 10 x 25 ft shafts of porphyry giving 70 m^3; 12 x 20 shafts of Carystian, 40 m^3; 8 x 25 ft plus 12 each of 20 and $16^2/3$ ft shafts of either Numidian or Docimian, totalling 130 m^3; eight each of 30 and 25 ft shafts of alabaster giving 160 m^3; and 20 m^3 of grey marble for the small niche columns.

As argued in Section 4.3.2, all the architectural elements arrived at the site as roughly squared blocks of about the required size. Before the elements were set in place, these blocks are assumed to be taken to the penultimate stage, with only the detail left to be carved in situ. The only surviving evidence for this from the site is a small Hercules Composite capital from one of the niches, which has the block for the figure on the fourth face left rough while the leaves below it are shaped (Fig. 139). The columns were also trimmed to their final shape leaving only the fluting or polishing of the shafts to be done at a later stage.

Two sets of figures have been used to arrive at the manpower requirements for carving the architectural members. The first of these are the usual 19th-century handbooks. The second are derived from two recent examples of anastylosis, the Stoa of Attalos in the Athenian Agora and

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25 For the details of the orders see Appendix 1.

the Marble Court of the bath-gymnasium complex at Sardis.[26] The 19th-century tables give no figures for the detail of the ornament, while the Sardis ones do not distinguish between the carving of the plain mouldings or the form of the capitals, and that of the details. Further problems are created by the relative ease or difficulty in working the various marbles, and the fact that marble was not a particularly common material in the 19th century for ordinary architectural work. Indeed, some of the 19th-century figures suggest that working in marble took five to eight times as long as equivalent work in granite,[27] which seems too high, and attempts to come to a hypothetical figure for elements from the Sardis baths using the 19th-century figures gave the same impression.

A set of working figures was arrived at using the estimating methods and relative values of the 19th-century handbooks in conjunction with the actual times taken for the modern examples. The key was provided by Burford's figures for the fluting of Ionic columns which average 5.7 days/m^3 (excluding the area of the fillets) compared with 16.5 days/m^3 from Hurst. If Hurst's figures are then all reduced by the same factor of 0.346 and applied to the method of estimating set out in the Student's Guide,[28] then an Ionic shaft two feet in diameter and 16^2/3 ft high would take 83 days to complete from a rough block, compared with 77 days in practice at Sardis. These reduced values were then used in assessing the work to capitals, bases, and entablatures at Sardis, and a series of values obtained for carving the detail of the ornament, by the square metre for capitals and wide bands of complex ornament such as friezes, and by the metre run for the smaller continuous mouldings, divided into simple (e.g. bead-and-reel) and complex (e.g. egg-and-dart) types.

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26 Stoa of Attalos - Burford 1969: 197, 246; Sardis - Yegül 1986: 154-55.

27 e.g. Hurst 1865: 219.

28 Dobson 1843: 84-91.

The results are not without problems. It was not, in fact, possible to obtain a single set of figures valid for all the Sardis examples; the larger order produced values too low for the smaller one and vice versa. This is understandable since the difference lies mainly in carving the detail, where the work must be relatively easier on larger surfaces. This does suggest, however, that by taking the figures obtained for the larger Sardis order and applying them to both smaller and larger examples from the Baths, the total result should be acceptable considering the added uncertainty over the relative difficulty of working the marbles used at Sardis and at the Baths. There is in fact some comparative evidence to suggest that the order of magnitude at least is right. From the rates of pay for sculptors in the 16th century and the cost of the various capitals for the new St Peter's in Rome, it appears that some of the marble Corinthian capitals for the chapels must have taken 250-300 days each to make,[29] while my calculations for the Baths of Caracalla give 210 days for each of the capitals of the 25 ft column shafts, 310 days for those of the 30 ft shafts, and 500 days for those of the giant frigidarium order.

At the construction stage the carving only had to proceed as far as the general form of the elements and the mouldings, and this was presumably done somewhere on site. The amount of work required is given in Table 17 below. In addition, a further 4,900 man-days are required for the pier capital blocks at the ends of the column screens and 5500 man-days for the architectural veneer blocks of the natatio facade, Rms 12 and other niches, giving a round total of nearly 105,000 days for a skilled stone cutter to prepare the architectural orders.

Further manpower was needed to set the blocks in place. If the blocks were moved on sleds along a prepared and lubricated track for most of the journey, and the average trip length is just over 100 m, then 1.75 man-hours/tonne would have been needed for each trip.[30] This does not allow either

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[29] Francia 1977: 99, 103.

[30] See Section 4.3.3. This assumes a speed of 0.1 m/second and that 6 men are needed per tonne.

for any difficulties in manoeuvring the larger blocks through the site, or for the loss of efficiency when large numbers of men were required; the giant columns called for at least 550 men each according to these calculations. If for the raising of the blocks we accept Landels rather low figure for raising weights with a treadmill of 12 tonne/m/man-hr, this will allow for a certain amount of time for manoeuvring the blocks rather than just lifting them. Altogether at least 2200 man-days were needed to move the blocks along the ground and a further 900 to set them in position.

Table 17: Manpower for Architectural Orders

Column size	Type	Work to shafts	Work to bases	Work to caps	No. cols	Total	Work to entabl.
41.67	granite	174	77	284	8	4280	2660
40	granite	161	75	256	8	3940	2440
30	granite	89	40	151	8	2240	3200
30	alabaster	52	40	151	8	1940	3180
25	porphyry	93	28	95	10	2160	3980
25	granite	62	28	95	20	3700	7420
25	(Tuscan)	62	28	62	36	5470	12250
25	marble	78	28	95	8	1610	2820
25	alabaster	36	28	95	8	1270	3550
20	granite	40	18	62	68	8160	7950
20	marble	51	18	62	18	2360	2520
20	(piers)	40	16	23	14	1110	690
16.67	marble	36	13	44	12	1120	710
15	marble	28	10	34	4	290	180
10	marble	13	4	17	12	410	280
6.67	marble	6	2	9	18	310	180
Total						40400	54000

At the decoration stage, the detail of the orders was carved in situ and the column shafts fluted or polished. The carving of the detail works out at: for the simplest mouldings such as bead-and-reel, 0.14 days/m run; for the more complex egg-and-dart or leaf-based cymatia decorations, 1.53 days/m run; for the taller mouldings with complex decoration and any sculptured friezes, 28 days/m². Thus a standard architrave with two astragals and two cymatia, both decorated, takes an average of 3.34 days/m, a decorated frieze 28 days/m², and a standard cornice 18 days/m² calculated on the vertical height.[31] The total for the entablatures and corresponding veneers where

[31] This latter figure has been worked out from two of the best attested entablatures, those for the screens natatio/Rm 1 and Rms 8/9/10.

these are securely attested comes to 35,500 man-days. For the Corinthian and Composite capitals a figure of 23 days/m² has been used for those faces which needed to be carved, while the Tuscan capitals have been calculated by the metre run of ornament as for the entablatures. The only finishing to be done to the bases is polishing, for which we can use the figure given by Burford for Pentelic of 0.79 days/m².[32] Altogether the capitals and bases needed a further 26,100 man-days. The same figure for polishing can be applied to the columns, and we have already noted the rate of 5.7 days/m² of fluting also given by Burford. The total comes to very nearly 5000 man-days, over one third of which is for fluting just 26 relatively small columns. Since the figures deduced from the Sardis data are for details worked before the elements were put into position while the details in the Baths of Caracalla were most likely carved in situ, the figures should be increased one and a half times according to 19th-century practice. The totals for finishing the orders would then be very close to 100,000 man-days.

8.1.6 Central block: finishing and decoration

8.1.6.1 Heating systems

The surviving visible hypocausts in the caldarium and tepidarium, and that exposed in Rm 19E in 1983, are of the standard Roman type with pilae of brick approximately 0.2 m square and spaced at 0.59 to 0.6 m centres; the piers stand on a layer of bipedales and support a second, which in turn supported the packing for the opus sectile floor, now no longer extant. Although we would normally assume that the piers were made from bessales, reports of a number of brickstamps from the piers of the caldarium hypocaust suggest that some of these were cut from bipedales.[33] Altogether the hypocausts would need nearly 30,000 bipedales and 241,000 bessales if all the pilae were of bessales, or to make an arbitrary division we could assume 16,000 bipedales and 97,000 bessales. Assuming that the tubulation extended to the height of the tenth bonding course in all

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[32] Burford 1967: 246, based on modern restoration work in Athens.

[33] Bloch 1947: 284-85, nos. 14-19.

the hot rooms except the tepidarium, then roughly 100,000 tubuli were required. These were fixed to the wall using iron holdfasts, with one for each pair of tubuli being a reasonable estimate. If each weighed roughly 0.06 kg, then these would use 3 tonnes of iron.[34]

There are no easily available figures for the laying of hypocausts and tubuli. The rate of 100 bipedales/day for a bricklayer and labourer used for the bonding courses ought to give the right order of magnitude for the two layers of bipedales. The bricks for the piers then follow the rate for brick facework (see Section 8.1.3) of 500/day, giving a total for the hypocausts of roughly 800 days for a bricklayer and labourer. A further 650 days carrying are needed at the standard rate. The tubuli need another 1000 days for a bricklayer and labourer, assuming they are laid at the same rate as the bipedales, plus a further 180 man-days carrying. The small amounts of mortar used in installing the heating system can safely be ignored.

8.1.6.2 Floors

Two basic types of floor treatment need to be considered, opus sectile and mosaic. The marble floors in the main rooms total some 6000 m^2. If this were 0.025 m thick then 150 m^3 of marble would be needed, which we can divide into, say, 100 m^3 of white or grey and 50 m^3 of coloured and granite. The sawing of Carrara marble in the 19th century appears to have taken about 0.83 days/m^2, which should give a low figure if applied to all the marbles and granites; this will therefore take some 5000 man-days. If the bedding for the slabs is 0.3 m thick (the same as for the mosaic floors) and composed of one part lime to three of crushed terracotta, this requires 1600 m^3 of terracotta and 530 m^3 of slaked lime, or 330 m^3 of quicklime. Crushing the terracotta and slaking the lime takes some 400 man-days each.[35] In the absence of any specific figures for

[34] Assuming that they are 0.12 m long and have a cross-section of 0.006 m.

[35] Crushing brick or terracotta - Rea 1902: 44, 4 yd^3/day = 0.27 days/m^3; slaking lime 1.2 days/m^3 (see Section 8.1.2).

laying marble floor slabs, we can use Rea's rate equivalent to 0.3 days/m² for setting York stone slabs of random sizes in mortar,[36] giving some 1800 man-days. This includes an amount for the preparation of a shallow mortar bed 0.1 m thick, to which we should add a figure for preparing the remaining 1200 m³ of the floor make-up. At the rate of 0.7 man-days/m³ for mixing mortar by hand as established for the foundations (see Section 8.1.2), and adding a further 0.16 days/m³ for spreading and levelling,[37] this requires 1000 man-days. As usual we must add a figure for carrying the marble and mortar, roughly 100 days for the 405 tonnes of marble and 1000 for the 1800 m³ of mortar.

Of the mosaic floors, 5050 m² are patterned black-and-white, 6000 m² patterned coloured marble, and 5000 m² plain black mosaic. The tesserae average 6000/m², and are roughly 0.025 m deep; for the black-and-white mosaics we can assume that half the tesserae are black and half white, while for the coloured mosaics one third each of grey-white marble, yellow or pink marble, and red and green porphyries were used. Thus some 190 m³ of <u>selce</u>, 60 m³ of limestone, and 50 m³ of each of the groups of marble were required, all of which probably comes from waste allowing us to discount the cost of the materials. The tesserae do, however, have to be made, each one requiring the equivalent of three cuts to complete, since each cut produces two faces. There are no recent figures on which to base the rate at which tesserae were produced, but the abilities of 18th-century rasp and file cutters to make up to 200 cuts/minute suggest the limits for this kind of human action. If we include an element for fetching the raw material and removing and sorting the waste, then 20 (= 60 cuts) tesserae/minute, or 14,400 tesserae/man-day will give the right order of magnitude. Thus the 96 million tesserae would need around 7000 man-days to produce.

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[36] Rea 1902: 112, assuming that the cost relates to the labour of a mason. At p.113 he gives a rate equivalent to 0.67 days/m² for the more difficult task of fixing marble wall slabs, which suggests his figure for stone slabs is of the right order of magnitude.

[37] Rea 1902: 56.

The tesserae were then laid in a shallow layer of lime over a 0.3 m thick bed of coarse opus signinum. Some 5000 m^3 were needed for this bed, comprising 4400 m^3 of crushed terracotta and 1500 m^3 of slaked lime. A further 200 m^3 of lime paste was needed for setting the tesserae, giving 1100 m^3 of quicklime altogether. Using the rate established above for mixing and laying the mortar bed of the marble floors gives a further 4500 man-days. The question of laying the mosaics themselves is more difficult. Again we can gain some idea from physical limitation, two tesserae/second being about the fastest that a person could pick up a tessera from a pile close by, orientate and place it in the necessary position without too much refinement. Allowing for supplying and selecting the materials, a rate of one per second is reasonable, with a slower average rate for complex patterns and simple figured scenes, say one every four seconds. These figures give a rate of 0.14 and 0.56 days/m^2 respectively. Thus the plain black floors might take a minimum of 700, the black-and-white 2800, and the coloured mosaics 3400 man-days to lay.[38]

8.1.6.3 Walls and vaults

The decoration of the walls and vaults involves some 34,500 m^2 of marble veneer, 16,900 m^2 of glass mosaic, and 40,400 m^2 of painted plaster or stucco. After the first bonding course extra time must be allowed for working from scaffolding; the 19th-century handbooks suggest as much as one and a half times the ordinary rates, which should include the extra labour required for raising the materials to the appropriate height.

The marble veneer was a mixture of white/grey, coloured marble and granites and porphyries in proportions assumed to be half white and half coloured. The sawing of the marble into slabs, without considering the needs for any intarsia, would have taken at least 29,000 man-days at the 19th-century rate given above for Carrara. The backing material for the marble veneer was a

[38] Although the black-and-white mosaics are a mixture of very simple geometric patterns, more complex patterns and large-scale figured scenes, it seems reasonable to take an average value for the whole rather than trying to create a scale of values to fit the different requirements.

mixture similar to that used for the floors, consisting of lime and crushed terracotta in the proportions of 1:3. The average thickness of the bed above the low sockle is 0.07 m, requiring 2400 m^3 of mortar comprising 450 m^3 of quicklime and 2400 m^3 of terracotta. The setting of the veneer according to 19th-century figures should have taken some 0.67 man-days/m^2 with the same for the final polishing;[39] altogether, including the extra for working from scaffolding, some 64,000 man-days were required.

The plastering for the stucco was done in at least three stages: a first rendering coat, 0.05 m thick, of lime and sand in the ratio of 1:3; a second, 0.025 m thick, in the proportion 1:2; and a third, the setting coat of lime and white sand or calcite, 0.005 m thick. Allowing for the different volumetric changes with the change in proportions, the 40,400 m^2 of plaster required 750 m^3 of quicklime and 2800 m^3 of sand. Slaking the lime alone would take some 900 man-days. Ancient plastering techniques were similar to those used in the 19th century before the introduction of plaster-board, but the rendering coats were thicker. The manpower figures for the rendering coats, given per unit area, are thus adjusted according to the volume of material applied, although the rates for the setting coat remain the same. Since it is clear that the walls were not left plain but were stuccoed and painted, a further figure is added to cover this. Rather than try to guess at a figure for decorative painting, I prefer to use the 19th-century constants for moulded decoration applied to the whole surface area. Allowing extra again for working from scaffolding, the plastering requires 31,000 days for a plasterer and labourer.[40]

The remaining parts of the walls and vaults were decorated with glass mosaic. The glass tesserae from the test excavations in the central block measured on average 0.007 m per side, giving some

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[39] Rea 1902: 113, for a 1" slab of Carrara. The figure for polishing compares well with the 0.79 man-days/m^2 given by Burford 1967: 246 for Pentelic marble.

[40] The rates derived from Hurst 1865: 238 are 1.9 days/m^3 for both rendering coats, 0.012 days/m^2 for the setting coat, and 0.36 days/m^2 for the decorative stucco work.

15,000 to the square metre or 254 million in all. Since the tesserae were cut from sheets of glass each one requires only four shared cuts, the equivalent of two full cuts. At the inclusive rate of 60 cuts/minute used for the floor mosaic, the tesserae would take 12,000 man-days to produce. The constants deduced for plastering the walls apply to the backing for the mosaic decoration. The one rendering coat 0.07 m thick, plus a layer of lime putty for bedding the tesserae 0.01 m thick, require 320 m^3 of quicklime and 1000 m^3 of sand. Laying the bedding coats takes 2600 days for a plasterer and labourer. Assuming that the mosaics were set in complex figurative and vegetal designs, we need a rather higher figure for laying, say an average of 8 seconds per tessera or 2.8 days/m^2, plus extra for working from scaffolding, a total of 71,000 man-days. Altogether, including the time needed for slaking the lime, preparing the mortar, cutting the tesserae, and laying the preparatory beds as well as actually laying the mosaic, the 16,900 m^2 of mosaic would have taken 89,400 man-days or 5.3 days/m^2. This can be compared with the rough figures worked out in the early 19th century for the mosaics of Monreale cathedral of 300 man-years for 6440 m^2, or 10 to 14 man-days/m^2 depending on the length of the year and the day.[41]

8.1.6.4 Manpower totals for decoration

The basic manpower requirements at the site for the finishing and decoration are summarised in Table 18.

Table 18: Manpower for Decoration on Site

Operation	Area m^2	Prep.	Lay sk.	Lay unsk.	Carry	Total	Labour per m^2
Hypocausts	5400	-	800	800	700	2300	0.42
Tubulation	9800	-	1000	1000	200	2200	0.22
Marble floor	6000	5800	1800	1000	1100	9700	1.62
Mosaic floor	16100	9000	6900	4500	3200	23600	1.47
Wall veneer	34500	29700	32000	32000	1700	95400	2.77
Stucco	40400	900	31000	31000	1800	64700	1.60
Vault mosaic	16900	12400	73600	2600	800	87100	5.15
Totals		57800	147100	72900	9500	287300	

41 Calculated by Petrasanta, cited by Demus 1949: 145.

This table omits a number of elements of the fittings and decoration for which it has proved too difficult to estimate the manpower figures. These include the installation of the hot pools (which were built up after the hypocausts were complete) and the fountain basins, the fitting of the doors and window frames, the glazing, and all the plumbing.

8.1.7 Manpower requirements for materials production

The previous sections have been concerned with the actual process of construction, but the production of materials also absorbs a given amount of manpower, as we saw in Chapters 4 and 5. The data for each type of material, divided into skilled and unskilled labour, is summarised in Tables 19-21 below according to the construction phases.

Table 19: Manpower for Locally Quarried Materials
(all unskilled)

	Tufa		Selce		Pumice		Pozzolana		Total
	cu.m 000s	Mday 000s	cu.m 000s	Mday 000s	cu.m 000s	Mday 000s	cu.m 000s	Mday 000s	Mdays 000s
Found.	-	-	94	564	-	-	54	24.3	588
Cistern	34	43	-	-	-	-	26	11.7	55
Substr.	110	165	-	-	-	-	84	37.8	203
Central block	77	96	-	-	5.9	7.4	74	33.5	137
Totals	221	304	94	564	5.9	7.4	238	107	983

Table 20: Manpower for Lime

	cu. m	Kiln loads	Man-days skilled	Man-days unskilled	Fuel tonnes
Foundations	17,000	283	8,500	29,000	34,000
Cisterns	8,000	133	4,000	13,600	20,000
Substructures	26,000	433	13,000	44,200	65,000
Central block	23,700	395	11,900	40,300	59,000
Decoration	3,200	53	1,600	5,400	8,000
Totals	78,000	1300	39,000	133,000	186,000

Table 21: Brick

	Bess. 000s	Sesq. 000s	Bip. 000s	Tub. 000s	Man-days skilled	Man-days unskill.	Fuel tonnes
Cisterns	720	180	35	-	1,700	6,100	1,000
Substruct.	2460	450	430	-	7,300	27,100	4,300
Central bl.	3360	646	1400	-	15,900	60,900	9,600
Hypocausts	97	-	46	100	700	2,400	400
Totals	6640	1280	1910	100	25,600	96,500	15,300

In addition the 290,000 m^3 of sand required for the fill of the site needed about 130,000 man-days to excavate, assuming that the conditions were similar to quarrying pozzolana.

Some rough figures for the production of marble and iron can also be supplied. For the 4000 m^3 of white marble and the 252 columns needed for the architectural orders during construction, 112,000 man-days were required for the quarrying and shaping without any allowance for moving the blocks within the site, while the 3600 m^3 needed for the decoration would require a further 80,000 man-days. All of this would have been skilled labour. The 102 tonnes of iron needed for the central block would have taken some 15,000 days of skilled and 30,000 of unskilled labour to produce. It is not possible to produce realistic figures for timber, scaffolding, ropes, baskets, glass for mosaics, or other metals.

8.2 SCHEDULING THE WORK

The preceding section was concerned only with the total quantities of materials and number of man-days required for construction and decoration. While this is sufficient to calculate the total cost of the project, it gives no indication of the actual numbers employed at any one time. The possible numbers are limited at the lower end by the time taken to build the whole structure, and at the upper end by the shortest **practical** time in which the building could have been erected. This latter is defined by a variety of factors including the length of the building season, the curing rate of concrete, the closest possible physical spacing of men engaged in tasks such as laying bricks or carving marble ornament, etc. In modern terminology this shortest possible schedule is called the critical path, and it has a value in determining not only the number of men and type of skills required at any given point in the construction programme, but also the supply pattern for the building materials. This in turn provides information on the size of the workforce needed to produce the materials, and the transport requirements.

8.2.1 Order of work

It has already been established (Section 2.3.1) that the maximum time between decision to build and completion of the central block was just over seven years, from the accession of Caracalla and Geta in February AD 211 and the death of Caracalla in April AD 217. At least a year must have been needed for the decoration and fittings, so that the basic construction had to be complete by the end of AD 215. A starting date of AD 212 for work on site is suggested by the date of the earliest bricks of Caracalla and the dedication of the aqueduct between the beginning of AD 212 and May 213. Some breaks in construction were necessary (or at least advisable) to allow the foundations, substructures, and walls supporting major vaults to develop strength, coinciding with the winter months when construction normally ceased. This period is also likely to have been avoided even in the preparation of the site since the heavy clays could not easily be dug in bad conditions. A provisional programme can thus be worked out as follows:

AD 211 - decision to build, select site, design, order materials, begin aqueduct
AD 212 - terracing, foundations, cisterns
AD 213 - substructures
AD 214 - walls and minor vaults of central block
AD 215 - major vaults of central block
AD 216 - decoration

We shall use this provisional programme as a framework within which to develop a critical path for the building of the Baths. At each stage the minimum practical time in which to complete the longest single task will be calculated in order to test the programme, while the average number of men employed will be calculated on the basis of either this number or the nominal year (220 days for construction or 290 days for tasks not dependent on the weather, see Section 1.3.2), whichever is the shortest.

8.2.2 Terraces, Foundations, and Cisterns

For the excavation for the terraces, the minimum time produces employment figures which are clearly too high. If the closest a man can dig to his nearest neighbour is two metres in each direction, the smallest patch he can work is 4 m^2; where the depth of terracing is at its maximum of 6.6 m, a man working a 4 m^2 patch would move 26 m^3 of clay. This would take about 5 days at 5.5 m^3/day. Spreading the 67,000 man-days required altogether over this minimum possible time of 5 days would require 13,400 men for the digging alone, plus a further 44,400 men for filling and removing.

Alternatively we can assume that the men worked in lines across the width of the site. If the men were stationed 4 m apart and each had a slice roughly 10 m wide, 2200 men would be needed over 21 rows with 105 men per row, plus 800 filling, and 6500 carrying each day for 30 days to finish the terracing - a total of 9500 men. If, on the other hand, only 10 rows were used 4500 men would be required over 60 days, or for six rows 2700 men over 100 days. It will be easier to make a choice between these various options once we have determined how long it took to make the foundations.

The digging and filling of the foundations should be seen as a continuous process rather than as two separate ones, with the shallower foundations starting to be filled before the deeper ones had been completely dug. Since all the filling and carrying, and most of the digging and mortar mixing could be done by unskilled labour, the labour force could be transferred from one task to another. The longest operation must have been the digging and filling of the main foundations of the central block. If each man has a stretch 2 m long, and a second man can only be fitted into a trench if it is over 2 m wide, then the minimum time for completion of the foundation trenches would be equal to the time taken by the man working over an area 4 m^2 and 6.5 m deep,[42] which works out at just 7.5 man-days.

Figures for the filling are rather more difficult to calculate. The logistics of the operation suggest that, for depths greater than 1-1.5 m, the actual filling and ramming must have been done by men standing in the trenches and being handed the mortar and caementa in baskets as required, using a rope as necessary. If those at the top of the trench were no closer than 2 m apart, and the widest area that each filler had to serve is 4 m (half the width of the caldarium ring), then critical volume to be filled will be 8 m^2 and 6.5 m deep. The component of the rate given by Rea for mixing and laying concrete which can be assigned to the laying is in the order of 0.15 days/m^3.[43] Since each cubic metre of fill requires 38 basket loads of caementa and 16.5 basket loads of mortar, this would mean that one basket load had to be deposited every two minutes, including compaction, a not unreasonable average figure provided the supply of materials was maintained. Thus the minimum time needed to fill our critical volume would be only 8 days.

Altogether the digging and filling of the foundations must have taken at the very least 16 days, needing a constant workforce of 18,300 men. If, however, we set the level of the basic workforce at 4500 men the foundations would have taken 65 days, and if at 2700 men they would have taken 110 days. Thus we can see that if all the available 220 days of the first year were used, a basic workforce of 2700 men would be required at the site, plus, say, 140 men slaking the lime over the first six months and 35 pairs of sawyers preparing the shoring timbers during the first half of the

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42 This figure is not as excessive as it may at first seem, since it has to include space for an extra man filling baskets between each two diggers at the most.

43 Rea 1902: 54.

building season.

These are, of course, average figures based on the individual actions, and take no account of any logistical difficulties. While clearly it would not be too difficult for one filler to be shared between three diggers during the excavation of the terraces, a certain amount of confusion may be imagined with the carriers. If, instead of being carried all the way to the carts and back by one man, the baskets of clay were passed from hand to hand, then some 1700 men would have been needed, stationed about 1.5 m apart in 6 rows extending the full width of the site to remove the clay, with a further 6 rows to return the empty baskets. This differs from our original figure of 1800 by only 6%, and does not substantially affect any conclusions on the size of the workforce, although it shows yet again how the movement of materials over short distances within the production centre is one of the more difficult factors to assess.

In order for the water from the new aqueduct to be available to use on site during the main construction phases, the cisterns must have been built at the end of the first season, requiring their foundations to have been completed before the rest of the terracing so that the foundations could develop sufficient strength for the building of the cisterns within the same season. The maximum number of men working at any one time laying the walls is conditioned by the perimeter of the structure. A reasonable minimum distance between bricklayers is two metres, or just over a normal span,[44] giving a maximum of 1600 men working at the face at any time. At this rate it would take about 120 days to build the cisterns, and if my schedule is correct the number could not have been much smaller.

This schedule also affects the amount of formwork which has to be prepared. Although the

[44] A distance of 3 florentine bracchia or about 1.8 m between masons was suggested by Filarete (Spencer 197: IV. 23v) for the building of his mythical city Sforzinda, in order to keep the peace (!).

chambers of the cisterns consist of 32 identical units at each level, all the vaults of the first level had to be laid at the same time to keep within the programme, but the formwork could be used again at the second level. Hurst supplies figures of 0.14 days/m² of a carpenter and 0.07 days/m² of a labourer for a barrel vault, and 0.29 plus 0.09 days/m² for a cross vault.[45] Thus for the 5900 m² of vaulting 800 days of a carpenter and 400 for an assistant were needed, and if these started work in AD 212 and the forms had to be ready just after the middle of the season, a mere 7 carpenters and 3 or 4 assistants would have sufficed. The boarding for the vaults required 150 m³ of wood or 220 of the smallest timbers in the Prices Edict.[46] Allowing four centres to each chamber (an average spacing of 4.3 metres) and three radial struts plus the main chord in each, and assuming eight or nine inch (0.2-0.22 m) square timbers for the main struts with half that for the curved pieces forming the perimeter, gives a total of 130 m³ of wood or 120 timbers. In addition, 240 days for a pair of sawyers were needed to convert the timbers to boards, and this could have been done by a single pair of sawyers working for the first half of the season.

8.2.3 Substructures

The substructures divide into four zones: the terracing structures over the north facade; the east and west sides of the precinct block; the galleries; and the central block with its drains and maintenance passages. In each zone, the maximum number of men is governed by the perimeter of the structure, although some allowance must be made for large areas where the centre is out of reach of the masons laying the face, such as the ring of the caldarium.[47] In this case the number of men depends on the horizontal area, and each man should be allowed at least 4 square metres;

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[45] Hurst 1865: 224.

[46] The marks of boards 3.5 x 0.294 (12 ft x 1 ft from the formwork of the maintenance passages under the central block are still clear. A thickness of 0.037 m (1½ inches) can be assumed from modern standard boards of those dimensions.

[47] It is interesting to note that the widest ordinary walls are seven feet or 2.07 m thick, so that the centre can just be reached by a bricklayer standing outside the wall face.

the same applies to the laying of the vaults, although here the area increases as the vault rises.

We can see how this works with the central block. Altogether, including the drains and maintenance passages, 240,000 man-days of masons and labourers are required, giving a minimum of 1100 masons and 1100 labourers over 220 days. The substructures are roughly 8 m deep and built in six stages, at the end of all but the last of which the level of the block is raised to create a new working floor. The widest areas to be filled are the blocks under the long bays flanking the frigidarium, roughly 11 m wide. For each stage 1.32 m high a mason could lay a two metre patch of face in 0.35 days, and two masons an area 11 m² and 1.32 m high (a volume of 14.5 m³) in 22 days, or three masons the same volume in 15 days. If the men filling the voids between the walls cover the same kind of area - 4 m² - then one man needs to fill 5.3 m³, which requires 210 trips if each basket contains 0.026 m³. The filling at each stage will take at least three days. Thus the six stages will take at least 150 days with two masons laying the core, or 110 days with three masons; in the first case a total of 1600 masons and labourers are needed, and in the second 2200 of each. We are therefore justified in using the lower number of 1100 masons and labourers obtained by maximising the time. As a further check, if the perimeter of the central block is divided by this number of masons, the average spacing would be a comfortable 4.3 metres.

In the north facade terrace structures a further factor needs to be considered. Here 44 of the 51 the vaulted chambers making up the facade are identical, making it feasible to reuse some of the formwork and centering. The logistics of construction allow us to plot the maximum amount of reuse. Calculations from the perimeter show that a maximum of 1600 masons could be employed at any one time; this provides the upper limit. The lower limit fixed by the available time is 420 masons. Using this number the walls could be finished in 115 days, leaving 105 days for the vaults. These calculations assume that all the vaults are laid concurrently over this period. If the vaults were laid in two phases and we allow a gap of 15 days between for the vaults to cure,[48] only 90 rather than 105 days would be available and 480 rather than 420 men would be needed, while if they were laid in three phases the time is reduced to 75 days and 580 men would be needed. At the same time we have to take into account the number of men who could actually work on the vaults at any one time. If the maximum horizontal area of vault to be laid in each bay is 162 m^2, then no more than 40 men could work on the vault of each bay, and at the early stages this would be more like 26. Thus if all the vaults were laid at once between 1300 and 2000 masons could be employed, while if one third were laid at once between 440 and 680 could work together. By using a fixed workforce of 480 masons the formwork could be moved three times and the whole process still take only 220 days. If we wanted to move the formwork four times, 520 men working continuously would be needed, while between only 330 and 520 could actually work on the vaulting at any one time. Clearly this again provides us with another limit, and the simplest solution seems to be to use a workforce of 480 masons and labourers and move the formwork three times.

Similar calculations can be made for the other zones of the substructures, but it would be otiose to examine them in full. For the lateral exhedrae the case is simple, since the formwork can only be used twice (once each side), and there is only a limited number of repeatable elements in the remainder of the lateral terracing structures. Altogether a workforce of 720 masons and labourers could erect both sides of the platform substructures in 220 days. For the galleries, the minimum number of masons is 390 and the maximum 740. Short sections of the barrel-vaulted forms could have been reused several times; four times would need 500 masons and labourers, three times 460. We shall assume, as we have for the facade, that the formwork was moved three times.

[48] Modern concrete made of Portland cement advises 15 days before the removal of formwork to deep beams (cf. Foster and Harington 1983: 432) and this should be considered the minimum for Roman concrete.

We can now calculate the labour required to make the forms for the vaulting, and the amount of timber. Altogether, 2100 man-days are required from carpenters plus 840 from their assistants to construct the formwork and centering for the substructures. Since the forms had to be finished at the latest by halfway through the construction period, some 20 carpenters and 8 or 9 assistants were needed over 100 days. The area of vaulting to be supported at any one time is 10,600 m^2, using 400 m^3 of timber. For a maximum spacing of 5 metres for the centres, about 230 m^3 of timber are needed from 580 balks of timber, and a pair of sawyers would take some 500 days to convert these to boards and timbers of the required size, or five pair working over 100 days.

Only two further elements need to be taken into account before we can come to the final figures for the number of men working on site to build the substructures. The carrying of the materials in question needs some 146,000 man-days, or 660 men over 220 days. In addition, a further 302,000 man-days of labour is required to fill the voids in the central block and raise the level of the platform, which could be distributed over 1500 men working 200 days.[49] Thus in total some 7700 men would be directly engaged in building the substructures on site over a construction season of 220 days.

8.2.4 Central block

Once the substructures have gained their full strength over the winter break, work could start on raising the central block. Since the area of construction is much reduced, it is clear that the total number of men employed on the site at any one time should be less than was required for the substructures. The maximum number of masons which can be fitted around the perimeter of the block at ground level is 2700, while rather fewer could be employed at the higher levels where there are more openings. Taking an average figure of the number of men needed to work on the

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[49] Assuming that the filling could not begin until the walls of the containing structures had reached a certain height.

structure from the ground to the top of the main block excluding the high vaults over a standard year of 220 days gives a workforce of 1900 masons, suggesting that this much of the structure could in fact have been built in one season if we do not allow for interruptions for setting in place the architectural orders or raising the centering of the vaults. The total number of men required on site for the first year of building the central block would thus be in the order of 4600, plus the marble workers, leaving only 1,300 needed for construction of the remaining vaults if spread over all 220 days of the next year. This allows an average of 470 masons working on these vaults at any one time, and it is unlikely that the numbers were much higher given the very reduced area over which they would be spread.

This does, of course, represent the maximum case, and other arrangements of the building schedule are possible. If the number of men working on the frigidarium and caldarium was maximised, as these take the longest to build, and the workforce was spread more thinly in other areas, then it would have been possible to maintain a more-or-less constant workforce of 2800 to 3000 men over the whole of two years on the central block, excluding the marble workers. The breaks in construction between the frigidarium and Rm 14 noted in Section 6.5.2 support this version of the building programme. In addition this would allow the walls to cure fully before the laying of the rest of the major vaults, and accommodate the breaks needed for the erection of the columnar orders and the centering more readily.

Following this two-year programme we can now estimate the amount of timber needed for the formwork. In the early stages of construction, formwork is needed only for arches and vaults of small span covering doorways and niches, and for the minor barrel-vaults of Rms 3a-d, 7 and 11. Even if it is assumed that none of the formwork is moved from one side of the building to another and reused, in all only 7,100 m^2 of boarding and 175 m^3 of timbers are needed up to the eighth bonding course, and this could all be made from material reused from the substructures while still allowing 25 to 30% wastage. This material can then be assumed to be reworked for the final time to provide formwork for the remaining small window arches (e.g. in the upper part of Rms 13, 14, 19, 20, etc). The major vaults and vault-end arches, if all built at the same time, would need some 23,400 m² of boarding and roughly 3000 m³ of timbers.[50] The sawing of the boards requires 1900 man-days, or 190 days for five pairs of sawyers. If all the centering had to be ready by the start of the second year of work on the central block, and the carpenters worked over twelve months instead of nine, then the forms could be prepared by 26 carpenters and 11 assistants. Over the standard year of 220 days, 34 carpenters would then be needed. It is unlikely that the preparation of the forms was begun before the start of construction of the central block, particularly if we are to allow for some reuse of material from the substructures. The variation in the width of many niches and of the doors between Rms 4 and 12 strongly suggest that the centering for these minor elements must have been prepared as necessary, while the asymmetries caused by the errors in setting out the central block, and the adjustments made to the walls to correct this, could not have been accommodated into the centering until after the final setting out of the superstructure. Furthermore, the constraints of access within the central block do not allow for the centering for the main vaults of any but the peripheral rooms being assembled outside the block (see Section 6.5.2).

The working pattern for the marble carvers is more difficult to ascertain, since here the profiles and mouldings could be carved in advance and the heights or lengths of the various elements adjusted during erection. Given the need for the architectural members to be specially ordered for the project (see Section 4.3.2), the earliest point that work could be commenced on the carving at the site was the start of AD 213, while all but the niche decorations of the natatio facade were

[50] To calculate the centering timbers needed for the major cross- and barrel-vaults, I have scaled down from the list of timbers ordered for the nave of new St Peter's in Rome (Scavizzi 1983: 107-108), excluding those required for the coffers and the rest of the boarding. For lack of any real parallel for the centering of the caldarium dome, I have simply assumed that it needed the same amount of timber as the frigidarium cross-vault, the total surface area and thus weight of concrete of the two being roughly the same.

required at the latest by the middle of AD 215. Assuming that the marble workers like the carpenters work twelve months rather than nine, the minimum number needed was 145 over two and a half years, while for the whole to be done over a single year of 290 days would need 360 skilled craftsmen. These figures do not include the workforce needed to move the elements and raise them into place. Although the total number of men is not great - some 3000 - this cannot be distributed evenly over time since a large number of them were required at discrete moments, such as the 500 needed to move each of the giant order columns, and none at all for most of the time. In order to prevent sudden peaks in manpower requirements, men must have been taken from other tasks, encouraging the view that the erection of the major orders formed a natural break in construction. It should also be noted that most of them would be required in the second season when the level of the workforce is assumed to be lower.

8.2.5 Finishing and Decoration

There are a few obvious constraints on the scheduling of the decoration. Wherever possible work is carried out from the top down, and there are the usual physical limitations on the number of men who can work on a given area at any one time. For vertical surfaces the two metre rule used for building applies, except that for the larger columns (30-ft shafts and over) one man can work on each face of the capitals and two or three on the shafts and bases. For floors work must start at one edge and work out, so that the number of men is related roughly to the length of the longest side. Otherwise, unlike the actual construction, the groups of specialists could work at different levels at the same time or move from one part of the building to another as the need arose. For finishing the architectural orders the maximum number of men is determined by the length of the entablatures, followed by the numbers and sizes of the columns. The maximum number for the entablatures is thus 1000 men, for the columns 280, while the average over 290 days is 350. We can thus adopt this latter figure, which is happily within the range already suggested for preparing the architectural orders at the construction stage. The longest consecutive operation - carving the detail and finishing the giant frigidarium order - takes 280 days for three men, and thus also fits well with our assumed year for decoration.

The decoration of the surfaces is more difficult to schedule. Since the marble floors are mainly in the largest rooms which would be complete only late in the programme, they would have required a relatively large workforce for a short space of time. If we allow 30 days for this element, then 60 marble workers plus 30 labourers are required. In contrast, the floor mosaicists could work first on the roof terraces, then on the palaestra terraces once the wall decoration there was complete, moving to the smaller and lastly to the larger rooms as the rest of the decoration was finished. Thus a relatively small workforce of 25 mosaicists and 15 labourers might be employed for the whole of the final year. If the wall veneer and the stucco or mosaic of the upper walls and vaults could be done simultaneously,[51] and allowing for 30 to 40 days at the end of the season for the floors, a workforce of 130 marble workers with their assistants, a similar force of plasterers and assistants, and 280 wall mosaicists served by 10 assistants are needed. The hypocausts and tubuli needed to be installed fairly rapidly to avoid holding up the floor and wall decoration, and could have employed teams of 40 and 50 men respectively over 40 days. Thus at the most 1250 men would be actually working on the decoration at any one time, not allowing for taking down and removing the scaffolding, with a further 30 to 40 for carrying the materials, but the actual numbers engaged in any specific task at any given moment would have varied considerably.

8.2.6 Equipment, maintenance, supervision, administration

As well as having the raw manpower necessary to carry out the programme outlined above, the

[51] This possibility is suggested by the evidence for all the marble veneer finishing in a narrow projecting cornice supported by an unusually high number of metal cramps. If these cornices were set in place before the rest of the marble veneer they would provide a neat edge at which to finish the upper wall and vault decoration irrespective of whether the veneer below was finished or not.

success of the operation also depended on the availability of equipment. For the excavation of the terraces and foundations a minimum number of digging tools were required, and in the later stages there was need for hoes for slaking lime and mixing mortar, trowels for laying mortar, points and chisels for working marble, and at every stage thousands of baskets for carrying the materials from one place to another. While we cannot be sure who provided the tools, we shall assume that they formed part of the stock in trade of the skilled workers who supplied their own. Baskets, as consumables, were a different case; if three are required for every one actually in operation to allow for filling and returning, then some 6000 were needed for the excavation, and these would have sufficed for the rest of the project. Ropes were also needed for lowering the fill into the foundation trenches and raising materials onto the scaffolding for the superstructure, while a variety of pulleys, cranes, capstans and treadmills were also essential along with special devices for raising the large column shafts.[52] While it is impossible to determine the exact number of these needed, at least two large treadmills were required to lift each of the largest centres for vaulting and the largest architectural elements, and both the scheduling of the construction and the area over which they were required suggest that as many as four pair of treadmills could have been used. Again for the central block, some 200 ropes up to 40 m long and pulleys were needed for raising basket-loads of materials; at 20 mm in diameter the ropes would have would have weighed about 10 kg each.

As well as allowing for the provision of equipment, some allocation has to be made for manpower above that strictly necessary to carry out the physical work. Some of this is required for supervision and administration, some for the maintenance of tools, while surveyors were also needed to set out the terraces, check the levels of the excavation, and then to set out the foundation trenches in the first year and again to set out the central block. Later periods give some indication of the proportion of supervision and administration to labouring force, which seems generally to

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[52] See Adam 1977: fig. 6.

have been between 3 and 20 percent, and often about 10 percent.[53] At five percent for supervision alone this would add a further 150 men to the workforce each year and twice that in the second year. The actual administration might have been only 10-20% of the supervisory force, if the figures given for the building of new St Peter's in Rome are any guide.[54] Smiths were needed for the maintenance of tools and for making items such as the vaulting bars and holdfasts for the wall veneer and tubuli. There is less evidence for the kind of numbers involved here, but in the building of Suliman's mosque in Istanbul in the 16th century the smiths comprised between 1.5 and 2.5 percent of the whole workforce.[55] Since this was for a masonry rather than a concrete structure the maintenance rate of tools was likely to have been higher than in the construction of the Baths excluding the marble carving, but if we include producing the elements indicated above this might not be too far out, say some 25 smiths and their assistants working throughout the construction period.

8.2.7 Removing waste

The removal of the unwanted clay excavated for the terraces and foundations from the site also raises certain logistic problems. Taking the maximum load for an ox-cart to be 1200 librae (cf. Section 4.1.1) or about 0.2 m^3 of solid clay, then 1,850,000 trips would be required to remove the clay from the terraces. If the clay were removed at the same rate as it was dug, then 18,500 trips would be needed every day for 100 days. One possible way of disposing of the unwanted material was to take it to the Tiber below the Emporium where it could be loaded as ballast on the barges

[53] e.g. one to every ten masons in Filarete's Sforzinda (Spencer 1967: IV.23v) which works out at one in thirty men including labourers; one ganger to ten or twelve navvies in the 19th century; 5 to 20% as the cost of office work and supervision in various 19th and early 20th century guides to estimating. In the Roman army the relation between centurions and ranks was 1:80 [were there junior ranks below these?].

[54] Goldthwaite 1980: 124. cf also the 1:10 relationship between the military tribunes and centurions in the imperial Roman army.

[55] Barkan 1962: Tables 1 and 2.

returning to the river mouth and used as land fill in the Ostian marshes.[56] Each trip of 2.5 km there and back would then take roughly 3 hours, and only 4 trips would be possible for any one cart in a day. Assuming, however, that the carts plus oxen are 4.5 m long and allowing 2 m between them, only 385 carts can be on a 2.5 km stretch of road in any one direction at the same time, and only 2700 trips could be made on that stretch of road in a 12 hour day, or 5400 over 24 hours.

In other words, it would have been impossible to remove the clay along a single route as fast as it could be dug out of the site; in fact it would have taken 7 times as long for a 12 hour working day, or 3.5 times for a continuous operation. In this case 680 carts and men would be required for a total of 680 days, or 1360 for 340 days and nights. If we add to this the transport required to move the material taken from the foundations, this gives a total of 960 days for our 680 carts, or 480 days and nights. Thus in order to remove all of this material before the start of the next season of building, at least two routes must have been used and the carts operated day and night.

8.3 SCHEDULING THE SUPPLY OF MATERIALS

To complete the scheduling we must also take into account the supply of building materials. The earliest that production is likely to have commenced for materials specifically designed for the Baths is the summer of 211, which would allow at least a full year before the filling of the foundations; the latest that it can have started is the spring of 212, not allowing for any material taken from existing stockpiles. Once construction proper had commenced, an assured supply of materials was essential to the completion of the project on schedule, yet each material imposed its own scheduling requirements. Two factors come into play here, the needs of production and the needs of transport. Lime had to be prepared in advance to allow for slaking, brick clay had to be quarried months in advance and allowed to weather before the bricks were made, marble had to

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[56] As was done after the Great Fire of Rome in AD 64. See Tacitus Ann. XV.42.

be transported long distances by sea, itself a seasonal occupation; pozzolana, on the other hand, had to be used fresh and regular supplies were required.

8.3.1 Production Schedules for Local Materials

The locally quarried materials are the simplest to produce and transport, and since supplies could be obtained from close at hand, any deficiencies were made up relatively easily. For the tufa and selce which need to be broken into small pieces after quarrying, we can assume that the work was distributed over the longer year of 290 rather than 220 days, and that production continued up to the final day on which the material is required; for pozzolana the year is only 220 days and it has to be used within three months of being quarried. By allowing the production of these materials to extend over the longest available time with respect to the needs of construction, it is possible to determine a programme for production that minimises the necessary workforce. The requirements are shown schematically below.

Table 22: Schedule for Locally Quarried Materials

Period	mid 211 – 212 – mid 212 – 213 – mid 213 – 214 – mid 214 – 215 – mid 215 – 216	Total days
Selce	¦-- 1300 men --¦ (mid 211 – 212)	430
Tufa	¦--------- 300 men ------¦---- 200 men ----¦ (mid 211 – mid 213; mid 213 – 216)	700+500
Pozzolana	¦170 men¦ ¦160 men¦ ¦100 men¦ ¦60 men ¦ (212–213; 213–214; 214–215; 215–216)	4x220
Pumice	¦-30 men-¦ (215 – 216)	250
Totals	¦-1600-¦-1770--¦--460----¦------300 men------¦	

The supply of lime for construction is more complex because of the need to allow at least three months for the slaking process, and because of the internal rhythm of the production itself (see Section 5.2.3). Each unit of 8 men producing 60 m^3 of quicklime per cycle could operate at the very most 14 cycles/year over the drier months with the winter being used for fuel collection. Once the lime slaking pits were established on the site, a continuous process of delivery, slaking and use could be established. If production started in the middle of 211, then 30 teams of eight men - a total of 240 men - would be needed until the middle of 213, when the teams could be reduced to 17 (140 men) for the next year, 11 (90 men) for the next, and only four for the final year to supply the lime for decoration, although this could also have been done by the 11 teams at the end of 215, which would allow the very thorough slaking necessary for plastering.

The supply of brick had to work to a rather different schedule. It is clear from the brickstamps that the actual production did not really begin until 212, although the clay would have been dug the year before, while all the bricks for construction were needed by the middle of 215 at the latest with only the few for the hypocausts in 216. The greatest demand was in 213 and 214. Using the firing patterns for the different items already established (see Section 5.3.4) and allowing for the maximum number of firings per year, the bricks could have been supplied by 17 teams of 10 to 11 men operating for all of 212-214 reducing to 9 teams in 215. The equivalent of another 12 teams operating for a year would have been needed to provide the brick caementa for the central block, but, as already been noticed, this presumably was supplied from waste; however, we should perhaps add a further four teams to the years 212-214 for this, giving a maximum number of men employed of 220 over three years. This rough figure of 17-20 teams accords well with the evidence of the brickstamps, where the number of officinatores dated to the reign of Caracalla and represented by more than one example is 22, and by more than three examples is 17 (see Appendix 2).

8.3.2 Transport for Local Materials

Again the locally quarried materials provide the simplest case. It is assumed that all the transport is by ox-cart with a load of 1200 librae or 323 kg. The table shows only the number required to move the materials without allowing for a return trip or for the possibility that carts are operating day and night. The first factor should approximately double the number of carts - and hence men and oxen - required, but by operating both day and night the actual time taken and the number of carts in operation at any time remains the same. Nor do the above figures take into account the problems of starting and returning to the same place, so that the actual numbers needed were likely to have been greater; even so the order of magnitude will not be affected. There would be no difficulty in fitting the carts for all these materials on the necessary roads since different routes - Via Appia, Via Ardeatina, Via Ostiensis, Via Laurentina - could be used.[57]

Table 23: Transport for Locally Quarried Materials

Period	mid 211	212	mid 212	213	mid 213	214	mid 214	215	mid 215	216	Total days
Selce	1500										220
Tufa		240 carts				110 carts					510+580
Pozzolana		550cart		570cart		310cart		200cart			4x220
Pumice								140cart			210
Totals	1500	2300		810		420 cart		450			

The transport of lime and brick is assumed to be in three stages, from the kiln site to the river or sea port by ox-cart, over the water by boat, and from the Tiber wharves at the Emporium through the city to the site, again by ox-cart. For road transport we can assume the standard cart-load, for river barges a maximum of 100 tonnes, with the same for the sea-going vessels bringing lime from Terracina. Most of these figures are quite small. For the section kiln to port, the various options for the lime require between 100 and 150 carts per day for the first two years and 50-90 for the rest, while the bricks need an average of 35 per day for the first three years and 15 for the last; for the transport through the city 60 are needed for lime in the first two years and 40 in the rest, while 40 are needed for brick in the first three years and 18 for the last. In addition, the lime would have filled 350 and 200 boat-loads and the brick 230 and 100. For comparison, if the lime had been brought from near Tivoli by road along the Via Tiburtina, some 1200 carts would have

[57] The concept of long and constant trails of ox-carts ferrying building materials to Rome from the Campagna may seem strange, but was again a common sight in late 19th century Rome to judge from photographs of the time.

been needed in the first two years and 650 in the rest.

The high number of carts required in the early stages in order to transport the selce has also to be taken in conjunction with the large number required for the removal of the spoil from the terraces and foundations. If these were two separate operations and we include the rest of the transport requirements, over 7,000 carts would be needed in all in the first full year of construction. This seems an excessively large number, but would be substantially reduced if the spoil was taken away on the return journey of the carts bringing the building materials to the site, either from the Tiber wharves or from the quarries, which could then act as land-fill sites. In this way the removal of the spoil could be absorbed in the transport of materials, and only some 4,00 to 5,000 carts would be needed in the period of peak demand.

8.3.3 Supply of Marble

We have already assumed that the earliest the marble for the architectural members could arrive at the site was the beginning of 213, to allow time for the orders to be dispatched, the marble quarried and hauled to the nearest port, and for the blocks to be brought to Rome; the latest is towards the end of 214, and early 216 for the wall veneer. In terms of quarrying and rough dressing this would have needed a workforce of only 200 men, but the total number was perhaps more like double that. Transport from the quarry site to the nearest port differs from place to place, and no real figures can be given, nor can we estimate the manpower needed in transferring from one mode of transport to another. Once on the water, however, the total marble requirements represent only 60 loads for a ship of 400 tonnes, and 240 loads for a river barge for the transhipment up the Tiber. Once unloaded at the Marmorata, the marble had to be moved some 2.5 Km to the site. If we assume that this always involved multiple yoking, and thus that a pair of oxen and a man were needed for each 0.23 tonnes of marble, then on average only 35 pair of oxen working 290 days in a year were required during the three years between 213 and 215.

However, since each 10 tonne block (the average size of the entablature blocks, see Section 8.1.5) would need upward of 40 yoke, this must be taken as the minimum number of available beasts. All the column shafts 25 foot long and over (114 of the total 252) would require even greater numbers of animals, or extra man-power if they were hauled on sleds.

8.4 THE PATTERN OF MANPOWER USAGE

If we put all these scheduling requirements together, it should be possible to establish a pattern of manpower usage in Rome and its periphery, including all aspects of materials production, construction and decoration. Transport by ox-cart includes the needs of moving lime, brick, timber and marble from the Tiber wharves to the site, plus that for the locally made materials (cf. Table 23). It has not been possible to show all the seasonal variation in the totals on Table 24 with any accuracy due to lack of space, and instead figures are given for periods of highest demand only.

Table 24: Manpower Usage in Rome and Periphery, I

```
Period                mid  212  mid  213  mid  214  mid  215  mid  216  mid
                      211       212       213       214       215       216

Local materials       |-1600-|-1800--|--460----|------300 men-----|

Bricklayers, etc.            |1600|   |-5500-|  |-2400-|  |-2400-|

General labouring          |-2800-|   |-2400-|  |-520--|  |-520--|  |-40--|

Wood workers               |-80-|     |-40-|    |---50----|

Marble workers                        |---------------180---------------|

Other decorators                                                  |-1000-|

Smiths                     |----------------------50--------------------|

Totals (maxima)       |-1600-| |6400|  |-8600-|  |-3500-|  |-3500-| |-1300-|

Yoke of oxen          |-3000-|-4700-|--1800---|------1000---------|---60+--|

Total of men          |-4600-|11,100|  |10,400|  |-4500-|  |-4500-| |-1400-|
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The first thing to notice about this table is the very high demand on both transport and manpower for heavy labouring in quarrying, digging, portering, and - with a higher level of skill - for bricklaying. During this same period even more labour of this kind was needed for building the aqueduct and the access road, and for clearing the site. The peak demands on labour could be levelled out to some degree by rearranging the suggested schedule to begin construction in AD 211, but this would exacerbate the demands on transport. Moving the completion of the substructures into AD 214 and using a higher level of labour on the central block would also be possible, the limitations here being the time taken to build the *frigidarium* and *caldarium* and the need to allow the fabric to cure sufficiently to add the high vaults. An alternative scheme for the construction period which minimises labour across the board rather than in segments is given in Table 25.

Table 25: Manpower Usage in Rome and Periphery, II

```
Period             211  mid  212  mid  213  mid  214  mid  215  mid  216
                        211       212       213       214       215

Local materials     ¦-1600-¦---1800---¦---------400-------¦--430--¦

Bricklayers, etc.            ¦1600¦3000¦ ¦-2800-¦ ¦2800¦3100¦ ¦-3100-¦

General labouring   ¦-2000-¦ ¦1700¦1300¦ ¦-1300-¦ ¦1300¦-660¦ ¦-660--¦

Wood workers        ¦--30--¦ ¦--------------20----------------¦

Marble workers                           ¦-----------180-------------¦

Smiths              ¦---------------------40-------------------------¦

Totals (maxima)     ¦-3400-¦ ¦4800¦4500¦ ¦-4900-¦ ¦4900¦4400¦ ¦-4100-¦

Yoke of oxen        ¦--3300--¦3800¦1700¦----------1200---------------¦

Total of men        ¦-6700-¦ ¦8600¦6200¦ ¦-6100-¦ ¦6100¦5600¦ ¦-5300-¦
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There is still a sharp peak caused by the transport of *selce* for the foundations coinciding with the start of construction proper, but there seems no way to avoid this. It is always possible that, if the *selce* was in fact waste from the stone quarried for road building, it was held at a depot closer to Rome than the quarries, and thus the transport requirements and the labour for production were lower than shown here. Given the hypothetical nature of this whole exercise and large uncertainties inherent in it, it would be foolish to try to refine the scheduling any further. Nevertheless, the figures do indicate the order of magnitude of the workforce required in different areas, and in the later periods of construction cannot be significantly reduced. Although I have separated out quarry workers, general site labourers, and skilled or semi-skilled wall-builders, there is no reason why there might not have been a certain amount of exchange of personnel between these areas depending on the demands of the moment.

8.5 THE COST OF THE BATHS OF CARACALLA

8.5.1 Construction

The cost of construction for the Baths, excluding the columnar orders which will be treated under decoration, has four main components: labour for materials (including fuel), transport of materials to the site, labour on the site, and incidentals such as equipment, scaffolding, maintenance and supervision on site. The costs are given in Table 26.

Table 26: Cost of Construction

Operation	Materials		Construction		Total
	Labour	Transport	Labour	Incidentals	
Terrace and Foundations	303,000	693,000	217,000	654,000*	1,870,000
Cisterns	68,000	135,000	186,000	14,000	404,000
Substructures	286,000	1,340,000	738,000	46,000	2,410,000
Central block	270,000	572,000	577,000	172,000	1,590,000
Total	927,000	2,740,000	1,720,000	886,000	6,270,000
% of Total	15%	44%	27%	14%	100%

* includes removal of fill from site

Some of these figures can be broken down further. The production of brick and lime accounts for 63% of the labour on materials, 42% on the supply of fuel alone. If we add the cost of removing the fill from the site to the other transport costs this brings the cost of transport to over 50% of the total. The cost of scaffolding and formwork represents just over 2% of the total[58].

8.5.2 Finishing and Decoration

The cost of decoration has been divided up according to the type of decoration, into four

[58] It is possible that my estimates for this element, particularly the formwork, are substantially too low.

categories: the main raw materials, the secondary materials (e.g. the mortar backing for marble), the labour for processing materials (e.g. sawing marble) and the labour of installation.

Table 27: Cost of Decoration

	Materials		Labour		Total	%
	Primary	Second	Process	Install		
Heating system	7,000	-	-	2,000	9,000	<1
Architectural orders	1,072,000	-	132,000	1,000	1,205,000	58
Marble floors	66,000	3,000	3,000	2,000	74,000	4
Mosaic floors	-	10,000	3,000	7,000	20,000	1
Marble walls	360,000	4,000	18,000	32,000	414,000	20
Stucco walls and vaults	12,000	-	-	16,000	28,000	1
Mosaic walls and vaults	279,000	5,000	5,000	53,000	342,000	16
Totals	1,800,000	22,000	154,000	106,000	2,090,000	100

The cost of finishing and decoration in the table covers only the main elements. I have not included any furnishings, such as the 1600 seats for bathers recorded as being in the Baths by Olympiodorus, the porphyry and granite fountain basins, the door and window fittings and glazing, or any of the plumbing. The bronze lattice decoration of the cella soliaris and the 100 or more pieces of sculpture have also been left out of account.

Partial figures can be given for at least some of these costs. Altogether there were at least 3,400 m^2 of glass in the windows, which at the rate given in DPE 16.5 would have cost some 12,500 KM[59] without taking into account the window frames and the actual glazing. If the bronze lattice of the "cella soliaris" were made of bars 0.02 m thick and covered 10% of the total area of the domed ceiling, it would need some 65 tonnes of ordinary bronze (DPE 15.70) costing roughly 100,000 KM; if this also included coffered panels of bronze 5 mm thick then the cost would be

[59] Assuming that the glass is 0.006 m thick and weighs 2.5 tonnes/m^3.

more like 330,000 KM. If the cost of workmanship in silver and bronze sculpture can be taken as any kind of guide,[60] the cost of making this ceiling out to be about 50% of the cost of materials, bringing this to a total of some 500,000 KM. The ten new colossal sculptures should have cost at least the equivalent to the most expensive marble sculptures recorded in inscriptions, roughly 30,000 HS or the equivalent of 3300 KM each,[61] giving 33,000 KM altogether, although the cost could easily have been higher and this does not, of course, include the 100 or so other statues presumably not of Severan date which may have come from other imperial properties. These items alone add a further 550,000 KM, and we could easily allow a further 100,000 for the remaining furnishings. The total cost of decoration would then be in the order of 2,750,000 KM.

8.4.3 Road and Aqueduct

It is not possible to give more than a general indication of the cost of these items, based on recorded costs of roads and aqueducts in earlier periods and elsewhere in Italy or the empire. Duncan-Jones has already pointed out that there seems to be a roughly standard cost for road building in the second century of HS 20 to 24/foot length.[62] At this rate, the Via Nova from the south end of the Circus Maximus to the end of the Baths, assuming that it was twice as wide as the normal extra-urban roads, would have cost in the order of 10,000 KM.[63] This does not allow for any embellishments, and the actual cost may have been much greater.

The recorded costs of aqueducts even from the same period varies immensely, e.g. from HS 600,000 at Verona in the first century AD to HS 350 million for the Aqua Claudia and Anio Novus at Rome, while from the east we find HS 3.3 million for the unfinished aqueduct at Nicomedia,

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[60] See Duncan-Jones 1982: 126.

[61] See Duncan-Jones 1982: 94.

[62] Duncan-Jones 1982: 124-25.

[63] The road was famous for its beauty (SHA, Cara., 9). See Lanciani 1893-1901: sheets 35, 41, 42.

HS 8 million for the aqueduct at Aspendos, and HS 28 million for that of Alexander Troas.[64] These are of course for new aqueducts, while much of the Aqua Antoniniana was a restoration of the Aqua Marcia. Nevertheless, there were substantial additions both at the head of the aqueduct and for the branch line to the Baths (including a monumental arch over the Via Appia) as well as extensive work along the whole length of the old Marcia, so that this must have been a substantial undertaking (see Section 2.4.2). The Marcia itself cost HS 180 million in the second century BC.[65] A reasonable estimate might therefore be ten percent of the original cost, equivalent to roughly two million KM. This would place it in the middle of the examples from Asia Minor,[66] which suggests that the order of magnitude could be right.

8.4.4 Total cost

Altogether then the total cost of the Baths is roughly 11 million KM, to two significant figures. Although it should be stressed that this is a hypothetical figure, provided the initial assumption on the compatibility of the Prices Edict is correct it represents a low rather than a high estimate and certainly gives the right order of magnitude. In fact, it is unlikely that the cost of any of the main components is out by more than 50%. If, for example, the length of the working day was taken to be 10 hours rather than 12 - and this is the largest single factor of variability - then the cost would be increased by only 20% overall. There is also the possibility of seriously under-estimating the time taken to construct the vault centerings, but this could alter the cost only by less than one percent. On the other hand, I may have over-estimated the cost of transport, which forms about 25% of the total, by allowing the rather low maximum load given in the Prices Edict.

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[64] Verona - CIL V 3402 = ILS 5757 (Duncan-Jones 1982: No. 442); Aqua Claudia-Anio Novus - Pliny, NH 36.123; Nicomedia - Pliny Epis. X.37.1; Aspendos - IGRR III.804 (cf. Ward-Perkins 1955); Alexander Troas - Philostratus Vit.Soph. II.548.

[65] Frontin., Aq. I.7.

[66] Assuming that the cost of corn in Asia in the early 2nd century was HS 3/modius (Duncan-Jones 1982: 146-47).

As a very rough check on the order of magnitude we can compare the cost of building the Baths of Caracalla with that of building the Baths of Neptune at Ostia (Fig. 140). Hadrian promised 2 million HS for these, which was paid by Antoninus Pius who had to add to this sum to cover the cost of decoration.[67] We do not know exactly what the 2 million was meant to cover, but since there is evidence for an earlier set of baths on a similar plan beneath it is not likely to have covered the cost of land or much in the way of foundations or substructures. In addition it was clearly not sufficient for the decoration. Thus if we can probably compare the cost of this building project with the cost of just the construction of the central block of the Baths of Caracalla, without allowing for the substructures or the decoration.

There are two possible ways to make this comparison. One is as a cost per unit area, the other as a cost per unit volume. Although there is ancient evidence for the former actually having been used in the Roman period, the latter is probably more realistic given that the height of the structure increases with the size of the rooms. The height of the Baths of Neptune has been assumed to be one and a half times the span of the largest vault (cf. Section 3.3.3). In addition, we need to allow for the open spaces of the palaestrae, and these have been deducted from the total area. Converting the cost of the Baths of Neptune into corn equivalents results in a figure of 3.9 KM/m^3, compared with a figure of 2.6 KM/m^3 for the superstructure of the central block of the Baths of Caracalla. Alternatively, using the area as a standard of comparison gives 52 KM/m^2 for the Baths of Neptune compared with 71 KM/m^2 for the central block. The basis for these comparisons is admittedly very rough indeed, but they do suggest that at the very least the order of magnitude for the Baths of Caracalla is correct.

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[67] CIL XIV 98 = ILS 334.

CHAPTER NINE: SOCIAL AND ECONOMIC IMPLICATIONS

INTRODUCTION

There is no doubt that the building of the Baths of Caracalla was a remarkable achievement. In the chapters which form the bulk of this thesis I hope I have given some feeling of how such a vast and complex structure came into being, from the moment the unknown architect was first given his brief until the last piece of sculpture was put into place. By examining all aspects of the generating process at the level of individual human actions it has been possible to move on from the broad generalisations which are the common response to structures of such imposing bulk. The study of the finer details has thrown new light on Roman methods of design, techniques of construction, and choices of decoration which are relevant to Roman architecture as a whole as well as to the Baths of Caracalla in particular. The supply of building materials, and the questions of transport which forms such an essential part of it, is another area which has benefited from this approach and can now be seen as an integral component in the building process. Finally, by operating at this level of individual human action it has also been possible to calculate quantities of materials and manpower and thus obtain some idea of the cost of the complex. Admittedly, a number of assumptions have had to be made in order to move from quantities of materials to quantities of labour, and there are difficulties in using the Prices Edict of Diocletian as a guide to real relative wages and costs. Nevertheless, the resultant figures are several removes from mere hypothesis, and far more detailed than any actual figures handed down in the literary or epigraphic sources.

All this, I believe, provides a more thorough analysis of the generating processes of a major Roman building than exists for any other structure, even including the Colosseum. Clearly, with a building the size and complexity of the Baths of Caracalla, there are areas which have not been looked at in as much detail as one might have wished. More could certainly have been done on the water supply and heating systems, on the architectural orders, and on the outer precinct. The particular reasons behind the decisions to pass over these aspects have been discussed in Chapter 2, but some of the motive can be put down to simple lack of space. Nevertheless, the chapters of this thesis which deal with the physical remains, the design, and the construction of the Baths of Caracalla put us in the position of knowing more about this building than about any other major monument of the imperial capital.

But this detailed understanding of the building is in itself just a starting point. The combination of ethnography, archaeology and history used in this thesis comprises, to borrow Kevin Greene's words form a wider context, "...an ideal battery of research tools for investigating the Roman empire, especially its economy".[1] Through the quantitative analysis we now have the kind of hard data essential to a serious assessment in social and economic terms of one of the largest single building projects undertaken in the city of Rome, or for that matter in any other city of the empire, with the sole possible exception of the city walls. This information can then be extrapolated to cover the other known building projects from the reign of Caracalla, and the whole put in the context of intensive public building in other periods.

To explore all the possible ramifications would be to write another thesis. In this final chapter I shall therefore restrict my discussion to a number of topics under three headings - labour, organisation, and economics - and to the short period of time during which the Baths of Caracalla were built. The first section, headed "Labour", follows directly on from Chapter 8, and, by examining the size and nature of the workforce required for the Baths, estimates the total workforce involved in or servicing the building trades in Rome, the surrounding area, and the more

[1] Greene 1986: 9.

distant countryside during the reign of Caracalla. This allows us to explore the relation between this workforce and the urban and rural populations, and to pose the problem of providing animals for the transport of building materials in an urban situation. Finally mention is made of the effect on manpower requirements at a distance by the demands for marble and metals.

Using the results of this analysis, the next section moves on to examining the implications for the organisation of large-scale building projects in the city of Rome. The existence of both design and organisational procedures is suggested, which allow such a project to be initiated at short notice by functionaries co-opted on an ad hoc basis, although the supply of materials was more likely under the charge of permanent officials. Most of the labour for both construction and the production of materials in the vicinity of Rome is argued to have been employed through the contract system, and a possible informal role for the collegium of the fabri tignuarii in this regard is proposed. This leads into a discussion of the role of patronage, operating from the highest level - imperial and senatorial - down through the ranks.

The reciprocal benefits of patronage within the world of public building were predominantly economic, and it is this aspect which forms the third and final section of the chapter. Concentrating once more on the Baths of Caracalla, this analyses the economic situation from the point of view of the emperor who has to pay and the workforce who receives payment. The cost to the emperor is put in the broader perspective of other major recurrent and occasional state expenses, including the army, the corn dole and direct donatives. By comparing the outlay on the Baths with known private fortunes it can be shown that only the emperor really could have afforded to build the Baths. As far as the recipients are concerned, the need for cash payments is stressed, and the further ramifications of the injection of ready money into the economy considered.

9.1 LABOUR

We have already seen in Section 8.4 (Tables 24, 25) that the Baths of Caracalla could have supported a workforce of some 6,000 men directly involved in producing materials and construction in the immediate vicinity of Rome during peak periods, plus at least 2,000 men and pairs of oxen for transport. This is a conservative estimate, and at periods of peak demand almost twice that number may have been required, depending on the scheduling strategy adopted, nor does this estimate allow for the building of the aqueduct and the access road. In addition, some 220 men were needed to produce the brick and 240 to produce the lime in various country districts within a hundred kilometre radius of the city, while a further number which can no longer be calculated were required to produce the formwork timbers, scaffolding poles, ropes, and baskets; more men were required for the transport of all of these to Rome. Supervisory and administrative staff have also to be added, perhaps as much as 10%. We can thus assume an average total of 8,000 to 10,000 in the city and its periphery, and at least 1,000 in the countryside, while accepting that the actual figures may have been higher than this at times.

This average figure, however, does not consist of uniformly interchangeable individuals, and this will affect the calculation of the total number of men involved in the project. The basic undifferentiated figure of 6,000 men thus needs to be broken down into groups depending on the types of skills required. In the more highly skilled trades - marble working, the various fields of decorating, and carpentry - it can be assumed that even the least skilled assistants formed part of a single workshop as apprentices, and would not generally be employed for straightforward heavy labouring. This will therefore add an extra 1,000 or so men to the number of individuals involved in building. The picture is less clear for the labourers working with bricklayers,[2] whose main job was to prepare the materials for the actual bricklayers including mixing mortar, stacking bricks,

[2] I use the term "bricklayers" to include those laying both face and core for want of a better word, since "masons" rather implies builders in stone.

etc. and whose few skills could be quickly learnt on the job. The same applies to the men working at the pozzolana, tufa and selce quarries. Since none of the material excavated was cube stone, very few of the workers need have been particularly skilled in the way that the marble quarrymen must have been; nevertheless, the activities of those actually working at the quarry face presumably needed at least supervision by experienced quarrymen, unlike the mere fetchers and carriers, or those who broke the stone into the required size of caementa (cf. Section 4.5). Given the low level of skills required, however, I am inclined to class all these as interchangeable with the general labourers.

The number of specialists in each of the highly skilled categories not surprisingly forms a relatively small proportion of the total workforce even with their assistants. All the marble carving could be done by about 200 men (2.9%), while a further 260 (3.7%) including assistants would be sufficient to lay all the floor and wall veneer. A similar number of plasterers and their assistants were needed, plus about 300 (4.3%) working on the wall and vault mosaics. The floor mosaics required rather fewer men, roughly 100 or 1.4% of the workforce all told, assuming these to be separate from the wall mosaicists. If individual workshops employed a minimum of five people (comprising, say, a master, two skilled workers, and two assistants/apprentices), no more than 50 to 60 of such groups would be needed in each area of speciality. Even fewer carpenters and sawyers were required, perhaps involving no more than 30 men, or 0.4% of the total, over the whole period,[3] and the number of smiths suggested is almost as low.

The picture is quite different if we consider the actual construction workers and quarrymen. The greatest number of skilled bricklayers employed was around 1,500 or 21% of the workforce. All the remaining 4,300 or so men belong to the unskilled or semi-skilled class and amount to nearly 62%, divided at the period of peak demand almost equally between quarry workers, brickies'

[3] Admittedly this is the area in which I feel my figures are the least secure.

labourers and general site porterage. Alternatively, if we grouped the bricklayers together with their labourers these would constitute 42% of the workforce. In the early stages of construction the quarrymen make up nearly 30% of the workforce. Most of this (20% of the total manpower requirements) is needed to produce selce for the foundations, but, as already discussed in Section 8.4, this material may have been waste from quarrying the stone for road building. The building of the aqueduct and access road for the Baths would also need mainly basic construction workers and quarrymen which would somewhat increase the percentage of the workforce in the less skilled and "heavy" part of the building trade. In addition to these men engaged directly in the construction or production of materials, there were those responsible for transport of materials and waste to and from the construction site. Depending on whether the selce was transported directly to the site from the quarry or came from nearer central depot, the number of carters involved must have been somewhere between 2,000 and 4,000 in the early stages of construction, making them one of the largest groups involved in any single sector.

In the earliest stages of the project - preparing the site and the materials for the foundations - the unskilled or slightly skilled workers at the quarries and excavating or portering on site comprise virtually the whole of the workforce with addition only of surveyors, smiths (for tool maintenance), possibly demolition crews, and supervisory staff. The skilled trades come in only with the building of the cisterns and then the substructures, with the marble workers only towards the middle of the project and the decorators at the end. This pattern of employment is of course fixed by the nature of the building, and could hardly be changed except at the expense of lengthening the construction programme. The high demand for unskilled labour right at the very start of the project, without which the construction schedule would unquestionably have been delayed, presupposes a large pool of men whose time was not already committed to some other occupation, that is of free day labourers who had no contract to work out. It may be no coincidence, if the Historia Augusta is to be believed (Sev. 23.2), that Septimius Severus left seven years' tribute of grain at his death, leaving presumably less work for the urban poor in the service of the annona which otherwise is usually seen as supplying the greatest single opportunity for employment for this stratum of society.[4] Equally, such a schedule allows time to engage the skilled workers or work gangs who are more likely to have contracts in hand, if only on private commissions.[5]

Even allowing for this time lag before most of the specialised craftsmen were required, it would have been impossible to complete the Baths in such a short space of time if there had not also been a substantial body of skilled workers available on which to draw. Indeed, the prior existence of such a workforce may almost be thought of as a necessary prerequisite for deciding to build the Baths at all. A brief glance at the major imperial building projects of the preceding 20 years shows that this was indeed the case. A major fire in AD 191 towards the end of the reign of Commodus destroyed much of the Templum Pacis, the Atrium and Temple of Vesta, the warehouses either side of the Sacra Via, and some part of the imperial residence on the Palatine. Most of this was restored or rebuilt under Septimius Severus, who also extended the Palatine to the southwest. Other building projects from his reign known from archaeological or literary evidence include the Thermae Severianae in Regio I, the Septizodium at the foot of the Palatine, another bath building in Trastevere, the new camp of the Equites Singulares, the Arch of Septimius Severus in the Roman Forum, a large temple to Hercules and Dionysus, and at least part of the Sessorian palace.[6] There were also restorations to the Pantheon, the Porticus Octaviae, the Theatre of Pompey, and the Temple of Honos and Virtus in Regio I. This list includes only public building, and if Ostia is any guide there was also a substantial amount of private building as well.

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[4] Cf. Garnsey 1980: 44; Brunt 1980: 92.

[5] For further on the organisation of the project and the contract system, see below Section 9.2.

[6] See Benario 1958: 714-18, and the relevant entries in Platner-Ashby 1929. For the Sessorian Palace see Colini 1955.

Thus even the known projects over the 18 years of Severus' reign would have been sufficient to produce a large body of skilled and semi-skilled building workers ready to be employed on the Baths of Caracalla. Some of them would have had specific skills of particular importance for the Baths. We have already noted (Section 7.3.1) that the architectural ornament is all of the so-called "Flavian revival" style, which, in contrast to the ornament of the Antonine period, clearly has its origins in the restorations on the Palatine and (presumably) in the Templum Pacis.[7] The aedicular facade of the natatio has its own particular precursor in the Septizodium, while for practice in large-scale terracing we need look no further than the substructures of the Severan extension to the Palatine itself. The high prestige value of some of the other projects, such as the restoration of the Templum Pacis and the Palatine, would have meant that craftsmen skilled in other types of decoration were also available.

The Baths of Caracalla were not, however, the only building undertaken in this period, and in order to assess the size of the workforce involved directly in or servicing the building trades we need to consider the evidence for other construction. A few imperial projects are mentioned in the literary sources, and these can be supplemented from epigraphical sources, including brickstamps.[8] The most important of these was clearly the Temple of Serapis, almost certainly to be identified with the colossal remains in the Colonna gardens;[9] Caracallan brickstamps from the general area of the Quirinal may relate to this building.[10] There was also a Porticus Severi possibly built by Caracalla in honour of his father.[11] Among the major works should also be counted the large

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[7] See Von Blanckenhagen 1940: 91-92.

[8] The list in Benario 1958: 718-19 is only partial and does not take into account the brickstamp evidence.

[9] SHA, Vit. Cara. 9, 10; CIL VI, 570; IG XIV, 1024. For the building see Nash 1968 (I): 376-83; Ward-Perkins 1981: 134.

[10] Examples of CIL XV.1 155, 164, 408b, 625, 626, 762a and b, 769b.

[11] SHA, Vit. Sev., 21, 12.

baths serving the legionary camp at Albano, which Lugli dated to the reign of Caracalla from its brickstamps.[12] The construction techniques used in this building are identical with those of the capital itself, making it a virtual certainty that urban builders were used in its construction, however much Roman soldiers did their own building in other circumstances. Repairs to imperial or public buildings which can be identified from brickstamps include the Palatine, the Horti Sallustiani, the Pantheon, the Praetorian Camp, and the Tiber wharves and banks.[13] The nature of the repairs made under Caracalla by C. Avilius Licinius Trosius to the Schola Xanthi at the west end of the Forum Romanum is not clear, but the building was certainly a public one.[14] Other groups of brickstamps dating to the reign of Caracalla come from the present Piazza Cinquecento (near the now demolished "Monte di Giustizia"), from a building under the Ministero delle Finanze just north of the Baths of Diocletian, and from various sites on the Esquiline and Aventine; there are also some from Ostia, but these are important only for the production of brick.[15]

Altogether these buildings might have needed anywhere from half to as much again as the Baths in terms of manpower and materials, and encompassed the same kind of skills. Certainly the Temple of Serapis involved both large-scale earthworks and terracing structures, and skilled marble workers, while the brickstamps are evidence of concrete construction in other projects. Thus if the totals calculated for the Baths were simply doubled this should give roughly the right kind of

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[12] Lugli 1915: 262, and see Tortorici 1977: 94-110 for the remains.

[13] Palatine: CIL XV.1 - 164, 203, 404, 408a, 408b, 424a, 624, 625, 762b, 769a and b; Steinby 1974: Nos. 19593, 19600-08, 19619-23, 19632-34, 19919-31, 19935-41, 19942-20006. Horti Sallustiani: CIL XV.1 - 157. Pantheon/Basilica Neptuni: CIL XV.1 - 155, 157, 404, 408a and e, 424a. Praetorian camp: CIL XV, 1 - 404, 408d, 759. Tiber wharves and banks: CIL XV, 1 - 113, 214, 381, 408b and d, 625, 626, 761, 762a and b.

[14] CIL VI 103, 1068. There are also brickstamps dating to the reign of Caracalla from this end of the Forum (CIL XV,1 769b, 408d, 759).

[15] "Monte della Giustitia": CIL XV.1 - 157, 164, 193, 237b, 404, 408a, c and e, 759, 762a and b. Ministero delle Finanze: CIL XV.1 - 164, 193, 381, 404, 408e. Esquiline: CIL XV.1 - 155, 214, 381, 408a, c and d, 602, 625, 626, 762a and b. Aventine: CIL XV.1 - 381, 408c, 759, 769a and b. Ostia: CIL XV.1 - 193, 381, 404; Suolahti and Steinby 1978: Nos 183, 191, 192, 204, 216, 229, 247, 363, 383, 385, 386, 387, 395, 530, 647 (128 examples in all).

figures for the whole of the building industry at Rome in this period, without having to worry about any imbalance created by differences in the nature of the projects. This would then suggest that between 12,000 and 16,000 men were employed in and around the city, plus about 4,000 to 5,000 pairs of oxen and their drivers, and some 1500 to 2000 or more men in the further countryside. Although some at least of the oxen could be replaced by donkeys or mules, this would not substantially affect the number of men involved. Of course, we cannot be at all sure that we are not missing some other large project altogether, but to put the figures any higher would be arguing completely ex silentio. In addition, the fact that the main structures in the outer precinct of the Baths were left to be completed at a later date does suggest that the resources were in some way stretched to their limit, whether in terms of the supply of (presumably) skilled workers or of materials (and again these would have to be those for which skilled labour was required).

It is of course quite possible that the figures were in fact higher given the minimising nature of the original assumptions about conditions of labour (see Section 1.3.2). In particular, if the working day averaged 10 hours and not 12, the total numbers of men involved should all be increased by 20%, while perhaps a further 10% could be added if we allowed a lower carrying capacity for an adult male. No allowance has been made either for the permanent slave gangs responsible for the maintenance of the aqueducts - some 700 strong - or for any similar group responsible for temples and other public buildings. Other workers we have not thus far counted include: sculptors; the suppliers of decorative materials such as window glass and frames, and coloured glass for mosaic tesserae; glaziers, bronze-smiths and lead-workers; the makers or suppliers of heavy moving equipment from pulleys to treadmills; and those involved with the transporting building materials by river. Thus we can postulate a possible body of between 20,000 and 30,000 men in and around the city involved directly in the building trade or supplying it with materials, with a further 2,000 to 3,000 or more in rural areas.

All these figures are highly speculative. One possible check on their feasibility, however, is the known size of the collegium fabrorum tignuariorum. The surviving fragments of a dedication to Septimius Severus and Caracalla refer to the 24th to 59th decuria of the collegium and there are other indications that the number of these was (at least) 60, giving a total number of men in the collegium of over 1300.[16] Thus if each member of the collegium represented the head of a small "firm" of 8 to 10 men this would be sufficient to include all the proposed bricklayers and carpenters plus their labourers and assistants.[17] If we accept that it was common practice for a builder to hire some day labourers to augment his own staff, then the size of the "firms" might be even smaller.[18] Of course, this is just an average and many of the "firms" would have been larger or smaller, nor were the heads of all "firms" in the city necessarily enroled in the collegium; nevertheless, the figures do, I believe, show that our estimate for the number of builders is reasonable. While some of the specialised skilled workers presumably belonged to the "firms" represented by the fabrii tignuarii, others had their own collegia at Rome, including the marmorarii, fabri ferrarii, and pavimentarii, and the above figures give some general indication of the possible size of these.

A distinct and fairly large sub-section of the building workers is that concerned with land transport, but it is impossible to tell how these carters were recruited. There is little epigraphic evidence for any collegium of transport workers at Rome before the late empire, when we hear of both vectuarii

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16 CIL VI 1060 and cf. AE 1900, no. 89. For the total numbers of men see Walzing 1895-1900: II.118, IV.713-14.

17 See Pearse 1975: 123-35 on the status of the members of the collegium, and the size and nature of the "firms" represented by them. Pearse argues that they were all employers rather than employed, and either freedmen or ingenuii, and adduces evidence for many of them representing small, family (or familial) concerns. He does not, however, go on from there to any estimate of the numbers involved in the building trade in Rome.

18 Cf. the fragment of Venuleius quoted by Brunt 1980: 87 on the combination of builders and day labourers for building an insula.

in connection with transporting lime to the city and cartabolenses working mainly for the annona.[19] The total of 4,000 to 5,000 pair of oxen needed constantly over 290 days of the year is too large to be met by, say, ploughing oxen pressed into service, or animals engaged in general agricultural carting unless we increase enormously the actual number of animals involved. Since 4 to 6 mules or donkeys were required to carry the same load as a pair of oxen, using pack instead of draught animals would not reduce the problem. The animals also had to be fed and housed, which demanded either a considerable supply of fodder - and thus a further extension of potential employment related to the building trade - or of pasture, which had to be sought outside the urban area. Since most of the transport required was between the main stone and pozzolana quarries, and these quarries were mainly in the rural areas on the periphery of the urban and suburban areas where large numbers of animals could be most easily kept, it is tempting to suggest that provision for transport formed a normal part of these quarry operations, although there is no way that this can be proved. At the same time, the ownership of an ox-cart or a string of baggage animals might have provided a steady extra income for a small-holder, while a large estate would profit from several. Whatever the arrangement, closeness to the city or to one of the major sources of building materials must have been essential. On the other hand, the carts and their animals certainly represent a significant investment. According to the Prices Edict a single two-wheeled cart "sine ferro" (whatever that means) and a pair of oxen would cost KM 108 (DPE 15.44, 30.14), giving a total investment of roughly half a million KM. The cost of the stock and carts, and the problems of maintaining them, demanded a certain level of wealth on the part of the owners, although the actual drivers might be slaves or day labour.[20]

If we accept that these crude figures do give some kind of realistic picture of the number of men

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[19] See Walzing 1895-1900: II. 116, IV.10.

[20] The Prices Edict of Diocletian has rates of pay for leaders of trains of baggage animals (DPE 7.17, 19.).

involved in the building and allied trades, they can then be used to help give some idea of the relative importance of construction for the population of the city. In this context I shall assume that population figures for the city includes sufficient of the extra-urban rural areas to extend to the major quarries supplying materials for the Baths (i.e. for a further 6 km beyond the Aurelianic walls), and that, as has already been stated, the quarry workers and general labourers are interchangeable.[21] The difficult question of where these labourers lived, whether in the urban or extra-urban areas cannot be resolved. Certainly the periphery of Rome was densely populated as the survey of the area of ancient Collatia has shown.[22] This region includes the tufa quarries along the left bank of the Anio, but whether the quarry workers formed a permanent part of the local population is impossible to tell, nor is there any indication if these were engaged full-time (by choice or constraint) at the quarries or drawn from local small-holders and their dependents looking to supplement an agriculturally-based living. At the same time, the distances involved are sufficiently small for a reciprocal exchange of workforce between the city and its outlying areas. Only in the case of the land transport for the quarry products is there a strong supposition as we have seen that the labour was actually based in the extra-urban areas.

The numbers for the city and immediate periphery represent at the most 4% of the presumed population of the city, although it may have been as low as half that.[23] Since this assumes that

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[21] The exception must be the pumice quarries at Marino, but the small number of men involved (30 over a single year) will not make any significant difference to the results.

[22] Qulici 1974. I have avoided talking about the suburbium of Rome because of the difficulty of defining this. The density of population in the countryside outside the city was clearly high, especially along the major transport routes, but at the same time these were clearly not urban sites. Some of the quarry areas nearer the city, such as the Fosse Ardeatine, probably could be classed as being within the suburbium, but the case is far from clear for the selce quarries, for example. At the fifth milestone of the Via Appia the tombs lining it are still closely packed, and this is no further out from the city than the ancient quarries. Rather than try to distinguish between urbs, suburbium, and the rural districts beyond, I will keep to the simple (if not particularly well-defined) distinction of urban and extra-urban areas.

[23] See Hopkins 1978: 96-8, who reconfirms Beloch's estimate of 800,000-1,000,000. The population may have already been in decline by the Severan period following the plagues introduced into Italy in the Antonine era, so that a figure of 800,000 should represent the maximum.

the same men were employed on all occasions, which would not necessarily have been the case especially for the unskilled labour, the labour might therefore be spread over some 5 to 6% of the population, if not more. This is comparable to the percentage envisaged by Brunt, based on the proportion of labour in the building trades in 16th-century Rome (about 6% of the population engaged on building new St Peter's).[24] What we cannot do is gain any idea of what percentage of the working populace this represents, to compare with the figure Brunt proposes as a possible model, that 33% of the wage earners of 18th century Paris were involved in the building industry. The recipients of the corn dole under Septimius Severus are said to have numbered 175,000, but while this presumably included some at least of the free building workers (skilled or unskilled) it did not necessarily include all of them, let alone their slaves, and it certainly cannot be equated to the wage-earners of Paris. A better guide might be the assumed number of adult males, who may have been one quarter of the population; the builders would then represent some 15% of these. As far as smaller distinct groups with which we might compare the building workers, we know nothing of what were probably the two largest sub-divisions, the familia Caesaris or the annona. The organisation of the workforce at the Horrea Galbana into cohortes would suggest that there was a substantial body of men, perhaps as many as 1,500, and these kinds of numbers might be applied to the other large warehouses.[25] The only large bodies of men for which we have actual numerical evidence in the city of Rome are the various military or semi-military corps. Under Septimius Severus the Praetorian Guard was increased to 10,000, the Vigiles to 7,000 and the Urban Cohortes to 6,000.[26] It is conceivable, then, that those involved in the building trade may have formed one of the largest single occupational groups in Rome and its immediate periphery.

I must repeat that the numbers which form the basis of this discussion are very crude and contain

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[24] Brunt 1980: 92.

[25] For the cohortes of the Horrea Galbana see Rickman 1971: 176-77.

[26] Smith 1972: 487-88.

a large degree of speculation. Nevertheless, I believe I have shown that the order of magnitude is roughly right, as is the general proportion of the total population formed by the men involved in the building trades, at least in Rome. As a simple figure 4 to 6% does not seem particularly large, especially when it is remembered that this includes materials and transport as well as construction, and a variety of specialisations within the building workers. At the same time, the builders in their various groups are among the largest single urban bodies known, even including the several military or paramilitary corps. Nor is this a question of large groups of slaves; much of the hard labour, it can be argued, was provided by the urban poor, while much of the possible slave labour must have been owned by the middling social strata, the officinatores of the brick industry or the heads of the building "firms" documented in the collegium of the fabri tignuarii.

All of the workforce so far discussed was required either in the city itself or in the immediate periphery. This forms by far the largest part of the total, but that part to be found in the more distant rural areas of central Italy needs also to be considered. The production of brick and lime may not have required many more than 500 or 600 men each, plus 300 to 400 carters operating between production centre and water transport; together these comprise only about one fifth of the workers required for the production and transport of the rest of the building materials. As was noted at the end of Chapter 5, some highly specialised labour was required to make the bricks and fire the brick- and lime-kilns, but the majority would require no special skills, and may have included women and children at least in the gathering of fuel. The transport requirements presumably would not have caused the potential problems faced by those of the metropolis, since the numbers required are at least an order of magnitude smaller, are needed over a larger area, and in rural areas would presumably not have needed any special arrangements for fodder and housing. Since the brickfields (at least) formed part of imperial estates, and the demand for transport must have been steady, we can assume that these also supplied the animals required to transport the finished products to the waterways.

Given the relative stability of demand for both brick and lime, it was feasible to keep a constant number of workers busy for most of the year. This combined with the known familial continuity among some of the officiatores in the brick industry, inclines me to see the production teams as permanent units in much the same way as the workshops of the skilled decorating trades. In addition, I have already shown that some of the other materials and products required for construction such as timber, scaffolding poles, baskets, and possibly rope must have come from agricultural estates (Sections 4.1.1, 5.6.1), and as usual we need to include those involved in transporting these materials to the city. Thus a considerable number of the permanent residents of these country areas were involved directly or indirectly in supplying Rome with building materials, although the numbers in any given place were presumably small, and the main demands on labour must have remained the more traditional ones. Both in the Farfa district, where there appears to have been a concentration of brickfields (Fig. 55), and in the limestone regions (Fig. 52), the most likely location for the kilns was at the junction of highlands and plains or river valleys. The hills presumably supplied Rome with firewood, olives, nuts and fruit, while the flatter areas may have favoured market gardening or general agriculture. As usual there is more evidence about the existence of luxury villas in these areas than for the nature of any agricultural operations,[27] but the Farfa survey at least has revealed a high density of population in that region.[28]

9.2 ORGANISATION

Much of the preceding section has been concerned with the overall manpower resources involved in construction during the reign of Caracalla and their relation to the rest of the population. But the successful completion of the great scheme to build the Baths could not be achieved simply by

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[27] I do not wish here to enter into the debate on the state of agriculture in central Italy in the high imperial period.

[28] For the Farfa survey see Moreland 1986, 1987.

the availability of both sufficient and sufficiently-skilled labour alone. The fact that the main part of this huge and complex building was completed in roughly six years also argues strongly for a very high level of planning and control of resources. Contrast the problems encountered by the citizens of Nicomedia and Nicaea in trying to build their aqueduct, theatre, or gymnasium during the reign of Trajan due to the lack of these very qualities.[29] The structured nature of the whole project emerges at every stage of design, construction, and decoration of the Baths; very little of the effect of the finished building appears in any way left to chance.

Two pre-existing conditions which must have contributed to the success of the project are worth singling out. Firstly, the Baths of Caracalla were not the first of their kind to be built. The existence of a "blue-print" for the design of the thermae going back at least to the Baths of Trajan has already been discussed (see Section 3.2.5). For the period between Trajan and Caracalla we have literary evidence to suggest that similar buildings were erected under both Commodus and Septimius Severus, but their total disappearance from the physical record argues for these being rather smaller structures.[30] If a set of design procedures could be passed down over a hundred years, then so, probably, could a set of specifications giving the amounts of materials and labour required and the planning of the construction. The existence of such a practice is suggested by Vitruvius when he says that an architect should be literate "uti commentariis memoriam firmiorem efficere possit" (de arch. I, 1, 4), and by the well-known Republican inscription from Puteoli which reads as a set of architect's specifications given permanent form.[31]

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[29] Pliny, Ep., X, 37, 39.

[30] For the sources see the relevant entries in Platner/Ashby 1929: 525, 32. Both lay in Regio I, and are presumed to have been situated to the south or south-east of the Baths of Caracalla. One possible candidate is the artificial platform immediately to the south of the Bastione del Sangallo in the Aurelianic walls, shown clearly in Lanciani's Forma Urbis under the title of Horti Serviliani (1893-1910: XLVI) but since demolished to make way for the Viale di Porta Ardeatina. Severan brickstamps are known to have come from this area as well as marble columns, etc. If the identification is correct, these may have been about a third the size of the Baths of Caracalla in total area.

[31] CIL I.577 = ILS 5317; Wiegand 1894.

The second factor must be the existence of a well-developed mechanism for organising such large projects. Even if it is unlikely that any one of the earlier Severan projects was quite on the scale of the Baths of Caracalla, there are numerous other earlier projects which could form models, from the draining of the Fucine lake and the building of the harbours at Ostia to the building of the Domus Augustana, the Colosseum, or, of course, the Baths of Trajan. With the Fucine lake, the figure for the workforce of 30,000 men over 11 years given by Suetonius (Claud. 20.3) has generally been accepted, but this total has recently been challenged by Thornton and Thornton. Using the same type of ethnological analysis as employed in this thesis, have shown that the actual figure is more likely to have been something in the order of 3000 men.[32] While they try to explain away this discrepancy in various ingenious ways, they overlook the obvious one, that Suetonius or his source has counted up the total man-years of labour, i.e. 3000 men over 11 years. In the same way they have calculated the manpower required in digging the harbour at Ostia, arriving at a figure of either 2,000 oxen and nearly 4,000 men or 5,500 men over 10 years.[33] Although in this latter case they are perhaps working from too little physical evidence, nevertheless the analyses do suggest that these projects were on a similar scale to the Baths of Caracalla.

Pearse has studied the sparse evidence for the administrative procedures used in running such large imperial building programmes, and this needs only a brief recapping here.[34] He is surely right in assuming that for labour at least there was an extension of the contract system - better attested in the Republic and in the provincial cities in the imperial period - which would operate for new constructions and/or whenever the task was too large for any permanent slave workforce, as certainly happened with the cura aquarum.[35] Pearse identifies the redemptor operum Caesaris of

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[32] Thornton and Thornton 1989: 57-71, 141-44.

[33] Thornton and Thornton 1989: 77-91, 145-49.

[34] Pearse 1975: 36-56.

[35] This view is further adopted by Brunt 1980: 84-88.

CIL VI.9034 as a major contractor for public works rather than a permanent official, and believes that the curatores in charge of new works were also engaged on an ad hoc basis for new construction projects. This implies that the organisational framework for the actual construction consisted more of a way of planning rather than a body of responsible officials, a situation in many ways parallel to that proposed here for the design process.

The supply of materials was perhaps a rather different case, since there must have been a steady demand outside of any particular project, and like the maintenance of the aqueducts this would have needed a permanent organisation to deal with it. Since we know that the distribution of imperially-owned building materials at Rome was under the control of the a rationibus by the end of the second century,[36] he may also have been responsible for acquiring these where necessary. By the end of the second century the supply for individual projects such as the Baths was assured in at least the two cases - bricks and marble - where the emperor owned the raw materials and had some control over production. This must have been the case even though the actual labour was contracted out. The organisation of the marble supply was presumably the charge of the a marmoribus, and the fact that most of the bricks for the Baths of Caracalla appear to have passed through the great tegularium of the Portus Licini (see Section 5.3.1), suggests that the officials in charge of this may have played a similar role for the supply of bricks. Unfortunately we have no evidence for the what must have the normal situation with regards the stone and pozzolana quarries in the vicinity of Rome and the lime-producing centres at this period even though these formed the bulk of the materials used. The most likely situation was that these were also operated under the contract system, and that like the brickworks in the first and earlier second centuries AD the raw materials were owned by the senatorial aristocracy including the imperial family.

This is, then, little enough evidence for the overall administration of major construction projects,

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[36] cf. CIL VI, 455 = ILS 5920.

but we are even less well informed on the organisation of the labour on a day-to-day basis. Given the size of the workforce, there must have been both a hierarchy of command and a division into work-gangs - one thinks of Hadrian's team of architects, builders and decorators organised into cohorts and centuries on military lines, and the two gangs of the permanent slave workforce attached to the cura aquarum with its various classes of workers.[37] There is further evidence in Vitruvius (de arch. 7.1.3, 7.3.10) and Statius (Silvae 4.3.40-58) that construction workers often operated in gangs, often termed decuria. While this does not necessarily indicate that the gangs contained ten men, it may be significant that this has historically been the average size of work gangs such as the railway navvies. Indeed, the continued use of work gangs in large-scale building operations in later periods affirms the usefulness of this pattern of organisation, and it is hard to see how any large enterprise which depended on the co-ordination of a large number of individual workers could operate otherwise.

We are left with the question of how the various work gangs necessary for any large-scale project were obtained. Where sheer muscle power was all that was required, any unskilled labourers including prisoners could be gathered and put into gangs,[38] but the problem was no doubt more complex for skilled workers. Here I am inclined to see a role for the collegium fabrorum tignuariorum, despite all the arguments against the collegia acting in any way as guilds for the benefit of their members within their respective trades. The division of the fabri tignuarii themselves into decuries and the fact that the individual members were the heads or owners of building teams (of whatever size) surely provided a ready-made structure which could be exploited for large-scale building projects. Even without any formal agreements, the social grouping of the decuries must have developed a sense of camaraderie among the members which would have

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[37] Hadrian - Aurelius Victor, Epit. de Caes. 14, 5; aqueducts - Frontinus, de aquis, 117.

[38] For the use of prisoners for construction works (rather than in mines) see Suetonius, Nero 31.3 and, away from Rome, Josephus BJ 3.10.10 for the 6,000 used on the Corinth canal.

fostered their joining together on projects which were beyond the capabilities of any single member and his staff. If similar informal arrangements operated on a larger scale across the whole collegium, then the problem of procuring a large skilled force especially at relatively short notice would be much simplified, with the added advantage of providing builders who were already used to working together and thus presumably to a similar standard. We have already discussed in Section 6.5.3 the evidence for different work groups in the Baths of Caracalla, and noted the high degree of uniformity achieved by the workmen within two distinct regimes divided along the main axis of the building. Such evidence is wholly consistent with the arrangements suggested above.

This kind of informal organisation, potentially of great benefit to the state, could then have easily led to the view expressed in the Digest (50, 6, 6 (5), 12) that the collegium existed precisely for that reason. In this light the presence of a redemptor operarum Caesaris as a magister quinquennalis of the collegium is only natural.[39] The reverse is also true, that in this way the state could be of benefit to the members of the collegium, either directly or through the patronage of the main contractor(s) for the project. These return benefits were if not essential at least advisable, given the potential political power of the collegium. The concern felt by the emperor and Senate about the dangers of large organised bodies of men is well-documented, and nowhere might it have been more justified than with a body of this size. I have already shown that the members of the fabri tignuarii together with their workmen formed a body possibly as many as 10,000 to 12,000 strong, without taking into account the rest of the workforce involved in the building trades, and might thus literally have been a force to be reckoned with if they had decided to act in unison against the authorities. But we have no indications in the sources that this in fact happened, and the reciprocal benefits of patronage on a large scale can be offered as one reason for it.

[39] CIL VI, 9034, and cf. Steinby 1983: 220. Pearse 1975: 69-71 tends I believe to rather underestimate this role of the collegium.

Within the process of supplying the materials and labour for any large building project there was thus ample opportunity for extending patronage at many different levels, and of reaping the benefits of it. The information on brickstamps gives us the clearest indication of this operating at the highest levels, among the senatorial order and the imperial family,[40] but the calculations for the Baths of Caracalla show that this particular aspect was "small beer" compared with the potential of the other main raw materials, including timber and scaffolding, and especially of supplying the means of transport. All of these areas had the added advantage of being classable as "agricultural" and thus perfectly respectable for the members of the order. As far as construction itself is concerned, the patronage worked at the next level down, through the chief officials of the fabri tignuarii and, to a lesser extent, presumably those of the other collegia involved in construction and decoration, and through them to the individual members. But above the magistri of the fabri tignuarii, and sometimes identical with them, were the main contractors, the redemptores. If Quintus Haterius, probably the main contractor for the Colosseum as Coarelli has demonstrated,[41] was typical in having links with members of the senatorial order who were also involved in brick production, then the decision of the emperor to build could have roused pleasurable anticipation at all levels of society of profits to come.

9.3 ECONOMIC

The financial aspect of all this patronage was paramount. Everything, or almost everything - materials, labour and organisation - had to be paid for. The only possible exceptions are the products of the state or imperially owned metal mines and marble quarries, and even here there was food at least for the workforce and high levels of supervision plus operating costs. I have already argued in Section 1.4 that in these cases the consumption of materials can also be though of as cost in the sense of a loss of revenue, the difference being of course that it did not require

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[40] Cf. Steinby 1982, 1983.

[41] Coarelli 1979.

an actual cash outlay. Even where slave labour was used for materials production and in construction or decoration, these are highly unlikely to have been state- or imperially-owned slaves, and their services must have been paid for in some way. At the higher levels of organisation, only the contribution of the permanent members of the bureaucracy could count against ordinary on-going expenditure; all the rest was extra.

We have already seen (Section 8.4) that the total cost to the state - or to the emperor - can be calculated at the equivalent of 11 million KM of wheat over 6 years on a low estimate, or, say, 2 million KM/year. The figure could have been half as much again, but is unlikely to have been as much as twice that unless some extraordinary expense such as gilding the caldarium dome or ceiling has to be added.[42] In terms of the largest state outlay - that of paying and supplying the army - this is clearly a very small amount. With 33 legions under Septimius Severus and an annual stipend of 500 denarii, the army would have cost something in the order of 40 million KM per year.[43] In addition, the military and paramilitary forces based in Rome demanded another 5 million KM,[44] while providing the annual corn dole for the 175,000 recipients in the city of Rome recorded under Septimius Severus required 7 million KM per year.[45]

These are all major recurrent and predictable expenses and, along with the maintenance of the imperial household and the normal operative costs of the city, had first call on imperial revenues.

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[42] Cf. the HS 288 million (c. 30 million KM) spent by Domitian on gilding the Capitol (Plut. Vit. Public. 15.3).

[43] This calculation is based on the cost given by Frank 1940: 5 for the army under Augustus, increased in proportion to the greater numbers and legionary salary under Septimius Severus. This results in a total of 704 million sesterces. If wheat is assumed to cost HS6/modius in Rome in the first century, and double that at the time of Caracalla, then the cost per KM works out at HS18.

[44] Worked out at 10,000 Praetorian Guards x 1,500 denarii, 7,000 Vigiles x 500 denarii, and 6,000 Urban Cohorts x 500 denarii.

[45] Dio Cassius 76.1.1.

In economic terms, these can be separated from major public building projects which were occasional events and made extra-ordinary demands on imperial finances. A better parallel for public building is expenditure on liberalitates. As far as congiaria are concerned, however, 11 million KM is a relatively modest sum. Trajan is estimated to have spent the equivalent of 100 KM from the Dacian booty alone on this, Antoninus Pius some 70 million KM over the 23 years of his reign, and Marcus Aurelius 80 million.[46] However, the largesse distributed by Septimius Severus to the dole recipients and the Praetorian Guard on the tenth anniversary of his reign amounted, according to Dio Cassius (Ep. LXXVII, 1.1-2), to just 11 million KM (HS 200 million).

It may not be wholly coincidental that this letter sum is very similar to that spent on building the Baths of Caracalla. The distributions made by Antoninus Pius work out at about 3 million KM per year, about the amount Caracalla must have been spending on his building projects. While we can only begin to guess at the total cost of Trajan's building programme, in addition to, say, 15 million KM for the Baths, the estimated two million cubic feet of marble for the Forum might have cost in the order of 20 million KM alone.[47] To this we must add the rest of the materials and construction for this, the Markets, and the Odeon. In all it is not impossible that Trajan spent as much of the estimated 700 million denarii from the Dacian booty on construction as on direct distribution of largesse. Of course, the figures are crude and selective, but they do suggest that direct payments and public building were alternative ways of distributing the same kinds of sums of money. Where the coffers allowed, as following the Dacian wars, both could be used; it is a pity that there are no useful indications of the cost of staging the public games which formed the third major type of extraordinary expenses to see if these too were the same order of magnitude.

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[46] See Frank 1940: 65, 76-77 for the basic figures and their sources.

[47] This is using the way of costing cubic feet of marble discussed in Section 4.3.5 and Appendix 5, and assuming an average basic cost of 100 denarii/P^2 to allow for a combination of cheaper white and more expensive coloured marbles being used.

Compared with earlier imperial largesse, the outlay on both congiaria and construction by the Severan emperors seems quite modest. Some confirmation is perhaps given by the amount Otho is said to have spent merely in completing the Domus Aurea of Nero: HS 50 million or 6 to 8 million KM according to Suetonius (Otho 7). This raises the question of the state of imperial coffers at the death of Septimius Severus and the kind of sums available for financing this grandiose building project. The literary evidence suggests that the fiscus was in a healthy state. In the epitome of Dio Cassius (LXXVII.16.3-4) it is recorded that Severus left "very many tens of thousands" of drachmae, while the Historia Augusta (Sev. 12.4) says that he left his sons a fortune greater than any other emperor, as well as (or including?) seven years tribute of grain which sufficed Rome and the rest of Italy as needed for five years (Sev. 23.2). We know that Antoninus Pius left 2,700 million HS at his death, equivalent to some 300 to 400 million KM, or enough to build twenty giant thermae. If Severus left anything like that figure - and one always has to be careful with the Historia Augusta on such matters - then it is not surprising that Caracalla was able to think of instigating two major building projects, the Temple of Serapis and the Baths of Caracalla.

Even if the cost of the Baths and the other Caracallan building projects was relatively modest compared with some of the great schemes of earlier emperors, it was still very likely beyond the pocket of even the wealthiest individuals. The evidence for private fortunes has been collected by Duncan-Jones.[48] The largest are the HS 400 million or about 50 million KM belonging to Cn. Cornelius Lentulus and Claudius' freedman Narcissus, while Seneca and several others were worth HS 300 million or 30 to 40 million KM. The largest private fortune in the early second century AD was less than the HS 288 million spent by Domitian on gilding the Capitol, say at the most 30 million KM. Compared with these, Pliny the Younger's fortune was relatively modest, perhaps HS 20 million or something over 2 million KM. It is not the overall size of the fortune, however,

[48] Duncan-Jones 1982: 343-44.

which needs to be taken into account when considering the potential of private individuals to finance large building projects, but their potential income. Most wealth in the ancient world was tied up in land, on which loans would need to be raised to generate cash for building expenses if it were not sold outright. Pliny appears to have made public benefactions of one kind or another in his lifetime amounting to perhaps as much as 25% of his fortune, but he is seen to be an exceptionally benefactor.[49] If the owner of the largest fortune cited above had likewise spent 25% of his capital on public building, it would just have paid for the Baths of Caracalla. Alternatively, if we count income as 6% of capital, then the largest fortunes would bring in the equivalent of 3 million KM per year, just enough to finance building on the scale of the Baths of Caracalla but leaving relatively little over to sustain the kind of luxurious life expected of men of phenomenal wealth.

We are of course to some extent just playing with figures here, and the margin of possible error in the actual numbers is large. It does, however, at least produce a consistent picture, that the building of the Baths of Caracalla, while a wholly conceivable and if anything relatively modest outlay for the state, was beyond the purse of all private individuals with only a handful of possible exceptions. In terms of the economics of liberality, then, the building of the Baths of Caracalla - and for that matter of any of the thermae - was indeed a powerful investment as a symbol of status, since it was quite literally beyond the power of even the richest of ordinary mortals.

But let us return to the building project as a form of largesse. The congiaria distributed to mark the occasion of Septimius Severus' decennalia went to the recipients of the corn dole and to the members of Praetorian Guard; the building of the Baths touched a different if overlapping segment of the population. Some of the recipients were still the unskilled urban poor, the free male citizens who, as Brunt has noted, must have required more than just the straight corn dole to survive in the

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[49] See Duncan-Jones 1982: 17-32 for Pliny's fortune and expenditures.

city. The total paid to these, however, was only some 1.3 million KM even if we included all the quarrymen and brickies labourers, or 800,000 to 900,000 KM if these latter are excluded. Taking the building "firms" headed by the fabri tignuarii to include their labourers, as much as 1½ million might have passed through the hands of the collegium and its members. In contrast, the amount payable for labour on all the basic decoration including the architectural ornament (but excluding the raw materials) was perhaps no more than 300,000 KM. The amounts paid to the brick- and lime-workers were also small, roughly 100,000 and 380,000 KM respectively. On the other hand, 3 to 3½ million KM went on transport, even excluding the long-distance movements of marble and metals, and most of this was for land transport in Rome and the surrounding districts. Thus it is clear that many of the direct payments would have been made to those at the upper end of the social and economic scale, who would then have dispersed the requisite sums down the next rung in the ladder, and so on. In the discussion on costs I have deliberately avoided adding any amount for profit (or for graft and corruption!), but profit there must have been. How much of this for those at the top was the intangible profit of prestige and the power to confer benefits we cannot say, but it seems unlikely that monetary gain played no part at all.

At least within the area around Rome and the hinterland which served it the materials, transport and labour had to be paid for in cash. Day labourers,[50] including skilled craftsmen if the Prices Edict is any guide, had to be paid directly, on a daily or at least a regular basis. The independent officinatores of the brickworks, and, presumably, the fabri tignuarii, would have been paid for a certain quantity of bricks produced or wall laid. Cash payments were essential for the operation of the contract system, irrespective of whether the major contractor or the state had to find that cash at the first instance. In this way too, a large building project can be equated with a direct cash disbursement, in that both put actual money into the hands of the people. As we have seen,

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[50] For the unlikeliness that condemned labour was used on public building works in Rome see Brunt 1980: 81, accepted by Millar 1984: 132-37 who treats condemnation to opus publicum in some detail.

most of this cash was distributed within the urban area and its immediate periphery, and rather less in the rural hinterland. The implications of this for the debate on the extent to which the Roman empire had a monetary economy or not cannot be entered into here, but it is striking how relatively little passed directly in the first instance outside the area encompassed by the city. Unlike cash donatives, however, large public building projects offered rewards not just on a single occasion but over a relatively long period of time, thus potentially acting as a magnet to draw new labour into the city or assuring, say, the small landholder with an ox-cart or two a regular source of income to set against the uncertainties of agricultural production. As well as providing an amenity or an adornment to the city, a major building project could offer both a stimulus to urban and extra-urban life and a buffer against its woes.

And, finally, we need at least to raise the question of the multiplier effect such a cash injection might have. If we allow that each person not engaged in food production needs the labour of five others on the land to feed him, then these too must benefit however distantly from the money spent on public building. The more immediate effects would be felt in the city itself and the myriad services it provided: housing, fuel, clothing, food and drink, doctors and prostitutes, tools and luxuries all needed to be paid for. Some of the money spent on such items and generated by the imperial building projects must ultimately have found its way back to the landowners large and small who provided the raw materials of these services, but with hefty slices taken out by shopkeepers, innkeepers, middlemen and transport operators all along the line. It is perhaps no wonder that building emperors were so popular with the people.

Building the Baths of Caracalla, therefore, was a powerful investment. Not only was the actual construction programme a form of largesse which could be seen to benefit all strata of society including one of the largest independent bodies of men in the capital - the fabri tignuarii - but the finished building was a permanent reminder of the power to command resources wielded by the emperor, and the emperor alone.

9.4 CONCLUSIONS

> "...there is a limit to what we can do with numbers, as there is to what we can do without them..." [51]

In the introduction to this thesis I decried the verbal arm-waving and general vagueness which large imperial building projects usually elicit from those having to come to terms with them. Without the quantitative analysis, whether of design procedure, materials production, construction or decoration, this thesis might have done little better. At the same time, our knowledge of such things as working conditions, wages, and costs of materials and transport are so limited for the Roman world that the figures presented taken on more of a provisional and hypothetical quality the further removed they are from the basic quantities of materials used for the building. In order to test the validity of the figures we need to put them in the wider social, political and ecomomic context of imperial Rome, and this is what I have tried to do in this final chapter. In doing so, I hope I have made a small contribution to the debate on euergetism, and to understanding the economics of liberality and the politics of public building.

But large-scale imperial building projects were only one of the areas in which builders in the Roman world were employed, and brick-faced concrete construction only one of the many building techniques used. In order to understand fully the building trade in Rome and its ramifications for the surrounding countryside and the more distant areas serving the capital with raw materials, more similar studies need to be done. Small-scale private housing and luxury villas, ashlar temples and concrete mausolaea, timber-roofed basilicas and arcaded aqueducts, all require different skills and different materials, and operate on different scales of magnitude and different organisational bases.

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[51] Quoted by Finlay 1984: 25, note 24, from N. Georgescu-Roegen, Analytical Economics (Cambridge, Mass., 1966), p. 275.

And there is the whole question of how repairs, alterations, extensions and demolitions fits into the picture which is slowly emerging of the Roman building industry. I have already begun work on an Ostian insula, and hope to tackle some of the other topics soon. Nevertheless, this is a field of study beyond the potential of a single individual, and if this thesis inspires others to attempt to combine quantitative analyses with their more qualitative studies of Roman buildings, it will have achieved one of its aim.

This has been primarily an archaeological thesis, based on detailed fieldwork and borrowing its methodology from the combined disciplines of archaeology and ethnology. But archaeologists are in their own ways historians, and it is to be hoped that this thesis will provide other historians with the impetus to investigate in more detail the economic, social, and political implications of building the Baths of Caracalla.

APPENDIX ONE

Catalogue of Architectural Orders

The information in the catalogue is set out in the following way:

Location of the order

(1) Documentary evidence, given under the headings: A - column shaft, B - base, C -capital, D - architrave and frieze, E - cornice, F - total height of order. In each case the main measurements and the source of information is given, plus a brief description or type except for F.

(2) Reconstructed order, using the documentary evidence as far as possible, supplemented by theoretical calculations based on Wilson-Jones 1989b. The information is given in the same order as in Section (1), except that the height of the entablature is given as a single figure (D/E).

Only two significant figures have been used except in some cases where precise direct measurements were possible.

Abbreviations:

Pall. - Palladio. The figure numbers refer to Zorzi 1959.
Bl. - Blouet 1828: Pl. XII
Can. - Canina 1848-1856: Tav. CCXI
Hül. - Iwanoff-Hülsen 1898

Screen between Rm 1 and the natatio

(1) Documentary evidence

A Diam. 1.1 m (Pall. Fig. 120, 124)
Upper diam. 1 m, alabaster, unfluted (Bl. Fou. T.)
Grey granite (Hül. 33)

B Ht 0.48 m, double scotia (Pall. Fig. 120, 124)
Ht 0.55 m, double scotia (Can. Fig. 3)

C Ht 1.4 m, Composite (Pall. Fig. 120, 124)
Ht 1.2 m, Composite (Bl. Fou. T; Can. Fig. 2)

D Ht frieze + architrave, 1.3 m (Bl. Fou. T; Can. Fig. 14)
Three-step architrave, astragal with bead-and-reel, cyma reversa with pendant leaf, astragal with bead-and-reel, cyma reversa with leafy scroll, fillet; peopled acanthus scroll.

E Ht 1.1 m (Pall. Fig. 120, 124)
Fillet, cyma recta sima with alternating acanthus scroll and leaf palmettes, fillet, cyma reversa with pendant leaf, vertical corona with leafy scroll, ovolo with egg-and-?tongue, astragal with bead-and-reel, dentils, cyma reversa with "tulip", arch and pendent leaf.

F ? 13.1 m (measured ht of vault springing)

(2) Reconstructed order, 36 P column (10.6 m)

A Lower diam. 1.1 m, Ht 8.83 m, alabaster

B Ht 0.55 m, double scotia

C Ht 1.2 m, Composite
D/E Ht 1.3 + 1.1 = 2.4 m
F Ht 13.0 m

Screen between Rms 1 and 2

(1) Documentary evidence
A Diam. 0.88 m, red Assuan granite (extant section in Rm 1W, frags from excavations in Rm 2E)
B nil
C ? Ht 1.0 m, Composite (extant in natatio)
D/E ? Ht 1.8 m (measured cutting Rms 1/2E)
F ? 10.6 m (measured cuttings Rms 1/2E)

(2) Reconstructed order, 30 P column (8.83 m)
A Lower diam. 0.88 m, Ht 7.36 m, red granite
B Ht 0.47 m
C Ht 1.0 m, Composite
D/E Ht 1.8 m
F Ht 10.6 m

Screens between Rms 4, 5, and 6

(1) Documentary evidence
A Diam. 0.87 m (Pall. Fig. 119L, 123L)
Upper diam. 0.81 m, alabaster, unfluted (Bl. Fou. S)
Ht ? c. 6.9 - 7.0 m (measured cuttings less known ht of base)
B Ht 0.44/0.43/0.42 m, double scotia (in situ; Pall. Fig. 119L, 123L, Bl. Fou. S)
C Ht 0.93 m, Corinthian (Pall. Fig. 119L, 123L)
Ht ? 0.88 m (measured cutting Rm 5W)
D Ht architrave, 0.63 m (Pall. Fig. 119L, 123L)
Ht frieze, 0.69 m (Pall. Fig. 119L, 123L)
Three-step architrave, astragal with bead-and-reel, cyma reversa with pendant leaf, astragal with bead-and-reel, cyma reversa with leafy scroll, fillet; plain frieze.
E Ht 0.62 m (Pall. Fig. 119L, 123L)
Fillet, cyma recta sima with alternating acanthus scroll and leaf palmettes, fillet, cyma reversa with pendant leaf, astragal with bead-and-reel, vertical corona with alternating masks and leafy palmettes, ovolo with egg-and-?tongue, astragal with bead-and-reel, dentils, cyma recta with upright acanthus and water leaf.
F ? 10.3 m (measured cuttings)

(2) Reconstructed order, 30 P column (8.83 m)
A Lower diam. 1.1 m, Ht 8.83 m, alabaster
B Ht 0.44 m, double scotia
C Ht 0.93 m, Composite
D/E Ht 0.63 + 0.69 + 0.62 = 1.94 m
F Ht 10.3 m

Screens between Rms 8, 9, and 10, and between Rms 8-10 and 12.

(1) Documentary evidence

A Diam. 0.87 m, fluted (Pall. Fig. 119R, 123R)
Upper diam. 0.80 m, giallo antico or pavanazzetto, fluted (Bl. Fou. R)
Diam. 0.88/0.89 m, grey granite, unfluted (two frags extant; Bl. Fou. R; Hül.[28])
Ht ? c. 7.0 m (measured cuttings less assumed ht of base)

B nil

C Ht 0.93 m, Composite (Pall. Fig. 119R, 123R)
Ht 0.97 m, Corinthian with eagle volutes (Bl. Fou. N)
Ht c. 0.9 m (measured cutting Rm 8/9E)

D Ht architrave, 0.54 m (Pall. Fig. 119R, 123R)
Ht frieze, 0.54 m (Pall. Fig. 119R, 123R)
Three-step architrave, astragal with bead-and-reel, cyma reversa with pendant leaf, astragal with bead-and-reel, cyma reversa with leafy scroll, fillet; plain frieze.

E Ht >0.71 m (Pall. Fig. 119R, 123R)
Ht 0.83 m (extent frag., Fig. 124; Bl. Fou. N)
[Fillet, cyma recta sima with alternating acanthus scroll and leaf palmettes, fillet, cyma reversa with pendant leaf, astragal with bead-and-reel, vertical corona with alternating scrolls and leafy palmettes], cyma recta with alternating scrolls and leafy palmettes, astragal with bead-and-reel, dentils, ovolo with egg-and-?tongue, cyma recta with vertical oak leaf and tongue, fillet, cyma recta with sinusoidal leaf patter, astragal with pendant leaf.

F ? 10.5 m (measured cuttings)

(2) Reconstructed order, 30 P column (8.83 m)

A Lower diam. 0.88 m, ? Rms 8/9, 9/10 Numidian or Docimian fluted, ? Rms 8-10/12 grey granite unfluted

B Ht 0.55 m

C Ht 0.93 m, ? Rms 8/9, 9/10 Composite, ? Rms 8-10/12 Corinthian

D/E Ht 0.54 + 0.54 + 0.83 = 1.91 m

F Ht 10.5 m

Screen 12/13 and Rm 12 portico

(1) Documentary evidence

A Diam. 0.60/0.63/0.67/0.69 m, grey granite, unfluted (3 frags extant; Pall. Fig. 121)
Diam. 0.64/0/59 m, giallo antico or pavanazzetto, fluted (extant; Hül.[28])
Diam. 0.88/0.89 m, grey granite, unfluted (two frags extant; Bl. Fou. R; Hül.[28])
Ht c. 5.85 m (measured cuttings less ht of base)

B Ht 0.39/0.37 m (Can. 5, 6)

C Ht 0.80/0.83 m, Corinthian with eagle volutes (3 exs extant)
Ht 0.81 m, Composite (Pall. Fig. 121)

D Ht architrave, 0.52/0.49 m (extant, Fig. 132; Pall. Fig. 121L)
Ht frieze, 0.54/0.49 m (extant, Pall. Fig. 121L)
Three-step architrave, astragal with continuous bead, cyma reversa with pendant leaf, astragal with bead-and-reel, cyma reversa with leafy scroll, fillet; peopled acanthus scroll frieze.

E Ht 0.74 m (Pall. Fig. 121L)
Fillet, cyma recta sima with alternating acanthus scroll and leaf palmettes, fillet, cyma

reversa with pendant leaf, astragal with bead-and-reel, vertical corona with linked leafy palmettes, cyma recta with alternating scrolls and leafy palmettes, astragal with bead-and-reel, ovolo with egg-and-?tongue, dentils, cyma reversa.

F ? c. 8.8 m

(2) Reconstructed order, 24 P column (7.07 m)

A Lower diam. 0.71 m, Screen 12/13 Numidian or Docimian fluted, palaestra portico grey granite unfluted

B Ht 0.38 m

C Ht 0.81 m, Screen 12/13 Composite, palaestra portico Corinthian

D/E Ht 0.52 + 0.54 + 0.74 = 1.77 m

F Ht 8.8 m

Screen between Rm 14 and frigidarium

(1) Documentary evidence

A Diam. 1.11 m, unfluted (Sangallo, Hül. Taf. N)
Ht c. 8.81 m (Sangallo, Hül. Taf. N)

B Ht 0.56/0.53/0.58 m (Bl. Fou. F; Anonymous Dest. Bl. 35v, 36r)

C nil

D/E nil

F Ht 13.1 m (if = vault springing)

(2) Reconstructed order, 36 P column (10.6 m)

A Lower diam. 1.11 m, ht 8.83, ? granite unfluted

B Ht 0.56 m

C Ht 1.2 m

D/E Ht 2.4 m

F Ht 13.1 m

Frigidarium pool screens

(1) Documentary evidence

A Diam. 0.88 m, red porphyry, unfluted (Bl. Fou. B)
Ht c. 7 m (measured cuttings)

B Ht 0.35 m (Bl. Fou. B)

C Ht 1.19/1.35 m, figured Composite (extant; von Mercklin 1962: 158-60)

D/E nil

F nil

(2) Reconstructed order, 30 P column (8.83 m)

A Lower diam. 0.88 m, ht c. 7m, red porphyry, unfluted

B Ht 0.35 m

C Ht 1.19/1.35 m

D/E Ht ? c. 1.2 m

F Ht c. 10.6 m

Giant Frigidarium and Natatio Orders

The elements of these two orders are not easy to differentiate, and there is no easy solution which fits both the cuttings in the two rooms and the extant and recorded fragments. The cuttings for the entablatures do not survive in all cases. Some of the larger fragments of columns and bases appear to belong to larger order than can be fitted in with the existing cuttings. Without a more detailed study than can be attempted here I am constrained to base the restoration on those elements which do fit in with the surviving sockets for the entablatures.

(1) Documentary evidence

A Diam. 1.63/1.65 m, grey granite, unfluted (Bl. Fou. B; extant)
Diam. 1.51 m, grey granite (Lanciani 1869)
Diam. 1.44 m, grey granite (extant; Anon. Dest. Blt. 35r)
Ht column including base and capital, frig. = c. 14.7 m, nat. = c. 14.2 m (measured cuttings)
B Ht 0.86 m (Anon. Dest. Blt 35r)
C Ht 1.85 m, Composite (Can. Fig. 1)
Ht 1.57/1.63 m, Corinthian (Pall. 121R, 122)
D nil
E Ht 0.95 m, from frigidarium (Fra Giocondo, Uff. 1538 = Hül. Taf. N)
F frig. = c. 18.4 m (measured cutting)

(2) Reconstructed orders, frig. 50 P column (14.7 m), nat. 48 P column (14.1 m)
A Frig. diam. 1.53 m, ht 12.3 m, nat. diam. 1.47 m, ht 11.8 m, both grey granite unfluted
B Frig. Ht 0.86 m, nat. c. 0.75 m
C Frig. Ht 1.85 m Composite, nat. Ht c. 1.6 m Corinthian
D/E Frig. Ht c. 3 m, nat. Ht ? c. 2.7 m
F Frig. Ht c. 18.4 m, nat. Ht c. 18.1 m

Natatio Aedicular Facade

There are few extant fragments but the basic scheme can be restored from the series of cuttings.

Lower main order: 24 P column (7.06 m), total ht order 8.72 m. ? Carystian unfluted shaft, diam. 0.74 m (extant); three-step architrave with standard moundings and frieze with peopled scrolls, ht 1.12 m (Bl. Fou. T; Anon. Dest. = Hül. Taf. Q).
Upper main order: 20 P column (5.88 m), total ht order c. 7.8 m. Frag. Numidian shaft, fluted, diam. 0.58 m; small figured Composite capital, ht 0.59 m.
Lower niche order: 12 P column (3.53 m)
Upper niche order: 8 P column (2.5 m)

Screen between Frigidarium and Natatio

From cuttings, this should be the same size as the frigidarium pool screens. Fragments of porphyry column is only recorded element (Bl. Fou. A) of appropriate diameter.

North facade framing doors to Rms 1 and 5

Architrave block in situ, 0.59 m high, and cuttings show total height of column c. 7.3 m. Restored as for palaestra portico order, red granite shafts.

Caldarium and Rms 19-22

Drawing by the Anonymous Destailleur (Blatt 13v = Hül. Taf. Q) shows a rectangular Tuscan pier capital for the caldarium. Rms 19-22 are also restored with Tuscan capitals and red granite shafts.

APPENDIX TWO

Catalogue of Brickstamps

This catalogue is based on the brickstamps published in CIL XV, Iwanoff-Hülsen 1898 (hereafter Hül.), and Bloch 1947 (hereafter Bl.), augmented with unpublished material from the excavations of 1873-4 contained in Biblioteca della Storia Dell'Arte e dell'Architettura, Mss Lanciani 37: Pellegrini Codice Scavi and Archivio Statale, Ministero della Istruzione Pubblica, Direzione Generale, Antichità e Belli Arti: Busta 101/102, Fasc. 134), Rapporto Pellegrini (hereafter R.P. with date). A few examples have been added from personal observation.

A. CARACALLA AS DOMINUS (AD 212-217)

Figlinae Bucconianae (= f. Vocconianae)

i CIL XV. 688 OPUS DOLIARE EX PRAEDIS D N AN
TONINI AUG EX FIGULIN
IS VOCONIANIS

Examples:
(1) Recorded only by Henzen. (688, 2 = Hül. 107 = Bl. 170).

Figlinae Domitianae: Maiores

ii CIL XV. 164 OP DOL . EX R AUGN FIGLIN
DOMITIANA MAIOR
nux pinea

Examples:
(2-3) Hypocaust of caldarium. (164, 13 = Hül. 7 = Bl. 9; Bl. 10).
(4-5) Cuniculus in W caldarium pier. (164, 14 = Hül. 17 = Bl. 20; Bl. 21).
(7) Pavement between caldarium and tepidarium. (164, 15 = Hül. 5 = Bl. 7).
(8) Wall of Rm 20E. (164, 16 = Hül. 48 = Bl. 65).
(9-10) South (?) pier of caldarium. (Hül. 24 = Bl. 31; Hül. 26 = Bl. 34).
(11-12) Central maintenance passage under Rm 12E. (Bl. 105, 106).
(13-15) Maintenance passage outside N facade, E end. (Pers. obs.).
(16-17) Maintenance passage outside W facade. (Pers. obs.).
(18) Cuniculus Rms 16/21E at terrace level. (Pers. obs.).
(19) Loose in Rm 18W. (Bl. 79).
(20-22) No context. (164, 17 = Bl. 129, 130; Bl. 131).

iii CIL XV. 762a[1] OPUS . DOLIARE . EX PRED
DOMINI . NT . AUG
canis sinistrorsum

Examples:
(23) Stair of W caldarium pier. (762a, 7 = Hül. 23 = Bl. 33).
(24-25) Walls of Rms 20W and 21W. (762a, 8 = Hül. 36, 37 = Bl. 48, 51).
(26) Hypocaust of caldarium. (762a, 9 = Hül. 14 = Bl. 19).
(27) East caldarium pier. (Bl. 25).
(28) Arch at base of Rm 18W. (Bl. 77).
(29) Lower window arch of W caldarium pier. (Pers. obs.).
(30) Excavations in S side of frigidarium. (R.P. sett. 5-10 maggio).
(31) No context. (? includes No. 30). (762a, 10 = Hül. 90 = Bl. 172-175).

Figlinae Domitianae: Minores

iv CIL XV, 174 OP DOL EX PR AUG N FIG DOM MIN
AEMILIAE ROMANAE
clava

Examples:
(31) Hypocaust of caldarium. (174, 1 = Hül. 15 = Bl. 17).
(32-35) Central maintenance passage beginning under Rm 12 E. (Bl. 107-110).
(36) Excavations in tepidarium. (R.P. sett. 19-24 maggio).
(37) No context. (? includes No. 23). (174, 2 = Hül. 79 = Bl. 132-134).

v CIL XV, 408c[2] OP DOL EX PR M AURELI ANTO
NINI AUG N PORT LIC
aries dextrorsum, superne caduceus alatus,
inferne (dextrorsum) crumena

Examples:
(38) Stair of W caldarium pier. (408c, 60 = Hül. 28 = Bl. 36).
(39-40) Stair of E caldarium pier. (408c, 61 = Hül. 21 = Bl. 28-29).
(41) Wall of caldarium. (408c, 62 = Hül. 29 = Bl. 38).
(42) Doorway Rms 20/21E. (408c, 63 = Hül. 46 = Bl. 64).
(43) In a room between Rm 12W and frigidarium, high up. (408c, 64 = Hül. 56, Bl. 80).
(44) Excavations in S side of frigidarium. (R.P. sett. 23 aprile - 3 maggio).

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[1] Steinby 1974-5: 38 places this stamp in the f. Dom. Maiores because of the signum, but it could also belong to the Dom. Veteres.

[2] Assigned to the f. Dom. Minores by Steinby 1974-75: 38 on grounds of the signum. By the time of Caracalla, the products of the several branches of the figlinae Domitianae, Terentianae, and Publilianae, all passed through the Portus Licini, as may have done the products of other figlinae connected with the Domitianae, including the Vocconianae, Oceanae, Ponticlanae, and Genianae. The only unassociated figlinae are the Favorianae.

Figlinae Domitianae: Veteres

vi CIL XV, 193 OPUS DOL DE PRAED AUG N EX FIGL
VET CAECILIA AMANDA
hilaritas sinistrorsum

Examples:
(45) Stair of E caldarium pier. (193, 2 = Hül. 4 = Bl. 6).
(46) Lowest bonding course, Rm 19E. (Bl. 68).
(47) Loose in Rm 12E. (Bl. 84).
(48) Excavations in S side of frigidarium. (R.P. sett. 5-10 maggio).
(49-53) No context. (193, 3 = Bl. 135-138; Bl. 140).

Figlinae Novae (Domitianae)

vii CIL XV, 203 OP DOL EX PR AUG N FIGL NOV
SABINA INGENUA
palma

Examples:
(54-55) Wall of Rm 22W. (203, 5 = Hül. 31 = Bl. 40-41).
(56) Excavations of 1912, probably from substructures of outer precinct. (Bl. 143).
(57) No context. (203, 6 = Bl. 142).

Figlinae Domitianae (unspecified)

viii CIL XV, 155 OPUS DOLIAR EX PRED DOM . NT . AUG
EX FIGULINIS DOMITIA
duobus palmae

Examples:
(58) Minor drain in W side of building, imprint in mortar. (Bl. 90).
(59) Drain (? or maintenance passage) under Rm 12W. (Bl. 92).
(60) Excavations of 1912, probably from substructures of outer precinct. (Bl. 127).
(61) No context. (155, 7 = Hül. 63 = Bl. 126).

ix CIL XV, 157 AUGUST . N . OP . DOL . EX . PR . DOM
FOR DOMITIANARU FIG .
aquila adversa alis expansis sinistrorsum respicit

Examples:
(62) Hypocaust pillar of caldarium. (157, 5 = Hül. 16 = Bl. 16).
(63) Wall of Rm 19E. (157, 6 = Hül. 49 = Bl. 67).
(64) Arch of door Rm 5/12E, imprint in mortar. (157, 7 = Hül. 60 = Bl. 81).
(65+) Wall of Rm 20W. Several exs. (157, 8 = Hül. 39 = Bl. 49).
(66) Arch of door Rm 18/20W. (Hül. 41 = Bl. 52).
(67) Loose in Rm 18W. (Bl. 78).
(68) No context. (157, 9 = Hül. 64 = Bl. 128).

Figlinae Favorianae (Faorianae)

x CIL XV, 214 OP DOL EX PR AUG N FIG FAOR
CALVENT MAXIMAE
Hercules

Examples:
(69) Wall of Rm 21E, in high position. (214, 5 = Hül. 45 = Bl. 61).
(70) Wall of Rm 22W. (214, 6 =Hül. 32 = Bl. 42).
(71-72) Bonding courses of Rm 21E. (Bl. 59-60).

Figlinae Genianae

xi CIL XV, 237b OP DOL EX PR DOM AUG N FI
GLINAS GENIANAS
protome Minervae (Romae)

Examples:
(73) Door Rm 19/20W. (237b, 10 = Hül. 40 = Bl. 53).
(74) Maintenance passage under Rm 12E. (Bl. 111).
(75) No context. (237b = Bl. 145).

xii CIL XV, 759[3] OPUS DOLIAREM EX PRAEDIS
DOMINI NOSTRI
Mercurius ariete sinistrorsum vehitur

Examples:
(76) Passage Rms 18/20W above terrace level. (Pers. obs.).
(77) Terrace over Rm 11W, lower step of stair. (Pers. obs.).

Figlinae Oceanae: Maiores

xiii CIL XV, 769a OPUS DOLIARE EX PRAEDIS
AUGG NN FIG C TER TIT
rota (vix stella) sex radiorum

Examples:
(78) Recorded by Pighius, not extant. Bloch (1947: 291) believes this could be an example of 769b where the erasure was still visible. (769a, 4).

xiv CIL XV, 769b OPUS DOLIARE EX PRAEDIS
AUG{G} {N}N FIG C TER TIT
rota (vix stella) sex radiorum

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[3] Appears on same tile as CIL XV 760a (Steinby 1973: 189-90, Tav. LX.2), and therefore belongs to f. Gen. from signum (Steinby 1974-75: 43-4).

Examples:
(79) Water channel in N side of frigidarium. (769b, 16 = Hül. 1 = Bl. 2).
(80) Arch in wall of Rm 22E. (769b, 17 = Hül. 42 = Bl. 58).
(81) Upper layer of caldarium hypocaust. (Bl. 13).
(82) Small drain in W side (? Rm 12), imprint in mortar. (Bl. 91).
(83) Loose in excavations in caldarium. (769b, 18 = Hül. 30 = Bl. 39).
(84) No context. (Bl. 178).

Figlinae Oceanae: Minores

xv CIL XV, 381 OPUS DOLIARE EX FIGULINIS OCEAN
IS MINORIBUS PRAEDIS D N AUG
protome galeata Minervae aut Romae

Examples:
(85) Wall of Rm 22E. (381, 3 = Hül. 44 = Bl. 62).
(86) Wall of Rm 18E. (Bl. 85).
(87) No context. (381, 4 = Hül. 102 = Bl. 147).

Figlinae Ponticlanae

xvi CIL XV, 404 OP DOL EX PRAED AUG N FIG
LIN PONTICLANAS
stella aut sol inter cornua lunae crescentis

Examples:
(88) Rm 18W, hypocaust. (404, 11 = Hül. 55 = Bl. 76).
(89-91) Hypocaust of caldarium. (404, 12, 13 = Hül. 9-11^{+} = Bl. 11, 18).
(92-3) Walls of Rms 19 and 20E. (404, 14 = Hül. 47, 50 = Bl. 66, 69).
(94-5) Wall of Rm 20W, high up. (404, 15 = Hül. 38 = Bl. 50).
(96) Arch above praefurnium of SE caldarium pier. (Bl. 23).
(97) Niche in N side of E tepidarium pool. (Bl. 32).
(98) Drain on E side, imprint in mortar. (Bl. 93).
(99) Excavations between frigidarium and tepidarium. (R.P. sett. 5-10 maggio).
(100-101) No context. May include No. 99. (404, 16 = Hül. 65 = Bl. 148)

Figlinae Publilianae

xvii CIL XV, 424b IMP M . AUR. ANTONIN AUG OPUS . DOLI
AR . EX . FIGUL . PUBLILIAN
cervus dextrorsum currens

Examples:
(102) No context. (424b, 11 = Hül. 86 = Bl. 155).

xviii CIL XV, 435[4] OP . DOL . EX . FIGL PUBLILIAN C CA
SINIUS NUMIDIAN FEC .
Mars dextrorsum respiciens

Examples:
(103) Lower bonding course, Rm 19E. (Bl. 71).
(104) No context. (435, 1 = Hül. 103 = Bl. 156).

xix CIL XV, 408a[5] OP DOL EX PR M AURELI ANTO
NINI AUG N PORT LIC
Mars dextrorsum respiciens

Examples:
(105) Rm 18W hypocaust. (408a, 13 = Hül. 53 = Bl. 74).
(106) Stair in Rm 23E. (408a, 14 = Hül. 19 = Bl. 26).
(107) Wall of Rm 22W. (408a, 15 = Hül. 33 = Bl. 43).
(108) Arch in wall of Rm 22E. (Bl. 55)
(109) Excavations in frigidarium towards tepidarium. (R.P. sett. 5-10 maggio).
(110) Drain on W flank of central block. (Pers. obs.).
(111) No context. (408a, 16 = Hül. 83 = Bl. 150).

xx CIL XV, 408b OP DOL EX P R M AURELI ANTO
NINI AUG N PORT LIC
Mercurius petastatus sinistrorsum respiciens

Examples:
(112) Hypocaust of caldarium. (408b, 33 = Hül. 8 = Bl. 12).
(113) Steps in Rm 23E, not in situ. (408b, 34 = Hül. 20 = Bl. 27).
(114) Rm 18E, hypocaust. (408b, 35 = Hül. 58 = Bl. 88).
(115-16) Wall of Rm 22W. (408b, 36 = Hül. 34 = Bl. 34, 35).
(117) Pavement of modern drain in Rm 12W. (Bl. 72).
(118-19) No context. (408b, 37 = Hül. 84 = Bl. 151-152).

xxi CIL XV, 408d OP DOL EX PR M AURELI ANTO
NINI AUG N PORT LIC

Examples:
(120) Drain in wall of Rm 18W. (408d, 78 = Hül. 52 = Bl. 73).
(121) Wall of Rm 19E. (408d, 79 = Hül. 51 = Bl. 70).
(122) Drain in wall of Rm 18E. (408d, 80 = Hül. 57 = Bl. 80).
(123) No context. (408d, 81 = Hül. 85 = Bl. 153).

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[4] Bloch 1947: 298 adds this to the imperial group as it has the same signum as CIL XV 408a. Cf. Steinby 1974-75: 79.

[5] Steinby 1974-75: 74 assigns this along with CIL XV, 408b and 408d to the f. Publil. because of the signum.

Figlinae Publilianae/Domitianae Minores

xxii CIL XV 408e OP DOL EX PR M AURELI ANTO
NINI AUG N PORT LIC
signum incertum

Examples:
(124) Stair in Rm 23W. (408e, 106 = Hül. 22 = Bl. 30).
(125) Channel in W caldarium pool. (408e, 107 =Hül. 18 = Bl. 22).
(126) High in wall between caldarium and tepidarium. (408e, 108 = Hül. 3 = Bl. 5).
(127) Arch in wall of Rm 23E. (408e, 109 = Hül. 43 = Bl. 56).
(128) Hypocaust floor of Rm 18E. (408e, 110 = Hül. 59 = Bl. 89).
(129-30) Wall of Rm 22W. (408e, 111 = Bl. 46, 47).
(131) Channel in wall of Rm 22E. (Bl. 57).
(132) Wall of Rm 18E. (Bl. 86).
(133-43) Small channel on E side. (Bl. 94-104).
(144-50) Central maintenance passage, E end. (Bl. 112-118).
(151) No context. (408e, 112 = Hül. 66 = Bl. 154).

Figlinae Terentianae

xxiii CIL XV 624 OP . DOL . EX . PR . AUG N . FIG . TERENTIA
AELI FELICIS
Victoria sinistrorsum

Examples:
(152-57) No context. (Bl. 160-65).

xxiv CIL XV 625 OP DOL EX PR AUG N FIG TERE
NT L AELIO PHIDELE
aquila adversa alis expansis sinistrorsum respicit

Examples:
(158) Hypocaust pavement in Rm 18W. (625, 6 = Hül. 54 = Bl. 75).
(159) Wall of Rm 22W. (625, 7 = Hül. 35).
(160) Cuniculus in N facade. (Bl. 1).
(161) Central maintenance passage, E end. (Bl. 119).
(162-63) Excavations in frigidarium towards tepidarium. (625, 8 = Hül. 67 = Bl. 166-67 = R.P. sett. 5-10 maggio).
(164) Excavations in tepidarium. (R.P. sett. 9-14 giugno).
(165) No context. Recorded by Pighius. (625, 8 = Hül. 67 = Bl. 168).

xxv CIL XV 626 OP DOL EX PR AUG N FIG TERENT
L AELII SECUND ET APRIL
[vase with flowers flanked by heraldic panthers]

Examples:
(166) Arch of door Rms 12/19E. (626, 11 = Hül. 61 = Bl. 82).
(167) Arch of door in W caldarium pier. (626, 12 = Hül. 6 = Bl. 82).
(168) Praefurnium arch SE pier of caldarium. (Bl. 24).
(169) Pavement Rm 12E. (Bl. 83).
(170-71) Central maintenance passage, E side. (Bl. 120-21).
(172) Maintenance passage, outside N facade. (pers. obs.).
(173) Excavations in frigidarium. (R.P. sett. 12-17 aprile).
(174) No context. (626, 13 = Hül 68 = Bl. 169).

Figlinae uncertain

xxvi S.21[6] OP DOL EX PRAED M AURE
LI ANTONINI AUG N
avis alis expansis sinistrorsum

Examples:
(175) Lower bonding course Rm 21E. (Bl. 63).

xxvii CIL XV 761 OPUS DOLIARE . EX . PRAEDIS . D . N . EX C
ONDUC . PUBLICIAES . QUINTIN .
aper dextrorsum currens

Examples:
(176) Stair in Rm 23W. (761,1 = Hül. 27 = Bl. 37).

xxviii CIL XV 762b OPUS DOLIARE EX PRE
DOMINI N AUG
aper sinistrorsum

Examples:
(177) No context. (762b, 35 = Bl. 176).

B. OTHER SEVERAN STAMPS

Figlinae Domitianae Novae

xxix CIL XV 205 OP . DOL . EX . PR . AUGG . NN . FIG . NOVAS AD205-211
FONT . PROCLI ET INGENUA

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[6] Steinby 1974-75: 47, 58 places this probably in the praedia Liciniana, while the signum is paralleled in both the f. Domitianae and the f. Terentianae.

Examples:
(178) Recorded only by Pighius, "retro thermas Antonianas ex ipsarum ruinis", ? from the cisterns or rear retaining wall. (205, 4 = Bl. 144).[7]

C. EARLIER STAMPS

Figlinae Caeponianae

xxx CIL XV 50c CAE SERVIL GELOTIS EX . FIG ISAUR — late Trajanic

Examples:
(179) Excavations of central section. (50c, 9 = Hül. 62 = Bl. 122).

xxxi CIL XV 70 EX . P . AR . FA CEP equus dextrorsum currens — AD 120

Examples:
(180) Pillars of caldarium hypocaust. (70, 2 = Hül. 14 = Bl. 12).

xxxii CIL XV 83a EX PRAED ARRIAE FADILLA STATI M LUCIFERI CAUPION

Examples:
(181) No context. (83a, 3 = Hül. 76 = Bl. 123).

xxxiii CIL XV 98 EX PRAED C . C . COSAN CAEPONIAN SEX ALFI AMAND PAETIN ET APRONIANO COS — AD123

Examples:
(182) No context. (98, 2 = Hül. 77 = Bl. 124).

Figlinae Domitiae Lucillae

xxxiv CIL XV 1030a EX FIG DOM LUC O D DION DOM LU SE SERVIANO ET VARO COS — AD 134

Examples:
(183) Channel in wall of room next to frigidarium. (1030a, 7 = Hül. 2 = Bl. 3).

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[7] Bloch 1947:298 does not think this necessarily belongs to the Baths, but I see no reason to reject it. The cisterns and aqueduct must have been among the earliest parts to be built and it would not be at all surprising to find bricks bearing slightly earlier stamps in this context.

xxxv CIL XV 1036 MYRTILI . DOMITIAE . P . F . LUC — early Hadrianic
DOLIAR . VERV
nux pinea cum foliis

Examples:
(184) Bipedalis loose in natatio. (Bl. 4).

Figlinae Caninianae

xxxvi CIL XV 132 C CRAECI VA EX F CAN DO LV

Examples:
(185) No context. (132, 1 = Hül. 78 = Bl. 125).

Praedia Quintanensia

xxxvii CIL XV 454c APRON ET PAET (IN) COS — AD 123
POMP VIT EX PR
ANNI VERI QUINT

Examples:
(186) Pillars of caldarium hypocaust. (454c, 37 = Hül. 13 = Bl. 15).

Opus Salarese

xxxviii CIL XV 481 SAL . EX . PR — before AD 123
AN . VER . Y

Examples:
(187) No context. (481, 4 = Hül. 87 = Bl. 156).

Figlinae Sulpicianae

xxxix CIL XV 562 SERVIANO III COS — AD 134
EX F VIL AUG SULPIC

Examples:
(188) Bipedalis loose in Rm 19E. (Bl. 69a).

xl CIL XV 586b COS AMB SUL — early 2nd century

Examples:
(189) Bipedalis loose in one of Rms 19-22W. (Bl. 54).

xli CIL XV 549d EX F DOM DOM SULP
PAET ET APRON COS — AD 123

Examples:
(190) No context. (549d, 32 = Hül. 88 = Bl. 157).

xlii CIL XV 575 EX FIGLINIS
CAECIL QUINTAE
SULPICIANI — early Hadrianic

Examples:
(191-92) No context.[8] (575, 2 = Hül. 108 = Bl. 158-59).

Figlinae uncertain

xliii CIL XV 723 O D ARIS . THA . EX . PR L CEIO COM CF
NIGRO ET CAMERIN
COS — AD 138

Examples:
(193) No context. (732, 7 = Hül. 69 = Bl. 171).

xliv CIL XV 853 Q . ASINI . MARCELLI — early Hadrianic

Examples:
(194) No context. (853, 5 = Hül. 70 = Bl. 179).

xlv CIL XV 968a P . CURTI . NYSI
caput bubulum adversum — ?late 1st to early 2nd century

Examples:
(195) No context. (986a, 1 = Hül. 92 = Bl. 180).

xlvi CIL XV 1369 M PONPEIO MACRI P IUVENT CELS
COS EX P . PLAUTI AQUIL
D amphora O — AD 164

Examples:
(196) No context. (1369, 6 = Hül. 96 = Bl. 181).

[8] Many examples of this stamp come from the Hadrianic house incorporated in the platform, and this may have been the source of these examples.

D. LATER STAMPS

xlvii <u>CIL</u> XV 1542 SECULO CONSTANTIANO
PROVISIO LIMENA

Examples:
(197) No context. (1542, 3 = Hül. 71 = Bl. 182).

xlviii <u>CIL</u> XV 1579b OF S OF DOM MERCAT

Examples:
(198) No context. (1579b, 18 = Hül. 110 = Bl. 183).

xlix <u>CIL</u> XV 1580a OF S OF DOM VICTORIS

Examples:
(199) Covering medieval tombs in outer precinct. (Bl. not numbered).

l <u>CIL</u> XV 1594d R . S . P (retrograde)
OF . FAB
SI

Examples:
(200) No context. (1594d, 18 = Hül. 97 = Bl. 184).

li <u>CIL</u> XV 1610 O F S O F IOBIA CLEMENS

Examples:
(201) No context. (1610, 9 = Hül. 98 = Bl. 185).

lii <u>CIL</u> XV 1631 S P . C
OF . TEM
S . II

Examples:
(202) No context. (1631, 6 = Hül. 72 = Bl. 186).

liii <u>CIL</u> XV 1643a R . S . P
OF . TER
S . III

Examples:
(203) No context. (1643a, 1 = Hül. 73 = Bl. 187).

liv CIL XV 1665a + REG D N THEODE
+ RICO BONO ROME

Examples:
(204) Stair to lower level in caldarium pier. (1665a, 3 = Hül. 25 = Bl. 35).
(205-207) No context. (1665a, 4 = Hül. 99 = Bl. 188-90).

lv CIL XV 1669 + REG D N THEODE
RICO FELIX ROMA

Examples:
(208-209) No context. (1669, 7 = Hül. 74 = Bl. 191-92).

APPENDIX 4

Shipping Costs in the Prices Edict of Diocletian

These figures are based on the assumption that wheat is the material in question, although it is clear from the Edict that as far as water transport is concerned the kastrensis modius was a standard shipping unit applicable to men and animals as well as any other goods. There is no direct evidence to indicate whether this was in fact considered only as a measure of volume, and if so, how this was applied to a sentient cargo. Rougé points out the difficulties in modern and historical expressions for the capacity of a ship, and the confusions that can arise between the different definitions of "tonnage", which can be weight based (displacement, burden) or volume based (total and usable carrying capacity).[9] Both concepts certainly existed in antiquity; tonnages in amphorae, medimnoi, and modii are all known, as are those in talents, and Hero of Alexandria (de mensuris, 17) gives a formula for calculating the capacity in modii.[10]

This is an important consideration in assessing the cost of transport for building materials. If a kastrensis modius equals half a Roman cubic foot or 0.0128 m^3 in volume, then one KM of wheat would weigh on average 10.1 kg, one KM of lime 10.9 kg, but one KM of marble 34.6 kg. This would make the cost of shipping marble very cheap. On the other hand, considerations of stability and freeboard, which are related to the size and shape of the hull and the density and distribution of the cargo, limit the volume and weight of objects carried[11], so that, for example, a vessel of 200 tonnes burden if carrying 200 tonnes of marble might have, say, 70-75% of its capacity free[12], and it could not carry a full load of marble in volume. The modern concept of stowage factor, the relationship of stowed cargo volume (including voids) to weight which allows known weights to be converted to stowed volumes, must have been known in some form to ancient seamen. Since the costs in the Prices Edict are in KM, which is a dry capacity measure used primarily of food staples, it is a reasonable hypothesis that the standard for conversion was in fact a kastrensis modius of wheat, and the ratios established for grain transport can be applied to building materials by weight.

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[9] Rougé 1981: 74-8.

[10] Evidence cited by Pomey and Tchernia 1978:235-6; Rougé 1981: 76.

[11] McGrail 1989: 353-6.

[12] The figures given in Tchernia etal. 1978:104-106 suggest a relationship of rough 0.57-0.51 tonnes for each m^3, and cf. Bonino 1985:45 for the largest of the Fiumicino boats. The Isola delle Correnti marble wreck contained 126 m^3 of marble, equivalent to 9840 KM in volume but weighing 350 tonnes (Kapitän 1961:284), or the equivalent of nearly 35,000 KM of grain.

APPENDIX 5

The unit of measurement for marble in the Prices Edict of Diocletian

The texts of the Edict invariably give the price of marble as a price per pedem,[13] which has nearly always been interpreted as a price per cubic foot.[14] References to cubic measurements, particularly cubic feet, are, however, rare in the ancient sources, measures of capacity being more usual to describe volume.[15] No other building materials in the Edict are described in terms of cubic measurements, bipedales being denoted at DPE 7.15 by the length of their sides without reference to their thickness, while timbers (DPE 12.1a-14) are defined by their height in cubits plus their girth (latitudinis in quadrum) in cubits or digits. On the other hand, pes quadratus could be used to denote both a cubic foot and a square foot,[16] and pes alone to mean a square foot,[17] just as a "foot" in the British building trade until recently often meant a superficial, i.e. a square, foot. If we are right in assuming that most of the marble sold on the market was for veneer, it would in fact be more natural to cost it in square feet (? of a standard thickness), since it would have been the area of floor or wall to be covered which was of primary interest to the purchaser. Given that the minimum thickness for floor veneer is about 30 mm, and the average thickness for wall veneer about 20 mm, and allowing for a certain amount of loss in sawing and polishing, then the cost of marble per cubic foot ought to be roughly 8-10 times the cost of the veneer, allowing a nominal figure for sawing.

This supposition - that the prices for marble in the Edict are for square feet of veneer rather than cubic feet - is, of course, not susceptible of any direct proof. Nevertheless there are other (albeit subjective) arguments which can be adduced in its favour. Firstly, the prices of the basic white marbles, if for a cubic foot, are low with respect to artisans' wages and the cost of other building materials, while the prices of even the most expensive coloured marbles are very low when compared with other luxury items. For example, a reasonably large room or court of dimensions 12 x 15 Roman feet, requiring 180 P^2 of veneer, would cost 720 denarii for materials if made of Lesbian or Proconnesian at 40 denarii/P^3. This is equivalent to only 12 days' wages plus food for an artisan, or less than three oak timbers 21 Roman feet long (DPE 12.10), or 180 bricks one foot square (DPE 15.90), or not quite five ordinary ladders (DPE 14.6). The marble for the same room paved in an equal mixture of Numidian, Docimian and Carystian would cost 3000 denarii, twice the price of a leather travelling bag but only one twelfth of a prime horse or mule (DPE 30.2,4) and one fiftieth the price of a first class lion (DPE 32.1a). Even if paved entirely in porphyry the materials would only have cost 4,500 denarii. If this really was the price of marble, we might have expected it to be much more widely used than it actually was.

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[13] pedem is rendered as π with a superscript o (a standard abbreviation for πous used elsewhere in the Edict) in the Greek versions from Pettorano and Geronthrae.

[14] e.g. Lauffer 1971: 280; Giacchero 1974: 305-6.

[15] I am grateful to Simon Corcoran of St John's College, Oxford, for several interesting discussions on the meaning of pedem in the section of the Edict dealing with marble, and for permission to draw on his unpublished paper on the topic.

[16] e.g. Balbus gromaticus, Ad Celsum, 97, ll.9-13; Festus, De verborum significatu, 312, ll.14-17.

[17] e.g. Columella, de re rustica, 5.1.9-13.

A confirmation that the price of marble in the Edict is too low to refer to cubic feet (and incidentally that stone for paving was thought of in superficial measure) comes from an inscription listing donations towards the building of the fishery toll-house in Ephesus in the reign of Nero.[18] From the list of donations, arranged in order of value, it can be deduced that the amount donated for paving an open area 100 cubits square in Phokaian stone (probably a white volcanic tuff) must have been in the order of 280 to 300 denarii, i.e. 1.25 to 1.3 denarii/square foot. If the cost of wheat in Asia Minor in the 1st century AD was normally HS 2 to 3/modius,[19] this gives a figure of, say, 85 to 170 denarii/P^2 for the cost of Phokaian stone at the time of the Edict. The resultant figure is rather higher than we might have expected (unless, as is not impossible, it includes the cost of laying the stone), but not surprising given the problems of converting costs between one period and another. Nevertheless,the order of magnitude should be right and it strongly suggests that the prices for marble in the Edict should also be for square feet, not cubic feet.

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[18] IEph. Ia (1979), no. 20 = JÖAI 26 (1930), 48-57. I am grateful to Dr J. Coulton for bringing this inscription to my notice and for his helpful comments on it.

[19] Duncan-Jones 1982: 146-147.

APPENDIX 3

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THE 'CELLA SOLEARIS' OF THE BATHS OF CARACALLA: A REAPPRAISAL

(Plates VIII–XI)

'Opera Romae reliquit thermas nominis sui eximias, quarum cellam solearem architecti negant posse ulla imitatione, qua⟨lis⟩ facta est, fieri. nam et ex aere vel cupro cancelli sup[er]positi esse, dicuntur, quibus cameratio tota concredita est et tantum est spatii ut id ipsum fieri negent potuisse[nt] docti mechanis.' SHA, *Vita Ant. Cara.*, IX, 4–5.[1]

'Among his works at Rome he left the magnificent Baths which bear his name, the *cella solearis* of which architects say cannot be imitated in terms of construction. For it is said that lattices either of bronze or of copper were placed over (under) to which the whole vault is entrusted and the span is so great that experienced engineers say it could not have been done.'

This short passage from the *Vita Caracallae* has been the source of endless fascination and dispute among all those who have had reason to study the still extensive remains of the Baths of Caracalla. The passage itself is problematic, as it includes five words, *solearis, cancelli, cameratio, concredita* and *mechanis*, which are not found elsewhere in the *Historia Augusta*—*solearis, cameratio* and *mechanis* not being otherwise attested in extant literature,[2]—and one critical alternative reading, *superpositi/suppositi*. Trying to fit any one particular interpretation of the text to the standing remains is even more difficult, and each new theory seems to create more problems than it solves. While some have been tempted to dismiss the text as hopelessly corrupt or even spurious, or to abandon the problem entirely because of the lack of structural evidence, in general considerable importance has been attached to this passage in any restoration suggested for the Baths of Caracalla.[3] It is the aim of this paper, therefore, to evaluate the previous theories about the *cella solearis* and the evidence for them and, with the addition of one detail of construction previously either overlooked or misinterpreted, to suggest a way that text and structure can in fact be reconciled.

The critical point, and the focus of the debate, is the meaning of *solearem* and hence of *cella solearis*. One of the earliest theories, which continues to receive some support today, was that *solearis* must be derived from *solea*, a sandal, and refer to the construction of the *cella solearis*, the details of which were given in the following lines of text. Guattani, who published one of the first monographs on the *cella solearis* in 1783,[4] gives three possible ways in which *solea* could refer to the ceiling: he connects

[1] Teubner, *Scriptores Historiae Augustae*, edited E. Hohl, 1965, 190–1.

[2] See C. Lessing, *Scriptorum Historiae Augustae Lexicon*, under the relevant entries; *solearis, cameratio* and *mechana* are in fact omitted from the Oxford Latin Dictionary.

[3] The passage was rejected entirely by Domaszewski, *Die Topographie Roms bei den SHA*, Heidelberg 1916, 7. On the other hand, in his review of Erika Brödner's *Untersuchungen an den Caracalla Thermen*, in *JRS* 1953, 210–12, J. B. Ward Perkins wrote: 'For the present the text of the SHA must remain the touchstone for the validity of any restoration.'

[4] G. A. Guattani, *Della Gran Cella Soleare nelle Terme di Antonio Caracalla*, Rome, 1783, 35 ff.

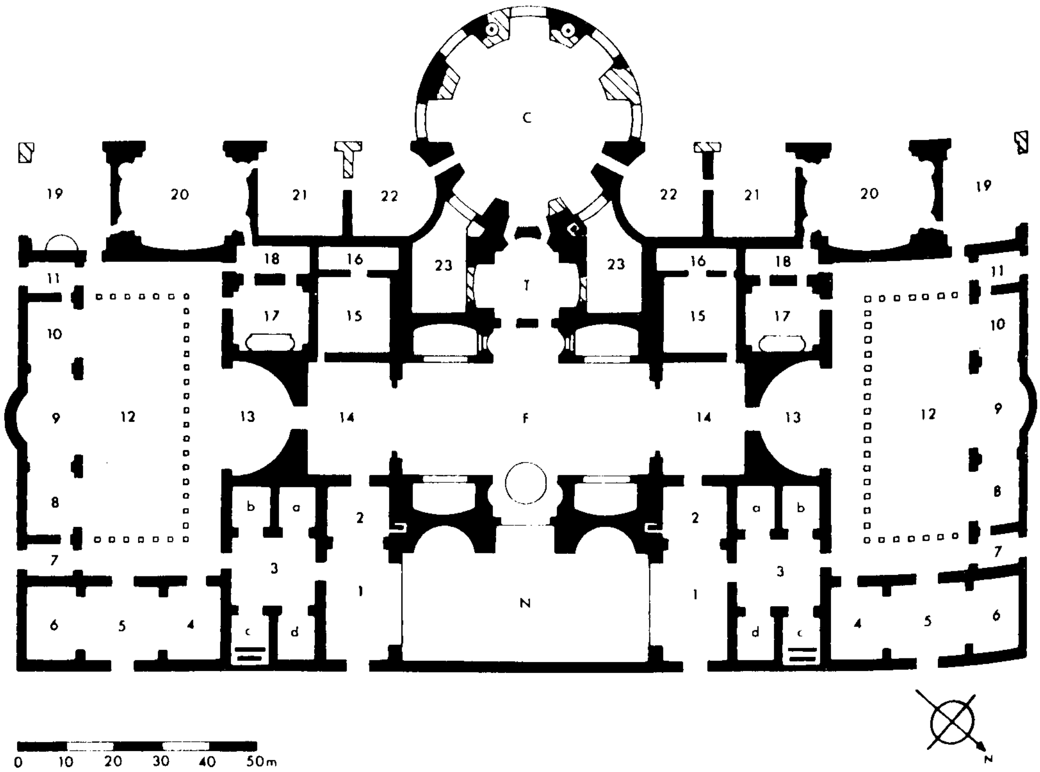

FIG. 1. The Baths of Caracalla

the interlaced straps of the standard Roman sandal with the *cancelli* of the description in the *Vita Caracallae*; he cites Festus 386L, 'Solea ut ait Verrius est non solum ea, qua solo pedis subjicitur, sed etiam materia robustea super quam paries craticius extruitur', as the basis for a construction of metal beams; and he provides a metaphorical explanation from the meaning 'a flat fish, the sole' which suggests a flat vault. His interpretation of the *cella solearis*, therefore, is of a flat ceiling constructed from interlaced metal beams, which he locates in the *natatio*, the only room of sufficient size which shows no trace of normal vaulting. He further cites as evidence the horizontal cutting in the upper part of the north wall of the *natatio* which he sees as the bed for the grid, the main beams of which were supported on the four large columns which once decorated this wall.

Guattani was followed by Canina[5] and Iwanoff,[6] but by few other of the architects who studied the Baths in the nineteenth century; in particular his theory was rejected by Abel Blouet, who produced a detailed monograph on the Baths in 1828 following the Conte Velo's excavations a few years previously.[7] Then, in the excavation of the *natatio* in 1872–3, large pieces of fallen vaulting were discovered

[5]Canina, *Gli Edifizi di Roma Antica*, Vol. III, Rome, 1851–6, 80–1.
[6]S. Iwanoff, *Architektonische Studien* III, Berlin, 1898, Tafel IX-XIII.
[7]A. Blouet, *Restauration des Thermes d'Antonin Caracalla à Rome*, Paris, 1828, 17.

which seemed to such notable scholars as Lanciani, Middleton and Huelsen, to prove Guattani's theories. According to Lanciani, the vaulting 'appeared to be pierced by iron bars about one metre long, with the upper end bent like a hasp, and a cross-piece at the lower end'.[8] Middleton gives a slightly different description, calling them 'compound girders, formed of two bars riveted together and then cased in bronze', while his sketch shows two T-shaped pieces joined back to back.[9] Aitchison follows Lanciani, but adds a few more details, such as the thickness of the concrete—2–2½ feet—and the fact that there was a mosaic surface on the upper flat face of the pieces of vaulting.[10] The restorations suggested by these scholars also differ in minor details: Lanciani sees the roof as being 'hung, as it were, to the girders by means of these iron crooks'; Middleton and Aitchison believe that the central section of the *natatio* was left open; and Huelsen, who is basing his evidence on the reports of the others, that the roof was not entirely flat but a very shallow segmental vault.[11]

A different interpretation of *cella solearis* was put forward by Brödner in her monograph on the Baths of Caracalla published in 1951.[12] She derives the word *solearis* from *sol*, and relates it to the common use of the word *solarium* for a terrace or balcony of a building. This she applies to the terraces around the so-called *palaestrae*, which she interprets as basilical halls with wooden roofs. This raises a number of difficulties, even for those few who accept her reconstruction of the *basilicae thermarum*; while an explanation of the *cancelli* is to be found in the identification of some kind of structural reinforcement in the barrel vaults of the terraces, the 'tantum est spatii' is forced to refer to the central basilical hall, which she restores with a wooden roof. There is also the problem that this gives us two *cellae soleares*, not one. While Brödner's theory has met little or no acceptance for the identification of the *cella solearis*, she has provided some arguments for the *natatio* being unroofed, the most convincing of which are the analogies with the Baths of Trajan and Diocletian, and the problem of providing adequate lighting.

Both Guattani and followers and Brödner base their interpretations on the word *solearis*, a word which occurs nowhere else in the extant body of Latin literature and epigraphy, and in fact has been omitted from the Oxford Latin Dictionary. As early as 1620 Claudius Salmasius had proposed that the correct reading was not *solearem* but *soliarem*, which he derived from *solium* in its well-attested meaning of bathtub.[13] Thus the *cella soliaris* is simply the (a?) room with bath tubs, and the description of the construction which follows is specific to the *cella soliaris* of the Baths of Caracalla, and need not refer to a flat ceiling at all. Guattani rejected this proposal on the grounds that there was no evidence for individual baths in the main bathing block; besides the form *soliaris* did not occur at all in the extant literary sources. In 1909, however, F. G. de Pachtere published an interpretation of the *cella solearis* based primarily on the recent discovery in the Large Baths at Mdaourouch in North Africa

[8] R. Lanciani, *The Ruins and Excavations of Ancient Rome*, London, 1897, 537.
[9] J. H. Middleton, *The Remains of Ancient Rome*, Vol. II, London, 1892, 163.
[10] G. Aitchison, *RIBA*, 23 May 1889, 282.
[11] Ch. Hülsen, *Architektonische Studien* III, Berlin, 1898, 33–4.
[12] E. Brödner, *Untersuchungen an den Caracallathermen*, Berlin, 1951, 14–18.
[13] Cf. Guattani, op. cit., 35.

of two inscriptions, one referring to a *soliarem cellam*, and the other to *soliis*.[14] From a close investigation of the meaning of the term *solium* in Festus, Celsus and Palladius, de Pachtere was able to relate the word specifically to hot pools, and therefore equated the *cella soliaris* with the *caldarium*. In the Baths of Caracalla this was identified with the large circular room with its six hot pools; certainly it has a suitably impressive span of 34 metres. Following a passage of Vitruvius describing the construction of hollow vaults in bath rooms, de Pachtere proposed a rigid lattice framework placed over the concrete vault and supporting it. Although the epigraphic evidence and his interpretation of it ought to have been conclusive, the structural explanation was not convincing, and was generally rejected on the grounds that the *caldarium* of the Baths of Caracalla has a 'normal' concrete vault,[15] although some scholars have found evidence of *dolia* being used to lighten the weight of the dome.[16] On the whole, the structural difficulties inherent in equating the *cella soliaris* in the Baths of Caracalla with the *caldarium* continue to lead scholars to look for another explanation of the word *solearis* despite the linguistic arguments.

Since de Pachtere's article, however, several more inscriptions relating to a *cella soliaris*, or to *solia*, have been discovered which can no longer be dismissed (see Appendix I for the complete list including those noted by de Pachtere). The most important of these is from the Thermae Hiemales at Thuburbo Maius (No. 4 in App. I), which specifically mentions a *s]oliarem cum soliis*. Further argument was added to de Pachtere's interpretation of the word *solium* by Maiuri,[17] who showed from other literary sources that the term could refer to a bath for more than one person, and that such a bath could form part of a public bathing establishment. In particular he saw the unusual hot pool in the Republican bath at Pompeii VIII, 5, 36 as an early example of such a *solium*. Furthermore, the inscriptions also provide evidence for the *piscina* as a separate entity from the *cella soliaris*, especially No. 2 where we find 'piscinalem istam ... et soliarem cellam' and No. 4 which records the 'cellam s]oliarem cum soliis ... refec[it...] esolidavit piscinam novam nomine cochleam ...'.[18] In the light of this it seems safe to reject the identification of the *cella solearis* of the Baths of Caracalla with the *natatio* completely and see if in fact there is any way in which the extant remains of the *caldarium* and the description of its construction as given in the *Vita Caracallae* can be reconciled.

But first we need to find some explanation for the mysterious iron bars found in the excavation of the *natatio* in 1872–3, which seemed to confirm the identification of the *cella solearis*. When they were first discovered they were treated as a novelty, the first physical evidence of the existence of an exceptional type of construction, rarely used and never on this scale, and hence a source of wonder to the writer of the *Vita Caracallae*. This is simply not true. While there are to my knowledge no bars remaining intact in any Roman building, there is ample evidence for their use not

[14] F. G. de Pachtere, 'Sur la *Cella Soliaris* des thermes de Caracalla', *MEFRA* XXIX, 1909, 401–6.

[15] Ward-Perkins, op. cit., 211; Brödner, op. cit., 18.

[16] For example, G. Rivoira, *Roman Architecture*, Oxford, 1925, 171–2; W. J. Anderson, R. P. Spiers and T. Ashby, *The Architecture of Ancient Rome*, London 1927, 104.

[17] A. Maiuri, 'Significato e natura del *solium* nelle terme romane', *La Parola del Passato*, 5 (1950), 223–7.

[18] I am indebted to John Patterson for this suggestion.

only in a number of other rooms in the Baths of Caracalla [19] but also in the Large, Small and Heliocaminus Baths in Hadrian's Villa.[20] They usually appear as rows of fairly evenly spaced rough cavities in the upper two thirds of the vaulting (Plate VIII*a*), and on close inspection traces of the metal, or merely the imprint, of the cross piece at the upper end of the bars can be seen; sometimes evidence for the shafts is also apparent (Plate VIII*b*). The cavities appear to result from deliberate robbing of the metal bars, a common enough practice in medieval and later Rome. Although this type of unwanted hole in a vault is likely to fall victim to zealous restorers, I have been able tentatively to identify the former presence of such bars in the apse of Rm 51 in the Domus Aurea;[21] in the apse of Section K (one of the hot rooms) of the Baths of Trajan;[22] and, albeit filled in, in the remains of vaulting on the south-east side of the present entrance to S. Maria degli Angeli, i.e. the vault over one of the hot pools in the *caldarium* of the Baths of Diocletian. Whatever the function of these bars, whether simply to support some kind of decoration or, in the heated rooms, to provide a double vault connected with the heating system, their use seems to have had a long history and to be particularly but not exclusively connected with bath buildings; the examples also all come from Imperial constructions where no expense was spared and the most advanced techniques were available.

Let us return to the Baths of Caracalla (Fig. 1). The clearest evidence for the relationship of these bars to any particular vault comes from the entrance rooms 4/5/6 east, where sections of fallen vaulting remain *in situ*. Some of the vaulting retains the black-and-white mosaic of its upper surface which formed a terrace and other sections show the intrados of the vault with the imprint of the *bessales* which line it. From this it is clear that the bars extended over at least the upper part of the intrados, with the cross piece set between 350 and 300 mm. from the face of the vault, which appears to be about one metre thick at the crown. This same relationship appears in a section of the vaulting which still remains against the north-east wall of Rm 5, and there the outer tile lining of *bipedales* and a small amount of the stucco decoration of the vault still remain (Plate IX*a*). The cavities in the springing of the vault on the north-west wall of Rm 1 (Plate IX*b*) west appear similar to those of 4/5/6, although the few remaining traces of decoration suggest that the vault in this case was covered with mosaic.[23] When the vaults of this room and its equivalent on the other side of the *natatio* collapsed I suspect that some of the pieces fell into the *natatio* itself, so that these two rooms are in fact the source of the

[19] I have already discussed these briefly in J. DeLaine, 'An engineering approach to Roman building techniques: the Baths of Caracalla in Rome', *Papers in Italian Archaeology IV: Part iv, Classical and Medieval*, BAR International Series 246, 1985, 195–206.

[20] Published by C. F. Giuliani, 'Volte e cupole a doppia calotta in età adriánea', *RM* 82, 1975, 329–42.

[21] Using the numbering system of the plan published in *ARID* Suppl. X. Tav. II. This area of the Domus Aurea was published by G. Zander 'La Domus Aurea: nuovi problemi architettonici', *Boll Centro* 12, 1958, 35–64, but he does not mention the cavities in the vault.

[22] The designation of the area is that of K. de Fine Licht, 'Untersuchungen an den Trajansthermen zu Rom', *ARID* VII Suppl., 1974. He does not discuss the cavities in the vault, 40–3, nor are they shown on his elevation, Taf. III.

[23] See F. B. Sear, *Roman Wall and Vault Mosaics*, Heidelberg, 1977, 127; confirmed by personal observation.

metal bars which encouraged Lanciani and others in their identification of the *natatio* as the *cella solearis*. Slight confirmation of this can be deduced from the opinion voiced by both Middleton and Aitchison that the central section of the *natatio* was unroofed; the vaulting from Rms 1 would not, of course, have travelled more than 5–10 metres horizontally leaving an area in the centre of the pool free. The final use of this construction in the unheated areas of the baths is in the *frigidarium* and its dependencies, Rms 14. The vaulting in these rooms also was double tile lined and decorated with mosaic.[24] Extant evidence for the metal bars in the *frigidarium* itself is restricted to a few of the typical cavities in the springing of the vault over the west pier (Plate X*a*), but fortunately this is substantiated by the excavation report of 1873, which records the finding of some iron hooks among the masses of fallen vaulting in the 'vasta cella centrale', which must be the *frigidarium*.[25] All these examples suggest that there was felt to be a need to attach the tile lining of the vault securely to the mass of the vault, no doubt in order to give stability to the subsequent decoration of stucco or mosaic. A rather different system was used in the 'Aula Planetaria', the heated room in the south-west corner of the Baths of Diocletian, but it was clearly for the same purpose. Here each tile lining the vaulted ceiling is held in place simply by an iron nail.[26]

Of the heated rooms of the Baths of Caracalla 17 east, 20 west and 21 east and west show clear traces of quite large bars; those in 20 west had shafts over one metre long. These were set into the concrete of the vault in the same way as the smaller examples from the cold rooms, but in no case does any trace of the decoration remain although a very little of the standard tile lining of the vaults can be seen. The increase in the size of the bars both in length and thickness suggests that the weight of whatever was supported by these bars was greater than that of the double tile lining plus stucco or mosaic of the unheated rooms. The imprint of the bars in the barrel vaults between the piers of the *caldarium*, left very clearly in the solid brick construction, shows that these were even larger, 1.4 m. long and 50 mm. × 50 mm.

[24]Sear, loc. cit. Traces of mosaic over the tile lining are still visible at the springing of the vault over the west pier.

[25]Archivio Centrale dello Stato: Ministero Pubblico Istruzione, Direzione Generale Antichitá e Belli Arti, Antichitá e Scavi, Roma. Rapporto Pellegrini, 1873–4, Busta 102, Fasc. 134.

1873: Terme Antoniniane o di Caracalla

7–12 Aprile: Proseguendosi a sterrare fino al suo piano la gran cella caldaria o vasta cella centrale, non s'incontrano fin qui che i massi caduti della sua volta; e non si é rinvenuta alcuna cosa relativa a frammenti della sua decorazione architettonica, e ne anche de scultura. Fra detti massi si é ritrovato qualche pezzo delle impernature o grappe di ferro che servivano a reggere gli ornati come altre in questo luogo discoperte.

14–19 Aprile: Proseguendosi lo sterro fino al suo piano della gran cella calidaria, o vasta cella centrale delle terme, si sono ritrovate fra i massi della sua volta caduti, tre chiavi, o palettoni di catene di ferro, il primo rotto alla lunghezza di cm70, e gli altri due a cm54. . . . Item 14: Tre frammenti delle chiavi di ferro nominate disopra.

Elsewhere part of the 'gran cella calidaria' is described as being 'verso il *propnigeo* da cui si entrava al grande *laconico* di forma rotunda'. It cannot, therefore, be the room usually designated the *caldarium* but must refer to the *frigidarium*.

[26]See I. Gismondi, 'La sala del Planetario nelle Terme Diocleziane', *Architettura ed Arti Decorative*, 1929, 385 ff. I am grateful to Dttssa Daniela Candilio and her associates at the Baths of Diocletian for the opportunity to examine the dome during restoration in December 1984.

in cross-section (Plate XI). Although modern restoration has removed the evidence, two photographs by Van Deman taken in 1911 of the inner faces of the two surviving *caldarium* piers reveal a line of the now familiar holes some 6.5 m. above the impost line of the great dome (Plate X*b*). Three metres above the modern restoration which conceals these holes on the west pier can still be seen a large roughly circular cavity usually interpreted as the remains of a large *dolium* used for lightening the vault.[27] I would suggest instead that it is now the only surviving evidence for the remarkable construction of the *cella soliaris* of the Baths of Caracalla.

, In trying to determine the exact nature of the construction using these iron bars in the *caldarium*, the difference in size between the bars in the cold rooms of the Baths of Caracalla or in the hot rooms of the baths of Hadrian's Villa, and those in the *caldarium* and the other hot rooms in the Baths of Caracalla, must be taken into account. It cannot simply be that the span involved is greater and thus the total weight to be supported is greater, as the largest bars measured are those on the barrel vaults between the piers of the *caldarium* where the span is 8·75 m. compared with a span of 15·5 m. in Rms 4/5/6. A drawing of the south-west façade of the Baths of Caracalla in the collection of Anonymous Destailleur bears the annotation over Rms 19 and 20 'conperto di legnamo o bronzo'.[28] This could, of course, simply be an extrapolation from the text of the *Vita Caracallae*, although it is worth remembering that this artist appears to have had an unusually detailed knowledge of the Baths. If this indicates a kind of latticed metal ceiling, which would need very solid supports, then its use also in the *cella soliaris* might be expected. As a parallel, one could think of the ceilings of fretted ivory through which perfume or flowers were scattered in Nero's Golden House;[29] and an iron latticed ceiling could be the explanation of the *concameratione ferrea* of CIL VI 543.[30] Other examples of the use of metal in ceilings, but of uncertain nature, are the ceiling and roof truss of the Pantheon porch,[31] and the bronze ceiling of the Basilica Ulpia, noted by Pausanias as 'a thing worth seeing'.[32] It is, however, also possible that there was simply an extension of the system found in the cold rooms.

It is now time to return to the passage from the *Vita Caracallae* and see how well our interpretation fits. The term *cella soliaris* is seen to be a common name in North Africa, at least during the fourth and fifth centuries A.D., for what is more usually called the *caldarium*. Given that the *Historia Augusta* is now generally dated to the late fourth century A.D.,[33] and the writer of it sometimes regarded as a North African,[34] it

[27] Cf. Note 16.

[28] Berlin, Staatlichen Kunstbibliothek, 4151.

[29] Suetonius, *Nero*, 31.

[30] The date is A.D. 115. It is interesting, although probably of no significance, that this inscription was found 'in vinea ad Thermas Antoninianas'.

[31] See K. de Fine Licht, *The Rotunda in Rome*, Copenhagen, 1968, 48–58. He suggests that there was a vaulted false ceiling either of bronze plates on a wooden base or possibly entirely of bronze suspended from the roof truss.

[32] Pausanias, V.12.6.

[33] As suggested originally by H. Dessau, 'Über Zeit und Persönlichkeit der S.H.A.', *Hermes* XXIV (1889), 337, and convincingly restated on numerous occasions by Syme, most recently in *Historia Augusta Papers*, Oxford, 1983, 219–20.

[34] See E. Birley, 'Africana in the *Historia Augusta*', *Bonner Historia Augusta Colloquium, 1968/69*, Bonn, 1970, 79–90.

is not really surprising that he should use the term with which he was more familiar to indicate the room which we, working from Vitruvius and other classical sources, prefer to call the *caldarium*. The 'et ex aere ... et tantum est spatii ...' suggests that there were two remarkable things about the *cella soliaris*, the construction and the extent of it. Given the 34 metre span of the *caldarium* dome, it is not surprising that the extent was a source of wonder. The real problem is the precise meaning of 'ex aere vel cupro cancelli sup[er]positi ... quibus cameratio tota concredita est', when *cameratio* is not otherwise attested in extant literary sources or in the epigraphic record, and the reading of *sup[er]positi* is uncertain. *Cameratio* could be a shortened form of *concameratio*, or equally a lengthening of *camera*, but in either case should refer to a vaulted or arched form, and in particular to the ceiling or intrados of the vault as opposed to *tectum*, the roof or extrados of the vault.[35] *Superpositi* and *suppositi* are the readings of the two most reliable manuscript traditions (P and Σ respectively), making it difficult to choose between them; however, in other parts of the *Historia Augusta*, *superponere* is only ever used in its literal sense of 'to place over or on top of'[36] while *supponere*, which occurs in one other passage, is used metaphorically to mean 'substitute'.[37] Taking into account that it would also be easier to lose the 'er' than to add it, *superpositi* seems to be the more probable reading. Those like de Pachtere[38] who have taken the reading *superpositi* have usually assumed that the object of this is *cameratio*, and thus that the lattice was above the vault. The object could, however, just as easily be the *cella soliaris*; and if we also take *cameratio* in the sense of ceiling rather than vault, the passage can then be translated as 'lattices of either bronze or copper were set over the room ... to which the whole of the ceiling was entrusted'. This interpretation would, of course, fit with the metal latticed ceiling suggested above, with no more special pleading than has been used by other scholars in defence of their interpretation of the passage.

On the other hand, this interpretation could also be applied to the better attested construction of a tile-lined vault supported by metal hooks, particularly if some kind of lattice was suspended from the bars which then supported the tiles forming the ceiling. This is, of course, suggesting a construction similar to that described by Vitruvius in Bk. 5, 10, 3, a passage used both by de Pachtere[39] in his analysis of the *cella soliaris* and by Giuliani[40] in his interpretation of the similar construction in the baths at Hadrian's Villa, despite the fact that in Vitruvius this construction refers specifically to wooden roofs. One other difficulty with this is that the grids in the *cella soliaris* are said to be copper or bronze, while all the examples of this construction so far discovered have used iron bars. As it is no longer possible to examine the evidence for the bars in the dome of the *caldarium*, it may be possible that in this case bronze or copper supports were used, or perhaps the grids themselves

[35] For example: *camera:* Vitruvius 5.10.3 and 8.6.3; Valerius Maximus 6.7.2. *concameratio:* Vitruvius 2.4.2 and 6.8.1; Frontinus *de Aquis* 126.

[36] *Maximus et Balbinus* 9, 4; *Quadrigae Tyrannorum* 4, 3.

[37] *Hadrianus* 4, 10.

[38] F. G. de Pachtere, op. cit., 402.

[39] F. G. de Pachtere, loc. cit.

[40] C. F. Giuliani, op. cit., 337–9.

were of bronze while the hooks which supported them were of ibon.[41] This interpretation would also account for the ese of the indefinite construction (*dicuntur*) which de Pachtere[42] believed to indicate that the construction was not visible from the room.

There are, however, at least two alternative explanations for the use of reported speech; either the author had simply never seen the *cella soliaris*, or the source of his information on the construction of it was one of the *architecti* or *docti mechanis*[43] who were so amazed by it. The nature of the passage as a whole, and particularly the section of reported speech with its unusual words, seems to me to support the latter explanation; rather than writing in the language of literature or oratory, the author has recorded the jargon of his professional source. In this case it is no longer necessary to assume that the construction was hidden, and so I prefer to imagine a latticed ceiling of copper or bronze as the remarkable feature of the *cella soliaris* of the Baths of Caracalla which so caught the attention of the architects of the fourth century. This bronze ceiling is admittedly pure speculation, but fortunately it does not affect the basic premise, that the *cella soliaris* is to be identified with the *caldarium* and that the construction over which the engineers shook their heads in disbelief is in some way connected with the well-attested use of iron supports for the ceiling decoration of what are otherwise 'normal' concrete vaults.[44]

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[41] Of these two possibilities, the latter is more probable on technical grounds. Iron has a much higher Young's modulus than bronze or copper (30×10^6 compared with 16×10^6) and thus an iron bar would suffer only half as much elongation under a given dead load as a bronze or copper bar of the same cross-section. There is therefore a considerable structural disadvantage in using bronze or copper in place of iron. De Pachtere's suggestion (loc. cit.) that bronze or copper would have the advantage of not oxidising in the warm, moist atmosphere as easily as iron would only be relevant if the metal were exposed, which it would not be if embedded in the concrete of the vault, or for that matter if protected by the plaster or mortar of the vault decoration. Finally, the evidence of the attested use of large, *iron*, supports in the hot rooms and the barrel vaults linking the *caldarium* piers requires a strong counter-argument of practical advantage for their replacement by bronze or copper in the *caldarium*, and I cannot see that this exists.

[42] De Pachtere, op. cit., 401.

[43] Although *mechanis* is another *hapax legomenon* I do not think that it is at all problematic. *Mechanicus* appears twice, both in the life of Alexander Severus; on the first occasion (*Alex. Sev.* 22, 4) 'mechanica opera ... instituit' appears in a list of his good deeds at Rome, and on the second (*Alex. Sev.* 44, 4) 'mechanicis' appear among a list of professionals including 'mathematicis' and 'architectis'. The *mechanici*, and hence the *docti mechanis*, would thus seem to be the engineers and specifically the civil engineers. The form *mechana* is clearly derived from the Greek μηχανή, and used in place of the Latin *machina* which does not occur in the *Historia Augusta*.

[44] This paper is an offshoot of a much broader continuing investigation into the construction of the Baths of Caracalla in Rome. Most of the material was collected during various periods of residence at the British School at Rome from 1982–1985 and I would like to thank Dr. David Whitehouse, Dr. Graeme Barker and all the staff at the School for their assistance during my frequent visits there. I am grateful to Dottssa. I. Jacopi of the Soprintendenza Archeologica di Roma for permission to work on the Baths, and to her colleagues at the site for their cooperation. My examination of the high vaults of some of the rooms would not have been possible without the help of Prof. Lucos Cozza and his associates from the Servizio Giardino of the Comune di Roma. Among the many people on whom I have tested these ideas I would particularly like to thank Amanda Claridge, Dr. Jim Coulton, Dr. John Patterson, Prof. Peter Wiseman and my colleagues from the Department of Classics at the University of Adelaide for their advice, encouragement and occasional disbelief.

APPENDIX I: Inscriptions relating to *cella soliaris* or *solium*

1) . . . us *cellam soliarem* a [fundamentis?] . . . [extru]ctam karissimis civib[us]
CIL VIII: 10607 (also = 14700). Sidi Ali ben Kassem, Thuburnica.

2) Pro tanta felicitate tempo[rum invictissi]morum principium dd.nn.per[pp augg. Valenti]niani et Valentis piscinalem istam . . . et *soliarem cellam* lacuniis densis ita foe[datas ut ima pavi]menti monstrarent, atque ita retentione[m caloris(?) prohi]berent, compellente religione sancta et [utilitate roma]norum civium, exquisitis diversorum co[lorum marmoribus] artificibus quoque peregrinis adductis et [adhibitis(?) splen]dentes, novoque omnino opere tes[s]ellatus pr[oconsulatu Jul.Festi cum] Fabio Fabiano v.c. et inlustre legato Numid[iae . . .] cur. reipublicae inter cetera in quibus iamdu[dum patriae contulit(?)] cum ordine splendido et universo popu[lo Madaur. restituit] felicit[er].
AE, 1907, 237 (i.e. Ward-Perkins' *Rev. Arch.* 410. 485, 237).
Mdaourouch, Large Baths. A.D. 366 367

3) B[eatissimo sa]eculo d.n. Juliani(?) perp[etui aug. thermas(?) inc]uria paene ad interitu[m redactas cam]eris omnibus et *soliis* e[. . . n]on tantum impioru[m . . .] voragini . . .
Recueil de Constantine XL, 1906 p. 417, no. 377 and p. 422, no. 411.
Mdaourouch, Large Baths. A.D. 361-363

4) . . . cellam *s]oliarem cum soliis* omni etiam refuso instrumento aeris et plumbi firma refec[it . . .]esolidavit piscinam novam nomine cochleam redditis veteribus exceptoriis adiecit . . . dedicavit.G.Optatianus.fl.p.p. c.u.r.r.p.
CRAI, 1917, pp. 71-4. (= *AE*, 1918, p. 385, no. 98)
Thuburbo Maius, Thermae Hiemales. A.D. 395-408

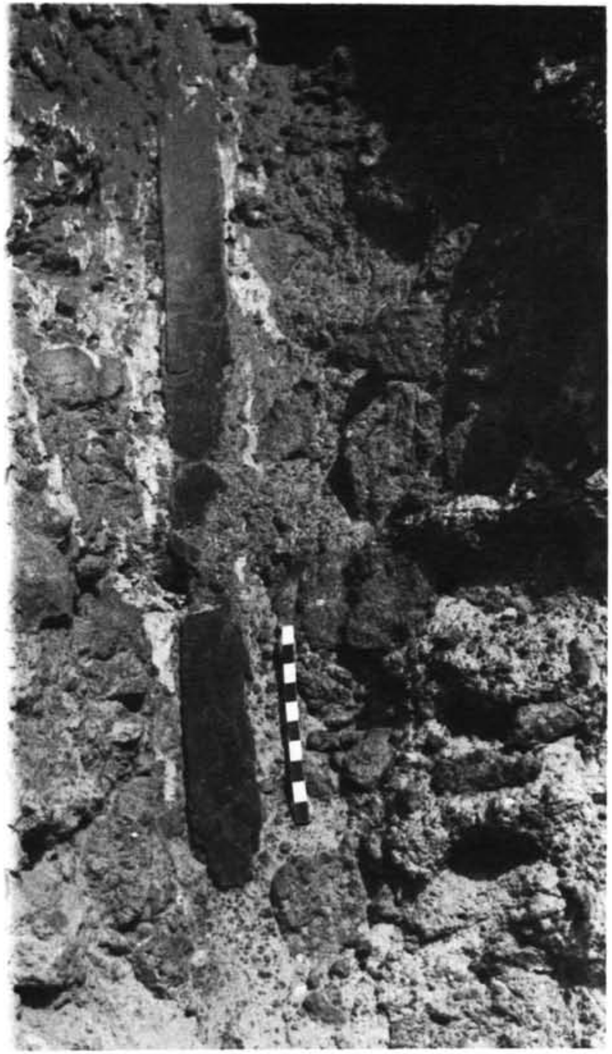
5) Salvis ddd.nnn. Valentiniano Valente Gratiano perpetuis auggg, proconsul[a]tu Petroni Claudi c.v. et Mari Victoriani l[e]gato Kartaginis c.v. oceanum a fundamentis coeptum et *soliarem* ruina conlapsum ad perfectionem cultumque perductos ingressus novos signis adpositis decoravit Flavianus Leontius alme Kart. principalis curator reip(ublicae) ordinis splendidissimi conlatione cum amore populi incoavit perfecit dedicavit.
CRAI, 1975, pp. 104-110. (= *AE* 1975, no. 873) Abbir Maius. A.D. 368-370

6) Saeculo felic(issimo) dd.nn.fl. Constanti et fl. Con[stantis] administrantibus etiam Fl.Dardanio amp. proc. c.v. et laegatis [p]ulcerrimum factum cum porticu . . . turpia foedabantur ad statuam i[. . . pisc]inalis ad restaurationem d[. . .]s colitumque nitent *soliar*[em cellam . . .]oleum a fundamentis perc . . . proneum aquiducti a fu[ndamentis . . .]ium *solium* vero inst[auravit(?) . . .]t C. Aurelius Stat[ianus. . . .] cur.r.p. una cum omn[ibus decurionibus . . .] sinsensium perfecit et [dedicavit].
AE, 1934, no. 133. Henchir-Haouli, Tunisia. A.D. 340-350

7) Pro tanta securi[tate temporum] dd.nn. Valentiniani [et Valentis perpetuo]rum au[gg therm] as aestivas olim splen[did.] coloni[ae nostrae(?) orn]a[mentum(?) sed tot re]tro annis ruinarum labe deformes pa[rietibusque omni(?)]um *soliorum* ita conruptis ut gravibus damnis adficerent [nun]c omni idonitate constructas et cultu splendido decoratas sed et patinas ampliato aeris pondere omni idonitate firmissimas proconsulatu Publi Ampeli v.c. Octavio Privatiano v.c. legato Numidiae Cec. Pontilius Paulinus ff.pp.pc. curator reip. pecunia publica perfecit porticum quoque ingredientibus ab atri[o] sed et pronaum eidem coherentem commeantibus per viam trabibus ti[g]nis . . . . ceterisque . . . . [Pont]ilius Pauli[nus] . . . ordine.
Inscriptiones Latines d'Algérie, I, 2101. (= *AE* 1918, no. 91) Mdaourouch. A.D. 364

8) [dd.nn.valente et valen] tiniano au.gg. *solium* estibalium therm[. . . .] is ut puro fonte pulcrior redderetur aspe . . .
CIL VIII 948. Mun. Tubernuc, Prov. Proc. A.D. 364-75

a Baths of Caracalla, Room 20, west



b Room 20, west, detail of vaulting showing traces of metal remaining from the shaft of an iron bar

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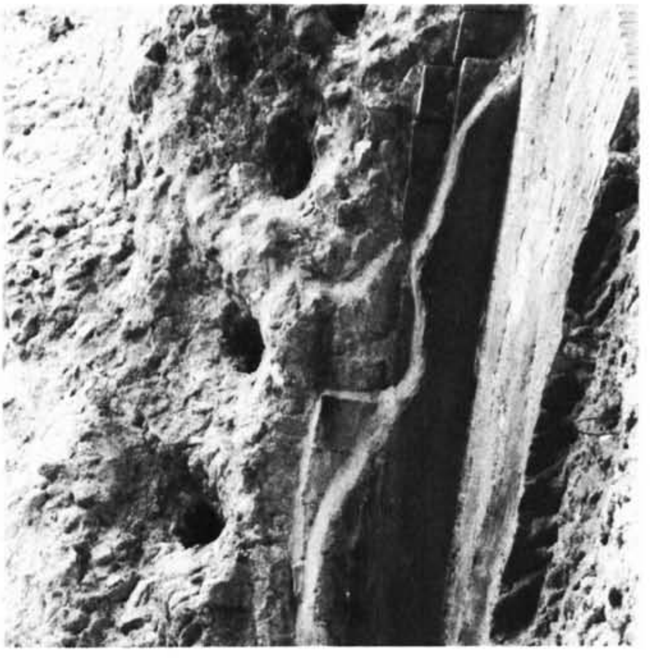

a Room 5, west, detail of vault in the north-west corner

b Room 1, west

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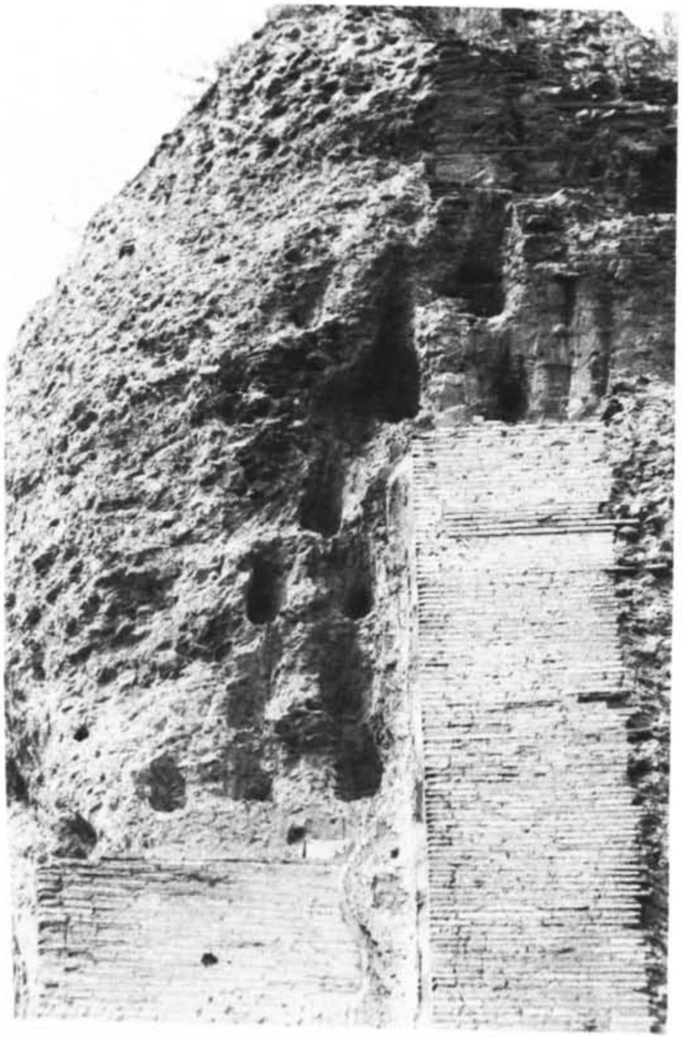

a Frigidarium, south-west pier

b South-west face, 1911. (Courtesy Fototeca Unione, Fondo Van Deman, 246, 247)

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PAPERS OF THE BRITISH SCHOOL AT ROME—VOLUME I

ERRATUM

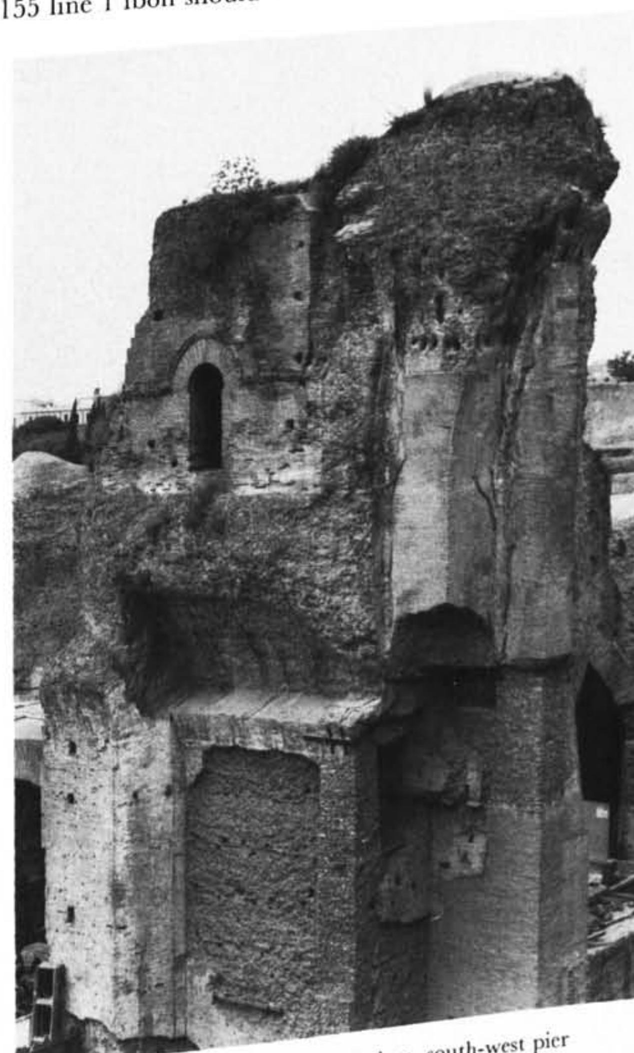
There was an error in the publication of the illustrations of Janet Delai "The 'Cella Solearis' of the Baths of Caracalla: A Reappraisal". They sl appeared thus:

p. 152 line 10—Plate X*a* should be Plate X*a* and *b*.
p. 153 line 4—Plate X*b* should be Plate XII*a* and *b*.
(see reverse of this Erratum).

All other Plates and references remain as printed.

Text—Page 155 line 1 ibon should be iron and line 2 ese should be use.

PLATE X



b Baths of Caracalla Frigidarium, south-west pier

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PLATE X

b Baths of Caracalla Frigidarium, south-west pier

THE 'CELLA SOLEARIS' OF THE BATHS OF CARACALLA: A REAPPRAISAL
BY JANET DELAINE

a

b

(*courtesy Fototeca Unione, Fondo van Deman, 246, 247*)

Baths of Caracalla. South-west face, 1911

THE 'CELLA SOLEARIS' OF THE BATHS OF CARACALLA: A REAPPRAISAL
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a and *b* Caldarium, west pier, traces of bars in the north face

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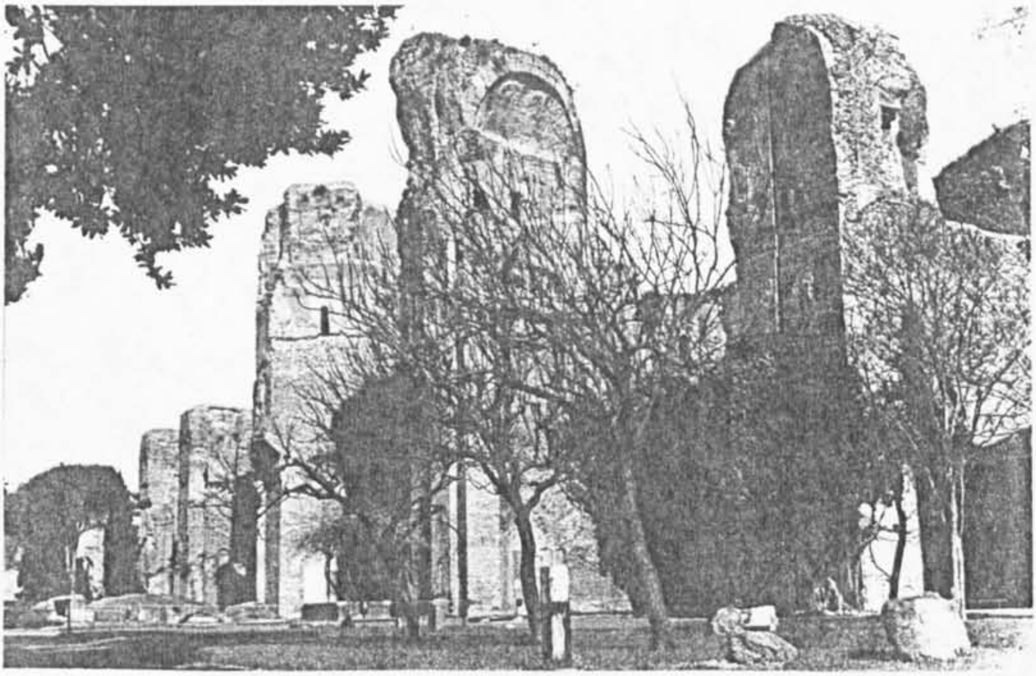
DESIGN AND CONSTRUCTION IN ROMAN IMPERIAL ARCHITECTURE

THE BATHS OF CARACALLA IN ROME

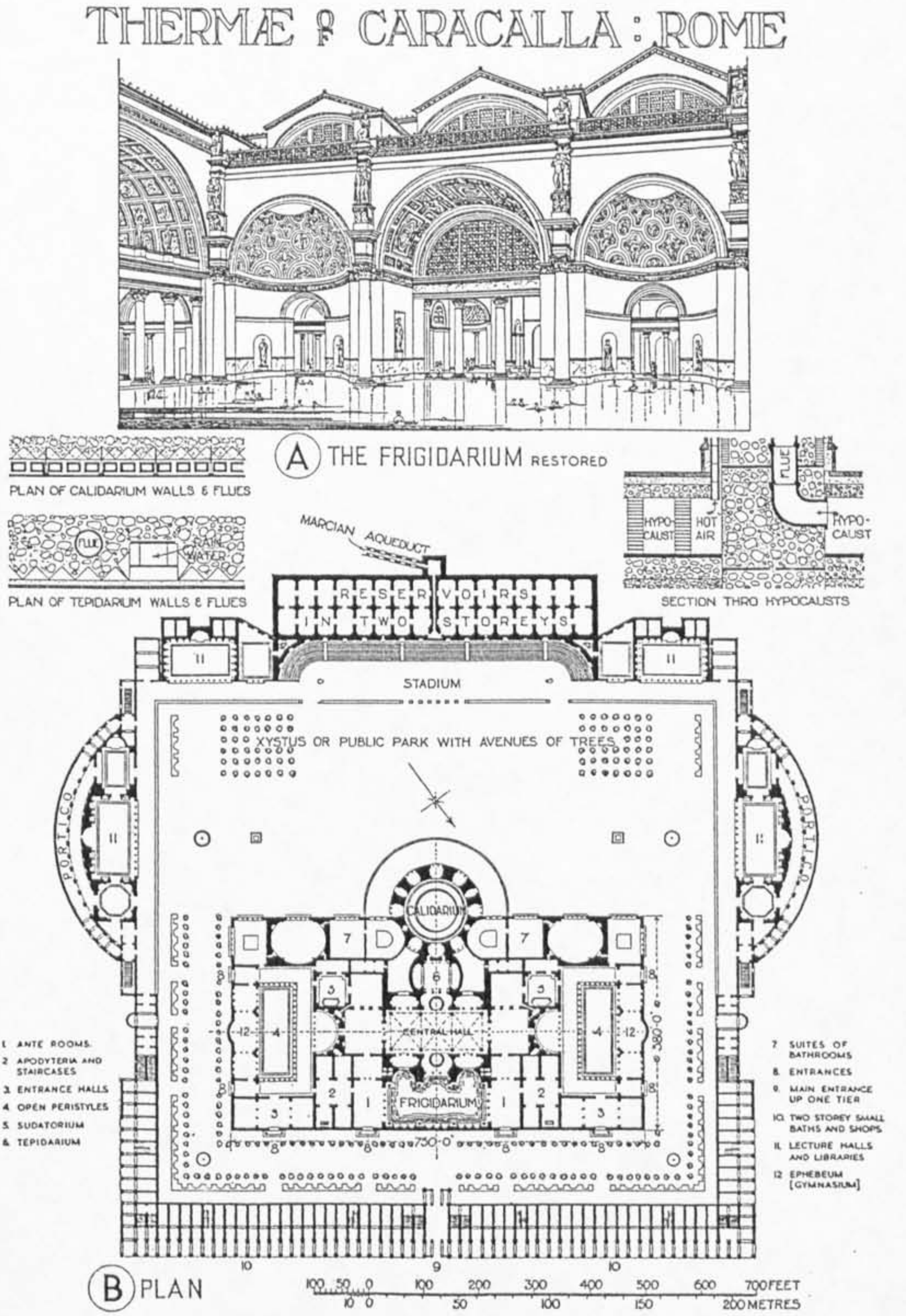


Janet DeLaine

PhD thesis submitted to the Department of Classics, the University of Adelaide

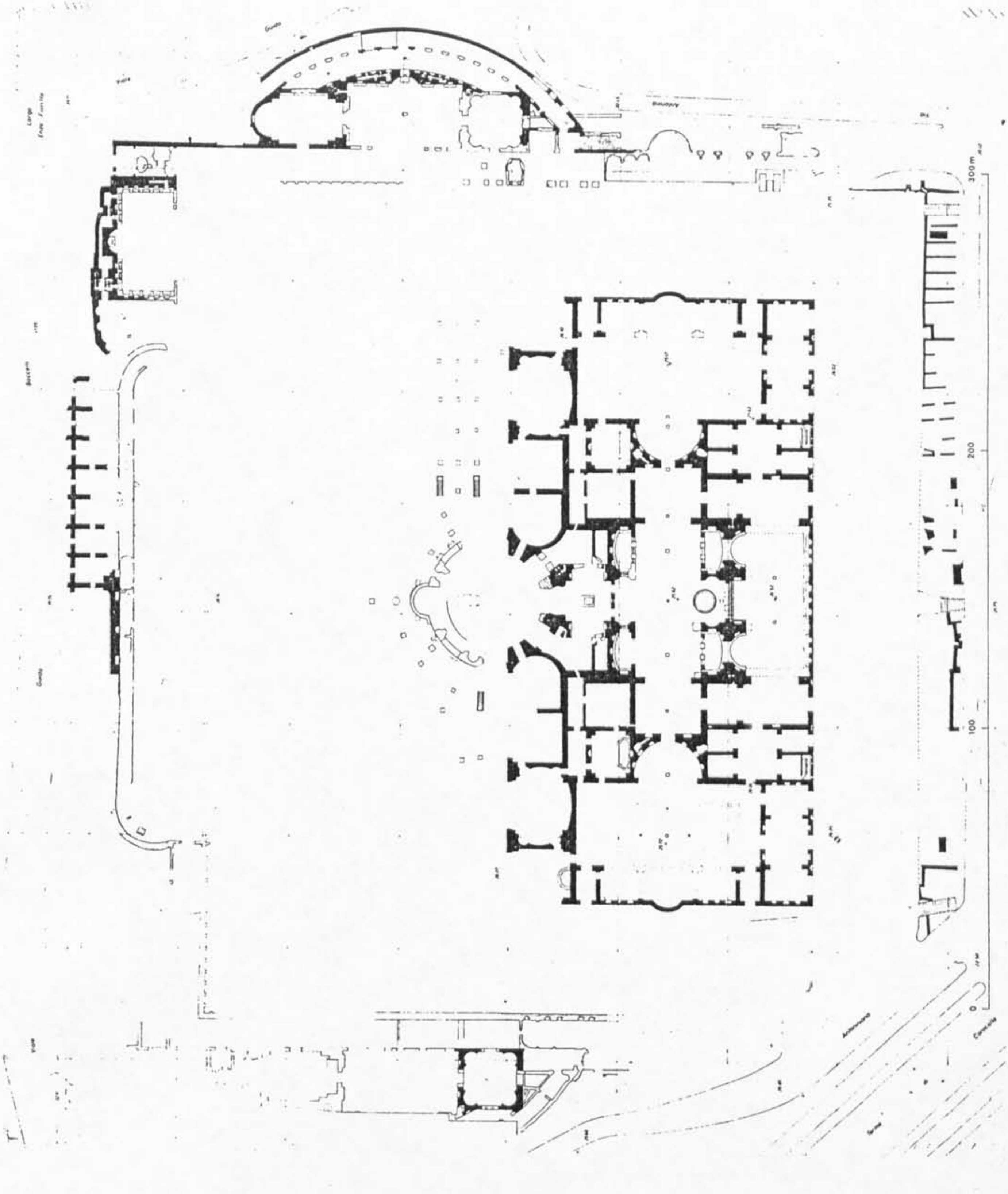
May 1992

Figure 1



Baths of Caracalla. Reconstructed ground plan and perspective, as illustrated in Banister Fletcher, <u>A History of Architecture</u>, p. 203 (17th ed., London 1967).

Figure 2



Baths of Caracalla, present state ground plan. From Conforto 1991, Fig. 1

Fig. 3: Baths of Caracalla, remaining pier of N facade.

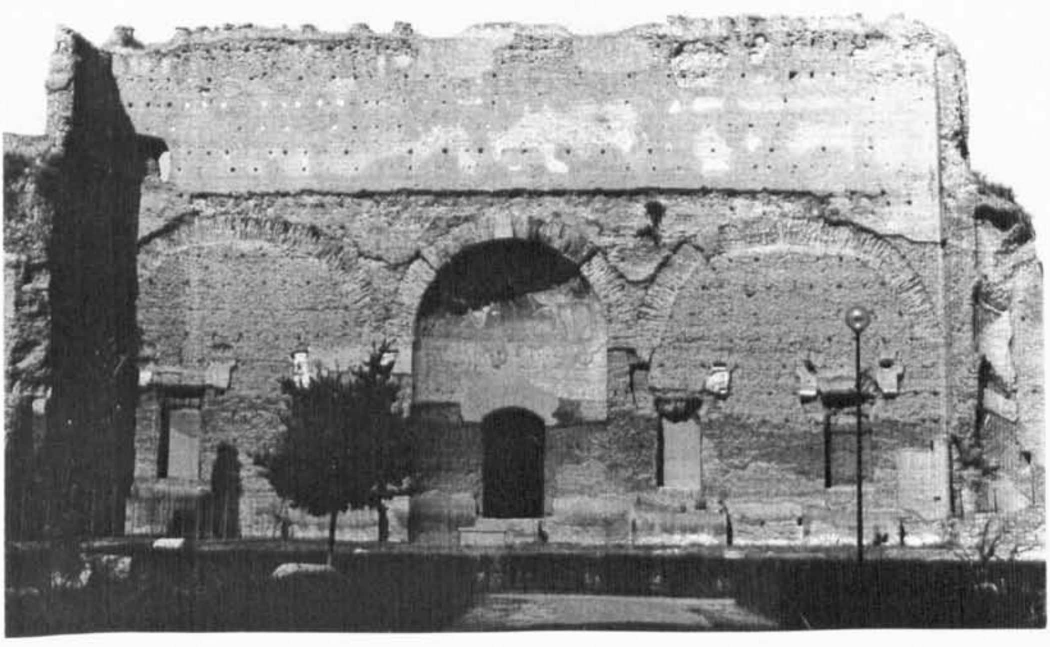
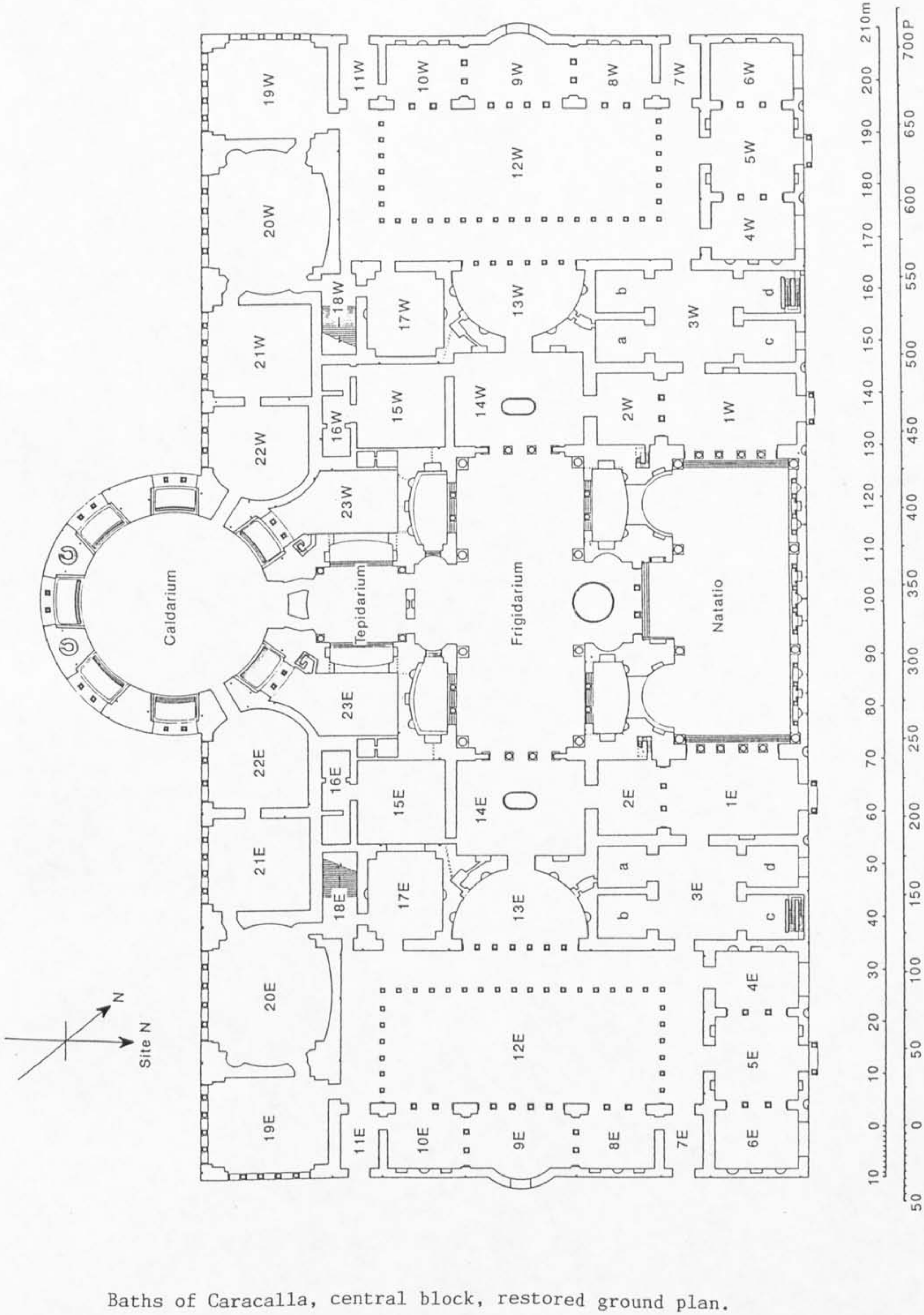


Fig. 4: Baths of Caracalla, outer precinct, central room of W exhedra.

Fig. 5: Baths of Caracalla, outer precinct, staircase to Aventine.

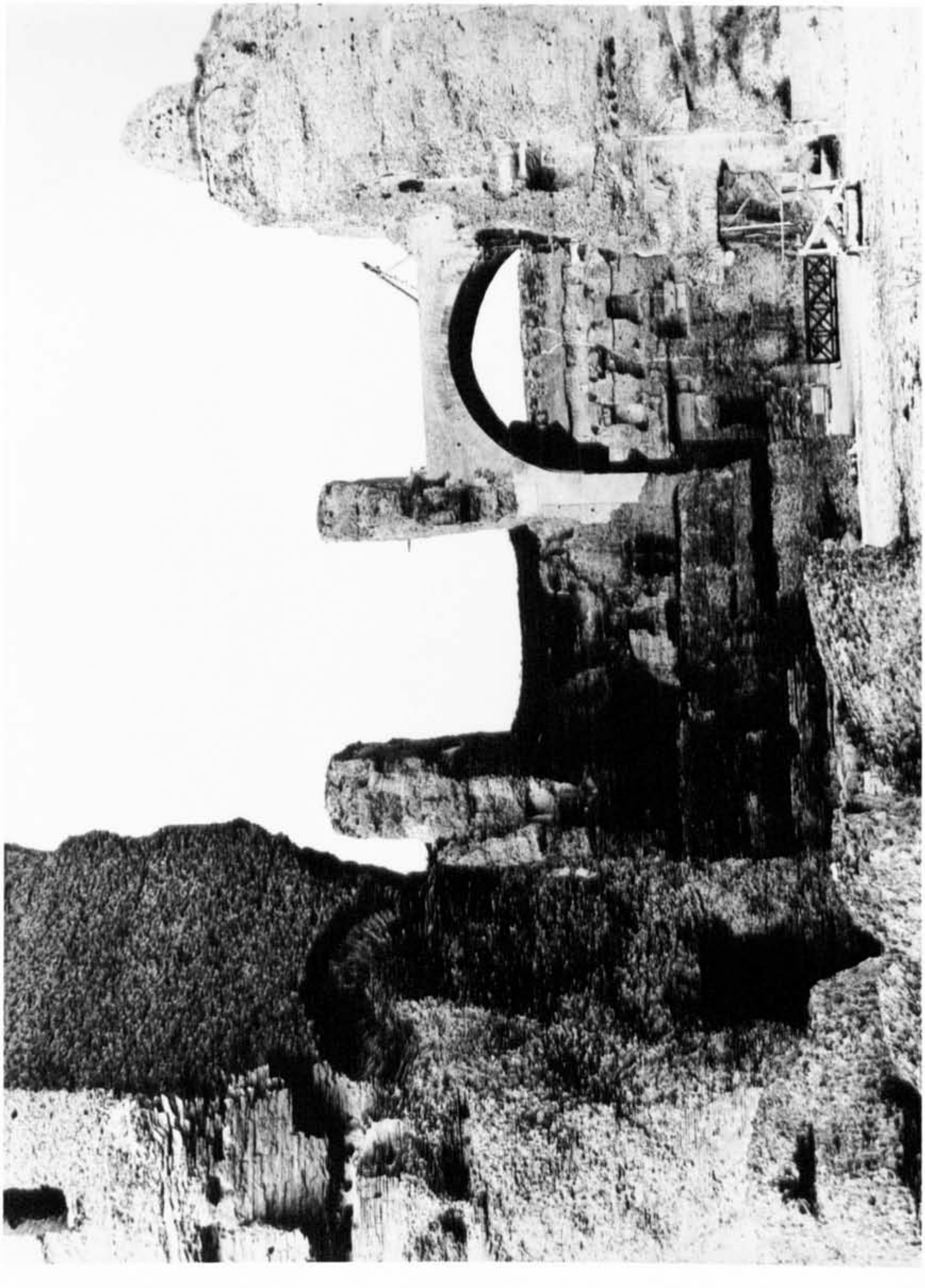
Fig. 7: Baths of Carcalla, central block, remains of outer caldarium piers.

Figure 6

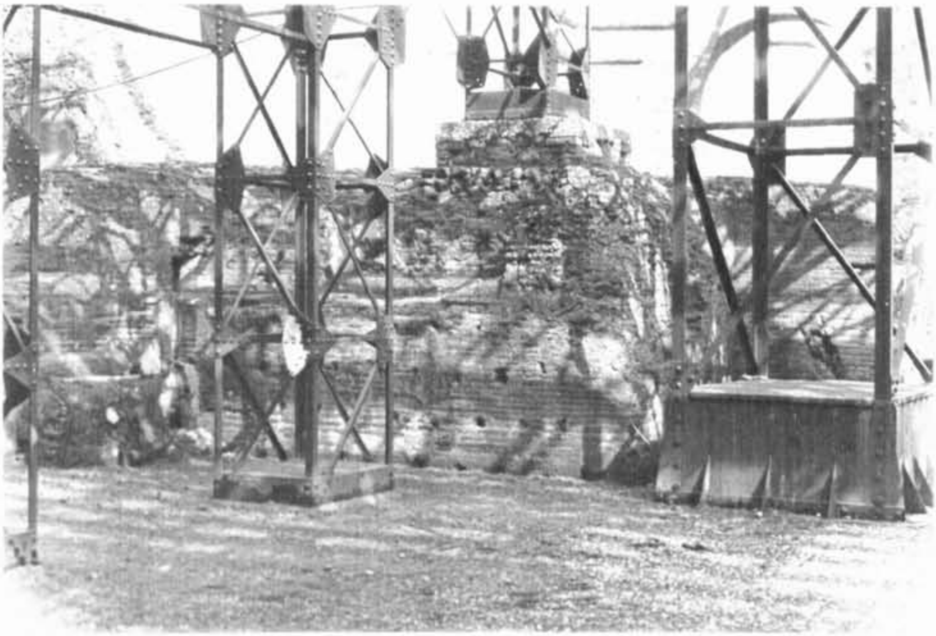


Baths of Caracalla, central block, restored ground plan.

Figure 8



Baths of Caracalla, central block, view from caldarium through to tepidarium, 1902-1903. Fondo Van Deman 48.



(a) Baths of Caracalla, central block, tepidarium with permanent scaffolding for the Opera stage.

(b) Baths of Caracalla, central block, Rm 23W later construction, under permanent scaffolding for the Opera stage.

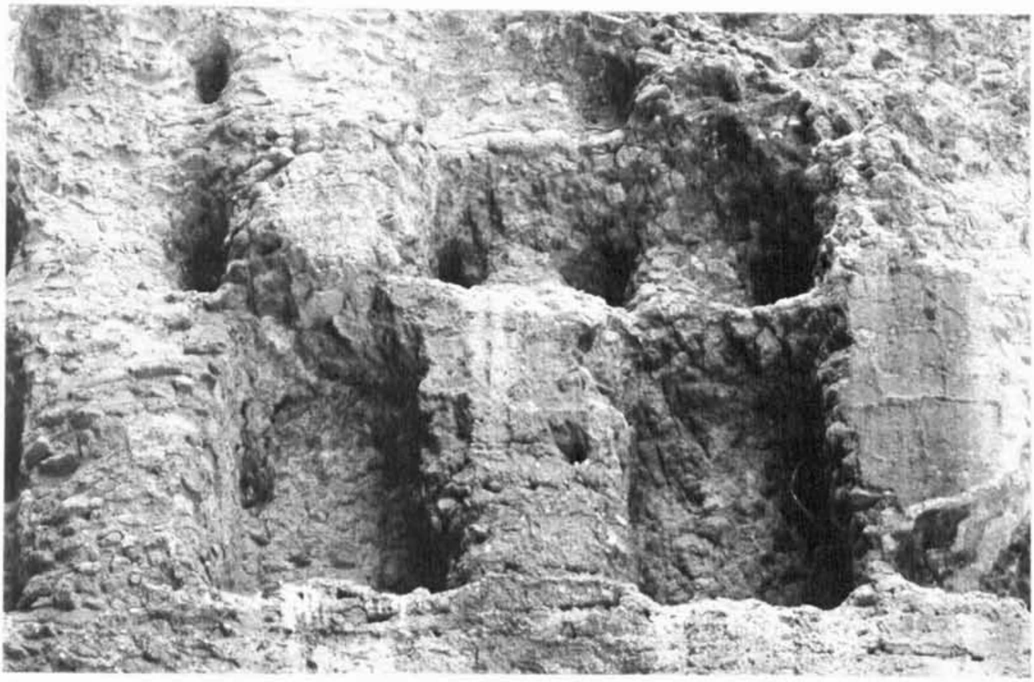


Fig. 10: Baths of Caracalla, central block, Rm 1W, robber holes in vault, NW corner.

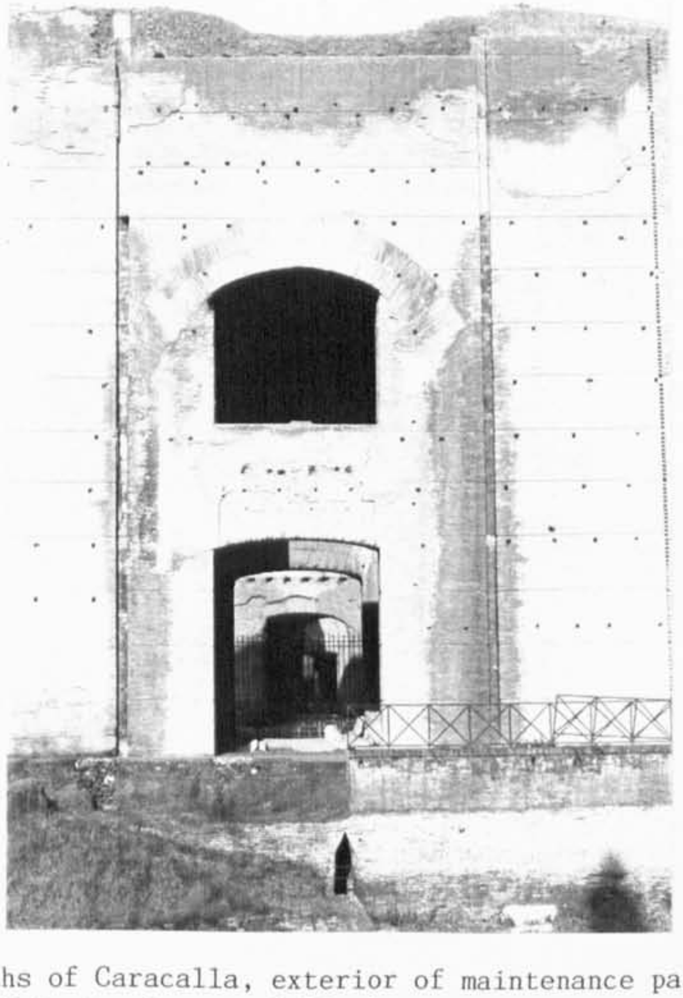
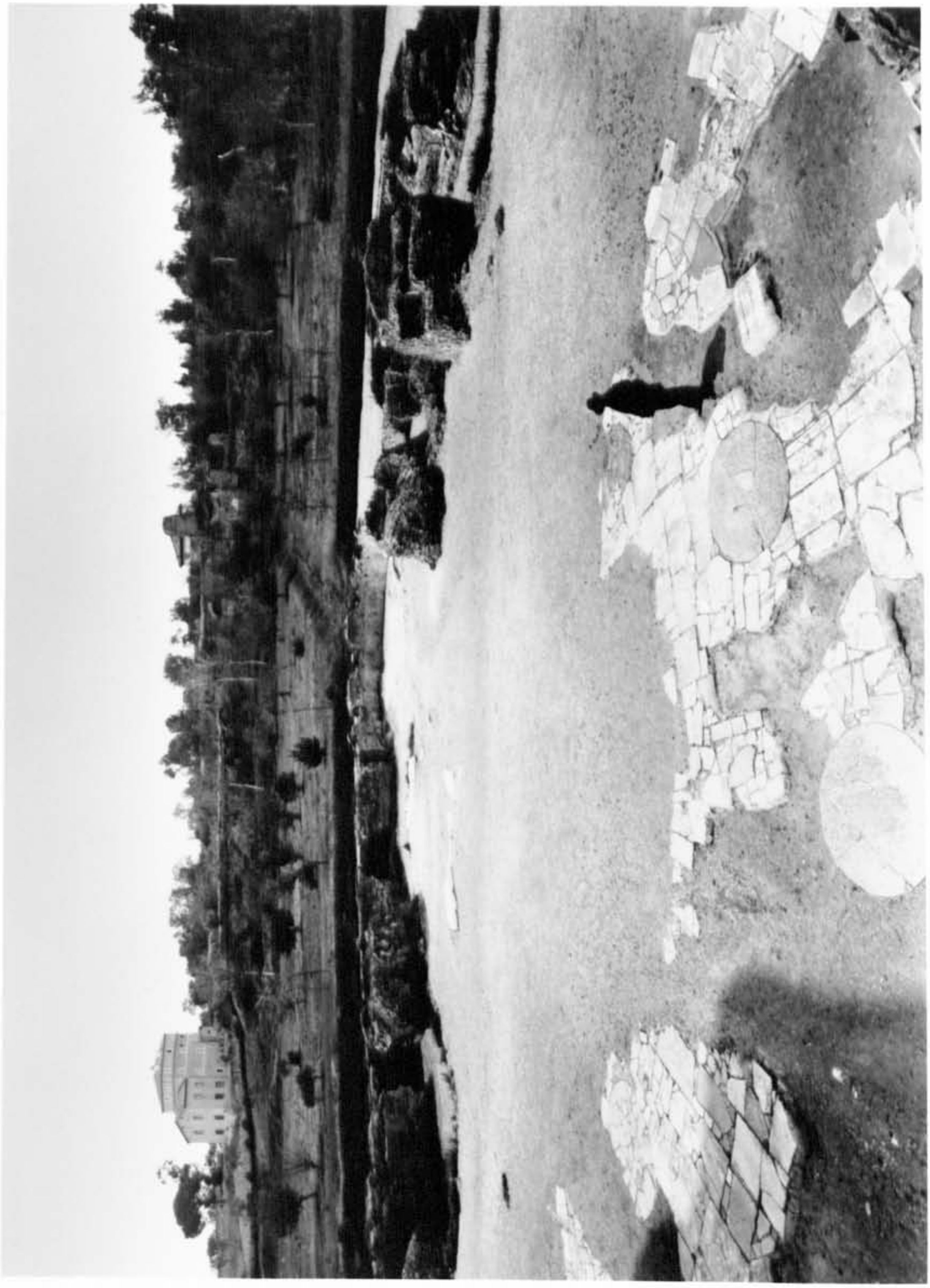
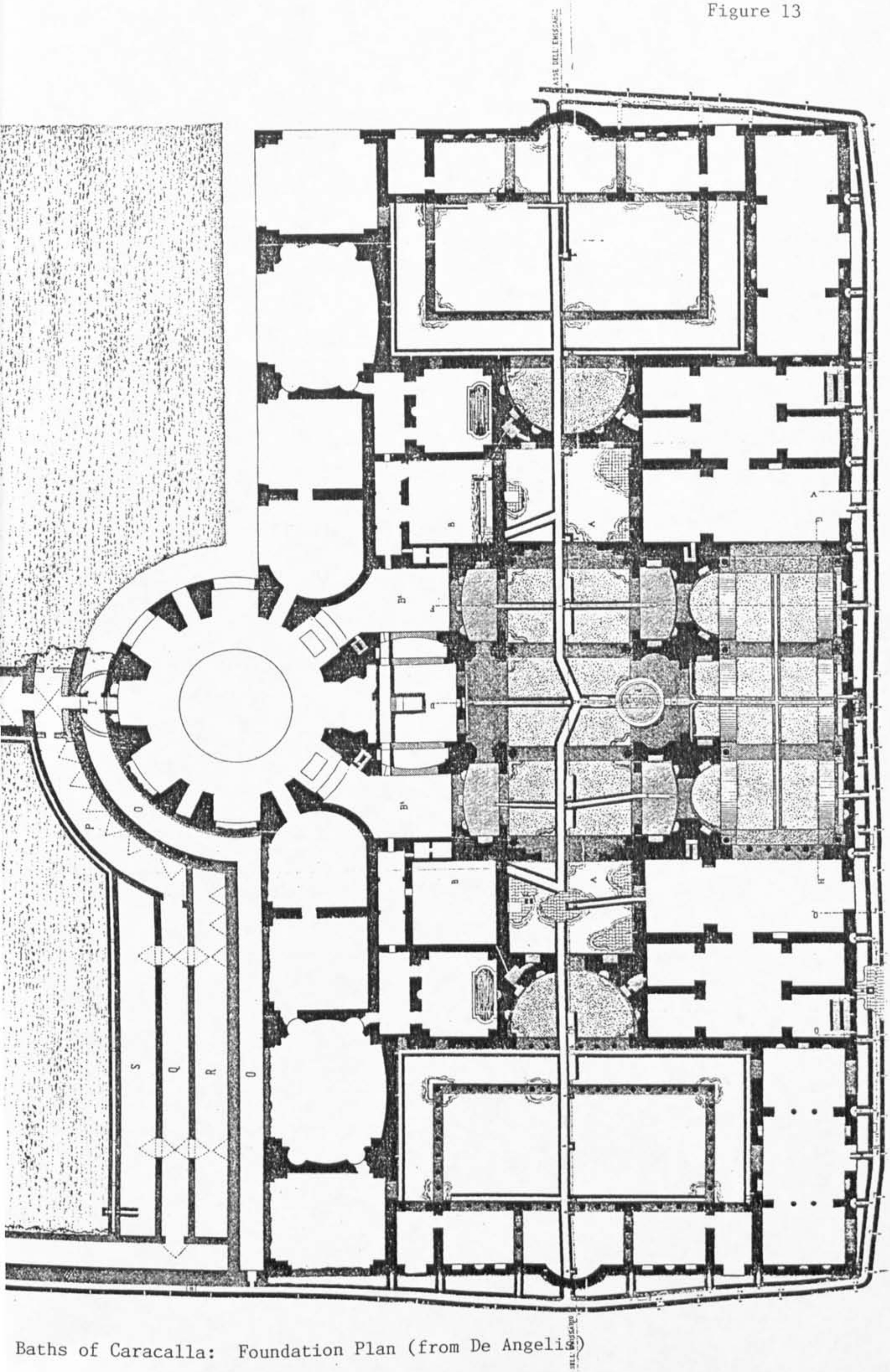


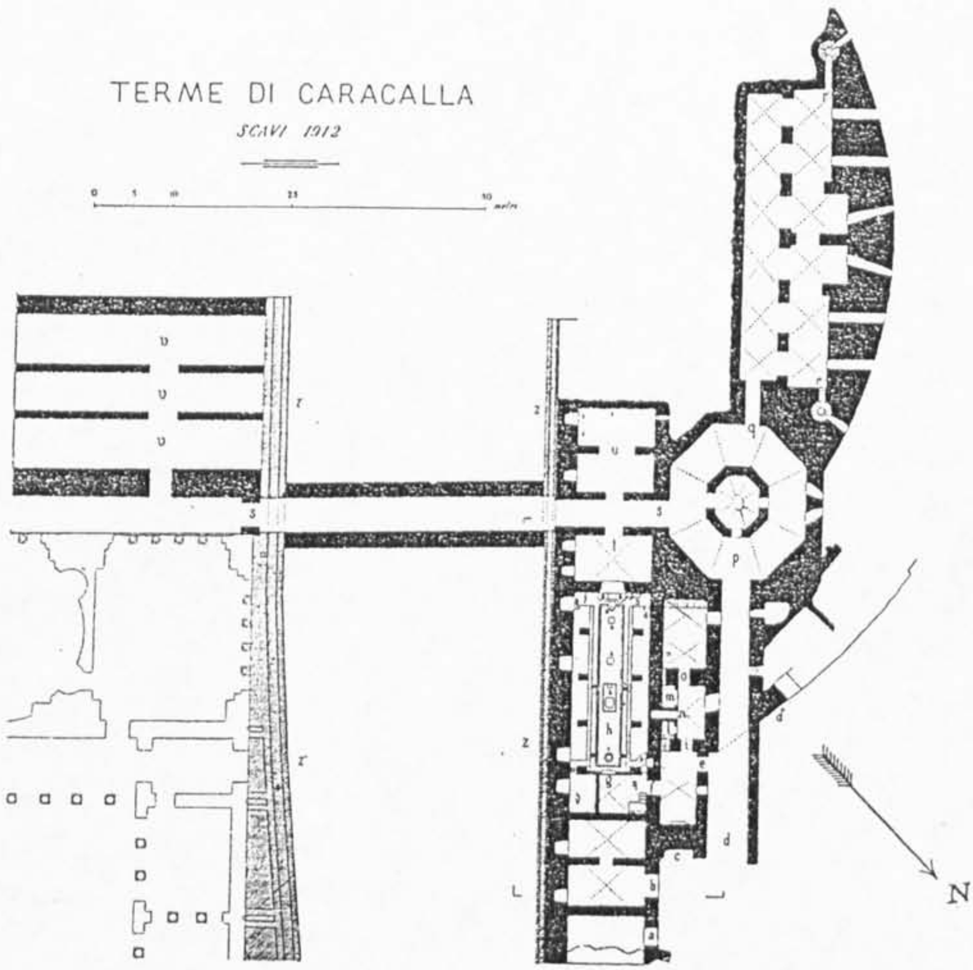
Fig. 12: Baths of Caracalla, exterior of maintenance passage at foot of E facde of central block.



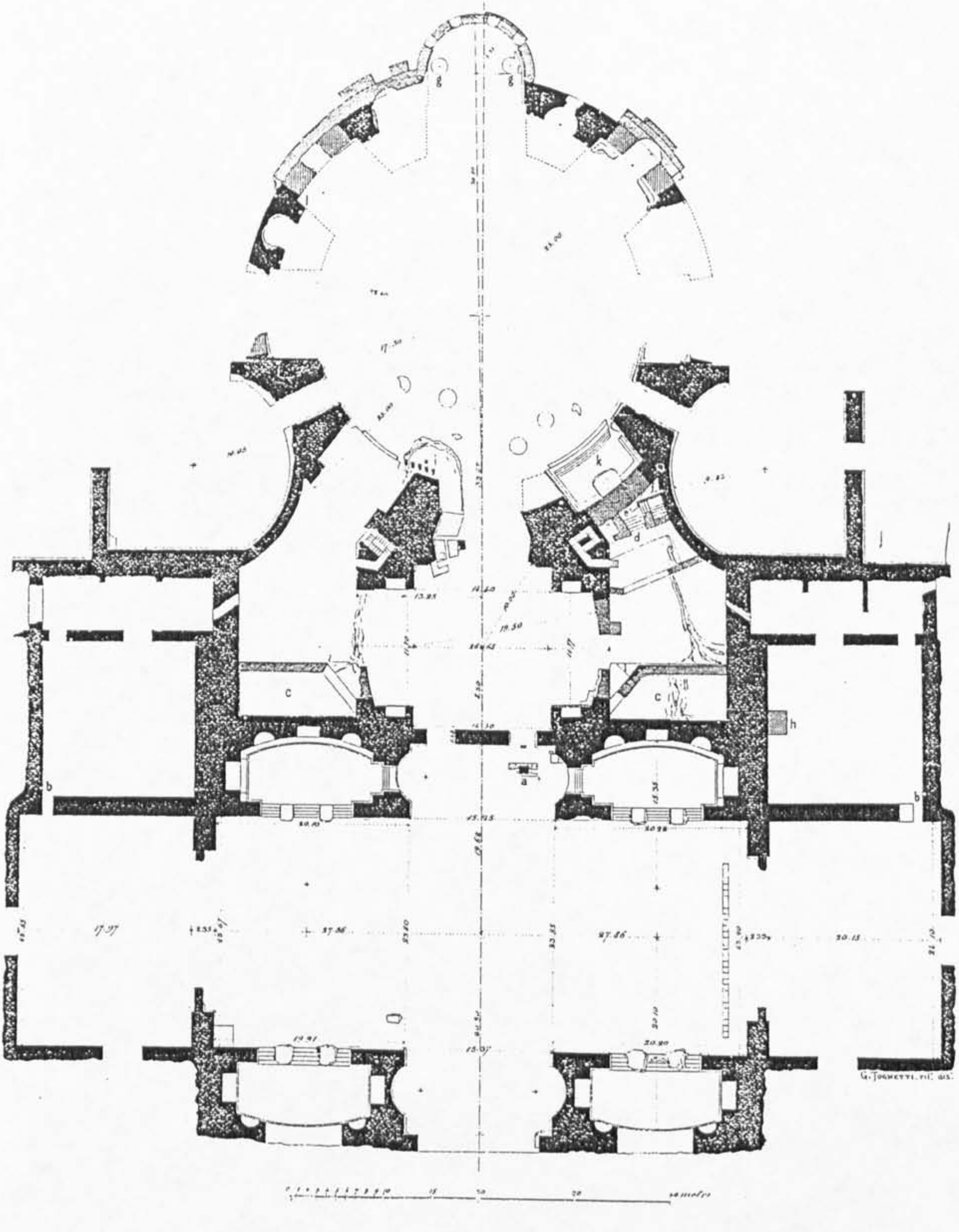
Baths of Caracalla, central block, caldarium c. 1880. Alinari PIN 6758.



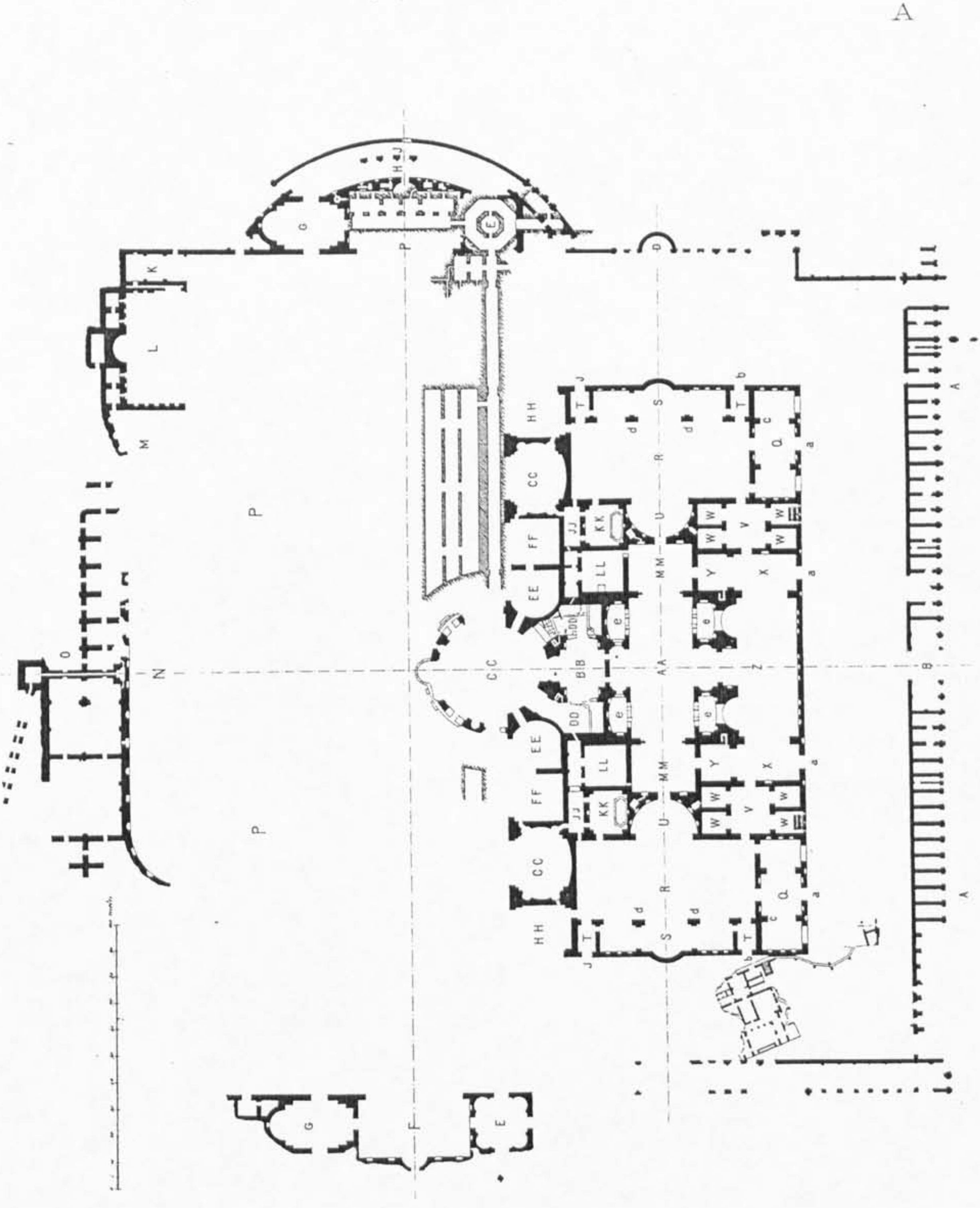
Baths of Caracalla: Foundation Plan (from De Angelis)



Baths of Caracalla, partial plan of substructures, W exhedra.
From Ghislanzoni 1912, Fig. 9.



Baths of Caracalla, partial plan of central block. From Hülsen-Iwanoff 1898, Tav. J.



Baths of Caracalla, ground plan 1898. From Hülsen-Iwanoff 1898, Tav. A.

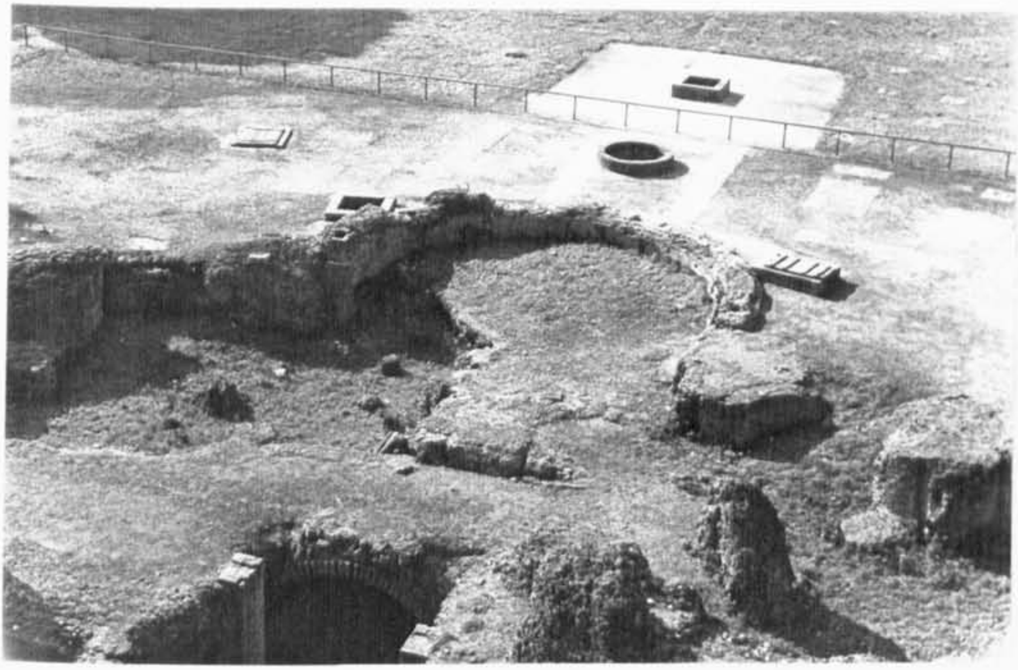


Fig. 17: Baths of Caracalla, central block, caldarium, Constantinian apse.

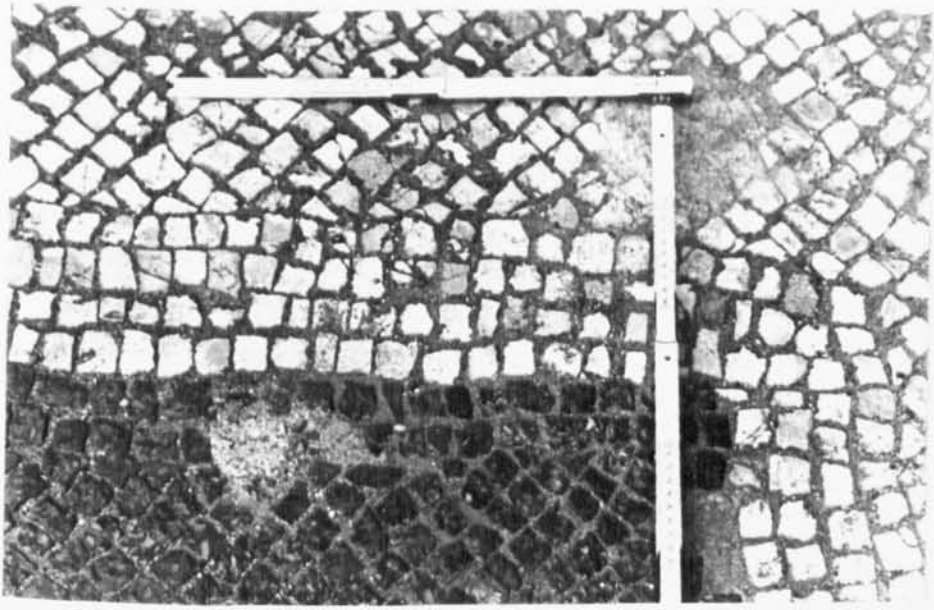


Fig. 18: Baths of Caracalla, central block, Rm 1W, floor mosaic.

Fig. 19: Baths of Caracalla, central block, Rm 17E blocked window in S wall.

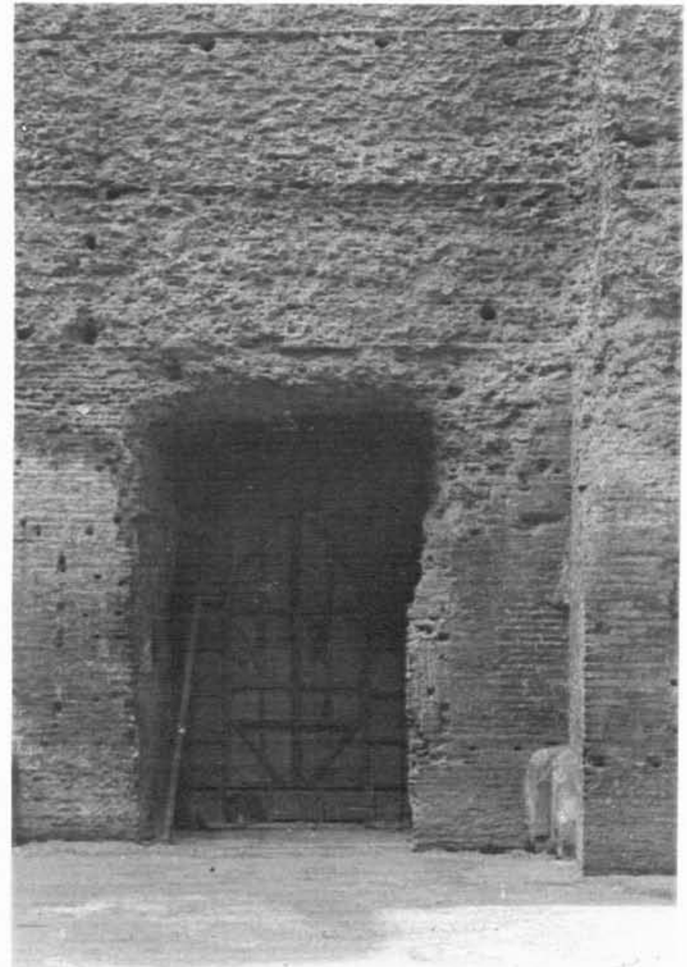


Fig. 20: Baths of Caracalla, central block Rm 17E, later door in S wall

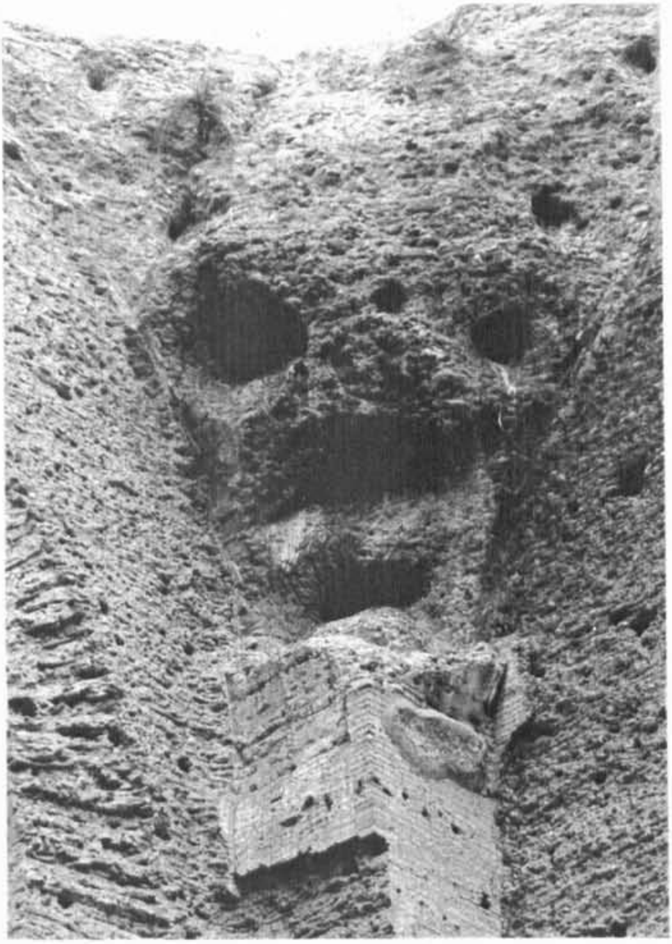


Fig. 21: Baths of Caracalla, central block, Rm 17E, double vaulting in NW corner.

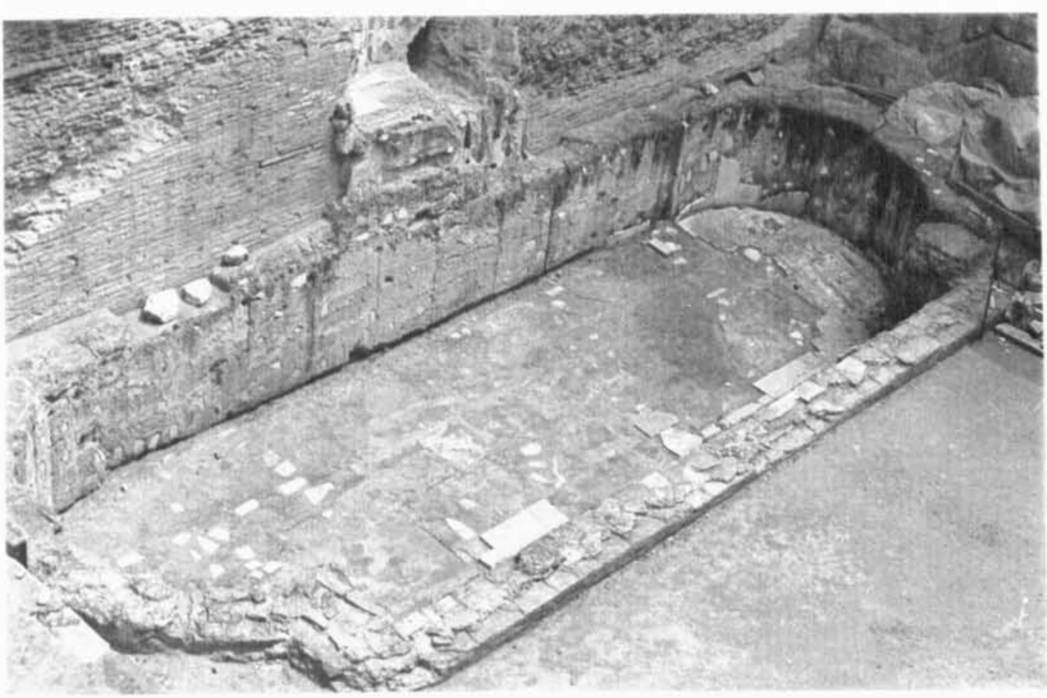


Fig. 22: Baths of Caracalla, central block, Rm 17E, later pool.

Fig. 23: Baths of Caracalla, central block, Rm 19E later pool construction.

Fig. 24: Baths of Caracalla, central block, door to terrace above Rm 18W from <u>palaestra</u> terrace.

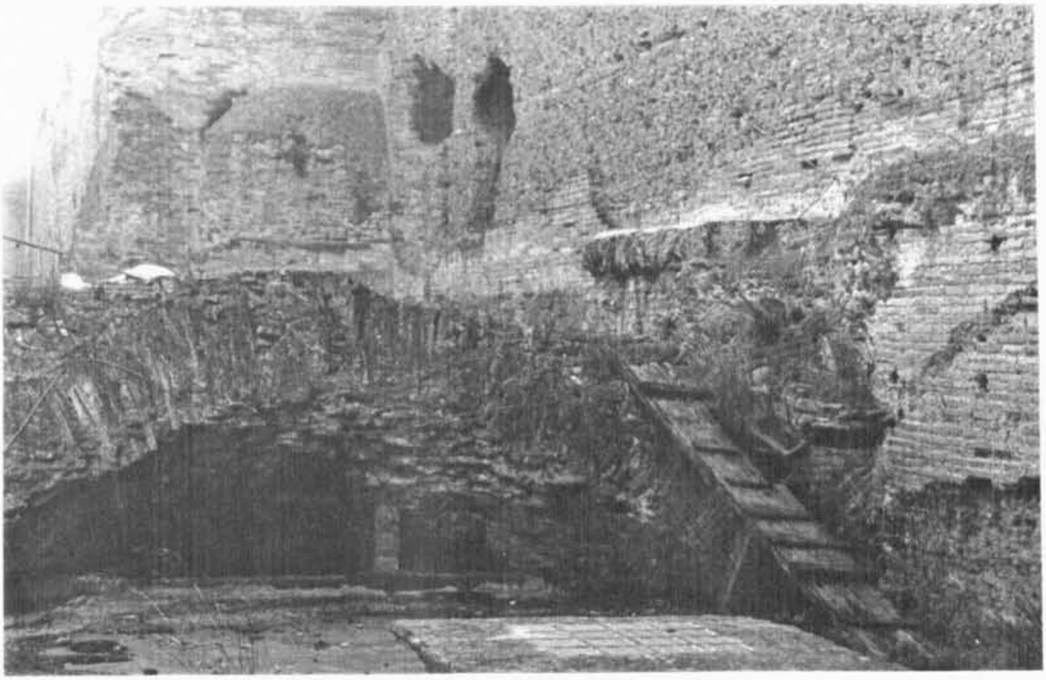


Fig. 25: Baths of Caracalla, central block, terraces over Rms 16-18E.

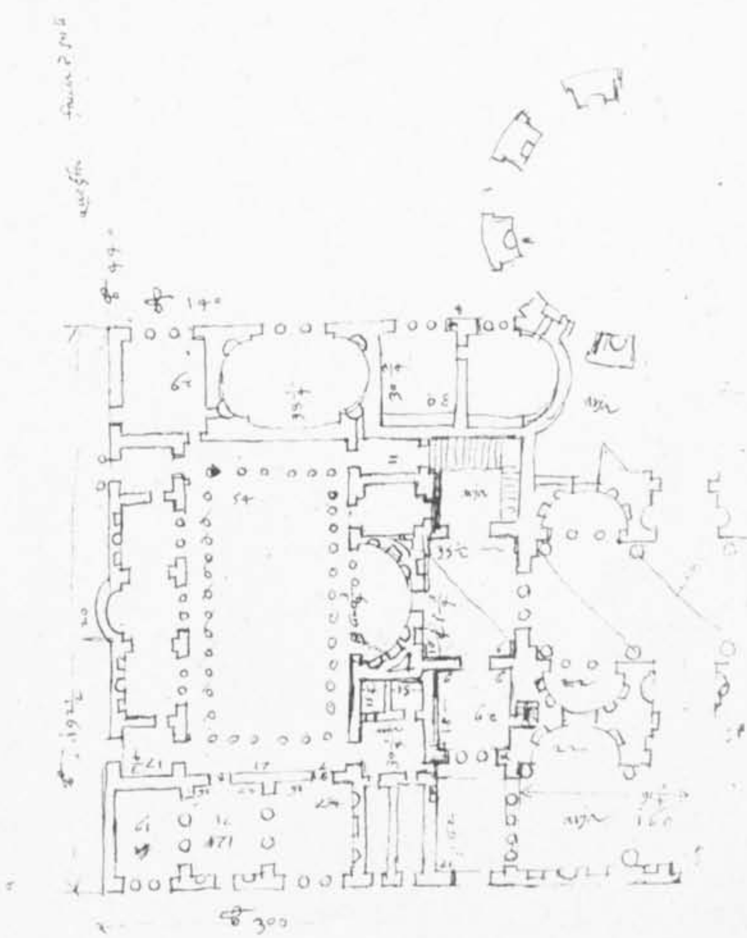
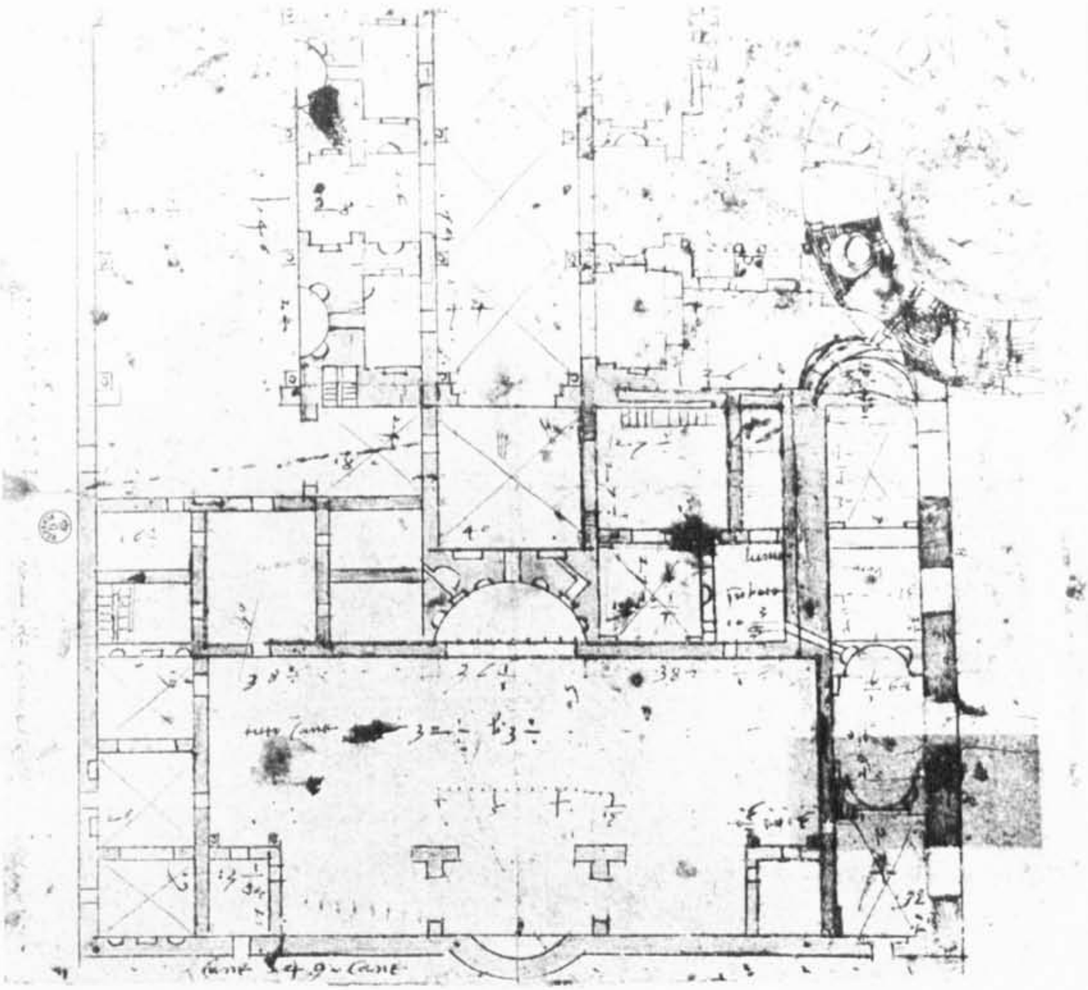
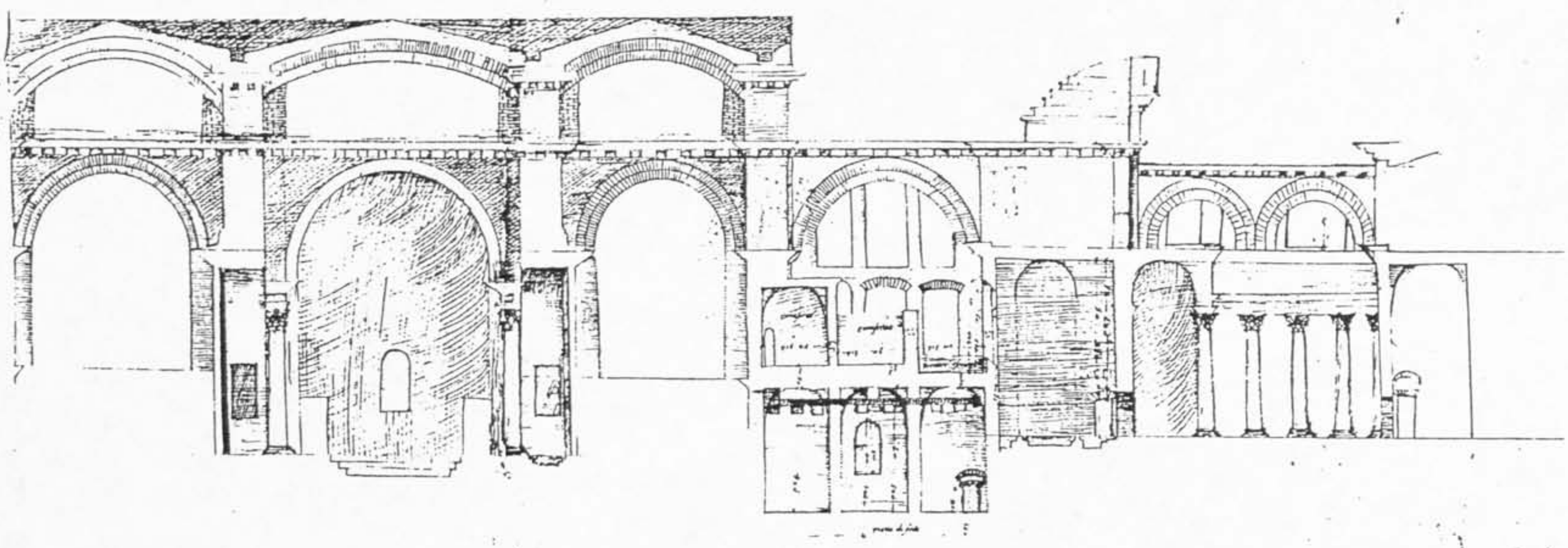


Fig. 26: Baths of Caracalla, central block, partial ground plan.
Detail from B. Peruzzi, Uff. Arch. 476r.



Baths of Caracalla, central block, partial ground plan. Antonio Abaco, detail of Uff. Arch. 1545r.

Figure 28



Baths of Caracalla, central block, partial longitudinal section. Anonymous Destailleur, Bl. 28v.

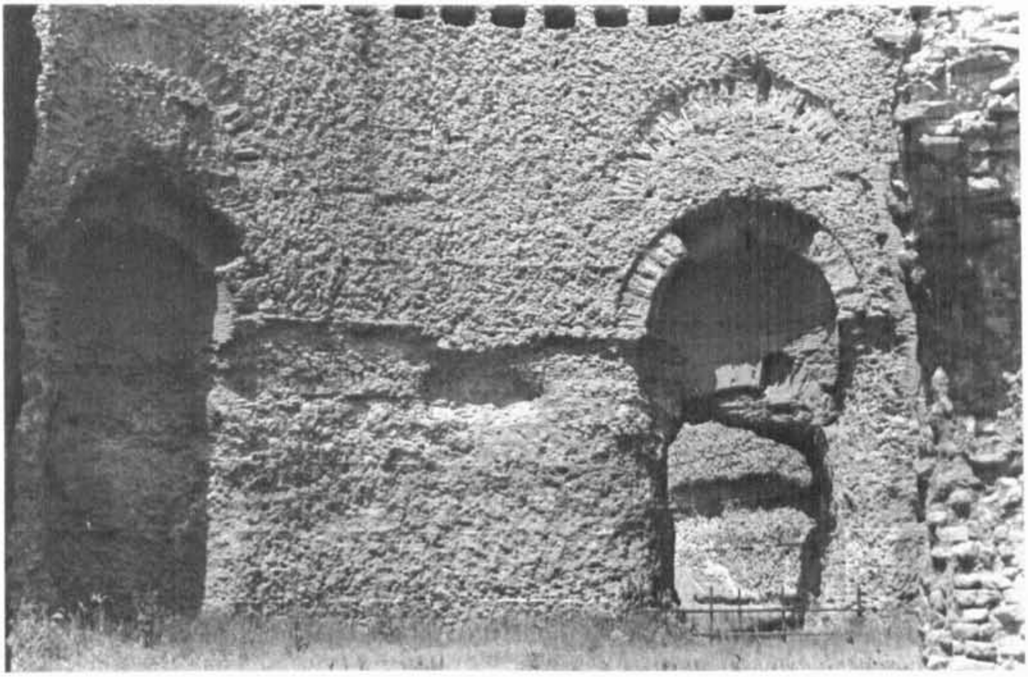


Fig. 29: Baths of Caracalla, central block, Rm 20W, detail of W wall.

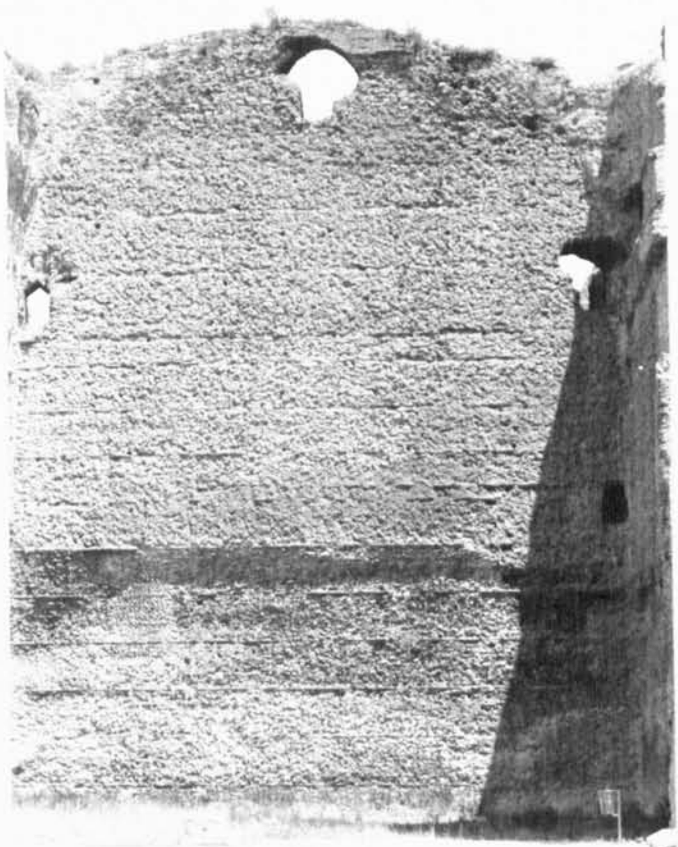


Fig. 30: Baths of Caracalla, central block, Rm 21E, N wall.

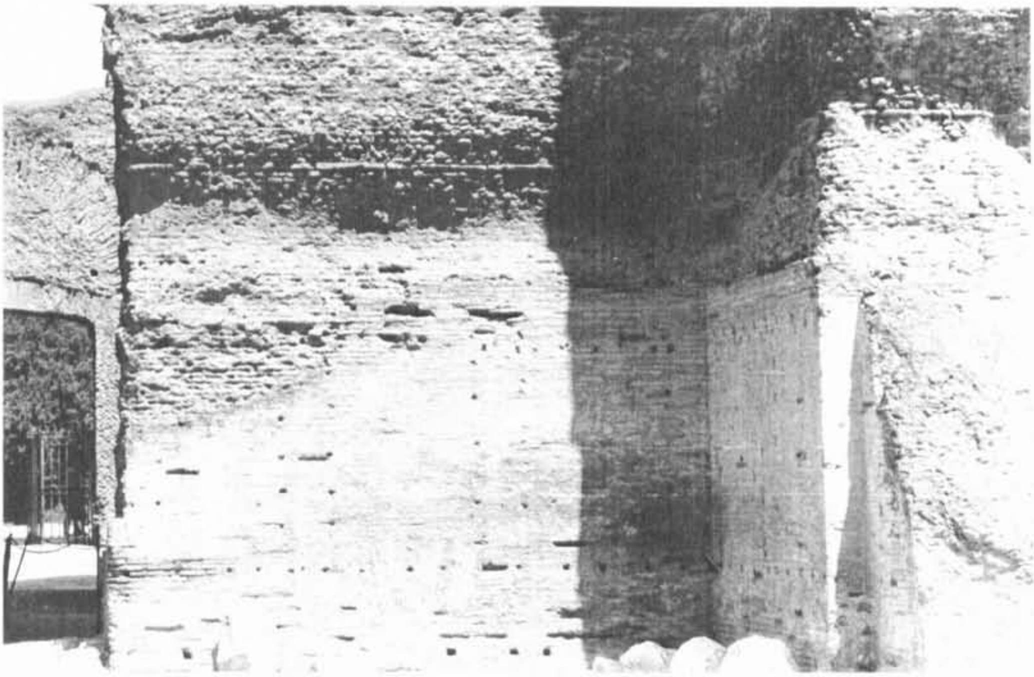
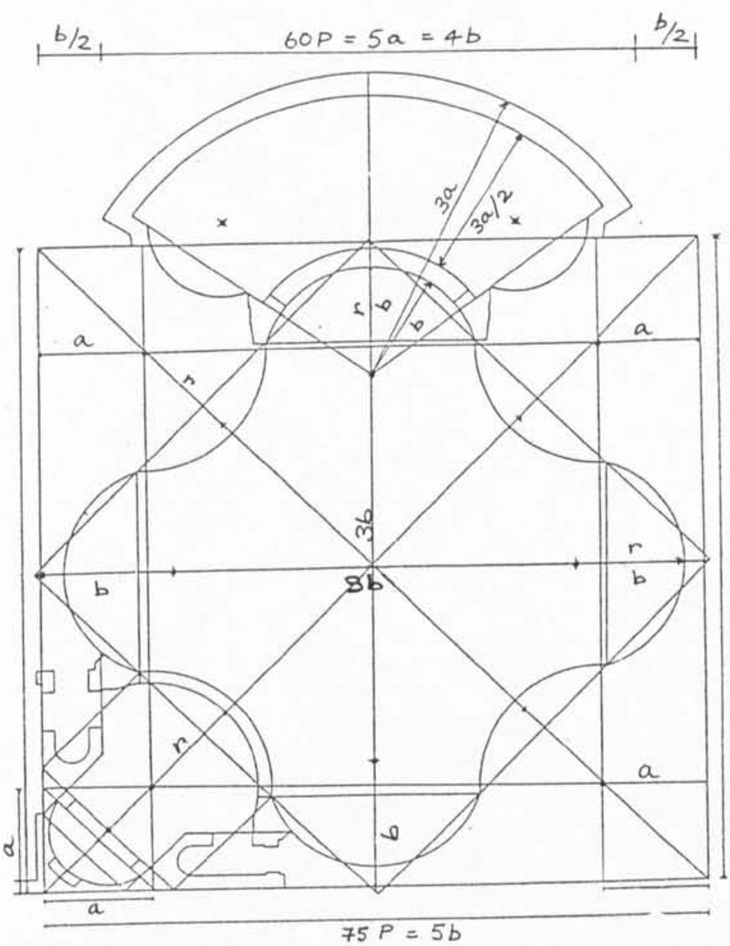


Fig. 31: Baths of Caracalla, central block, Rm 14W, detail of N wall with relieving arch showing location of flue.

Fig. 32: Baths of Caracalla, central block, Rm 19W.

Figure 33

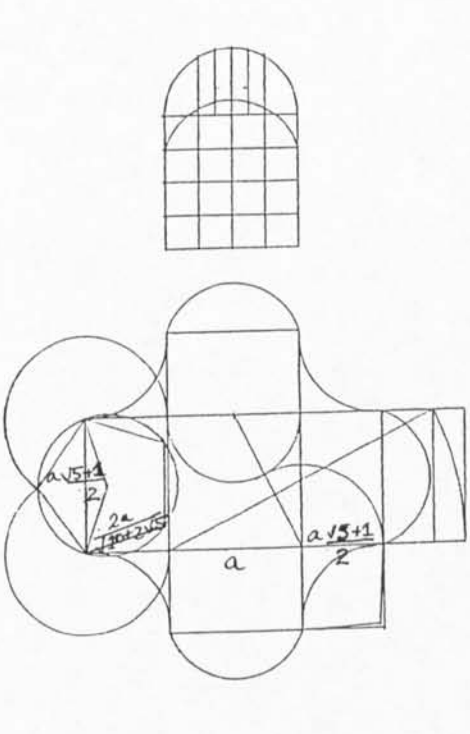


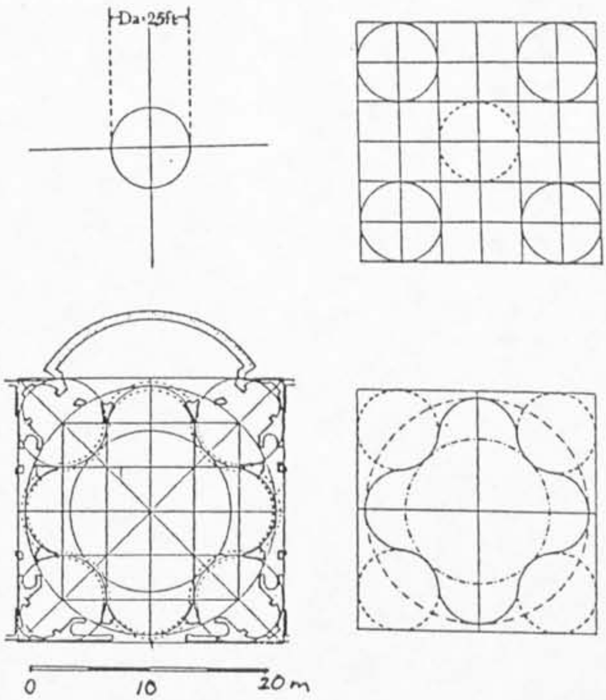
(a) Scheme according to Rakob. a=12 P, b=15 P $r=12\frac{1}{2}$ P.

(b) Scheme according to Hansen using Golden Section.

(c) Scheme according to Jacobson using a modulus of 25 P.

(a) left





(b) (c)

Tivoli, Hadrian's Villa, design schemes for the Piazza d'Oro.

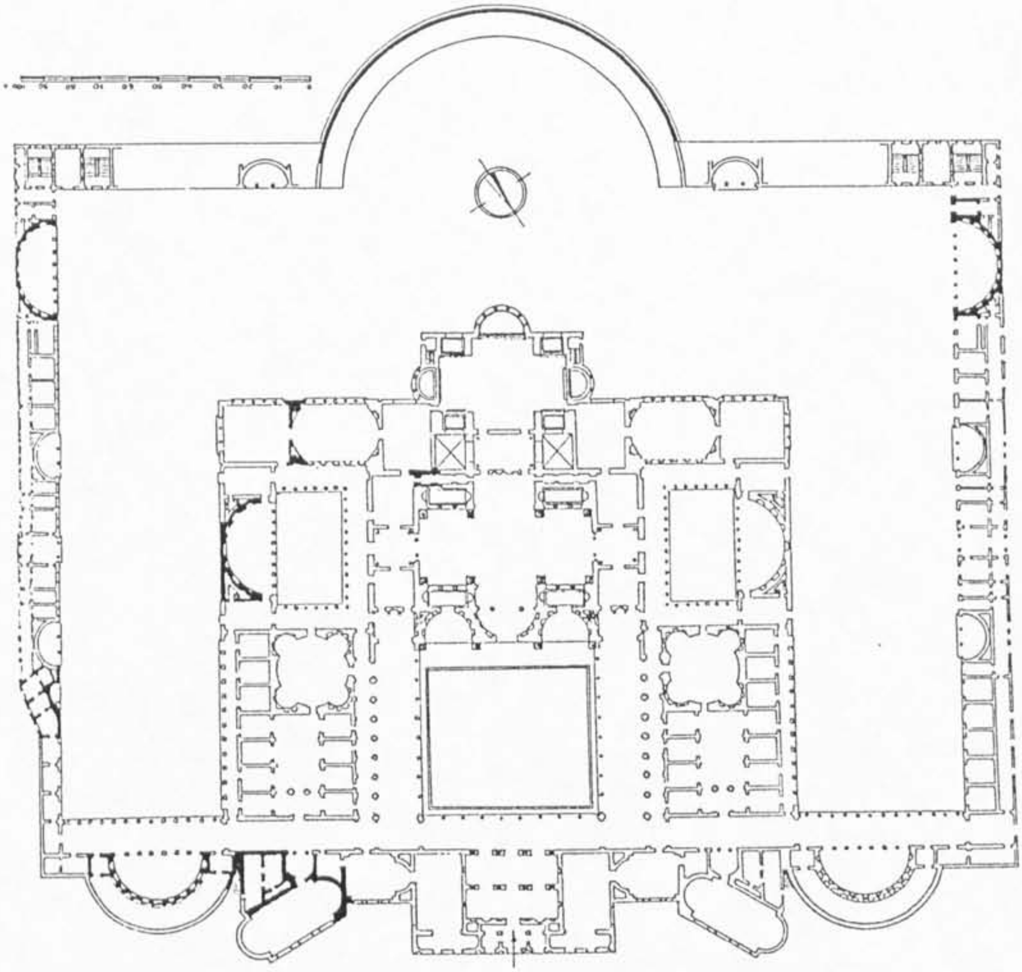


Fig. 34: Baths of Trajan, restored ground plan. From MacDonald 1982.

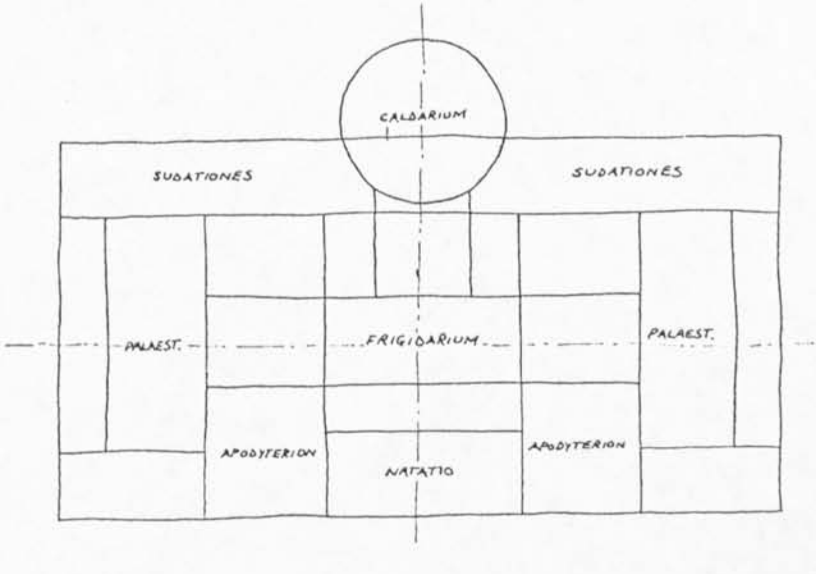
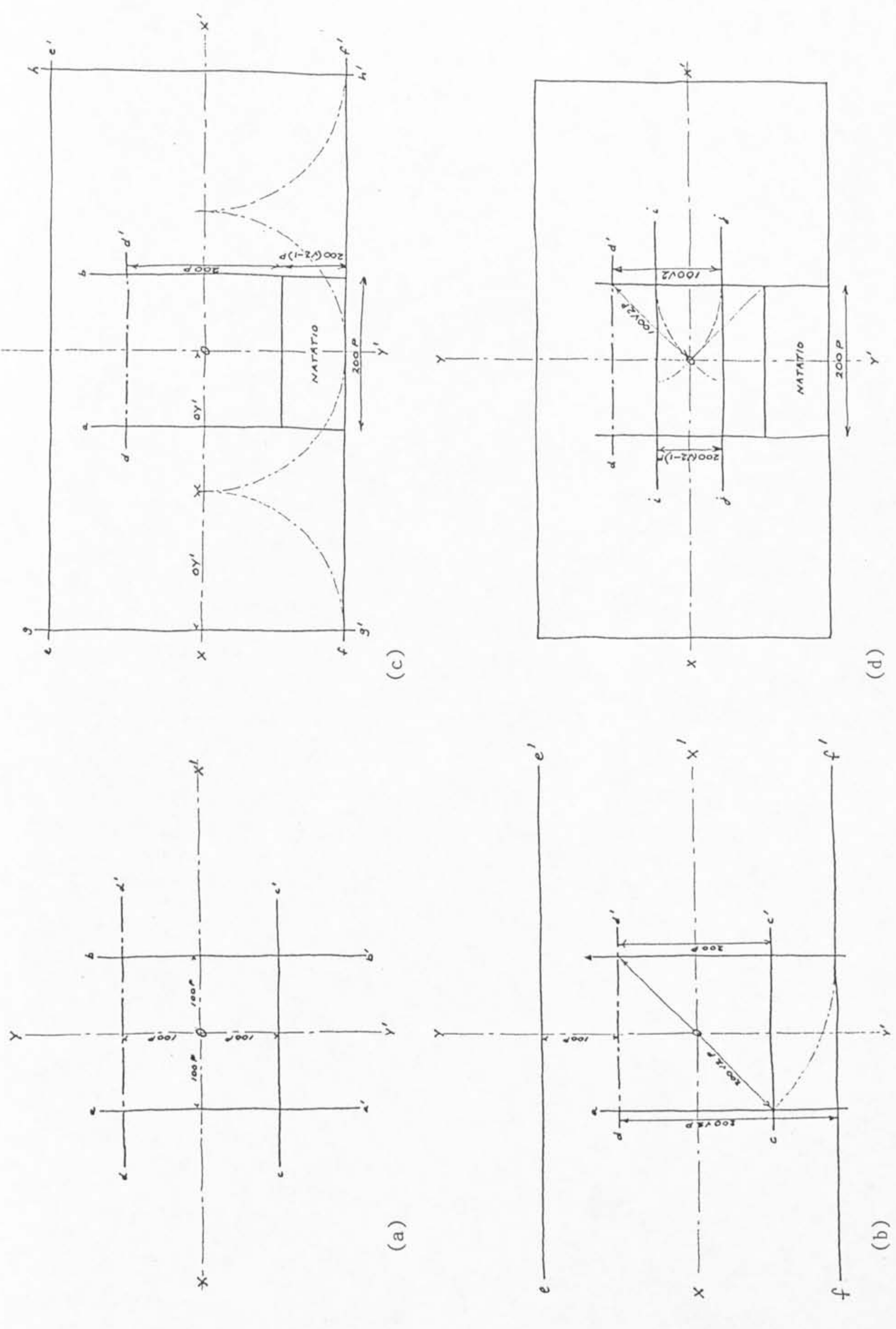


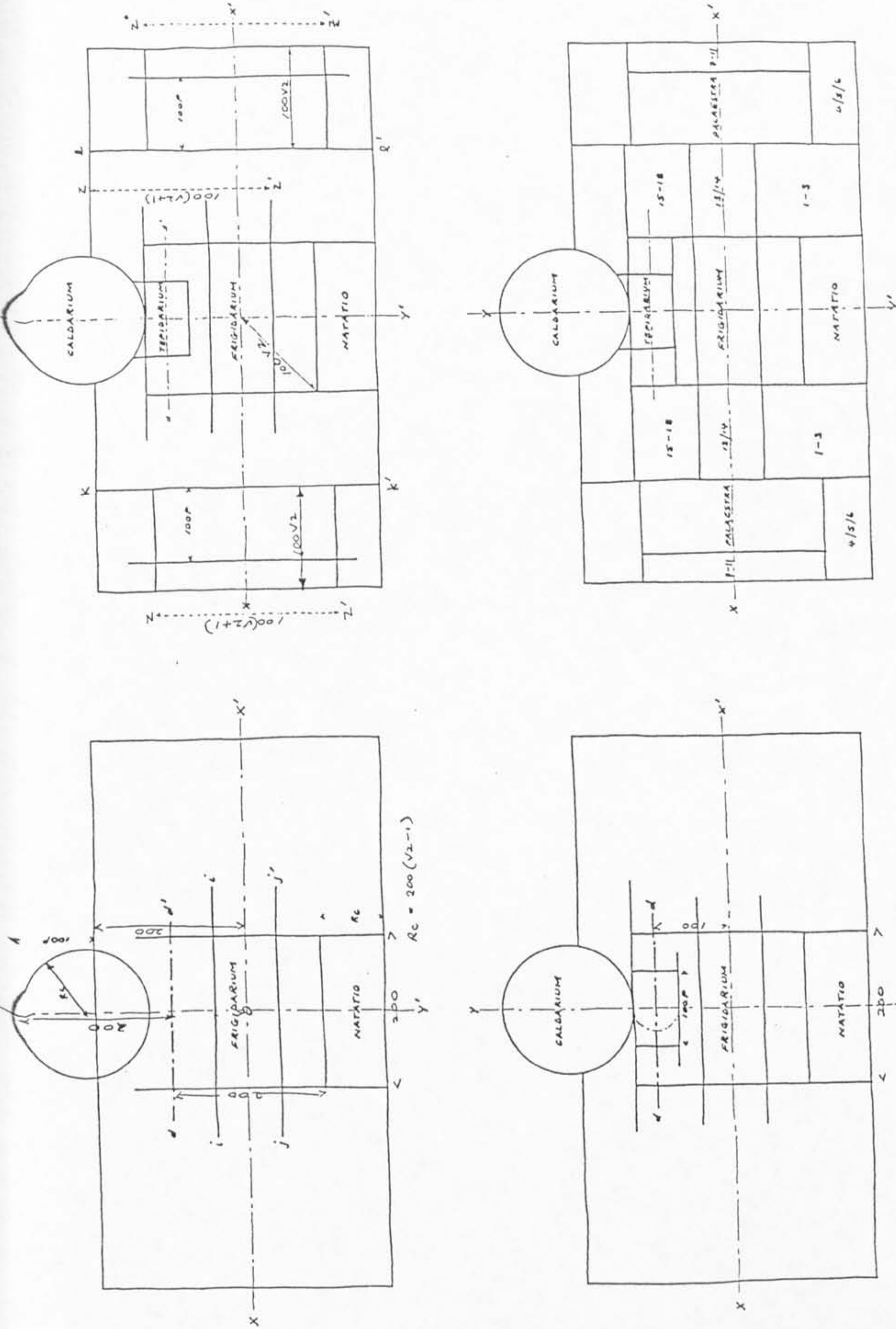
Fig. 35: Baths of Caracalla, suggested architect's rough plan for central block.

Figure 36a-d



Baths of Caracalla, central block, design analysis.

Figure 36e-h



Baths of Caracalla, central block, plan design analysis.

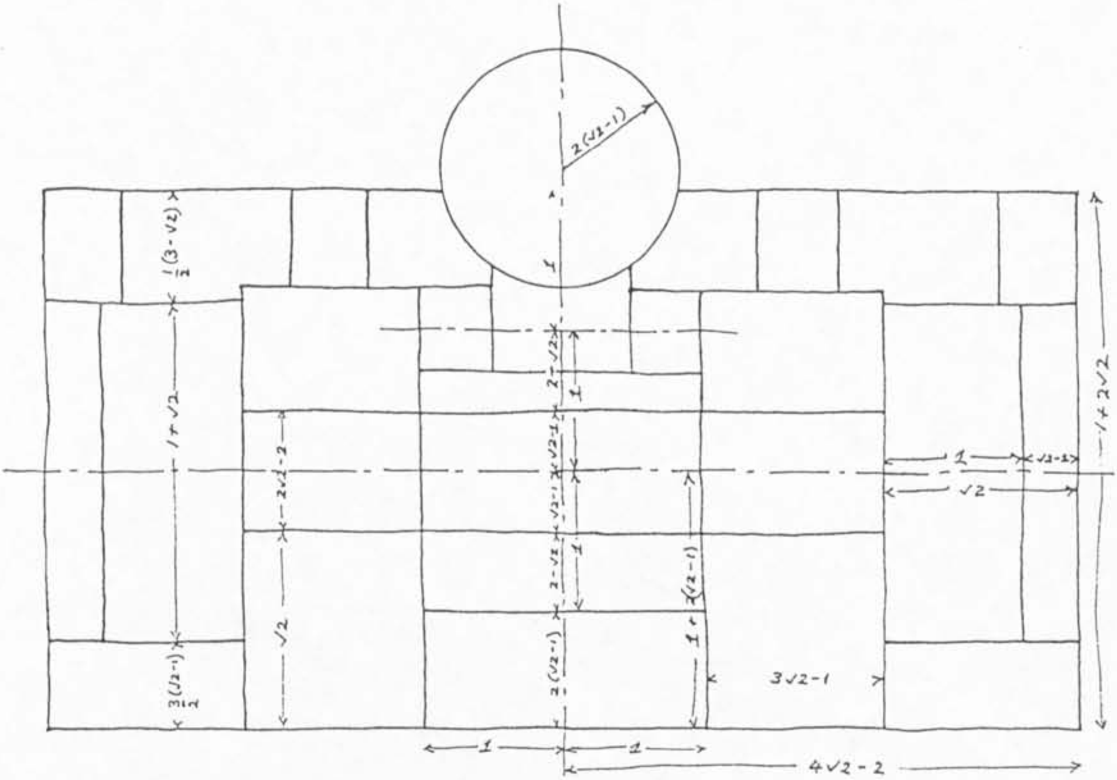


Fig. 37: Baths of Caracalla, central block, √2 relationships in plan design.

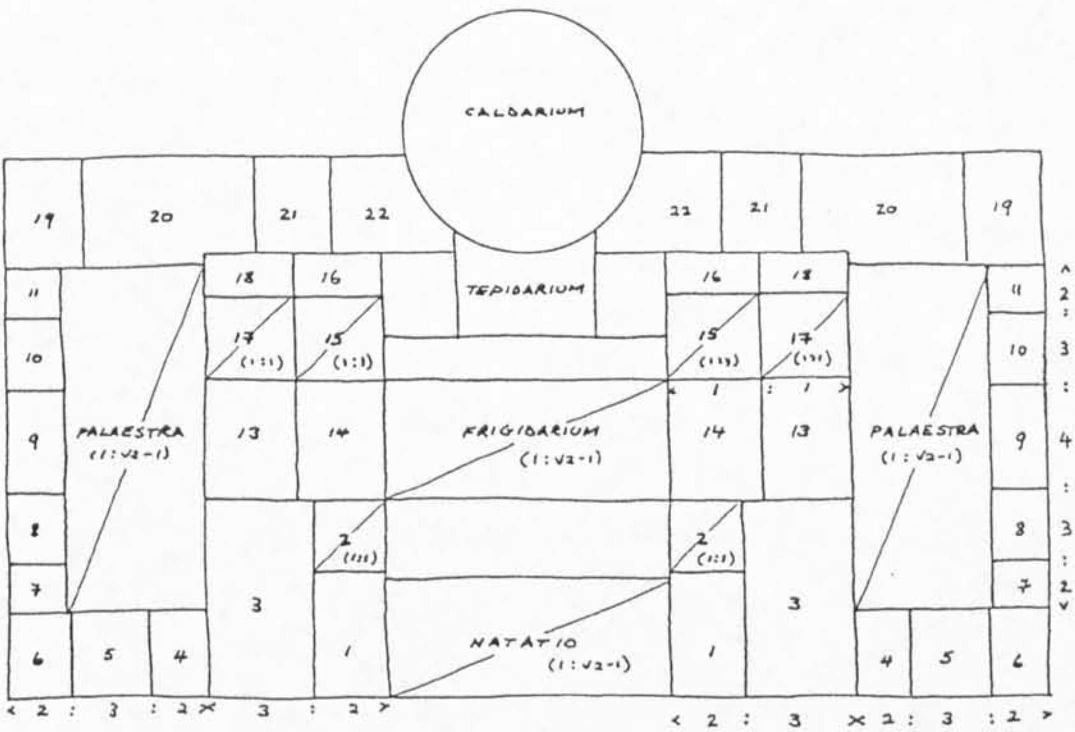
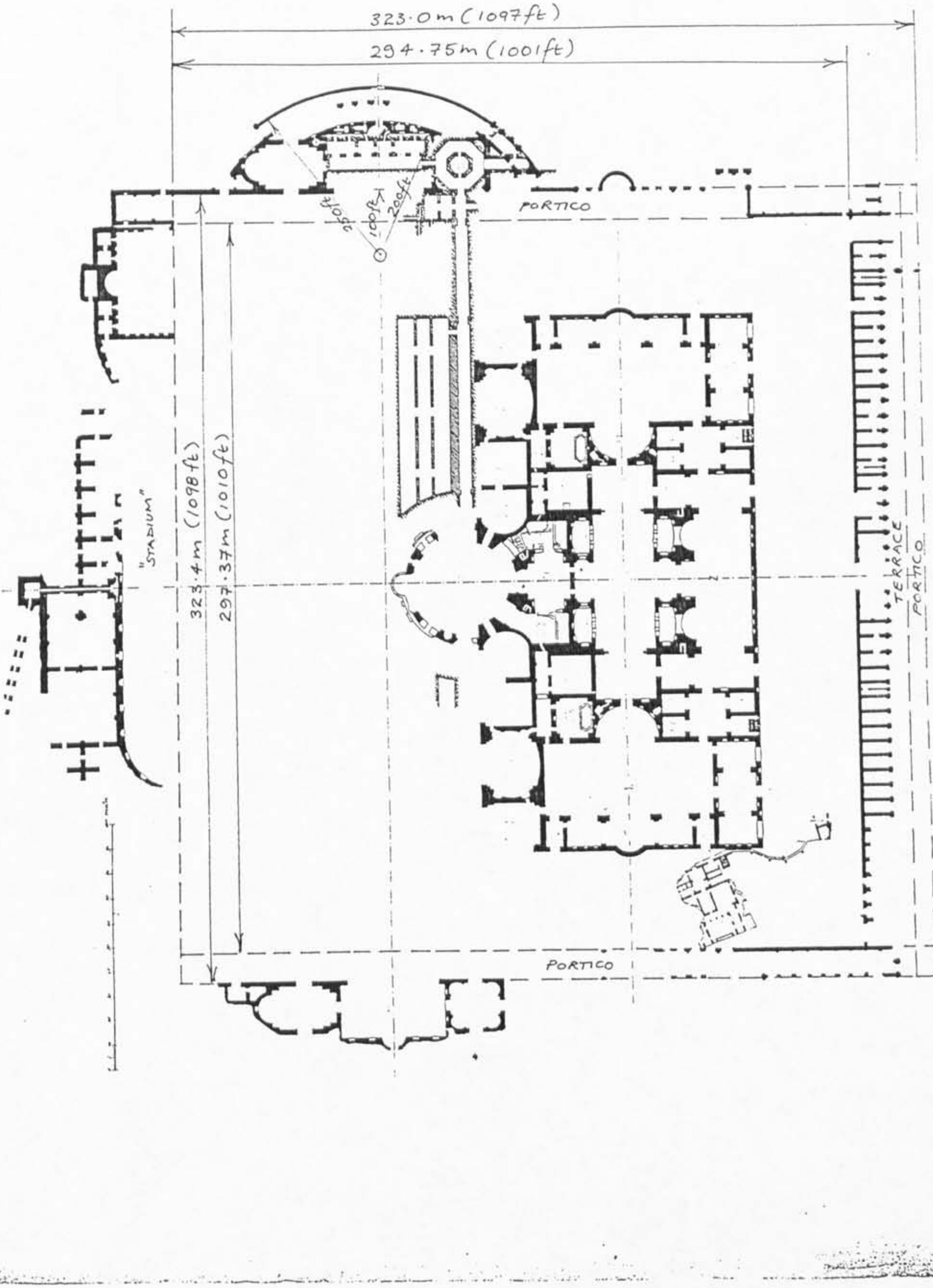


Fig. 38: Baths of Caracalla, central block, subdivision of minor spaces in plan.

A



Baths of Caracalla, ground plan. Adapted from Iwanoff-Hulsen 1898, Tav.A with measurements from Blouet 1828, Pl. III.

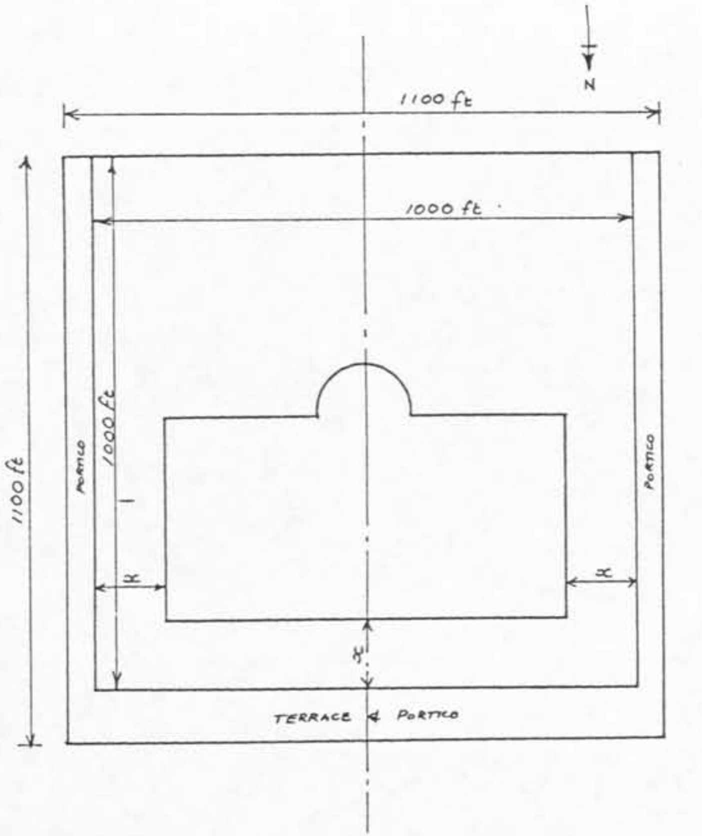


Fig. 40 (above): Baths of Caracalla, first scheme for precinct design.

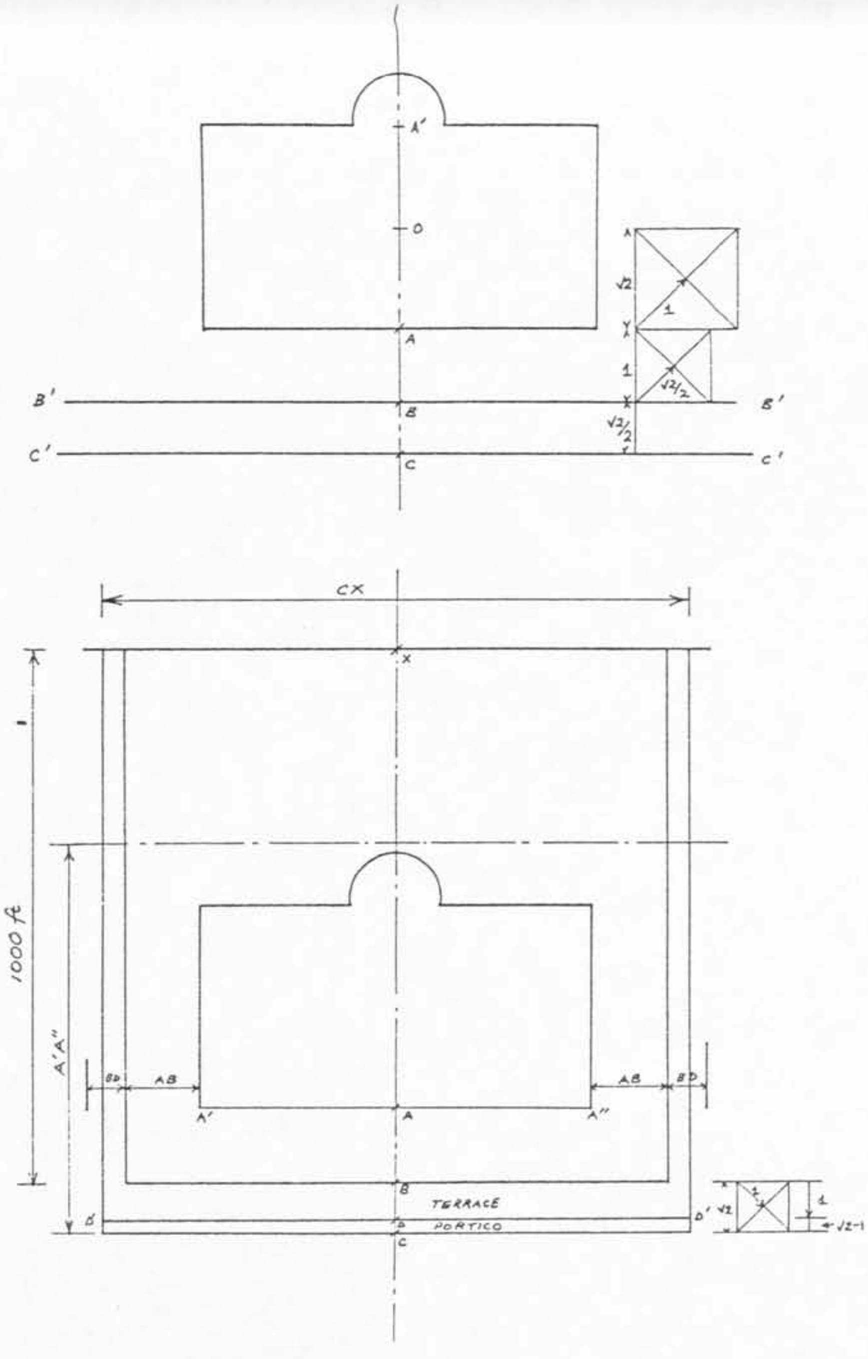
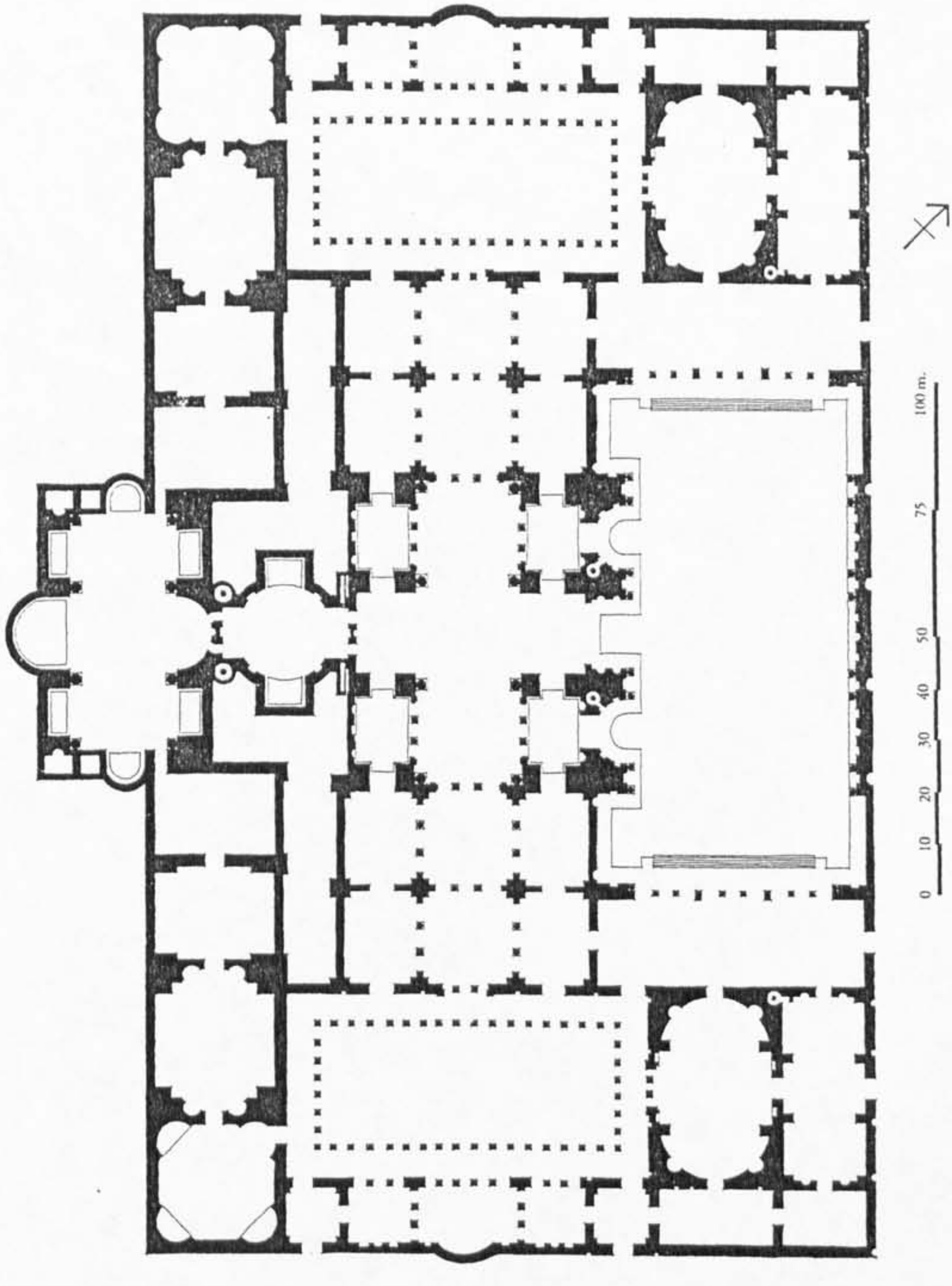
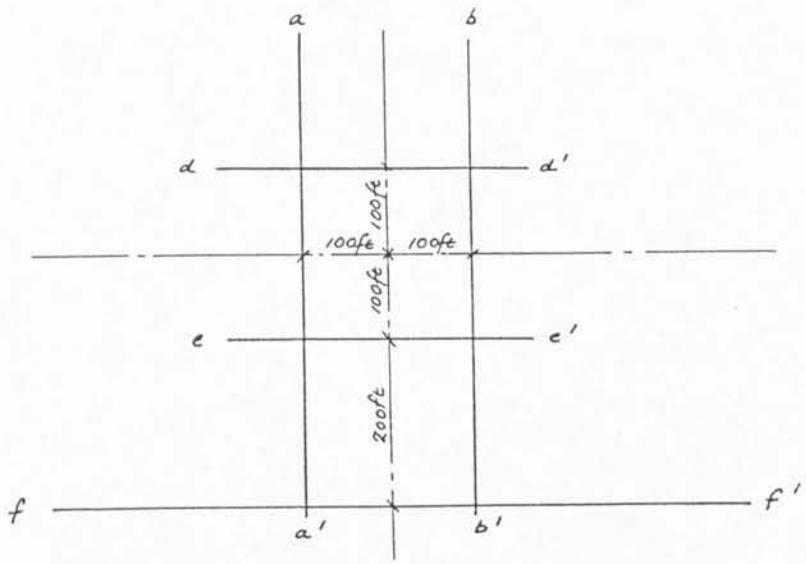


Fig. 41 (right): Baths of Caracalla, √2 scheme for precinct design.

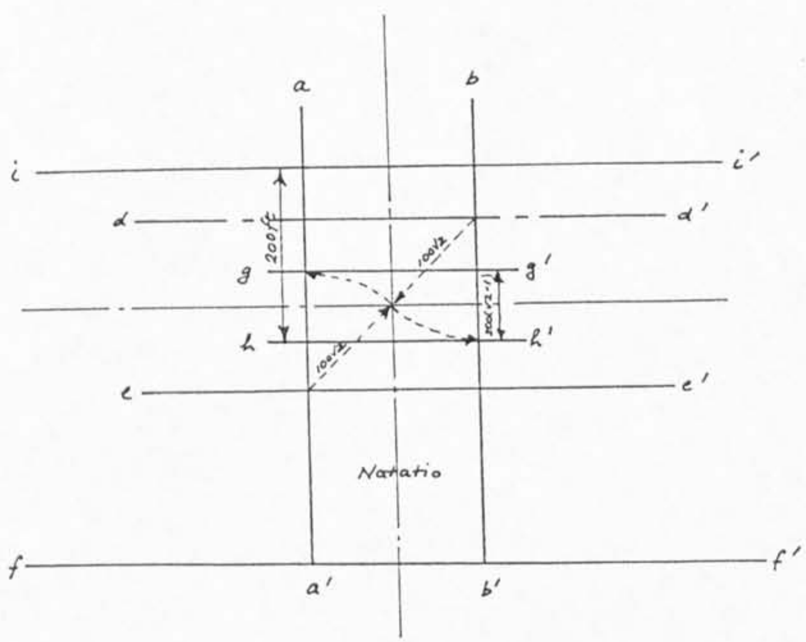
Figure 42



Baths of Diocletian, central block, plan. From MacDonald 1986: Fig. 170.

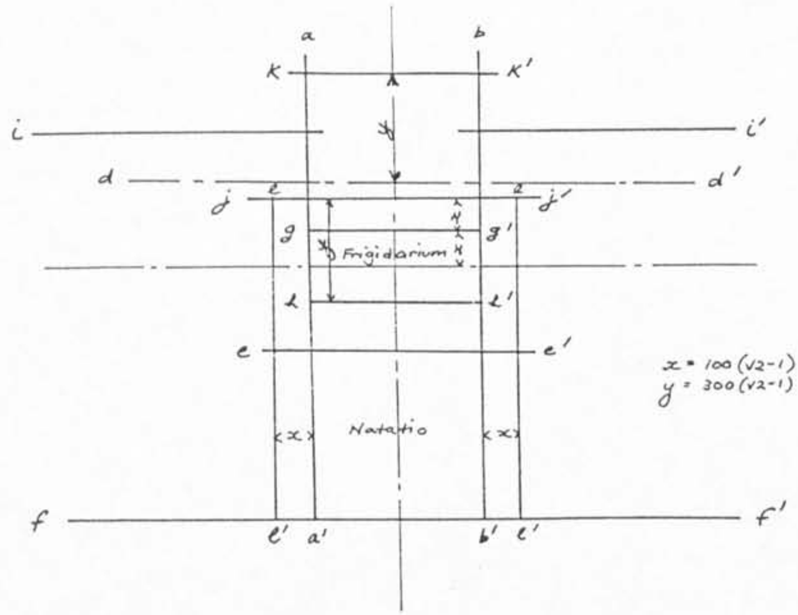


(a) Define central 200 ft square and north boundary.

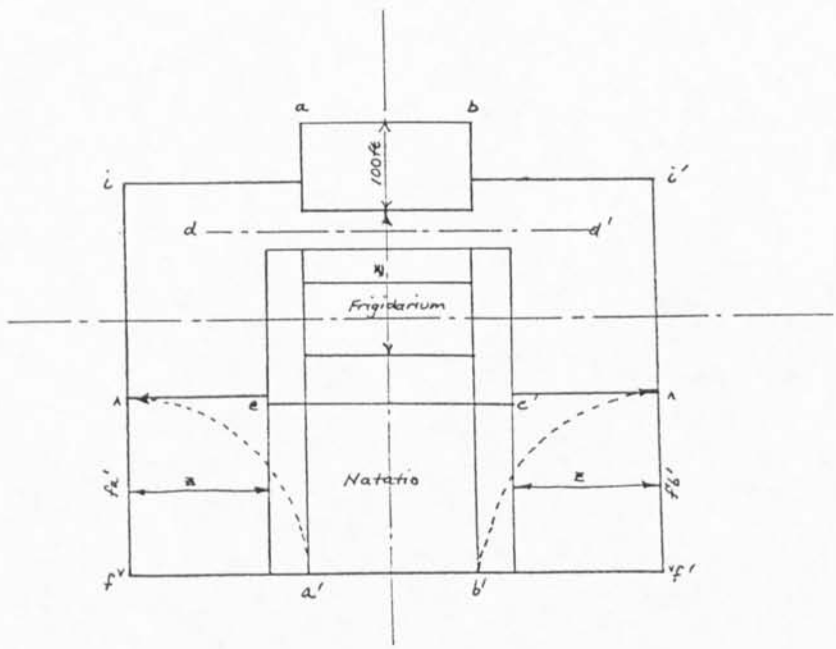


(b) Define central <u>frigidarium</u> using $\sqrt{2}$ construction, and main south boundary.

Fig. 43: Baths of Trajan, main block, plan design analysis.

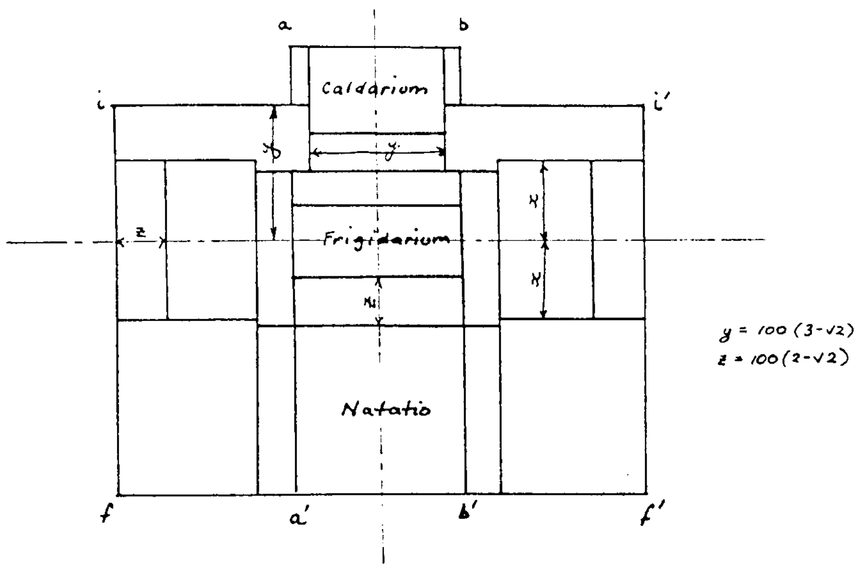


(c) Define outer S boundary of caldarium and rooms flanking natatio and frigidarium.

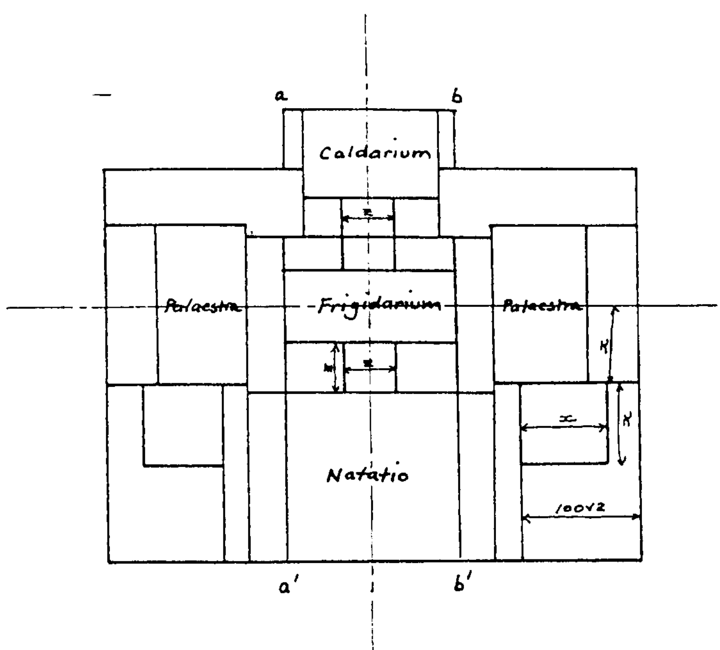


(d) Define inner N boundary of caldarium, and E and W boundaries.

Fig 43: Baths of Trajan, main block, plan design analysis



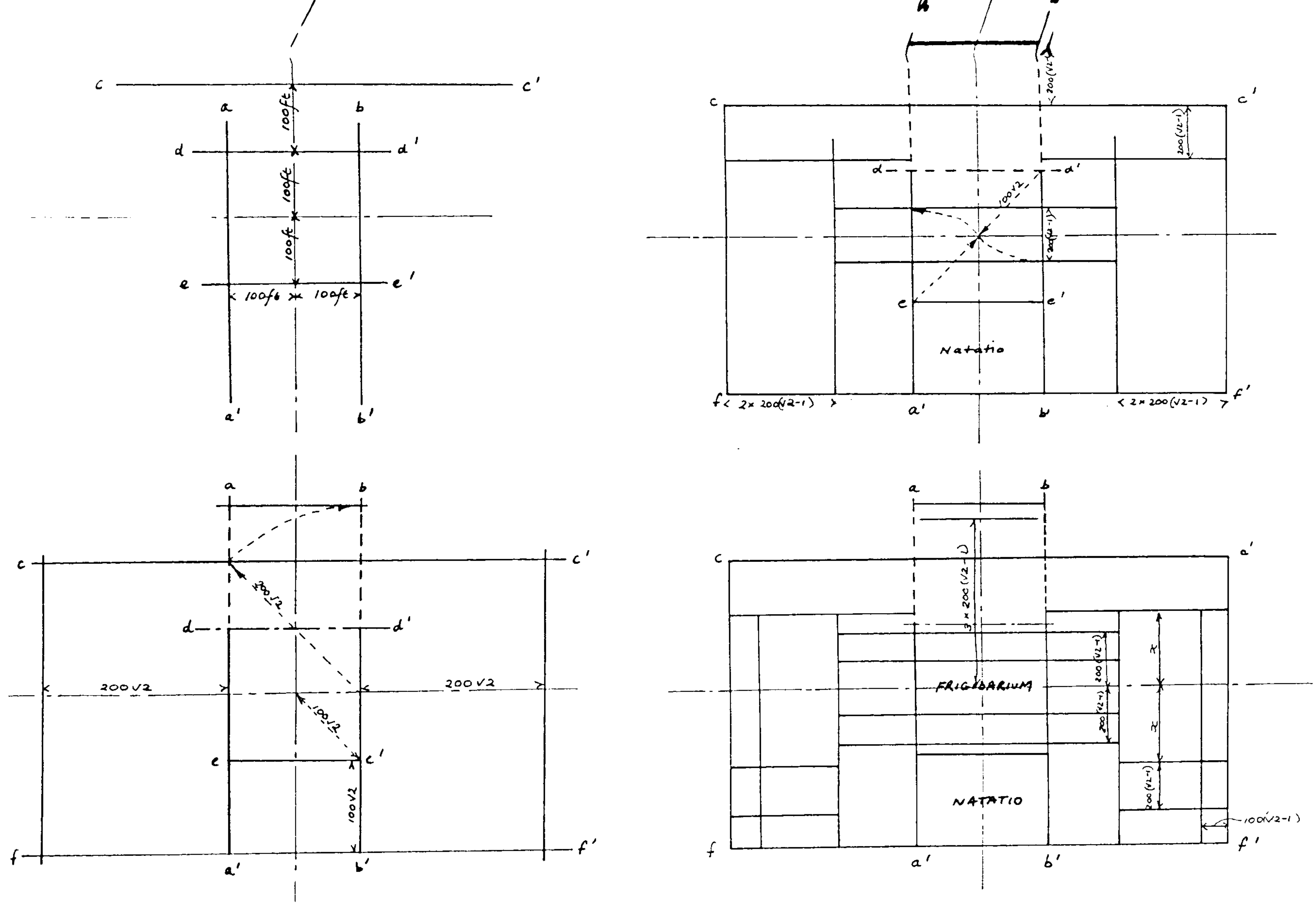
(e) Define boundaries of palaestrae and flanking exhedrae.



(f) Define tepidarium and minor rooms flanking natatio.

Fig. 43: Baths of trajan, main block, plan design analysis.

Figure 44a-d



Baths of Diocletian, plan design analysis. Steps follow similar pattern to baths of Caracalla and Trajan

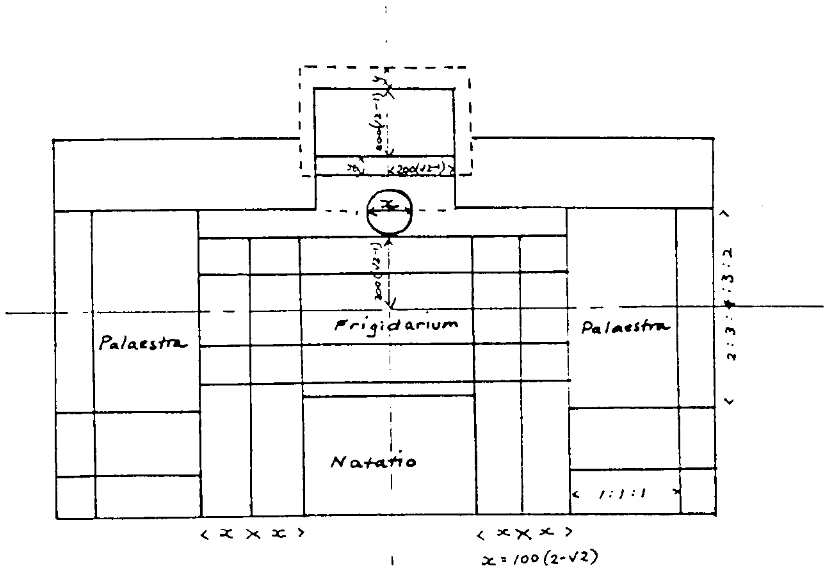


Fig. 44e: Baths of Diocletian, plan design analysis, final stage

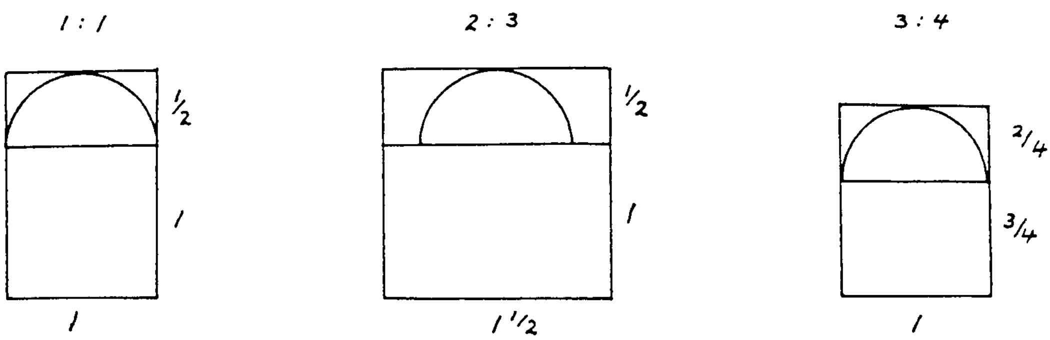
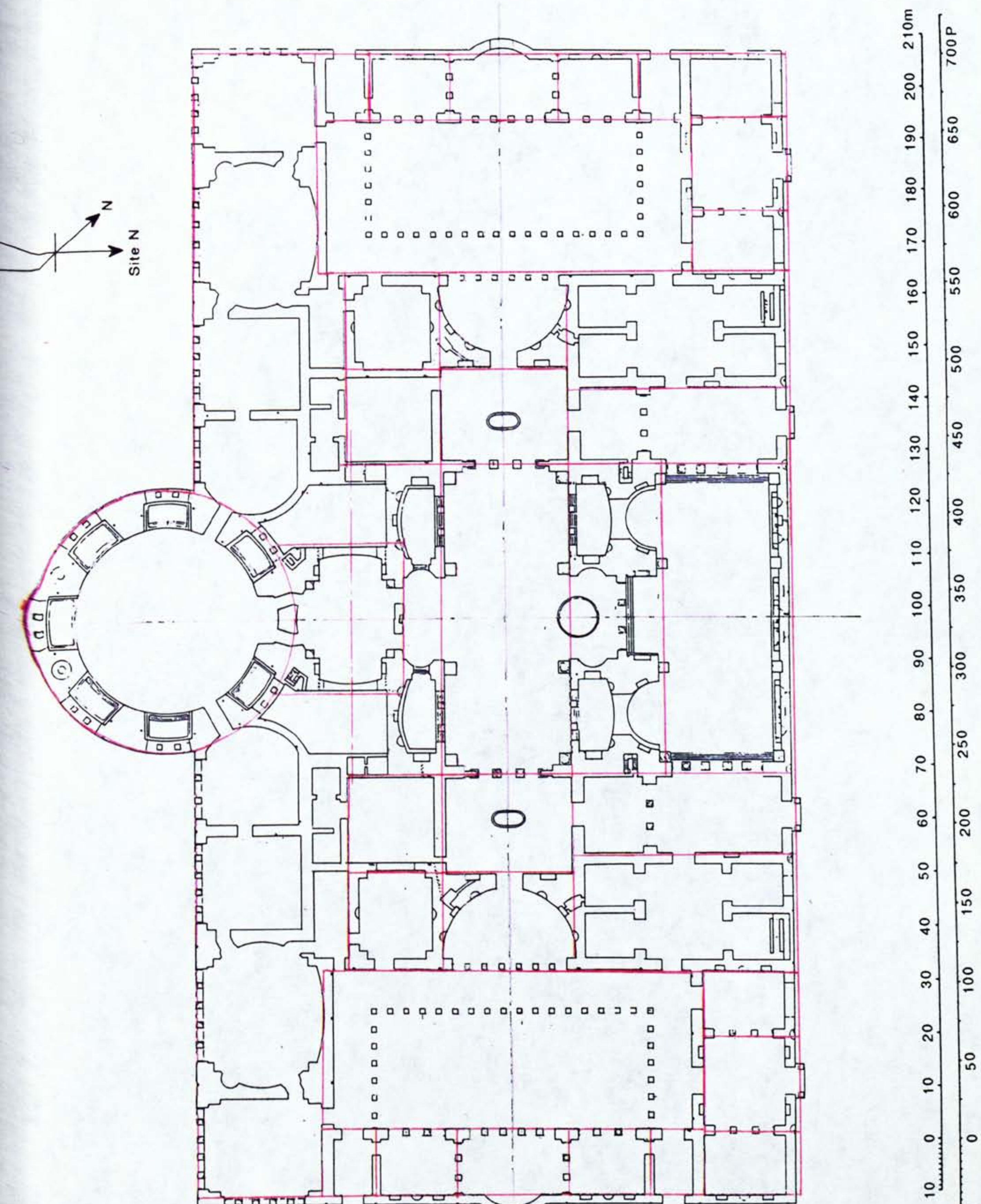
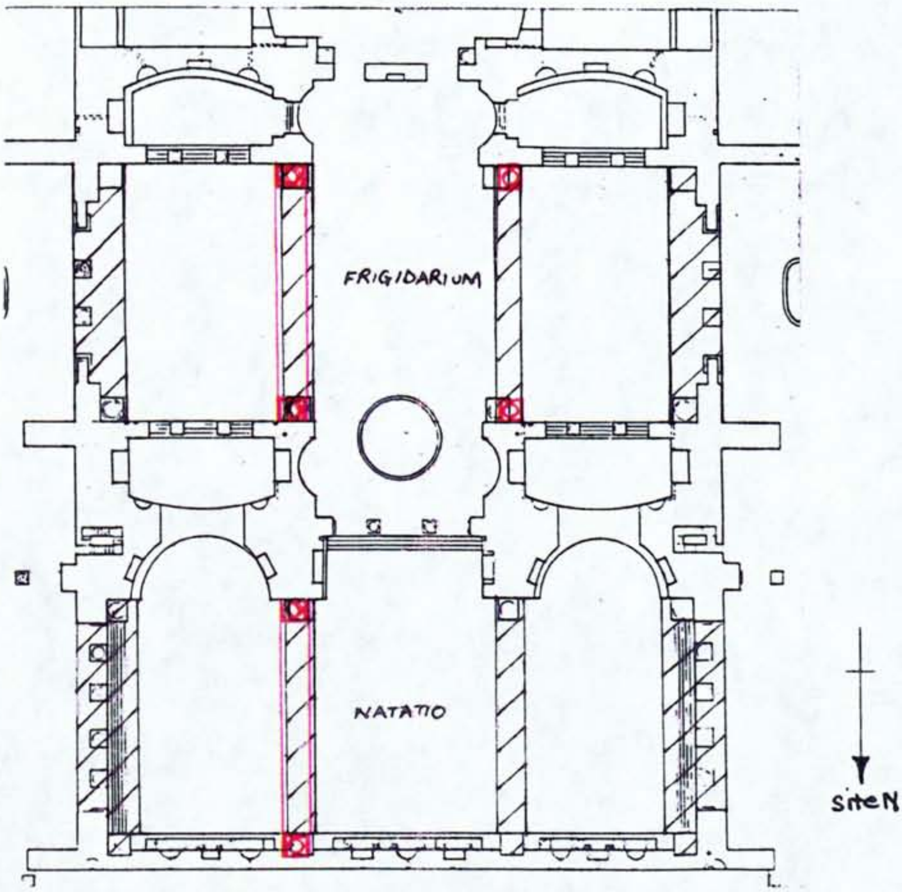


Fig. 45: Standard patterns for the elevation of cross-vaulted rooms.

Figure 46

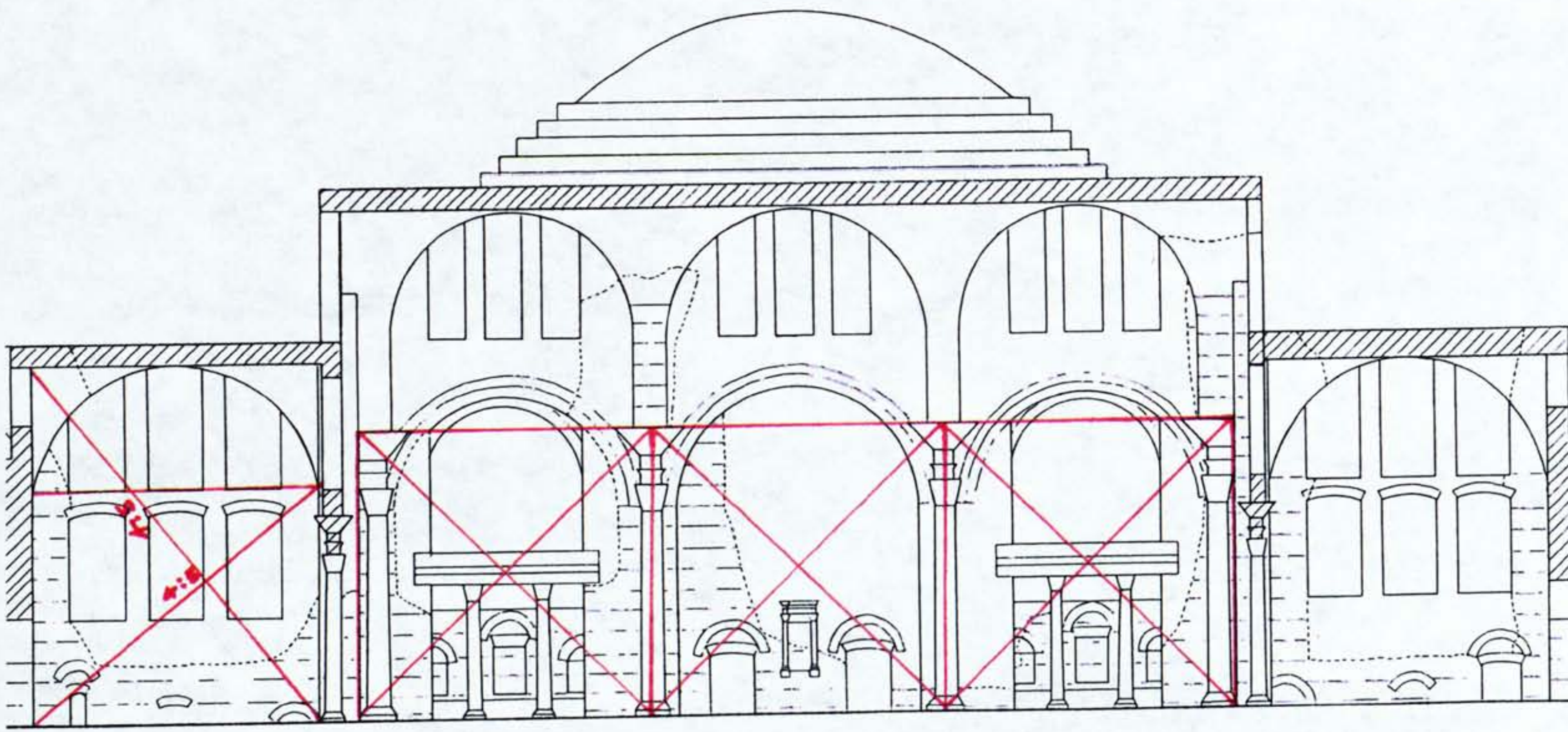


Baths of Caracalla, central block, ideal plan in red superimposed on plan as built.

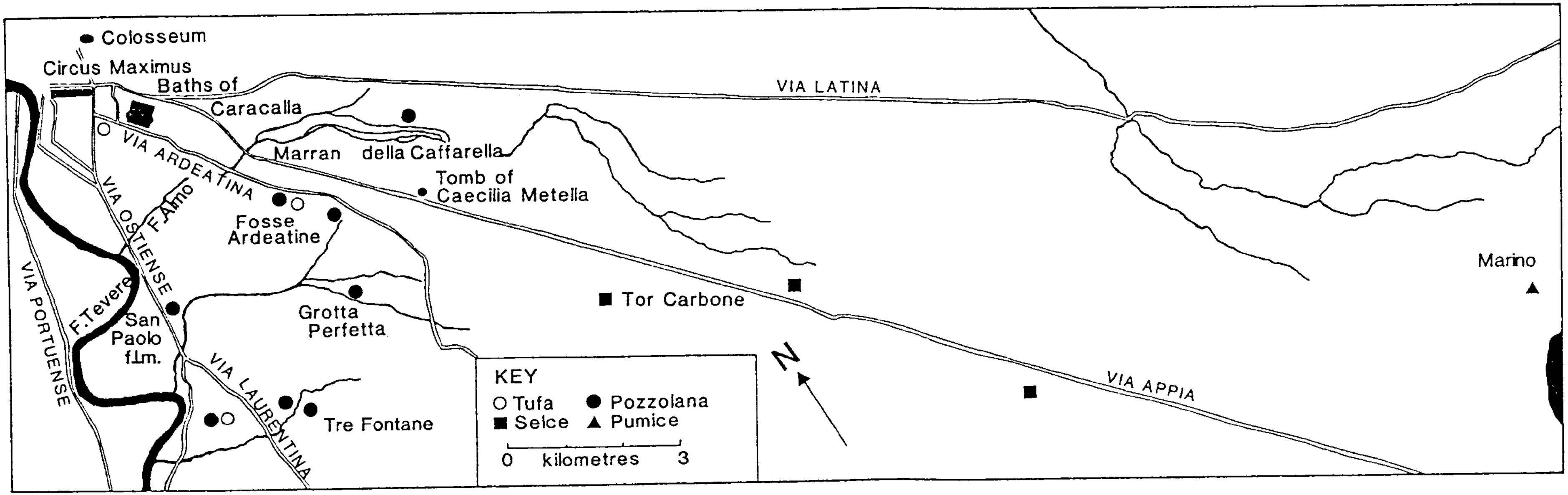


Baths of Caracalla, central block, plan of frigidarium and natatio showing foundations (hatched) and ideal distribution of columns in red.

Figure 48



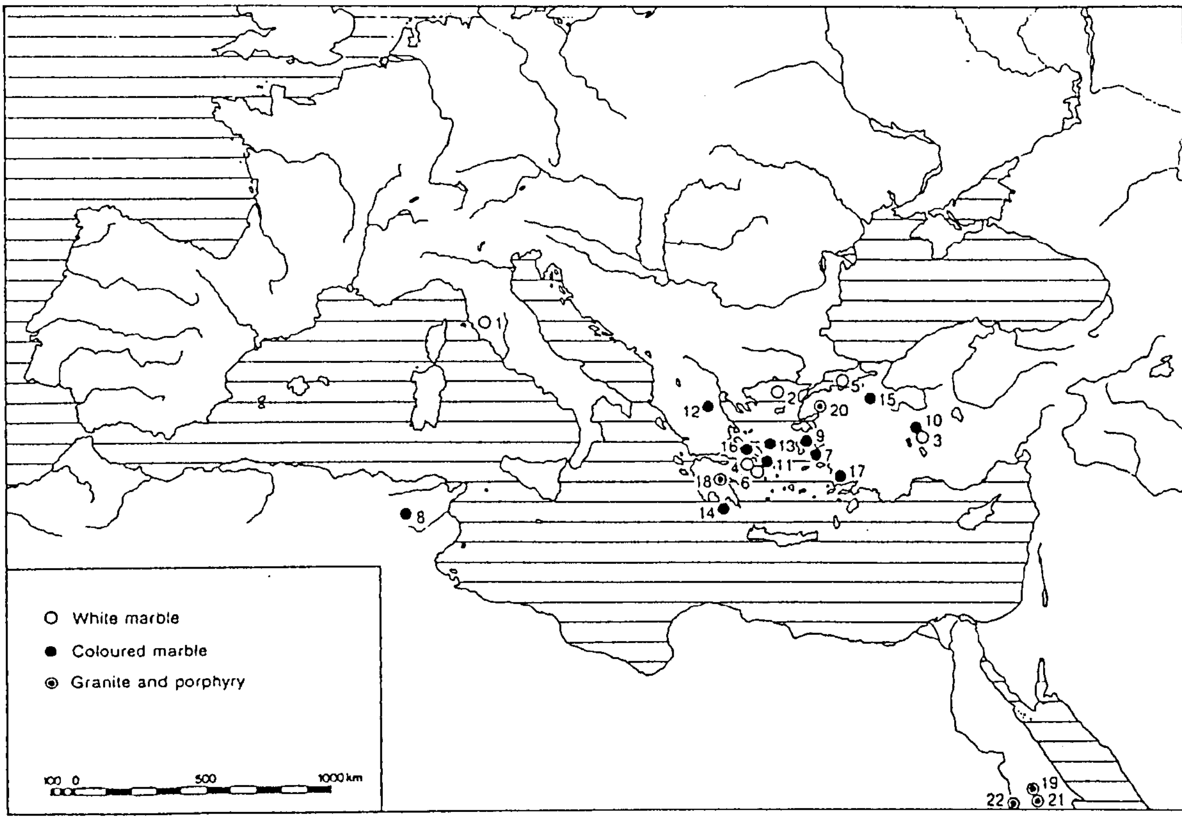
Baths of Caracalla, central block, elevation of <u>frigidarium</u> and Rms 14 with design scheme.



Rome and the Campagna, showing the sources of locally quarried materials used in the Baths of Caracalla.

(a) Baths of Caracalla, central block, Rm 3E, brick facing, exposed core and bonding course.

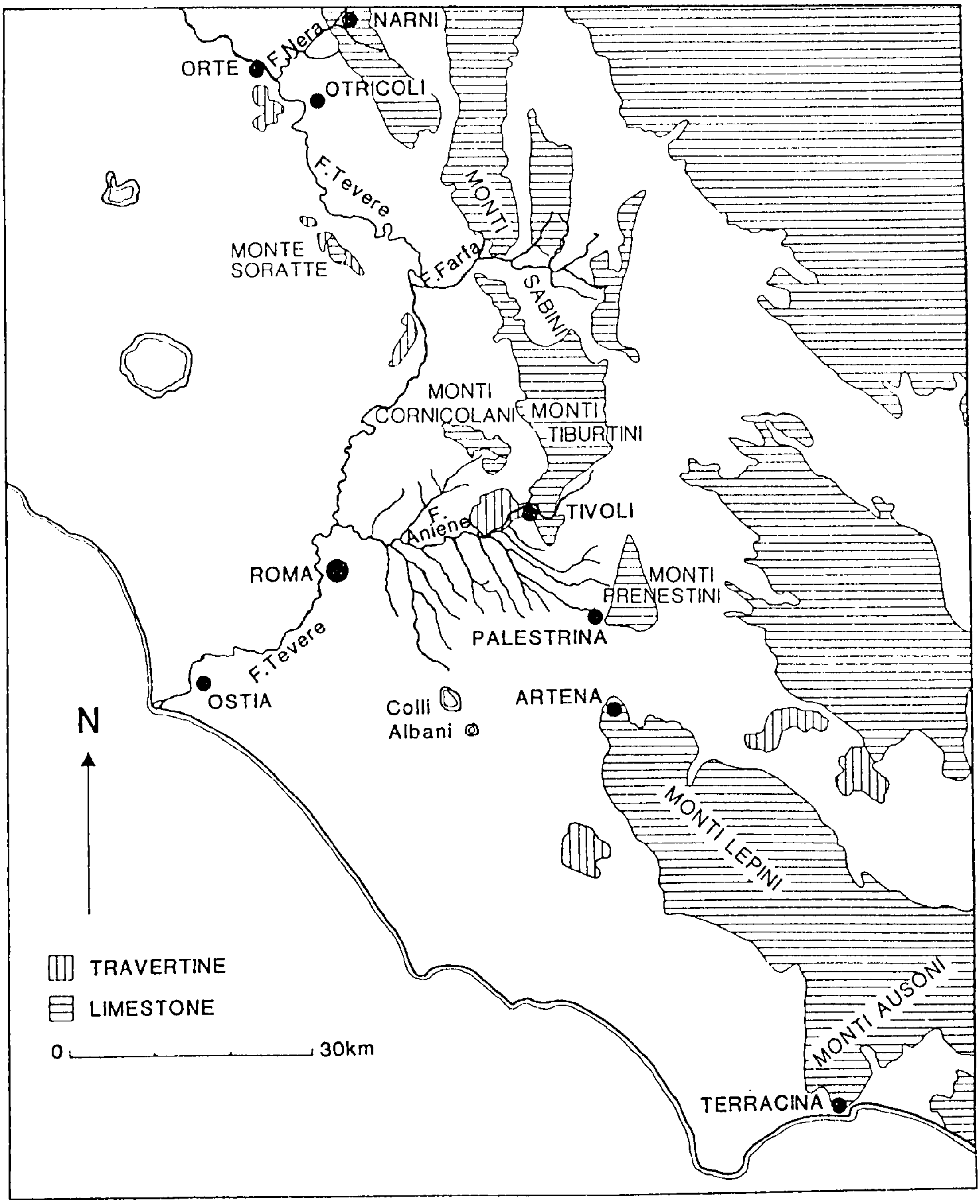
(b) As above, detail of exposed core.



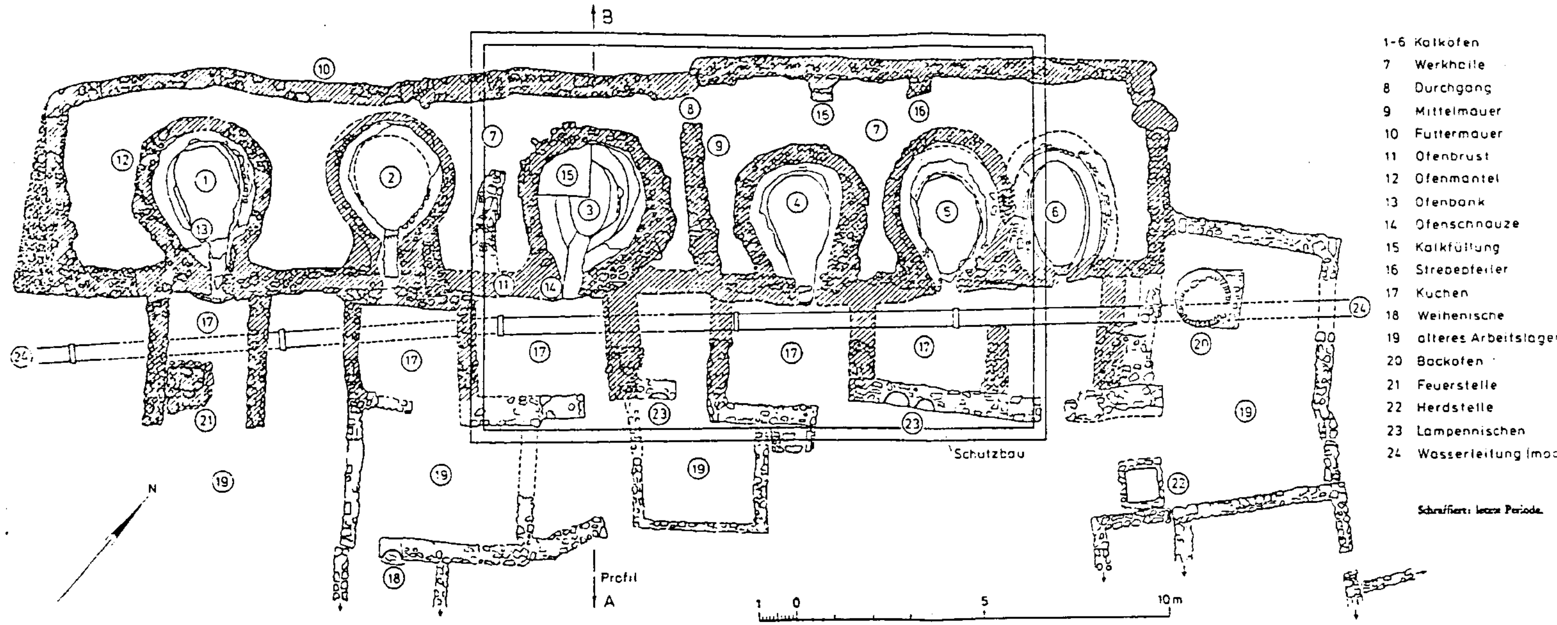
Sources of the main marbles used in the Baths of Caracalla.

1. Carrara (Luna)
4. Mt Pentelicon
5. Proconnesos
7. Teos (africano)
8. Chemtou (Numidian)
9. Chios
10. Docimium
11. Carystos
12. Thessaly (verde antico)
14. Cape Taenarum (rosso antico)
15. Vezirken (breccia corallina)
18. Sparta (green porphyry)
19. Gebel Dokhan (red porphyry)
21. Gebel Fatireh (Mons Claudianus)
22. Assuan (Syene. The dot on the map should be roughly 300 km further south.)

Adapted from Dodge 1988, Fig. 7.1.

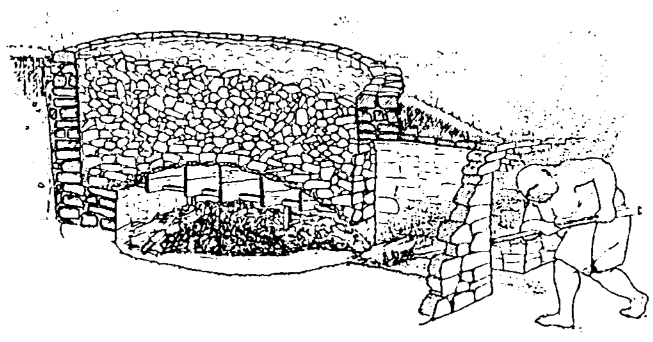


Rome and central Italy, showing the limestone areas.

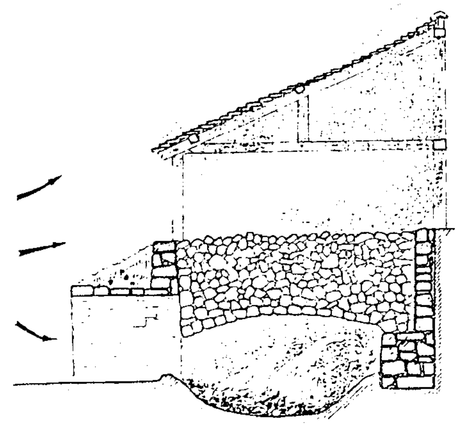


(a) Iversheim, serial lime kilns. From Solter 1970, Fig. 15.

(b) Reconstruction of a Roman periodic lime kiln. From Dix 1982, Figs 2 and 3.



Reconstruction of a periodic lime-kiln ready for firing



Firing the lime-kiln. Draught channelled across the top of the kiln drew hot gas and air from within, creating a turbulence domain at the bottom.

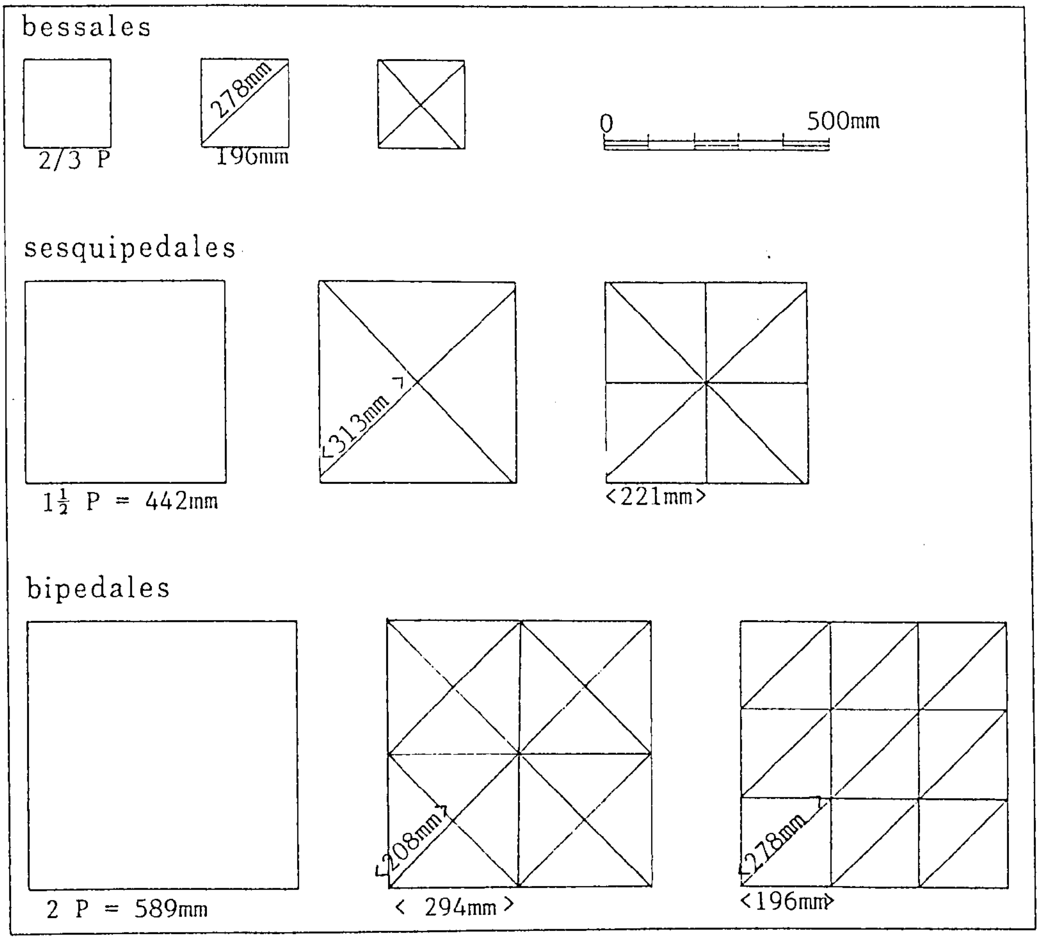


Fig. 54: Standard sizes of Roman brick with divisions into triangles for brick facing.

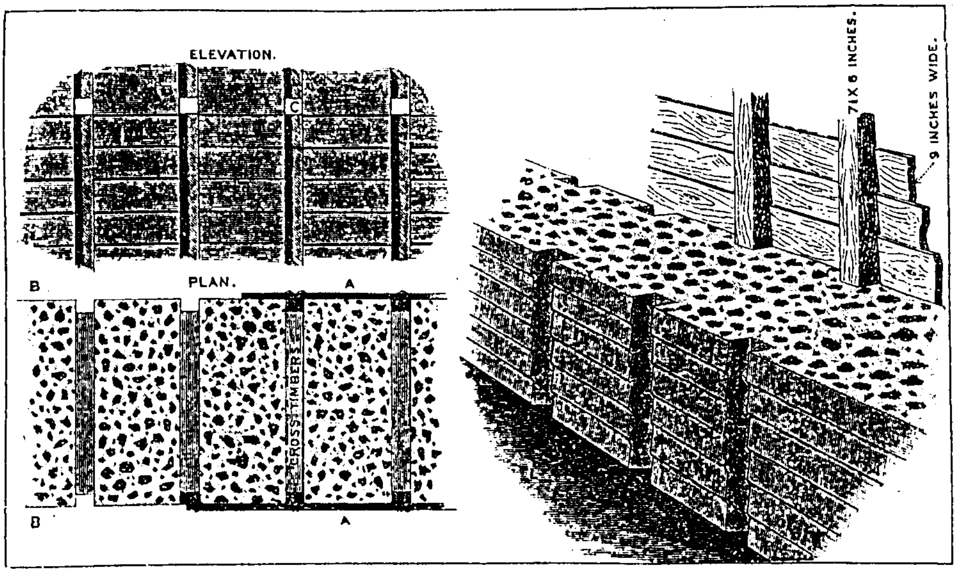
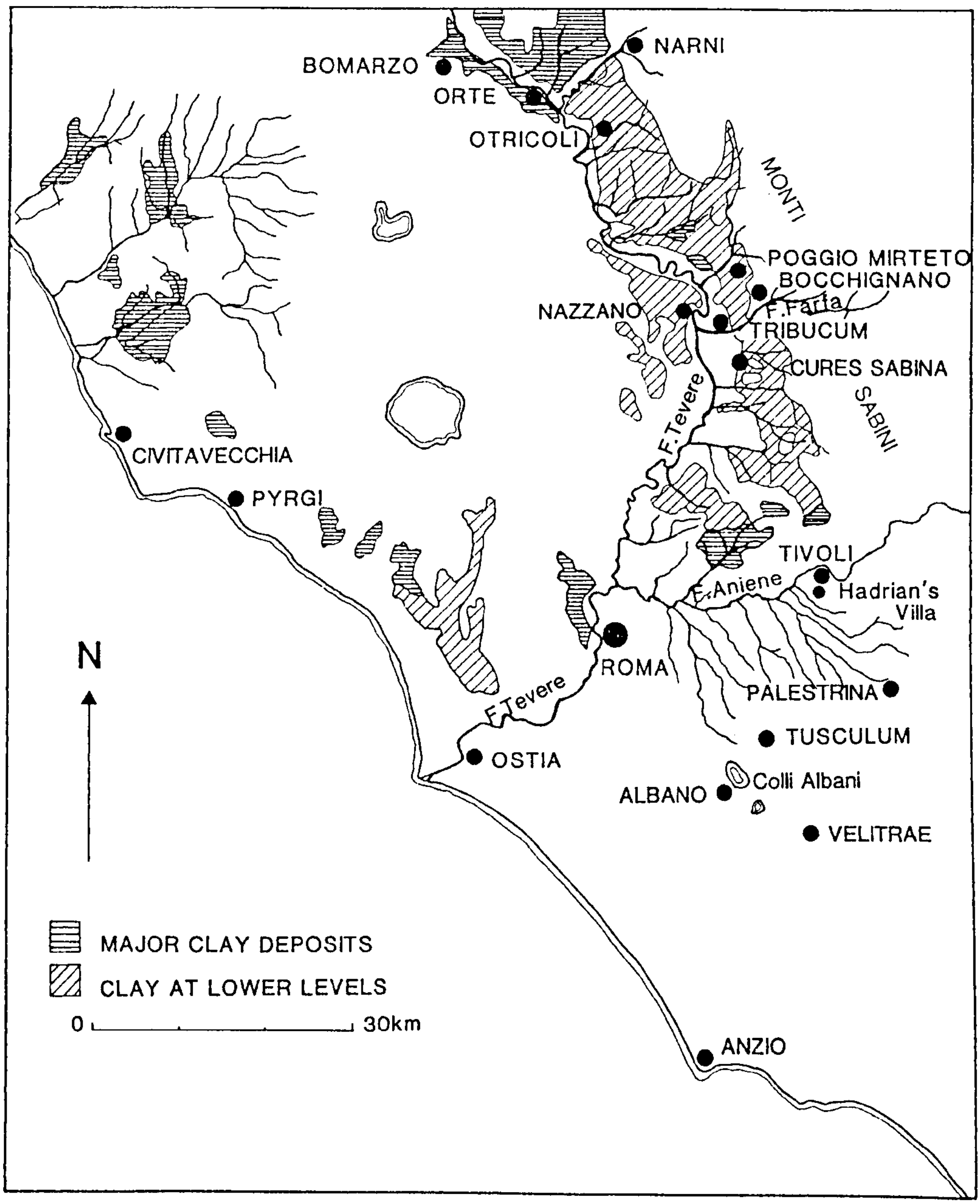
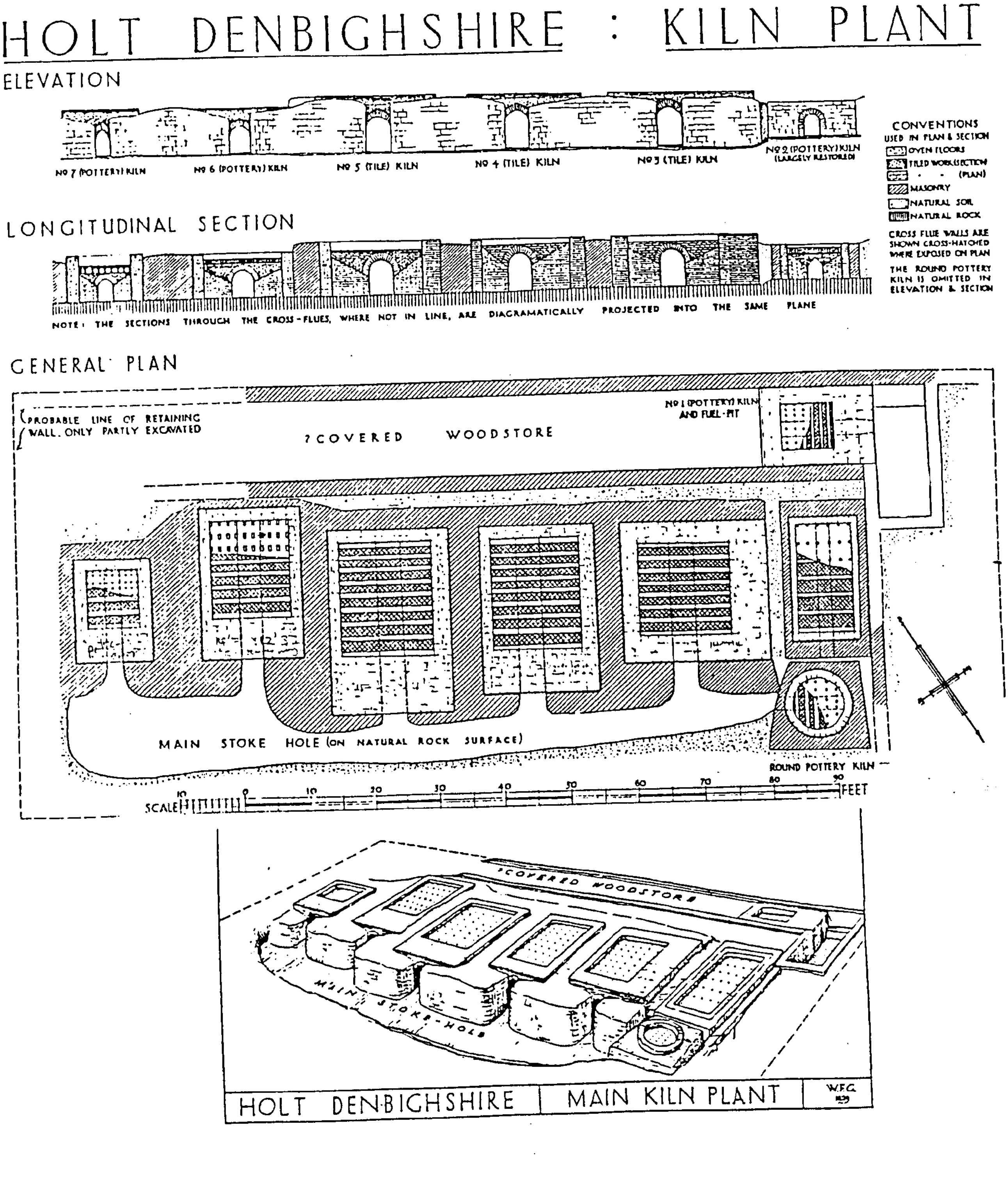


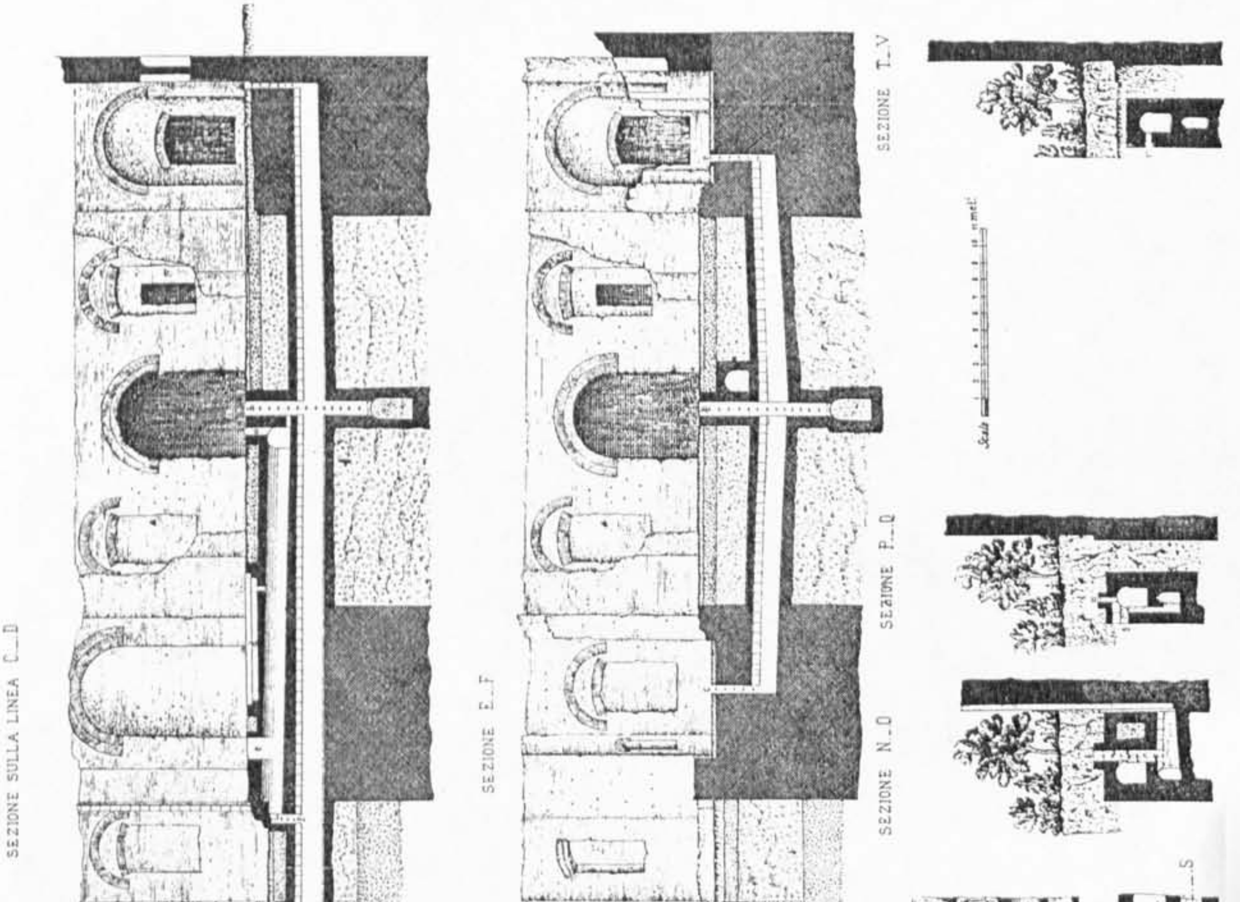
Fig. 57: Roman foundation construction. From Middleton 1892 (I), Fig. 3.



Rome and central Italy, showing sources of clay.



From Grimes 1930, Fig. 19.



Baths of Caracalla, central block, sections through maintenance passages and drains. From De Angelis 1903, Tav. 2.

Fig. 59: Baths of Caracalla, central block, Rm 9W, robber holes from travertine sub-bases of columnar screens.

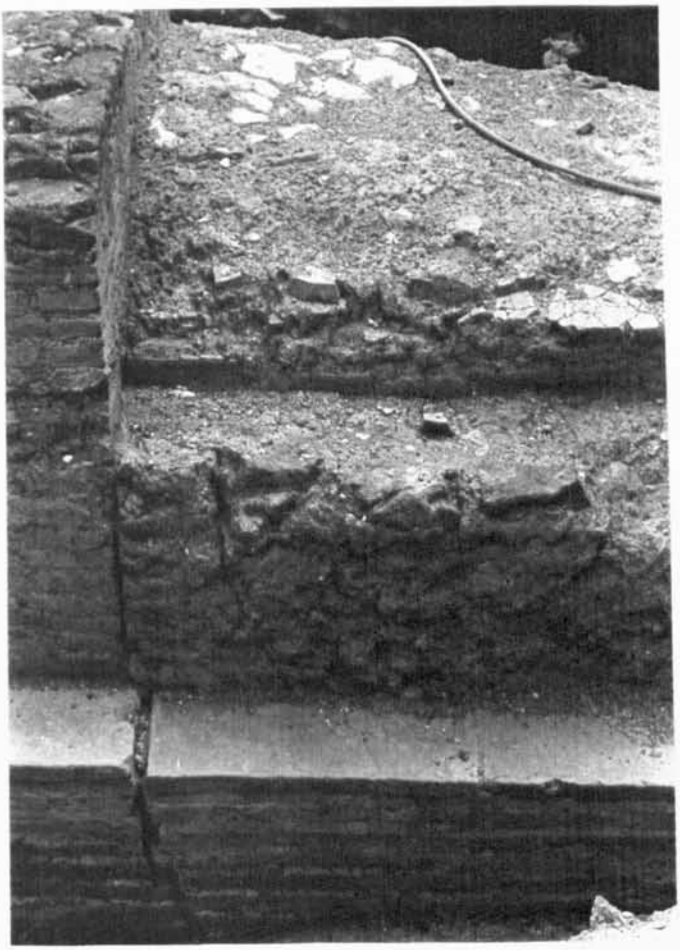
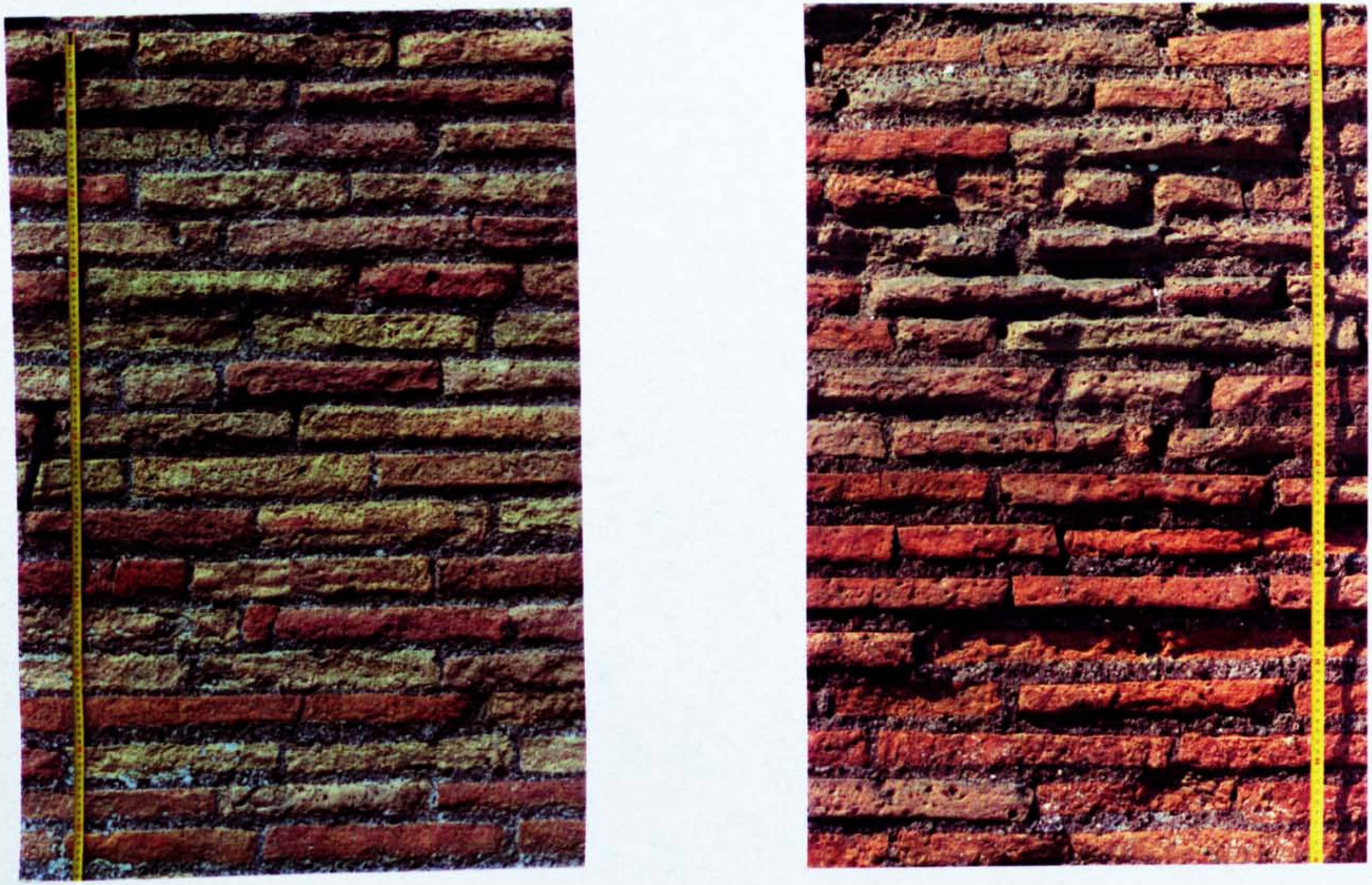


Fig. 60: Baths of Caracalla, central block, Rm 9E, foundation abutment.

Figure 61



(a) Baths of Caracalla, central block, Rm 19W, Type A brick facing

(b) Baths of Caracalla, central block, Rm 3W Type B brick facing

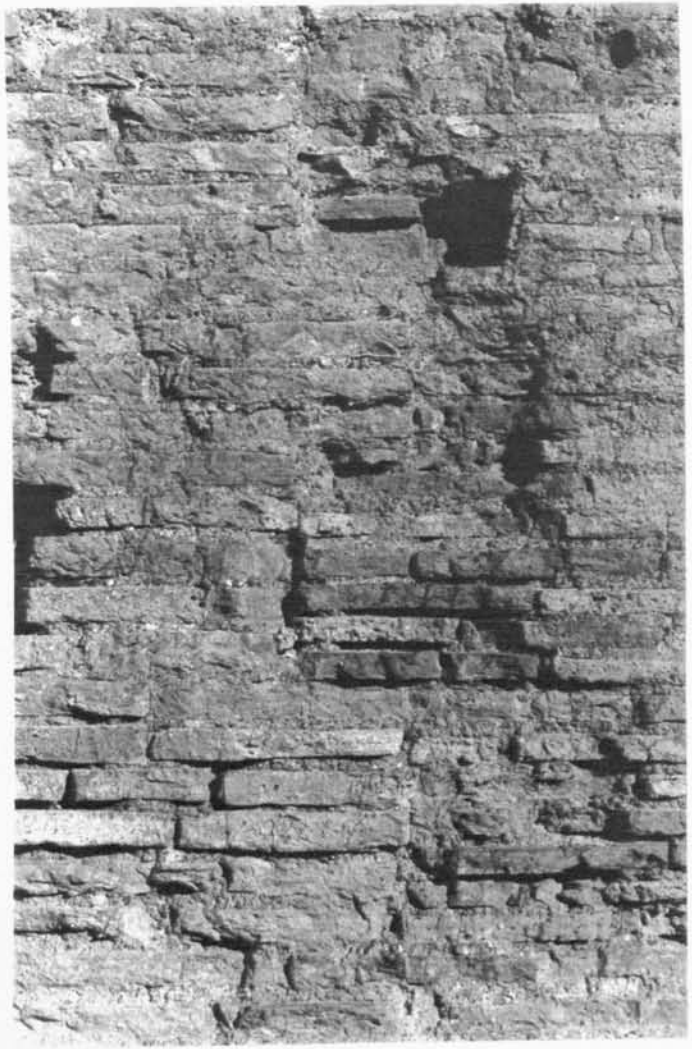


Fig. 62: Baths of Caracalla, central block, E caldarium pier, join in brickwork.

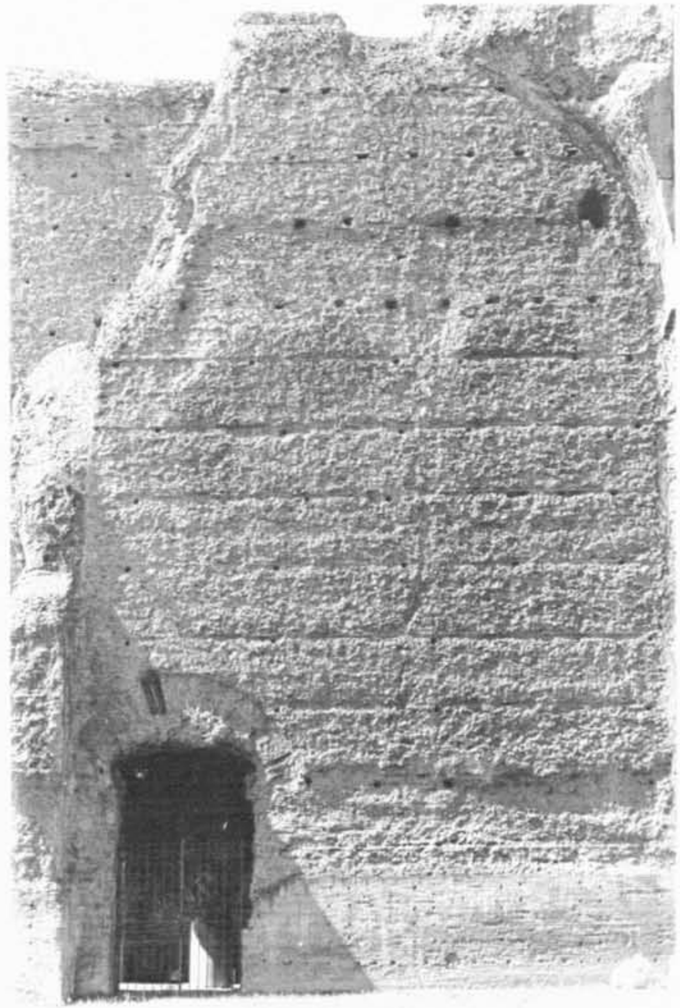


Fig. 63: Baths of Caracalla, central block Rm 10W, S wall.

Fig. 64: Baths of Caracalla, central block, Rm 12W, S wall, bonding courses and putlog holes.

Fig. 65: Baths of Caracalla, central block, Rm 4E, W wall, bonding courses and putlog holes.

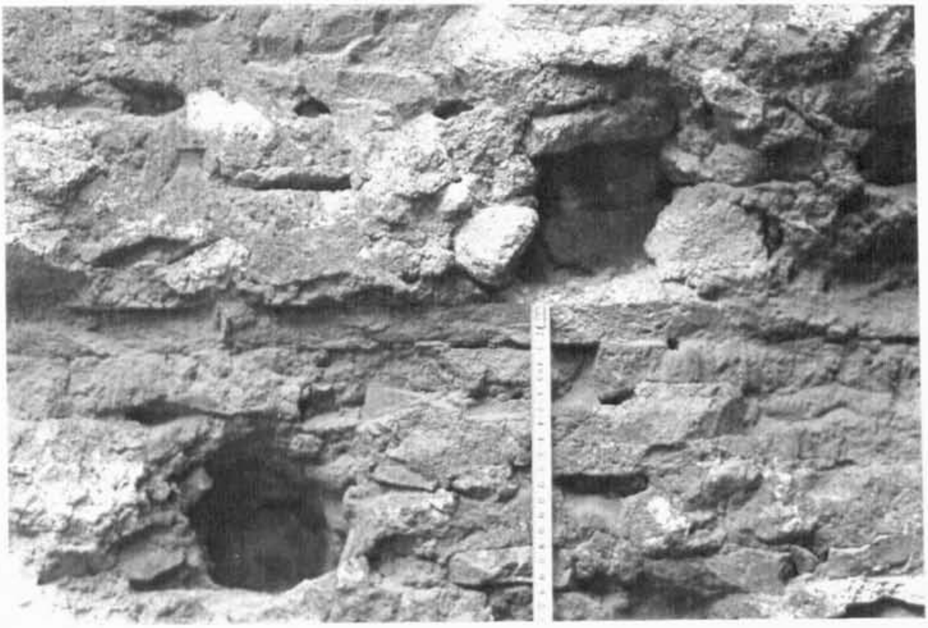


Fig. 66: Baths of Caracalla, central block, Rm 15E, putlog holes.

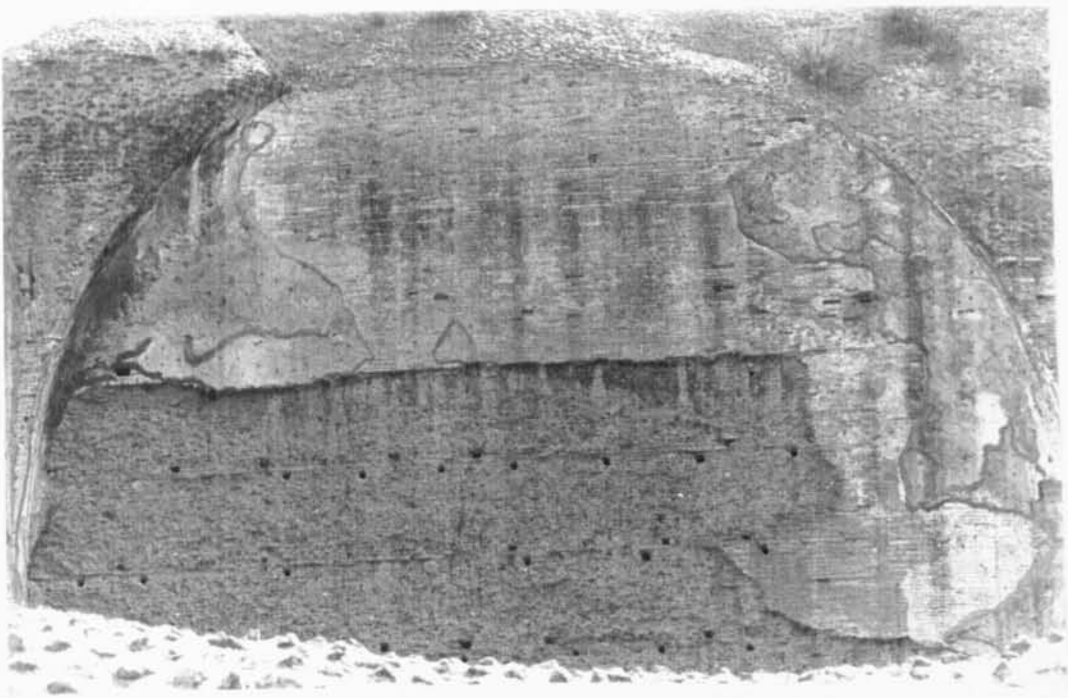
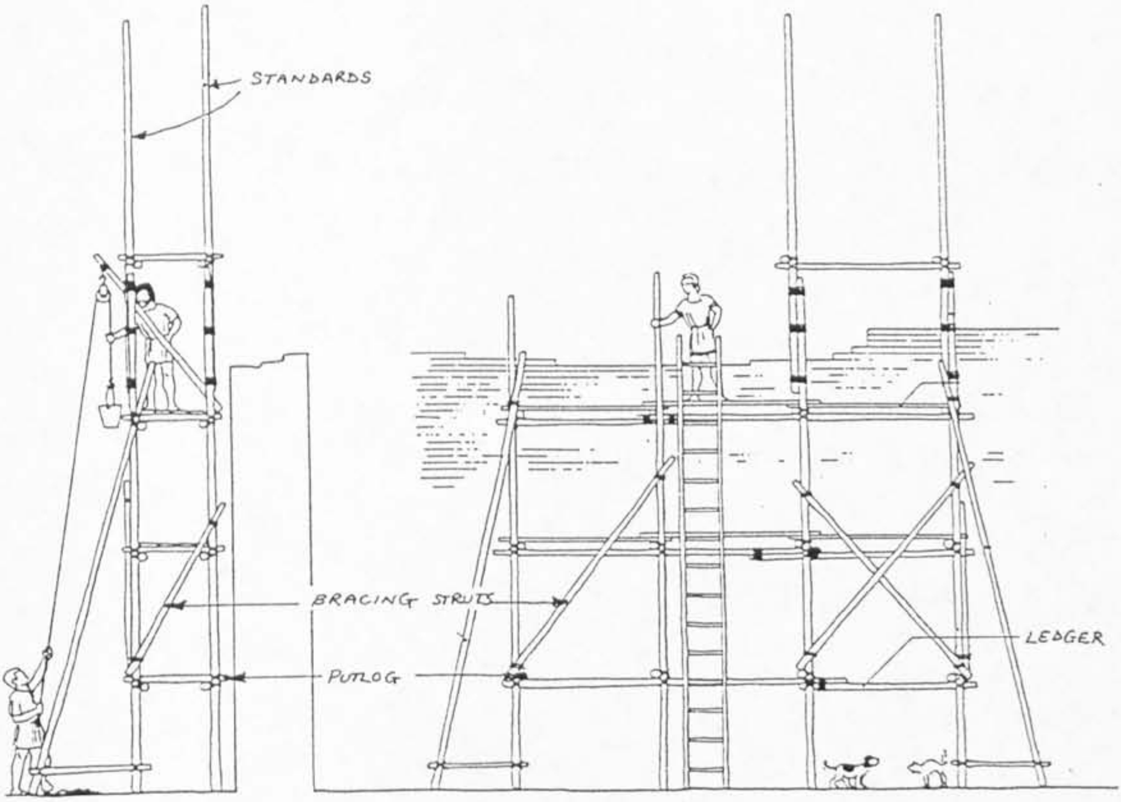


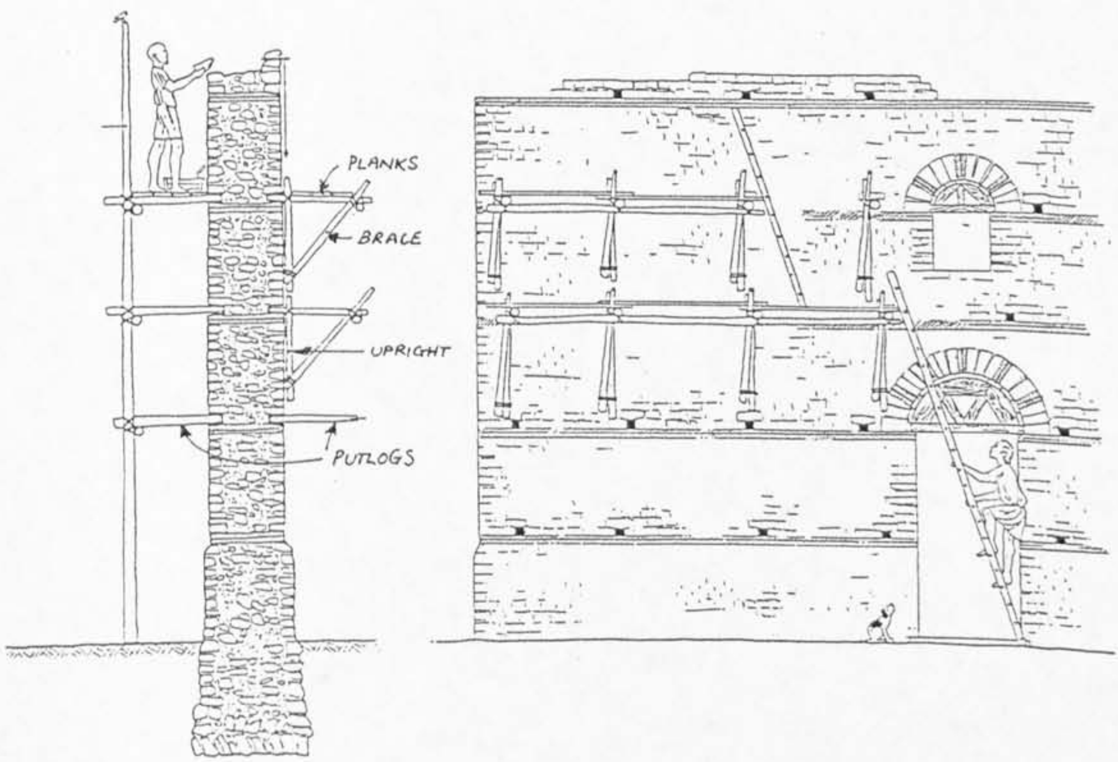
Fig. 67: Baths of Caracalla, central block, Rm 3E, upper part of W wall.

Fig. 68: Baths of Caracalla, central block, Rm 3W, N wall of terrace showing through putlog holes.

Fig. 69: Via Latina, Tomb of Trebius Justus, construction scene.

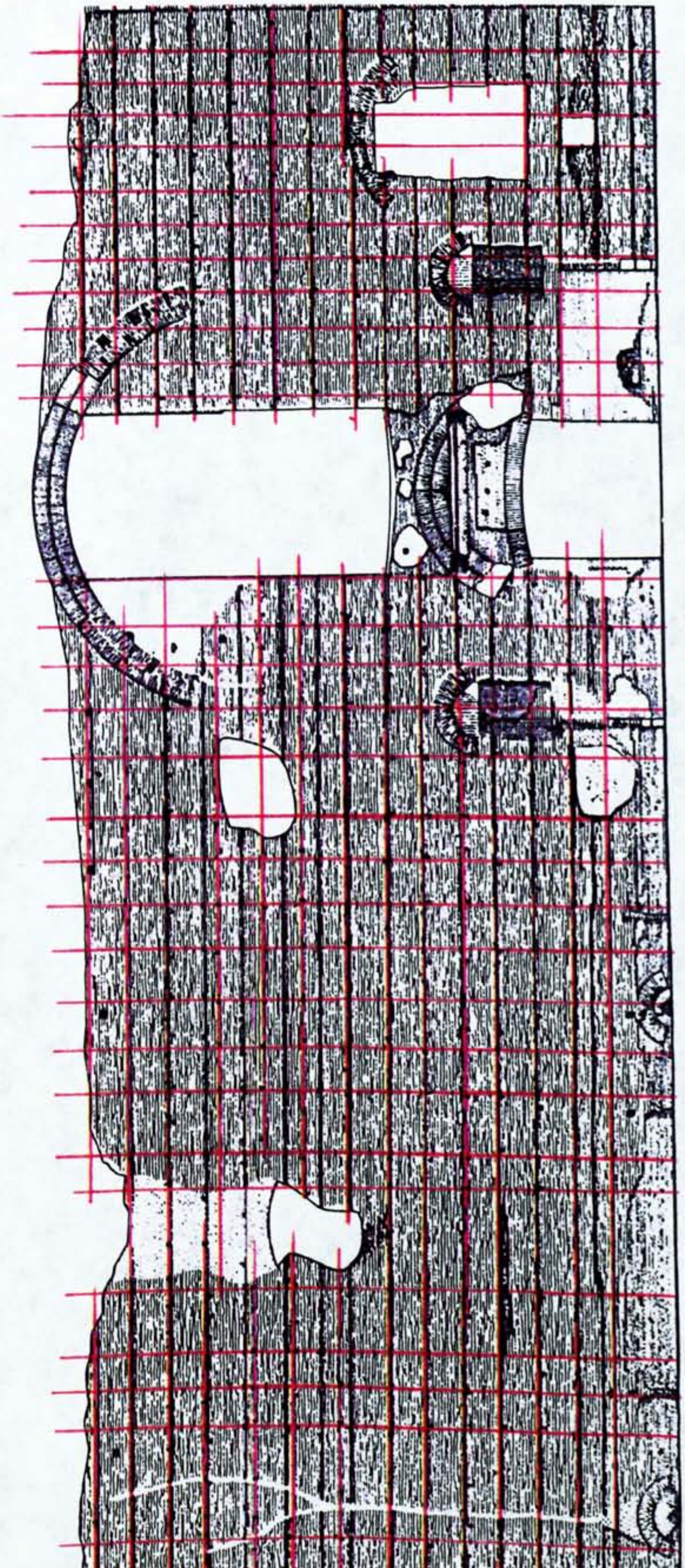


a) Free-standing scaffolding (after Adam 1984, Fig. 179)



b) Engaged scaffolding (after Adam 1984, Fig. 180)

Figure 71



Baths of Caracalla, central block, N facade elevation, present state with pattern of scaffolding superimposed in red. Adapted from Conforto 1991: Fig. 4b.

Fig. 72: Baths of Caracalla, central block, Rm 4W, detail of arch construction over door to Rm 12W.

Fig. 73: Baths of Caracalla, central block, Rm 12W, arch over door to Rm 7W.

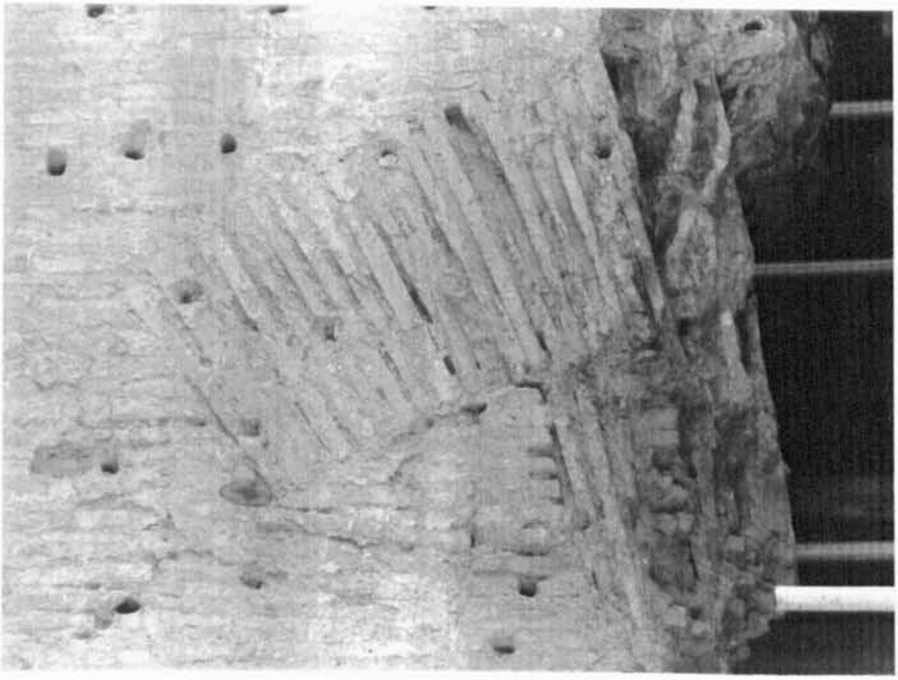


Fig. 74: Baths of Caracalla, central block, Rm 3W, detail of door arch to Rm 3Wb.

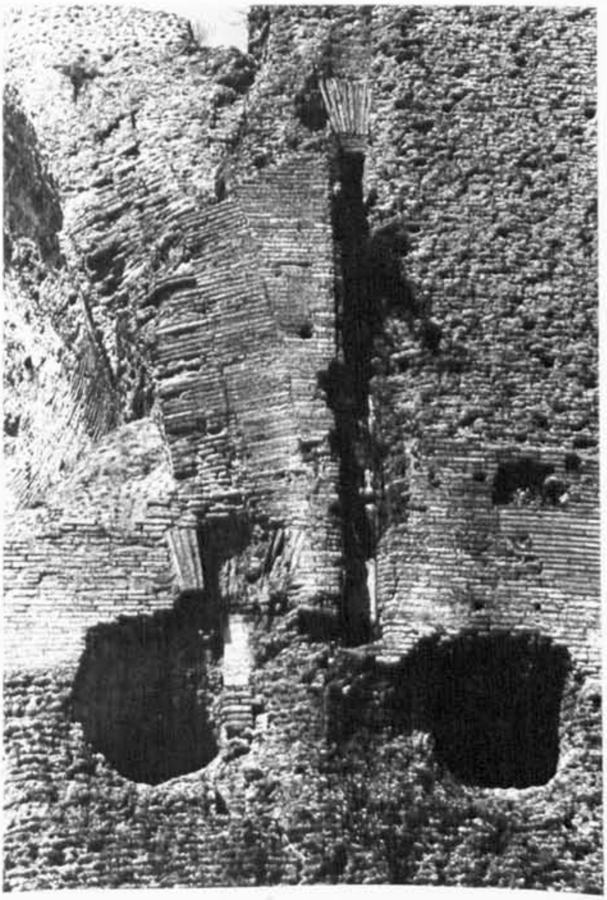


Fig. 75: Baths of Caracalla, central block, Rm 12W, detail of drains at terrace level, E wall.

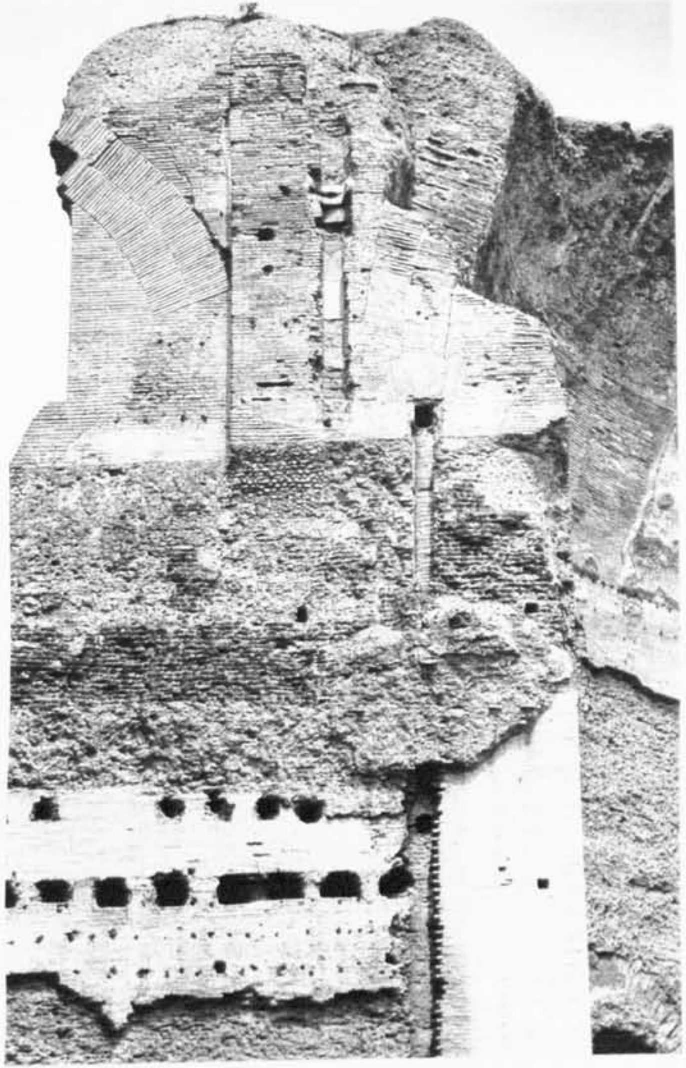


Fig. 76: Baths of Caracalla, central block, Rm 12E, vertical drain slots in W wall.

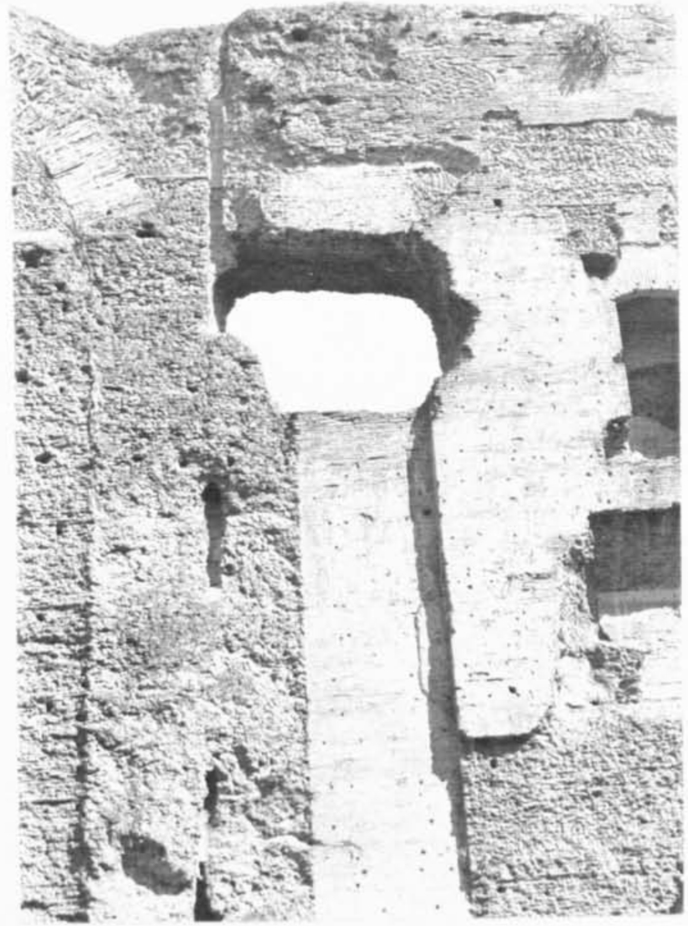
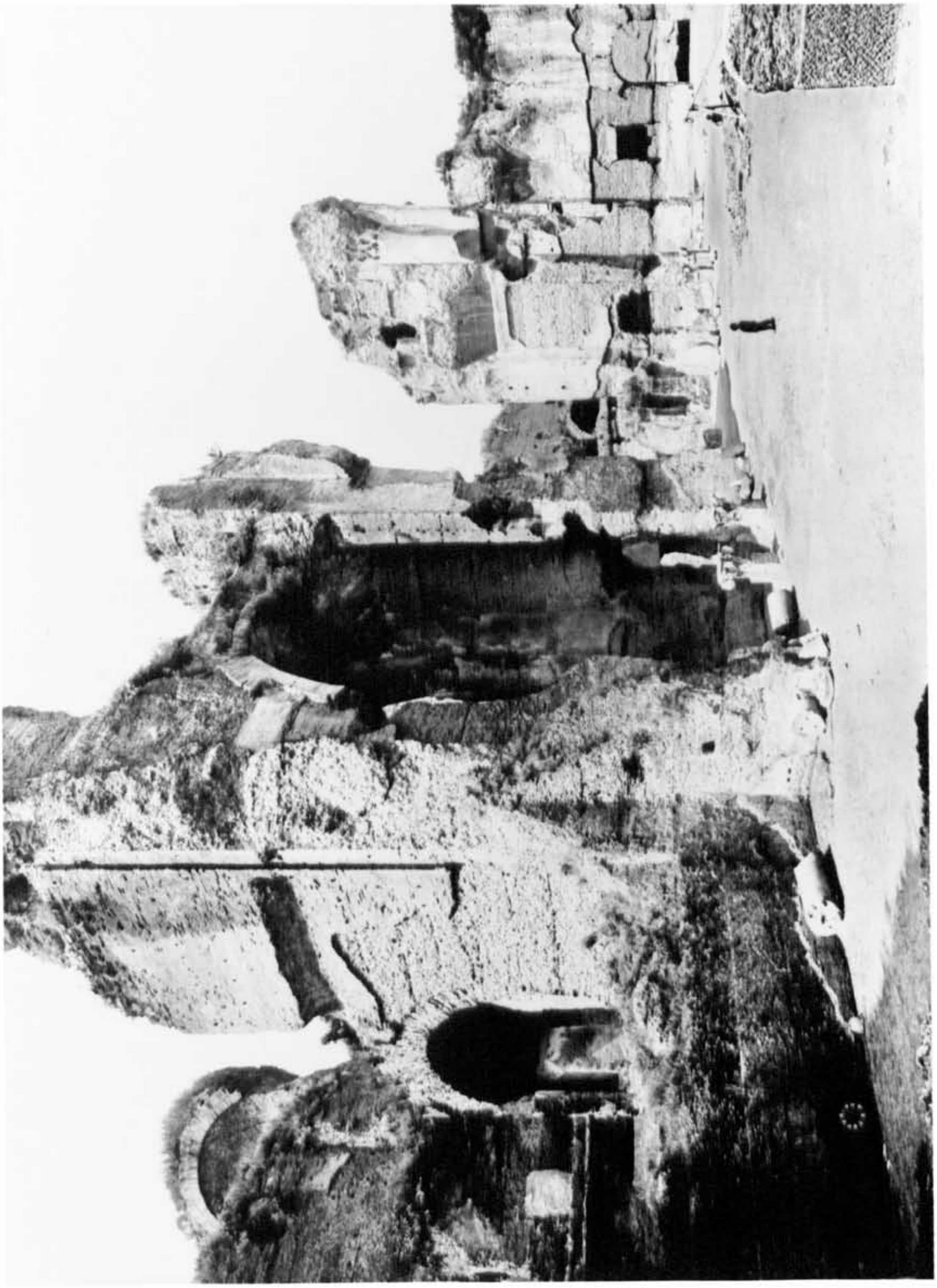


Fig. 77: Baths of Caracalla, central block down-pipe in thickness of wall.

Fig. 78: Baths of Caracalla, central block, N facade, door to Rm 5W, architrave block.

Fig. 79: Baths of Caracalla, central block S facade to Rm 19W, sockets for columnar order.

Figure 80



Baths of Caracalla, central block, view along <u>frigidarium</u> c. 1875.
Alinari No. 573.

Baths of Caracalla, central block, view along frigidarium after restoration. Alinari No. 576.

Fig. 82: Baths of Caracalla, central block, _natatio_, S wall, sockets for corbels

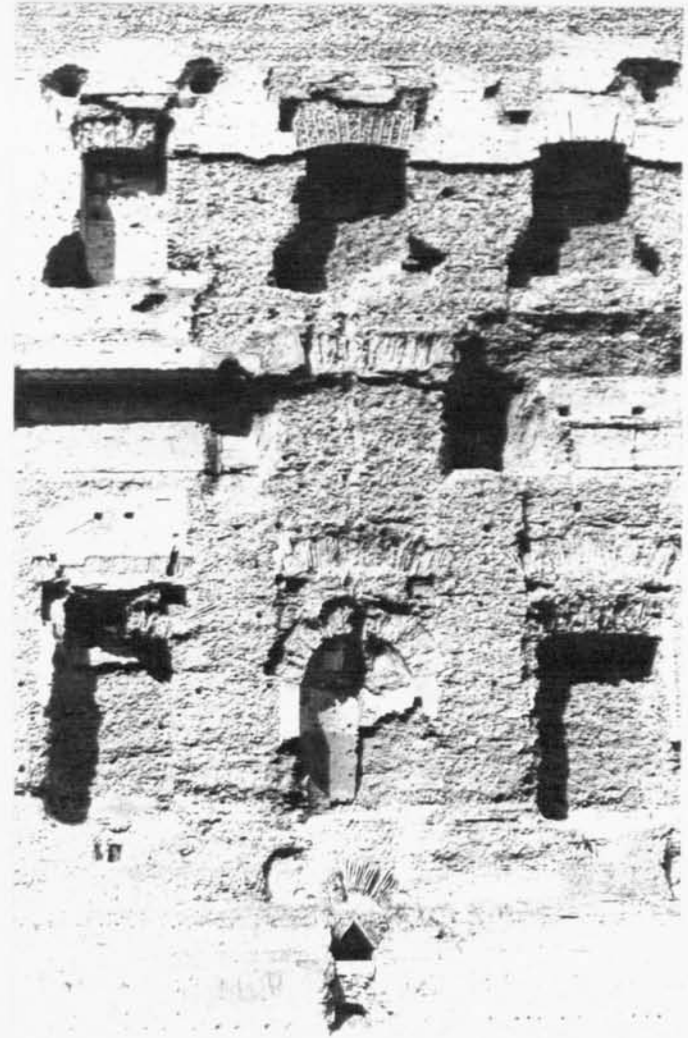


Fig. 83: Baths of Caracalla, central block _natatio_, sockets for columnar order

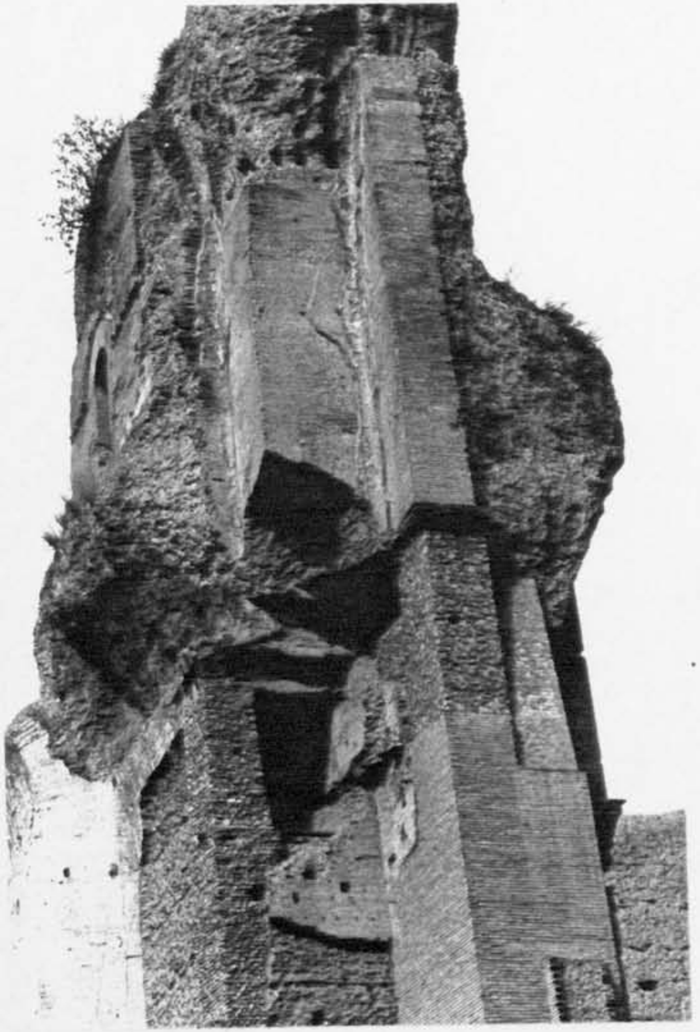
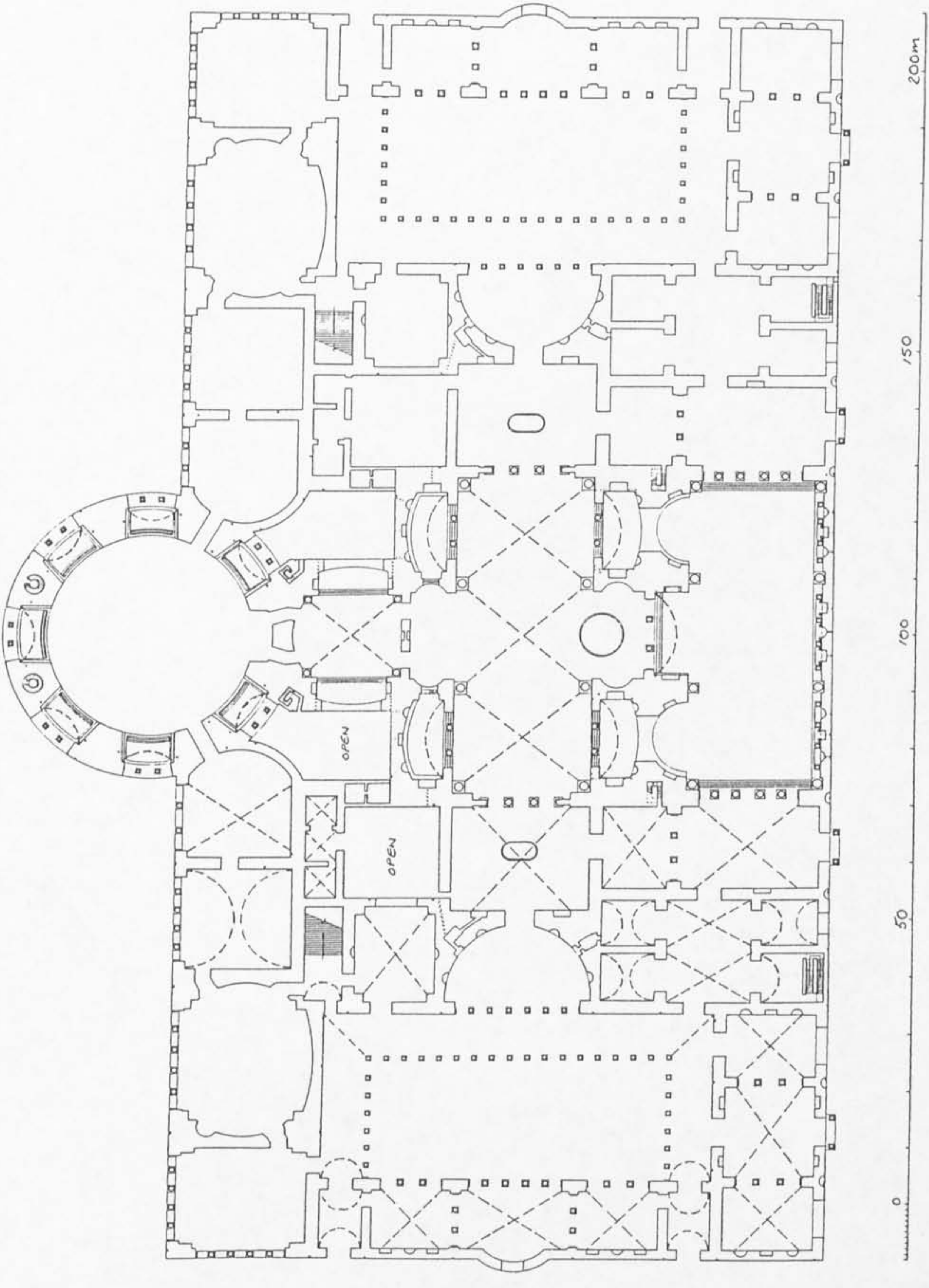


Fig. 84: Baths of Caracalla, central block frigidarium, SW pier, sockets for entablature.

Fig. 85: Basilica of Maxentius, NE corner corbelled entablature blocks.

Figure 86



Baths of Caracalla, central block, restored pattern of vaulting.

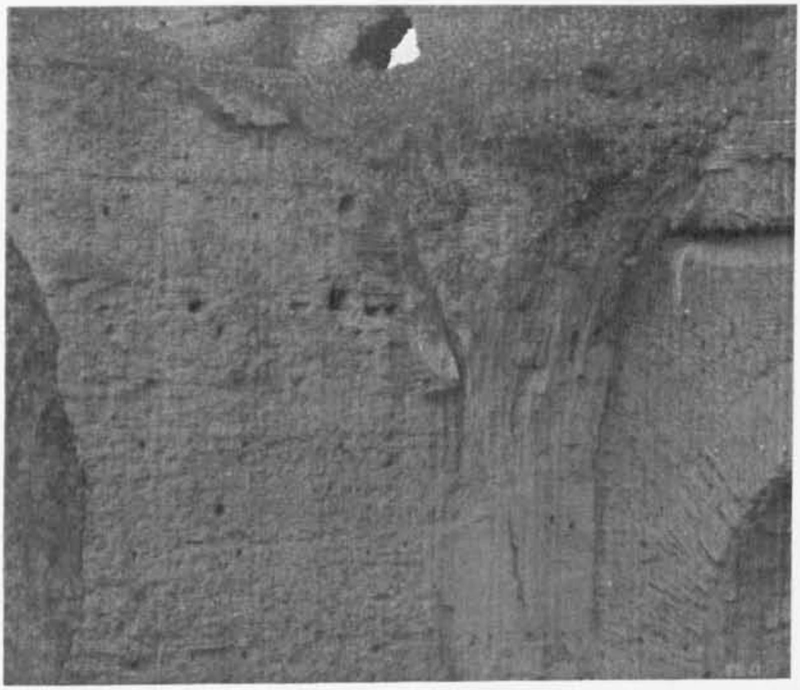


Fig. 87: Baths of Caracalla, central block, Rm 4E, vault construction

Fig. 88: Baths of Caracalla, central block, Rm 3E, vault construction with pumice in upper levels.

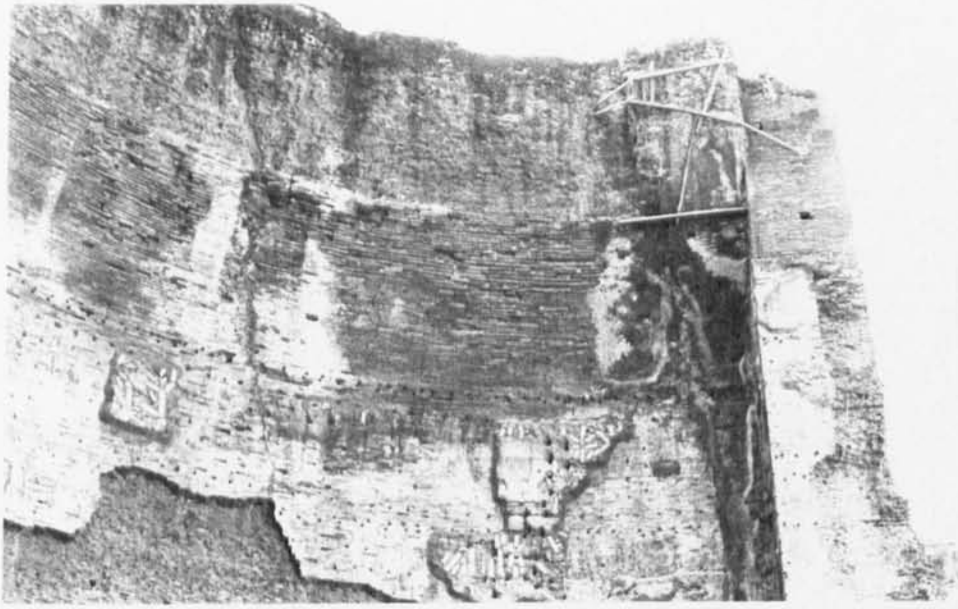


Fig. 89: Baths of Caracalla, cenral block, Rm 13W, brick construction at vault springing.

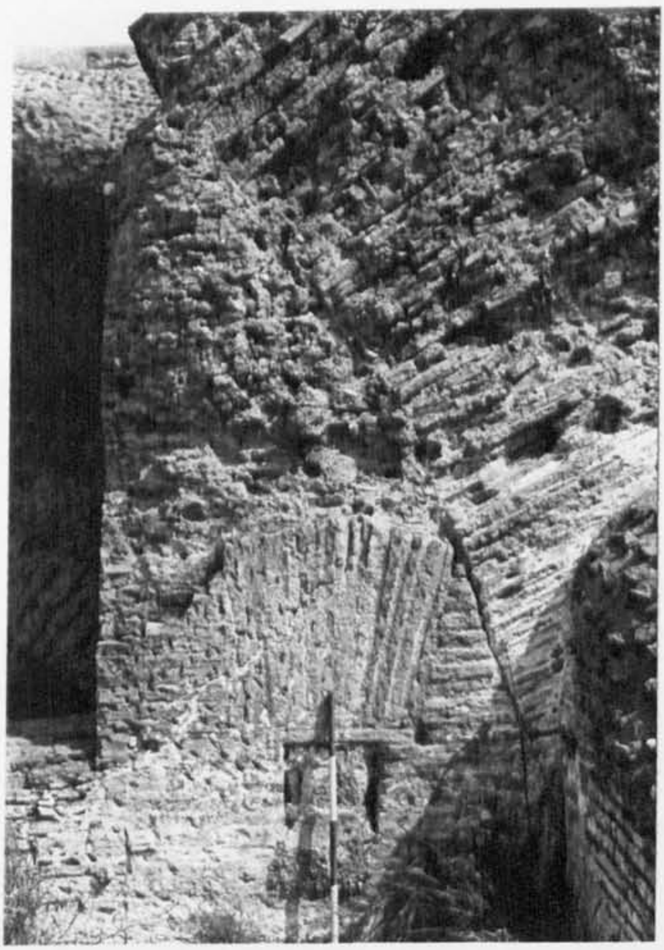


Fig. 90: Baths of Caracalla, central block, Rm 4W, vault-end arch at Rm 12W terrace level.

Fig. 91: Baths of Caracalla, central block, SW pier of frigidarium, detail of end-vault arch.

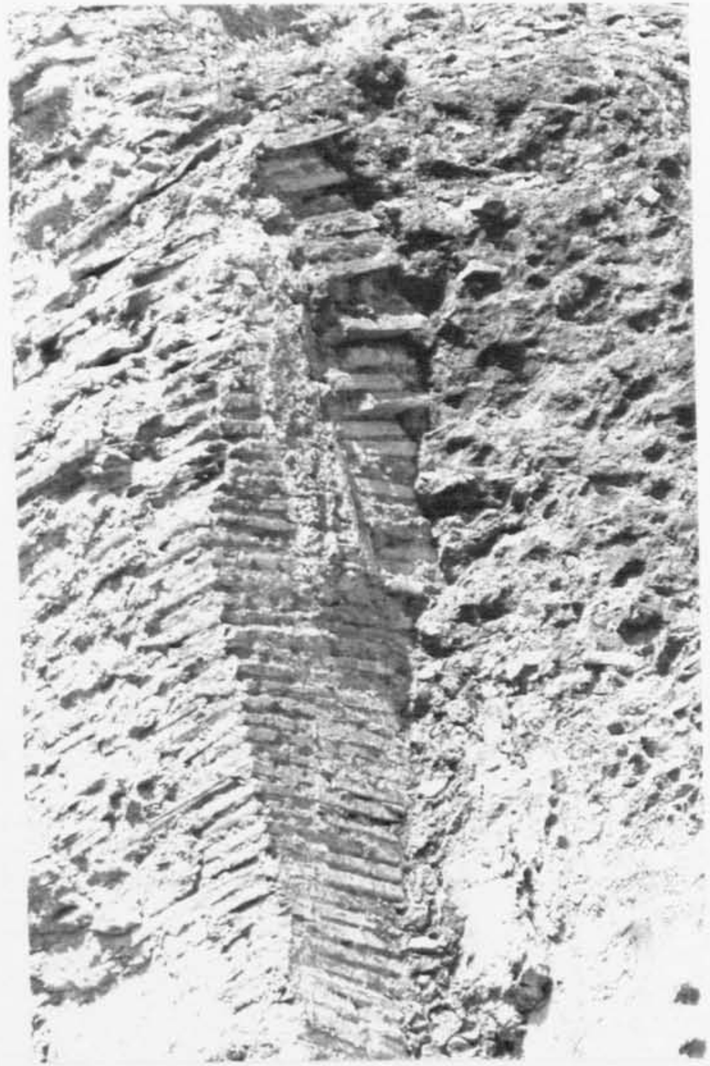
Fig. 94: Baths of Caracalla, central block, Rm 1W, N wall, vault construction.

(a) Baths of Caracalla, central block, Rm 21W, E wall and vault.

(b) Baths of Caracalla, central block, detail of vault construction as above.

Figure 93

(a) Baths of Caracalla, central block, Rms 9-10W dividing arch.



(b) Detail of arch and vault construction shown left.

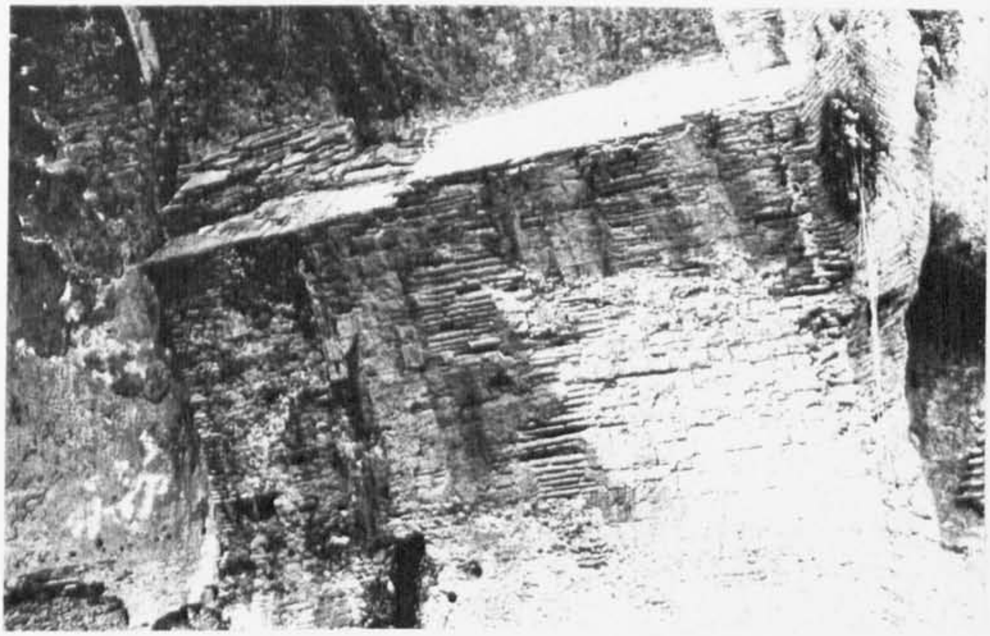


Fig. 95: Baths of Caracalla, central block, natatio, brick vault of central S bay.

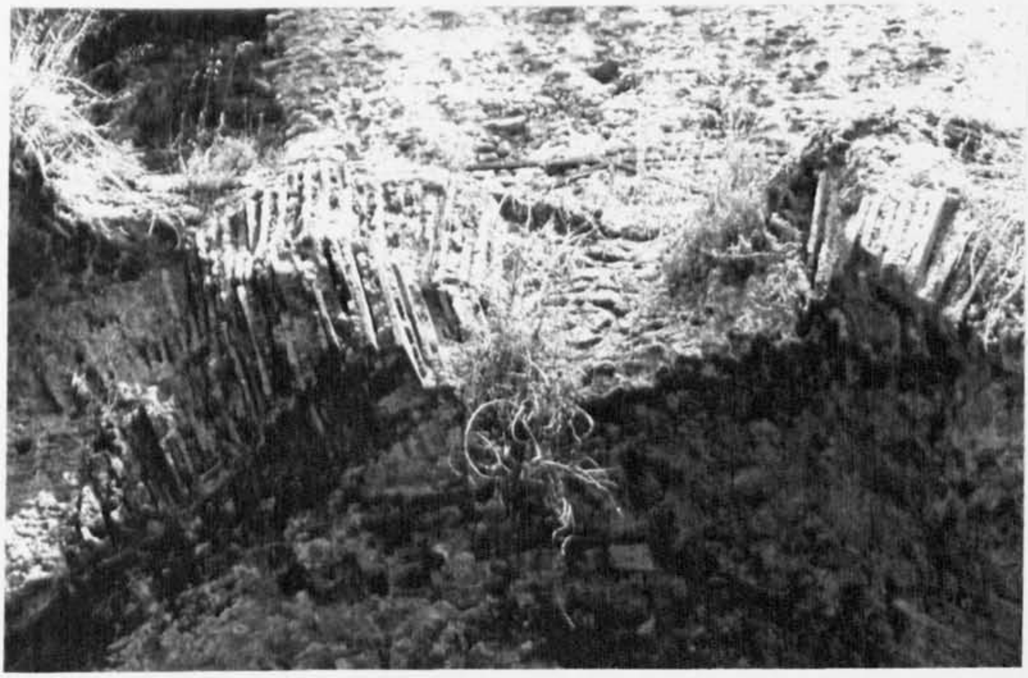


Fig. 96:, Baths of Caracalla, central block, Rm 3Wc, remains of brick vault.

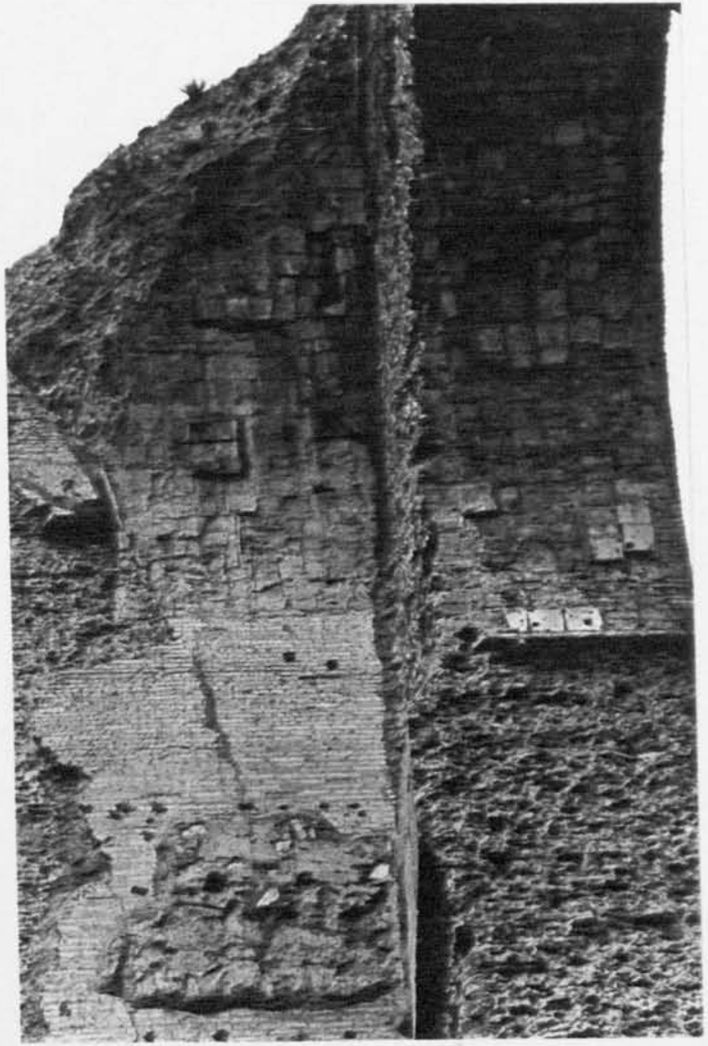


Fig. 97: Baths of Caracalla, central block, Rm 4E tile linings on vault and window arch.

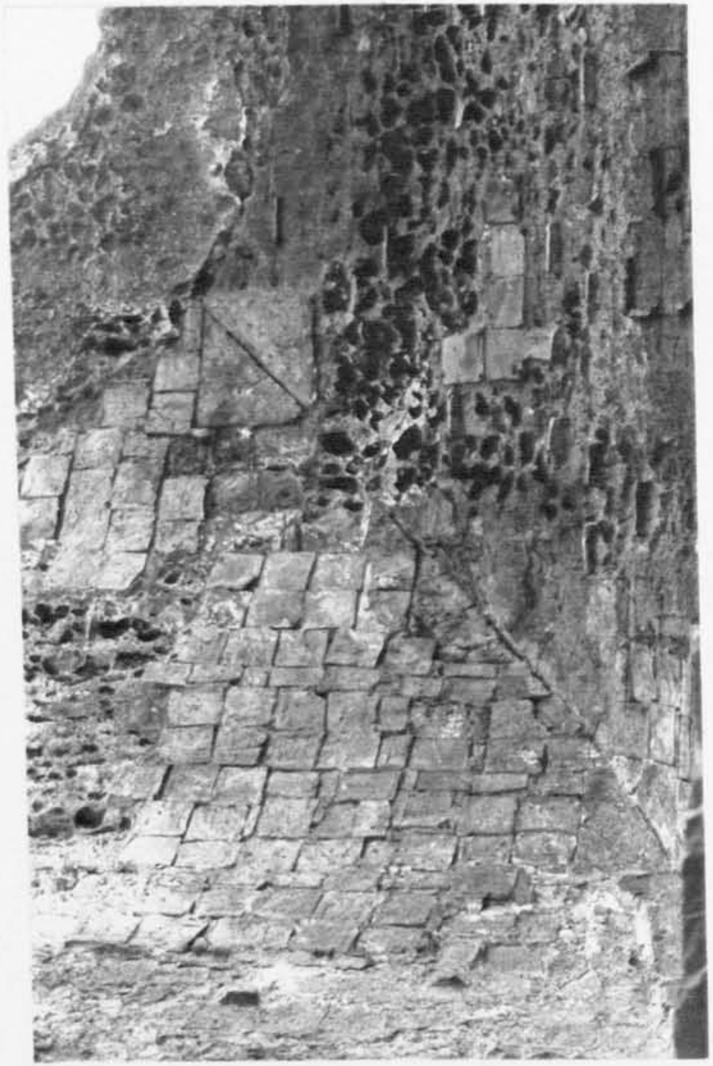
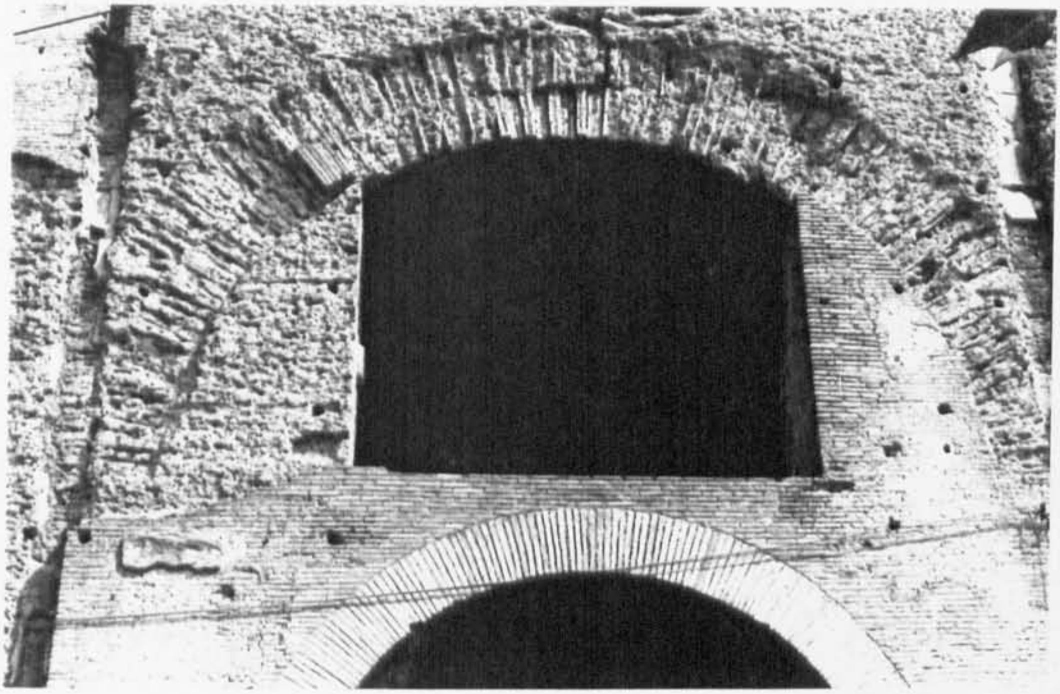
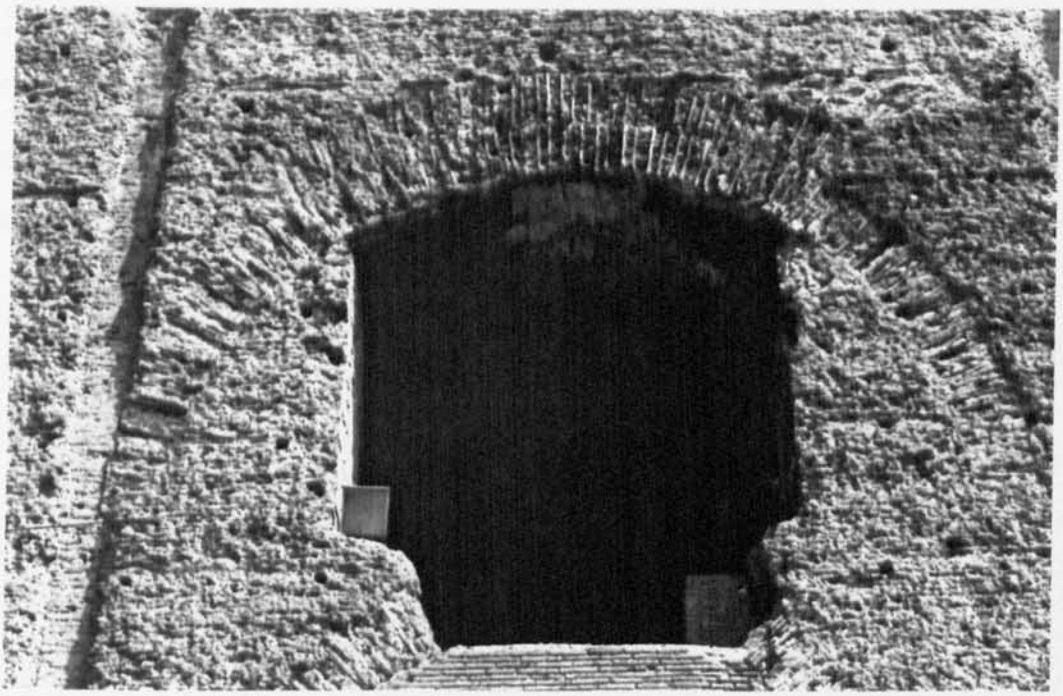


Fig. 98: Baths of Caracalla, central block, Rm 12W, detail of portico vault.



(a) Baths of Caracalla, central block, W facade, window to Rm 7W.



(b) As above, window to Rm 11W.

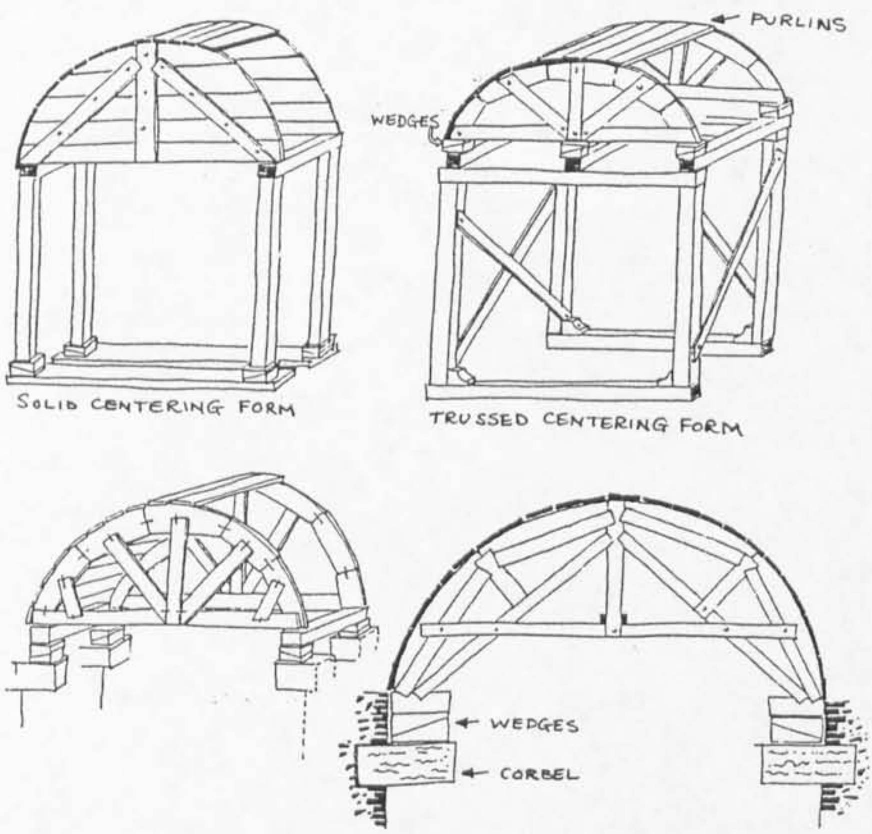
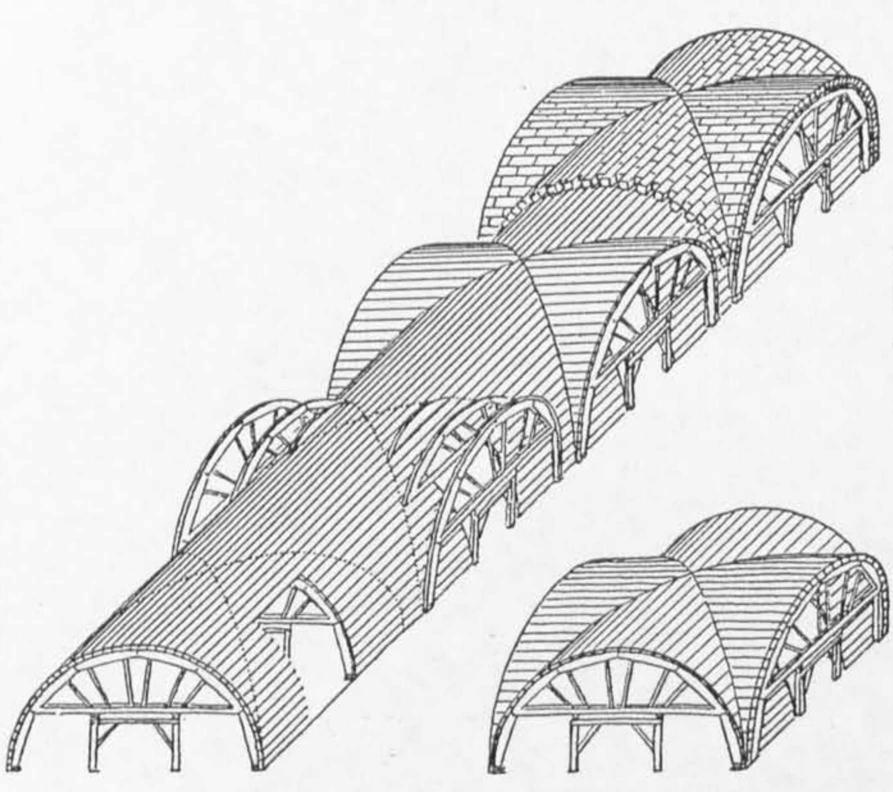


Fig. 100: Centering for barrel-vaults. After Giuliani 1990, Fig. 3.29.

Fig. 101: Centering for cross-vaults. From Fitchen 1961, Fig. 20.



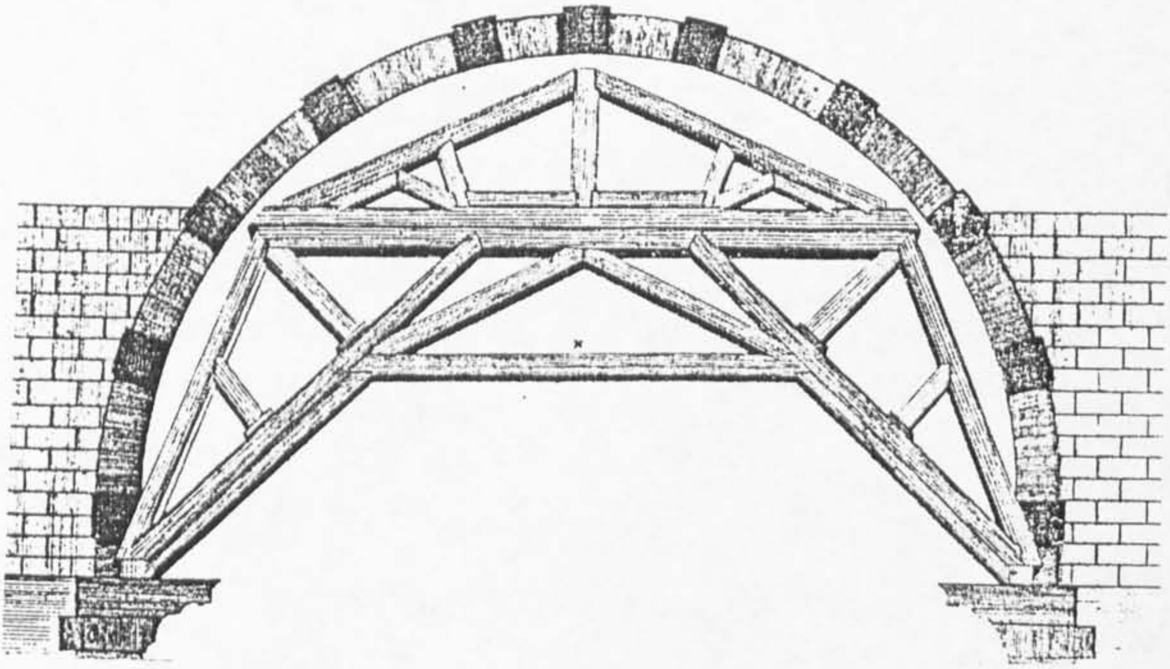


Fig. 102: Centering for the nave of new St Peter's in Rome. After Zabaglia 1743, Tav. IV.

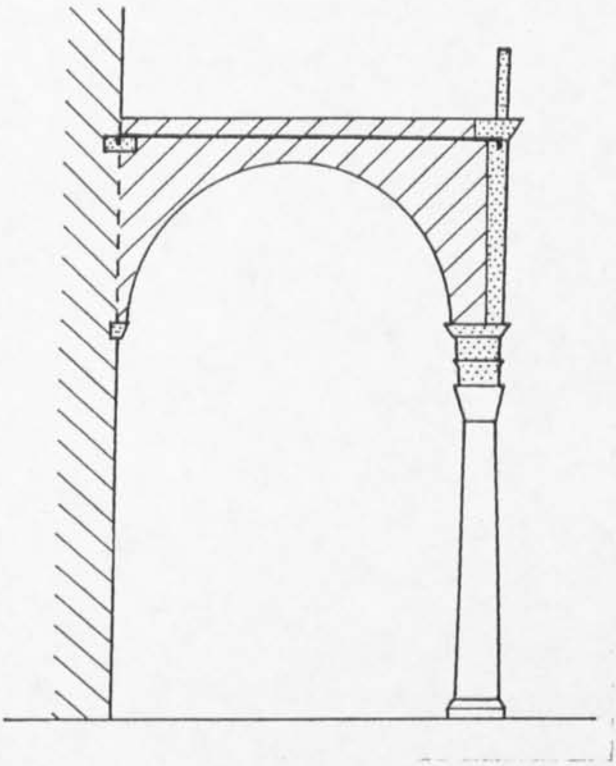
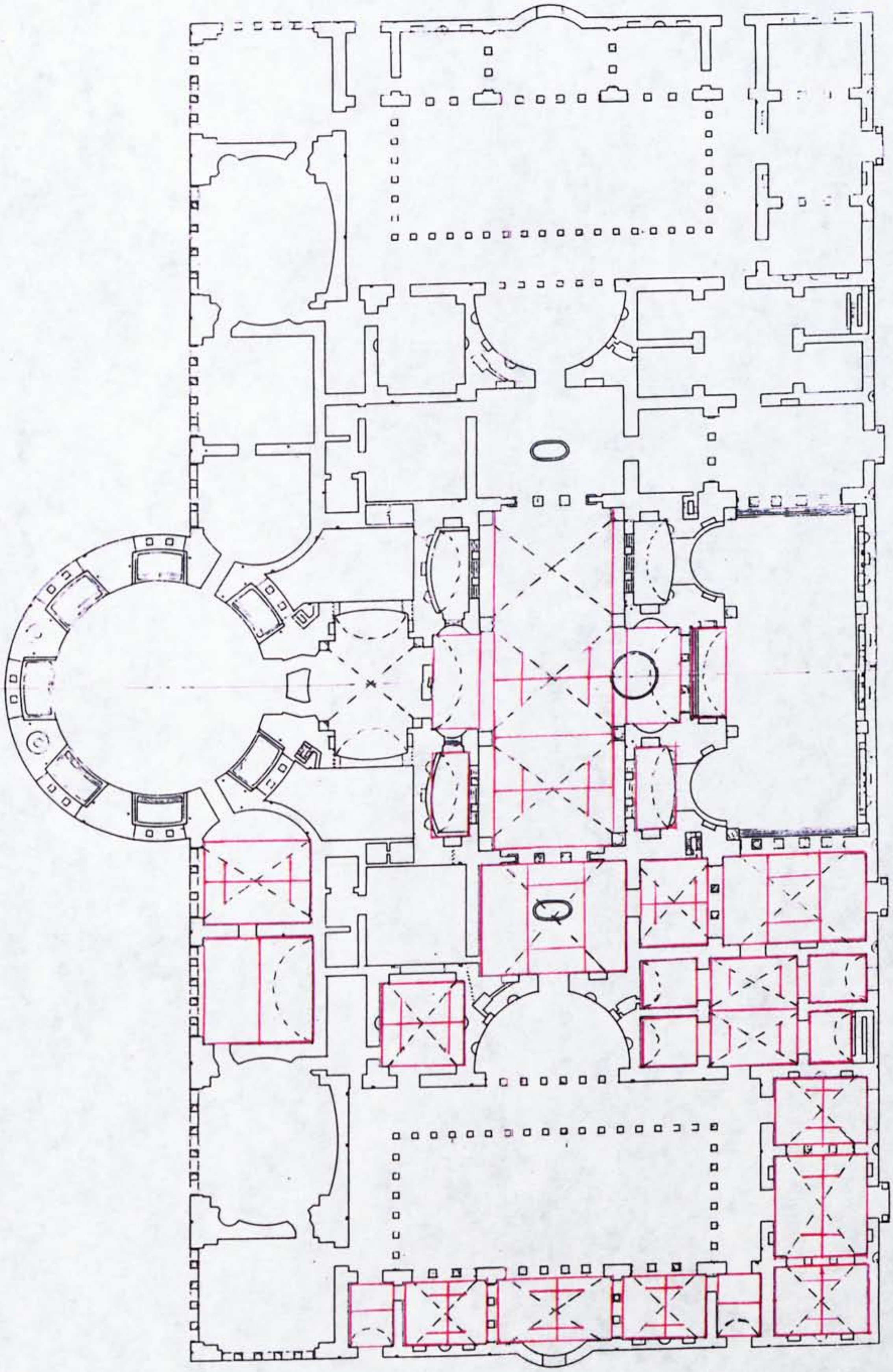


Fig. 104: Baths of Caracalla, central block, reconstructed system for the construction of the palaestra porticoes. Diagonal hatching represents concrete in section, shaded areas are stone in section.

Figure 103



Baths of Caracalla, central block, proposed minimum pattern of vault centerings.

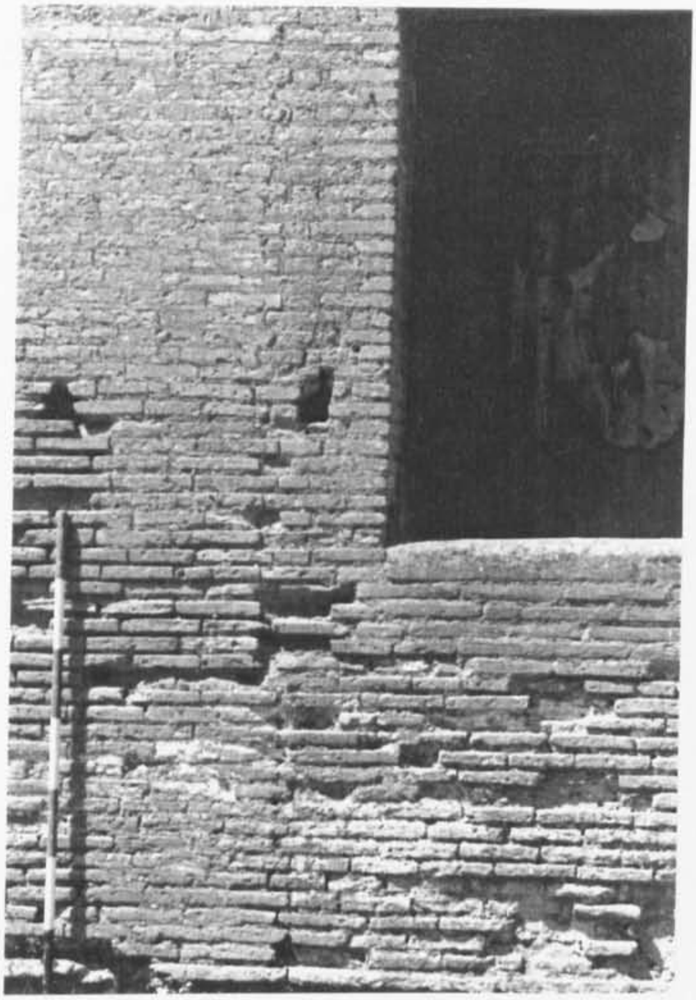


Fig. 105: Ostia, Insula dei Dipinti, construction join in garden facade.

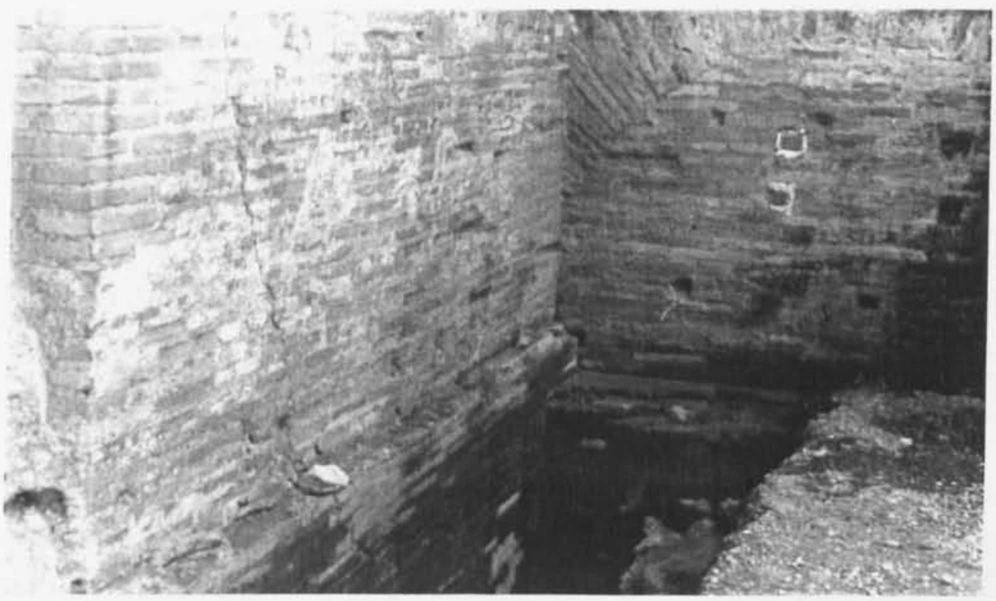
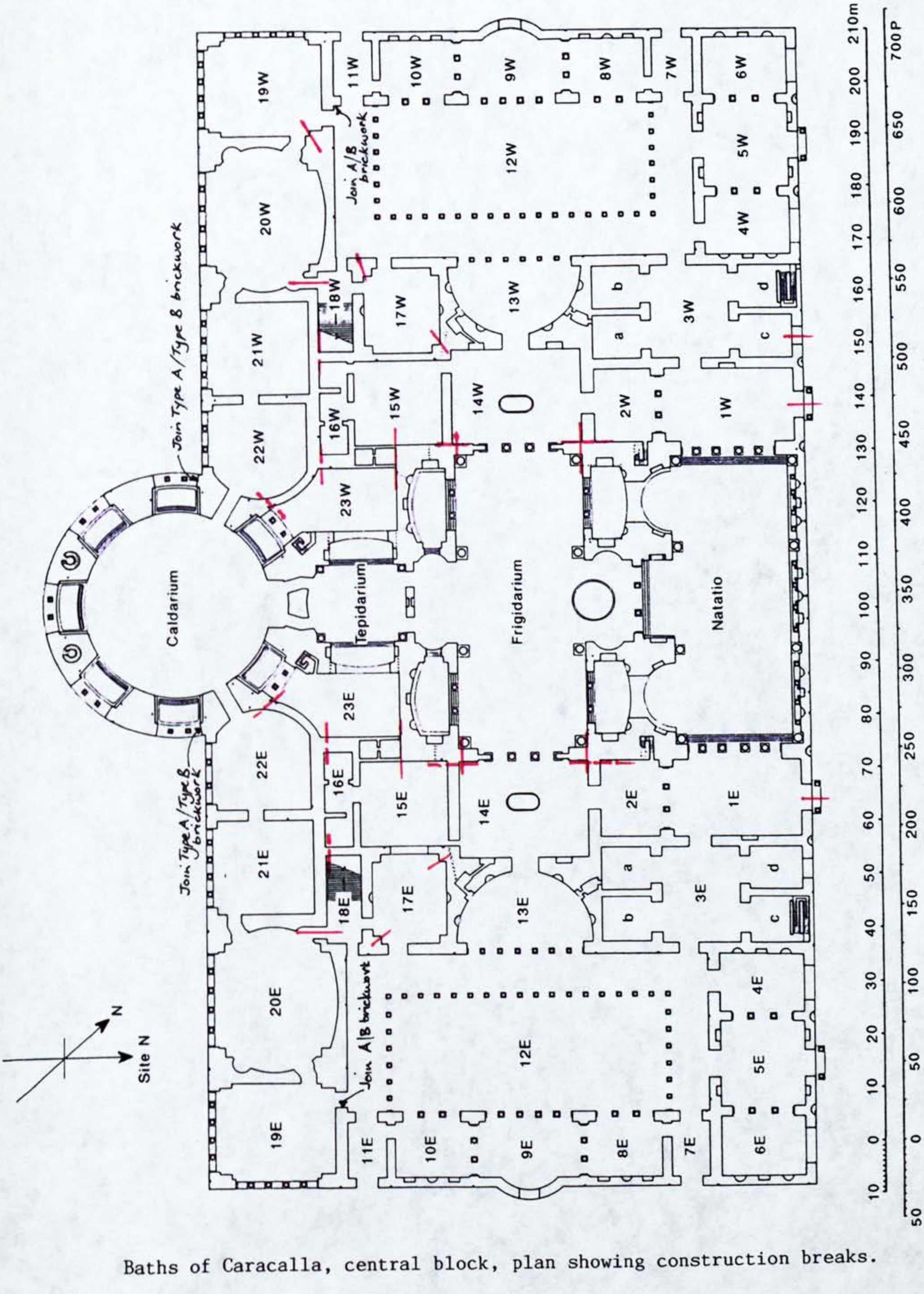


Fig. 106: Baths of Caracalla, central block, construction joint Rm 14W.

Figure 107



Baths of Caracalla, central block, plan showing construction breaks.

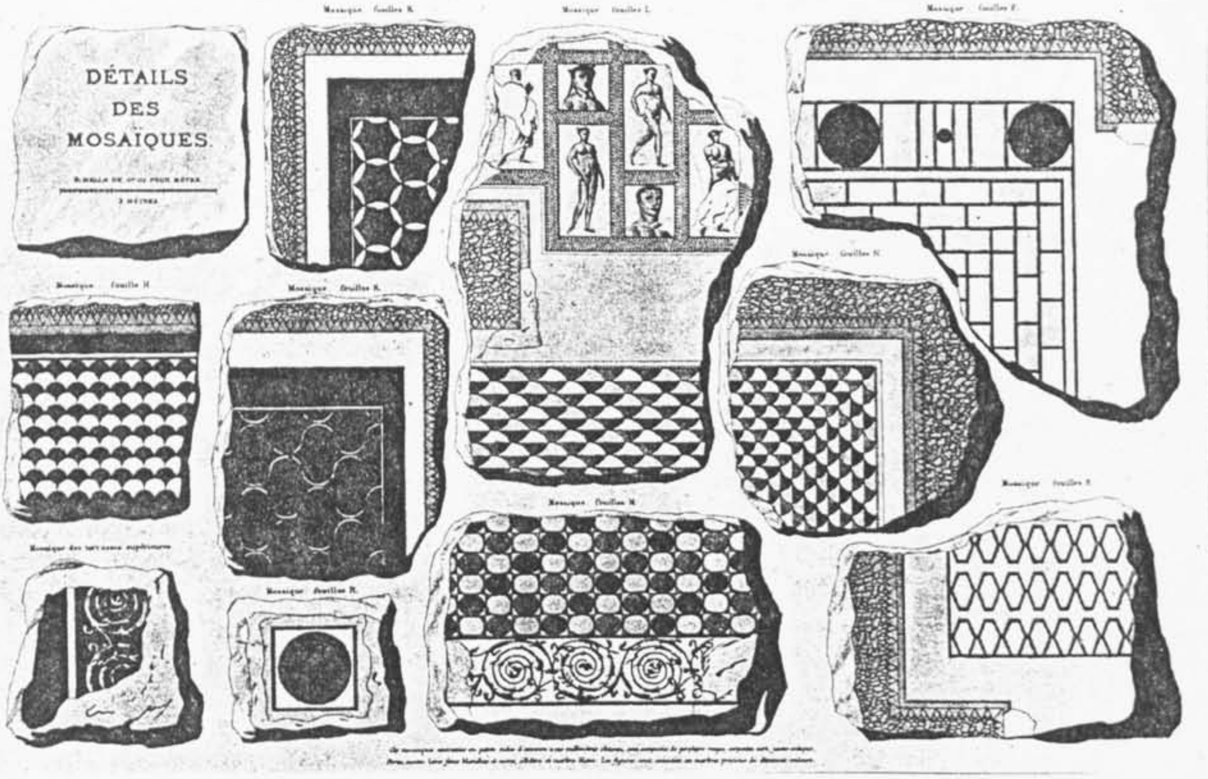


Fig. 108: Baths of Caracalla, central block, floor mosaics. From Blouet 1828, Pl. XIV.

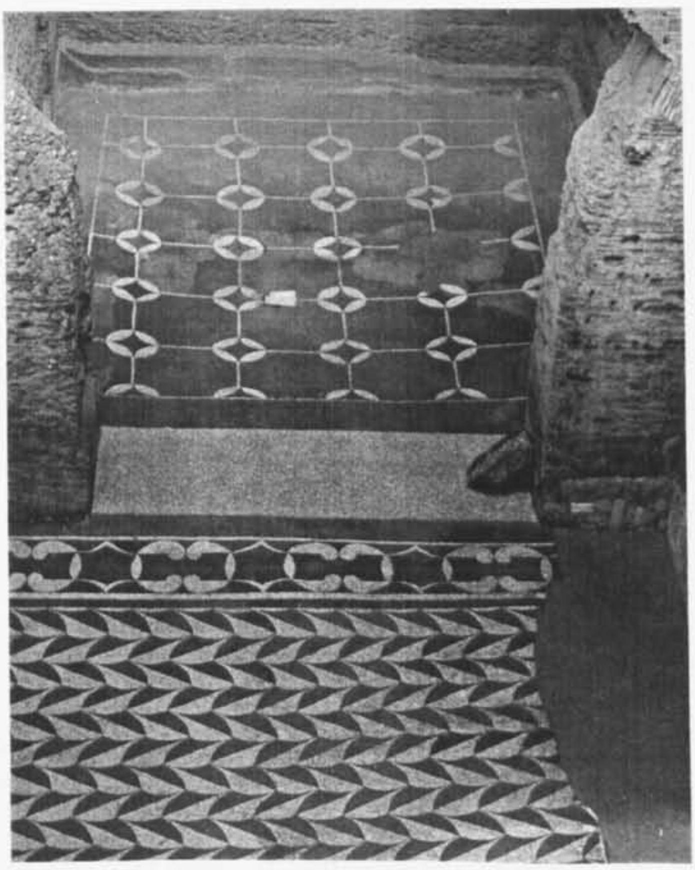
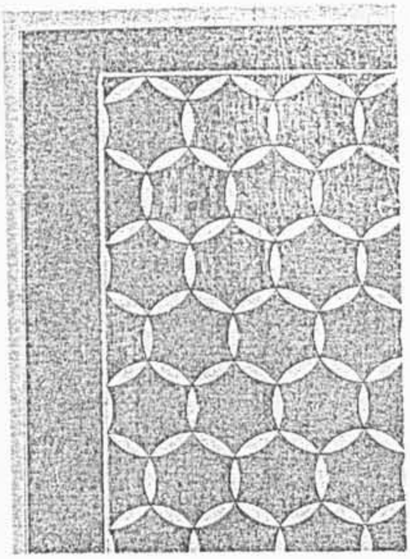
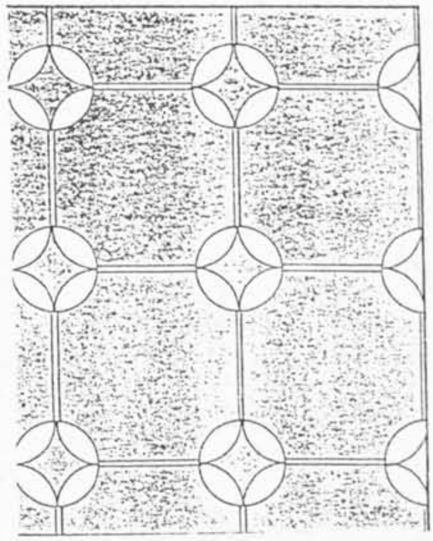


Fig. 109: Baths of Caracalla, central block, Rms 3W and 3Wc, mosaics.

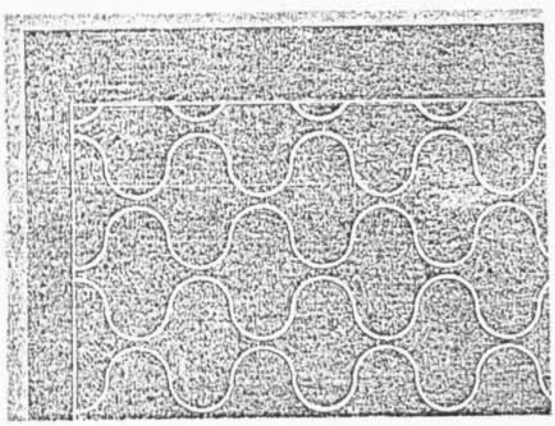
Figure 110



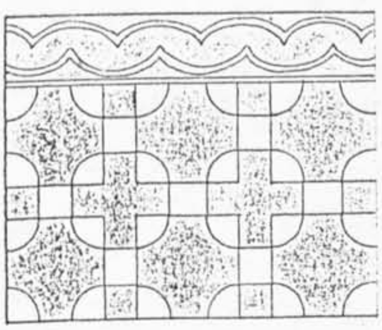
(a) Rm 3Wa



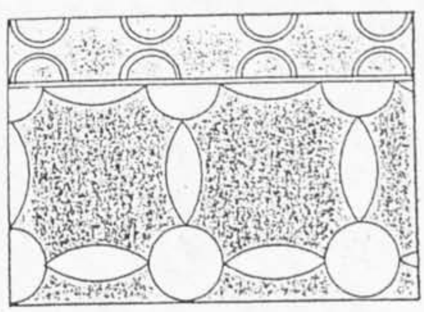
(b) Rm 3Wd



(c) Rms 3Ea, d



(d) Rm 3Ec



(e) Rm 3Wc

Black-and-white geometric mosaics. (a), (c) from Canina Tav. CCXII, Figs 4, 8; (b), (d), (e) from Blake 1940: Pl. 34, a, b, e.

Fig. 110: Baths of Caracalla, central block, Rm 12W, portico mosaic.

Fig. 112: Baths of Caracalla, central block, Rm 12W, palaestra mosaic.

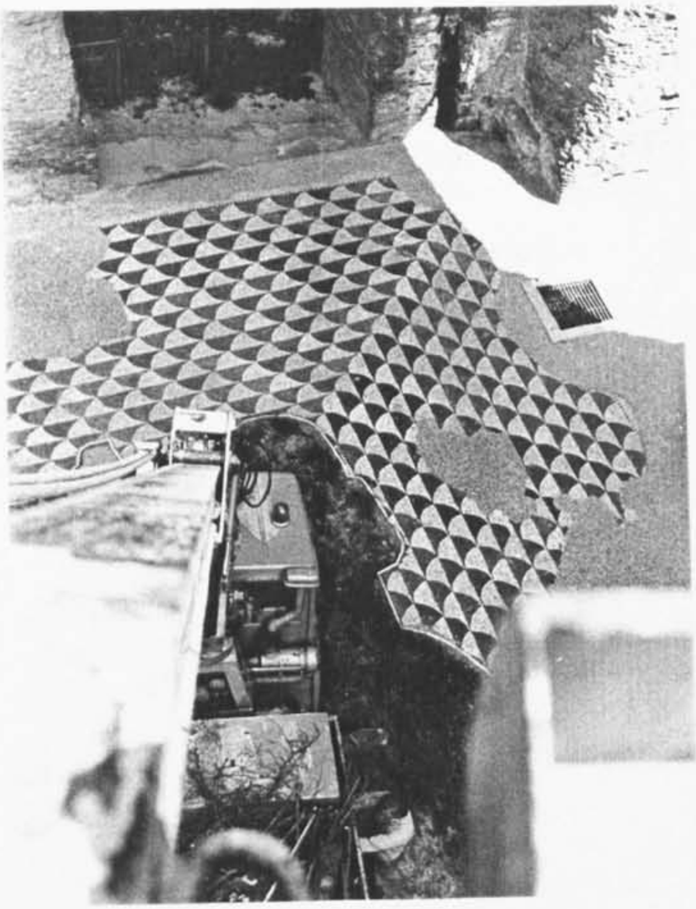
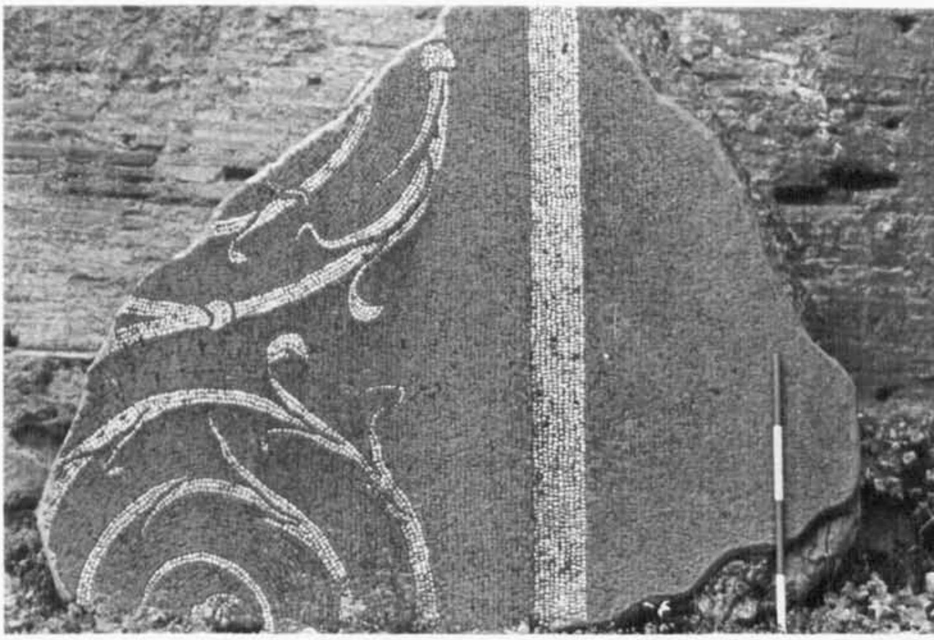


Fig. 111: Baths of Caracalla, central block, Rm 12W, portico mosaic.

Fig. 113: Baths of Caracalla, central block, terrace over Rm 11E.



(a) Baths of Caracalla, central block, mosaic from terrace over Rms 4-6W, border pattern.

(b) As above, ?acanthus clump from corner.

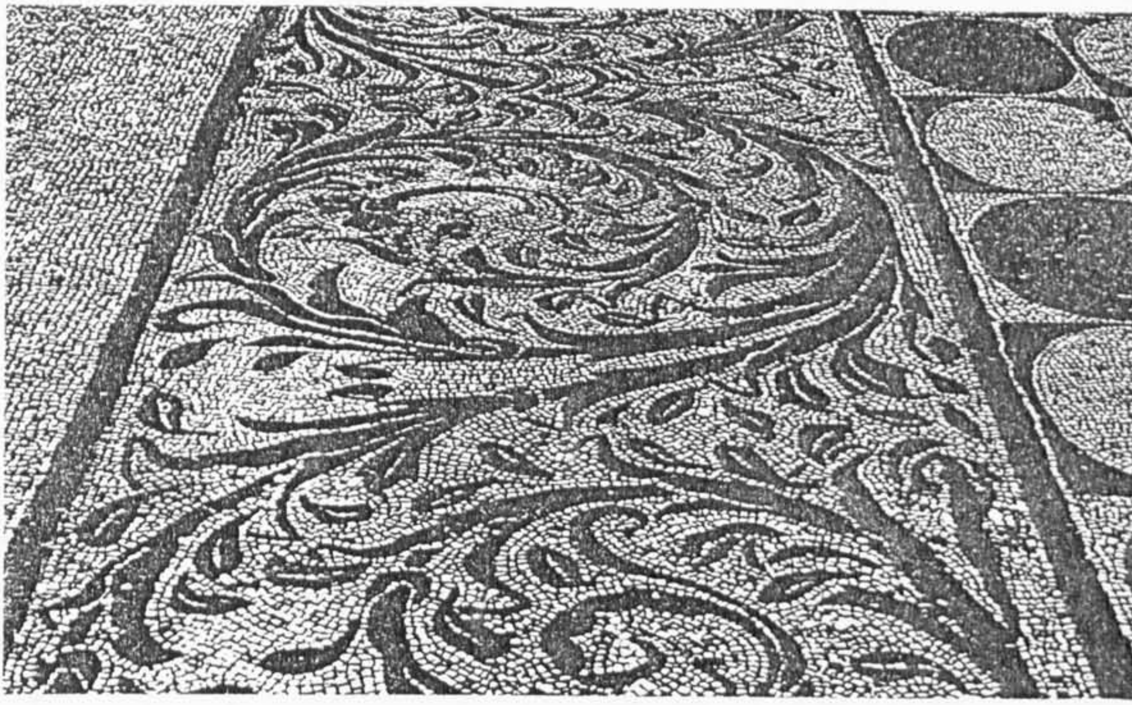


Fig. 115: Baths of Caracalla, central block, Rm 12E, palaestra mosaic.

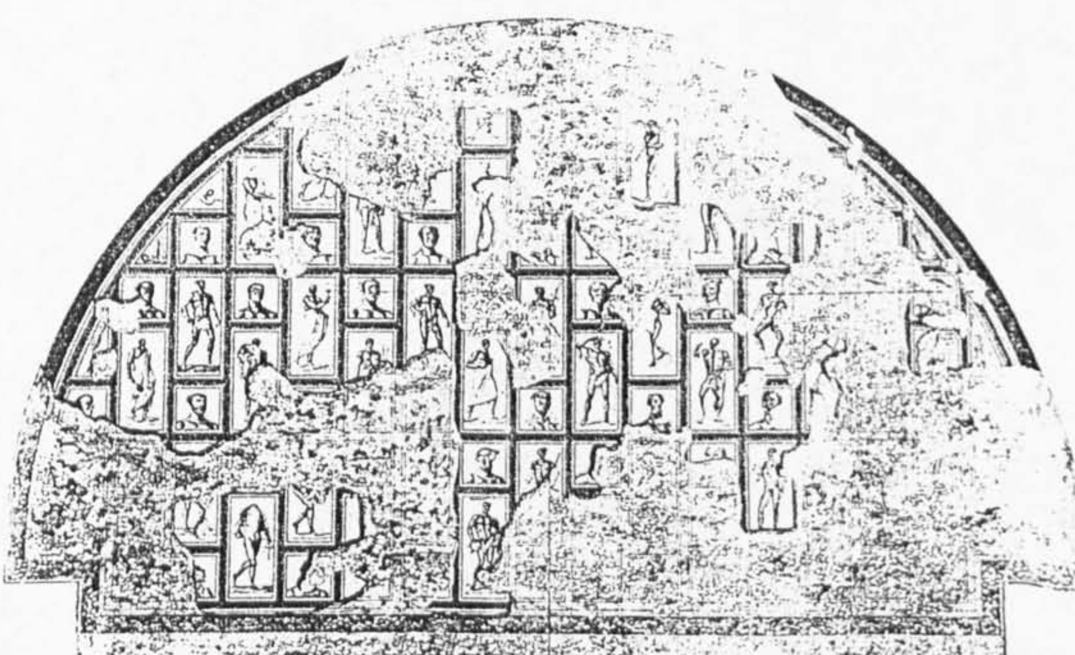


Fig. 116: Baths of Caracalla, central block, reconstructed mosaic from Rms 13, now in Lateran collection of the Vatican Museums.

Fig. 117: Baths of Caracalla, central block, NE *frigidarium* pool.

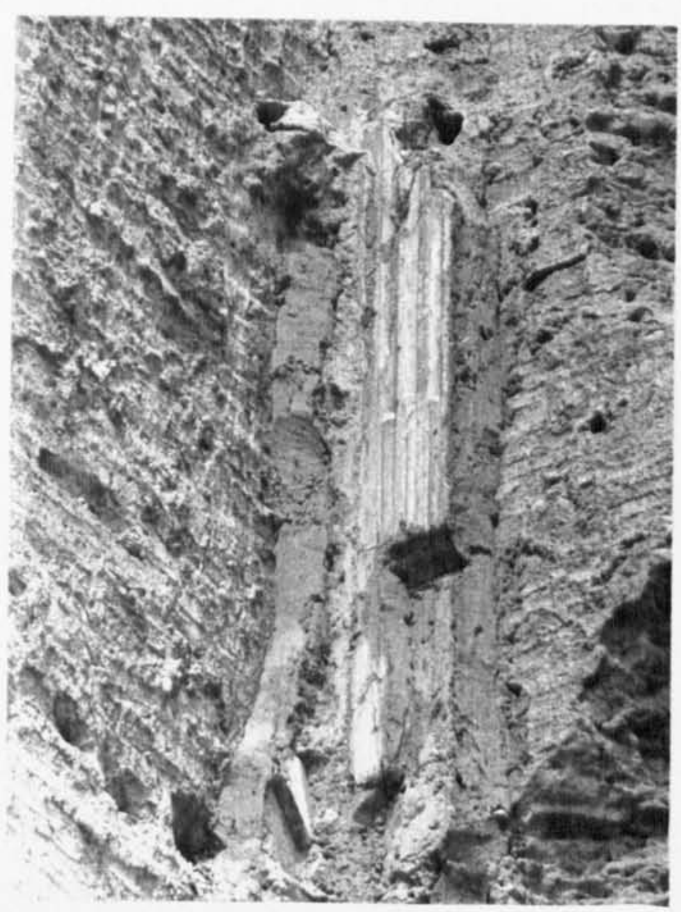
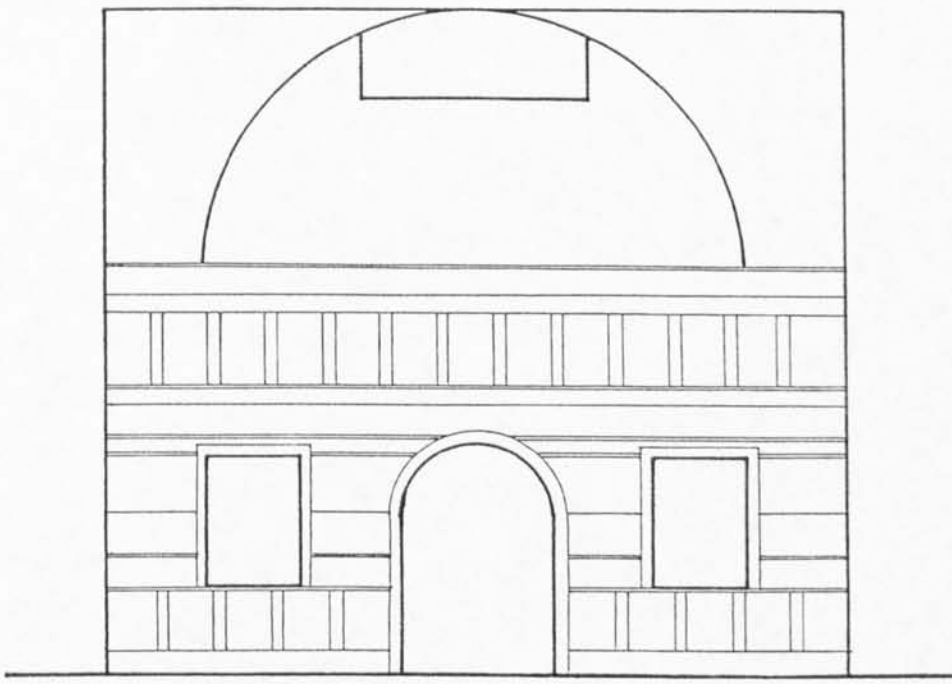


Fig. 118: Baths of Caracalla, central block, Rm 14W, marble veneer.



Baths of Caracalla, central block, Rm 14, reconstructed pattern of marble veneer based on cramp holes.

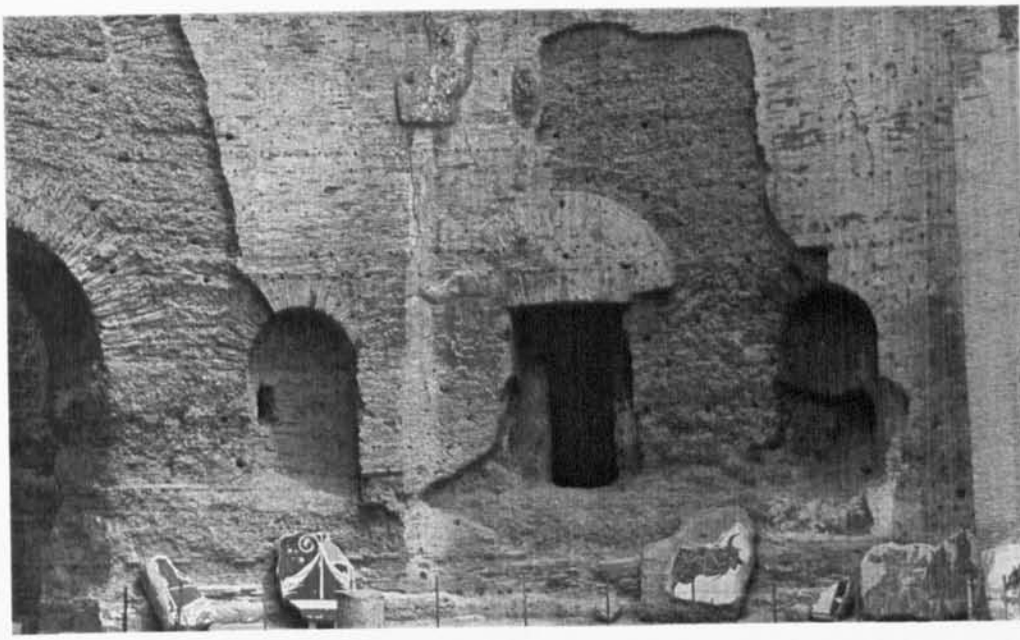


Fig. 120: Baths of Caracalla, central block, Rm 13E, veneer cramp holes.

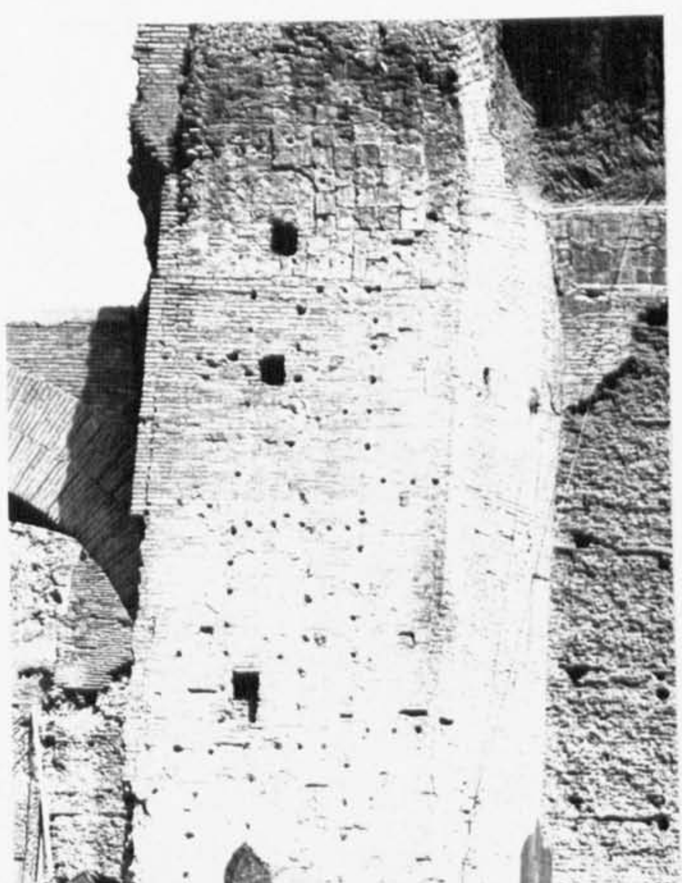


Fig. 121: Baths of Caracalla, central block, window jamb of SW *frigidarium* pool with veneer cramp holes.

Fig. 122: Baths of Caracalla, central block, Rm 8E, stucco decoration.

Fig. 123: Baths of Caracalla, central block, Rm 3E, surface of brick picked to form key for plaster.

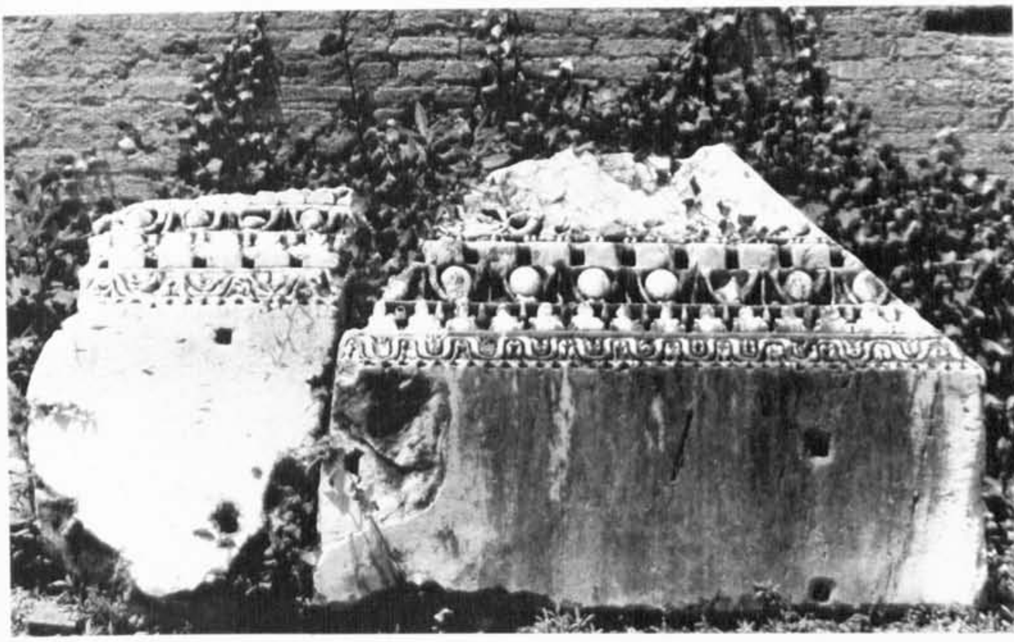
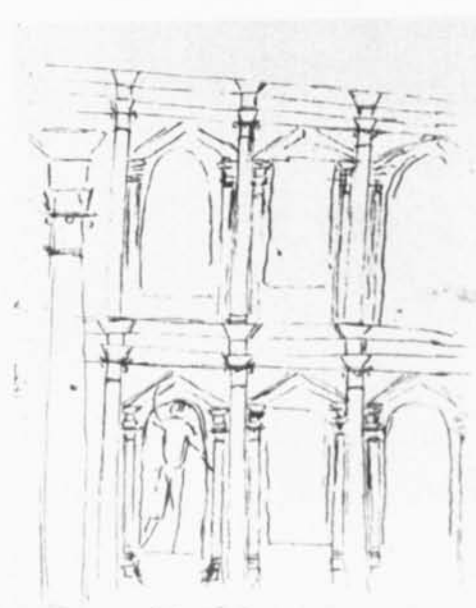


Fig. 124: Baths of Caracalla, central block, cornice fragments.

(a)

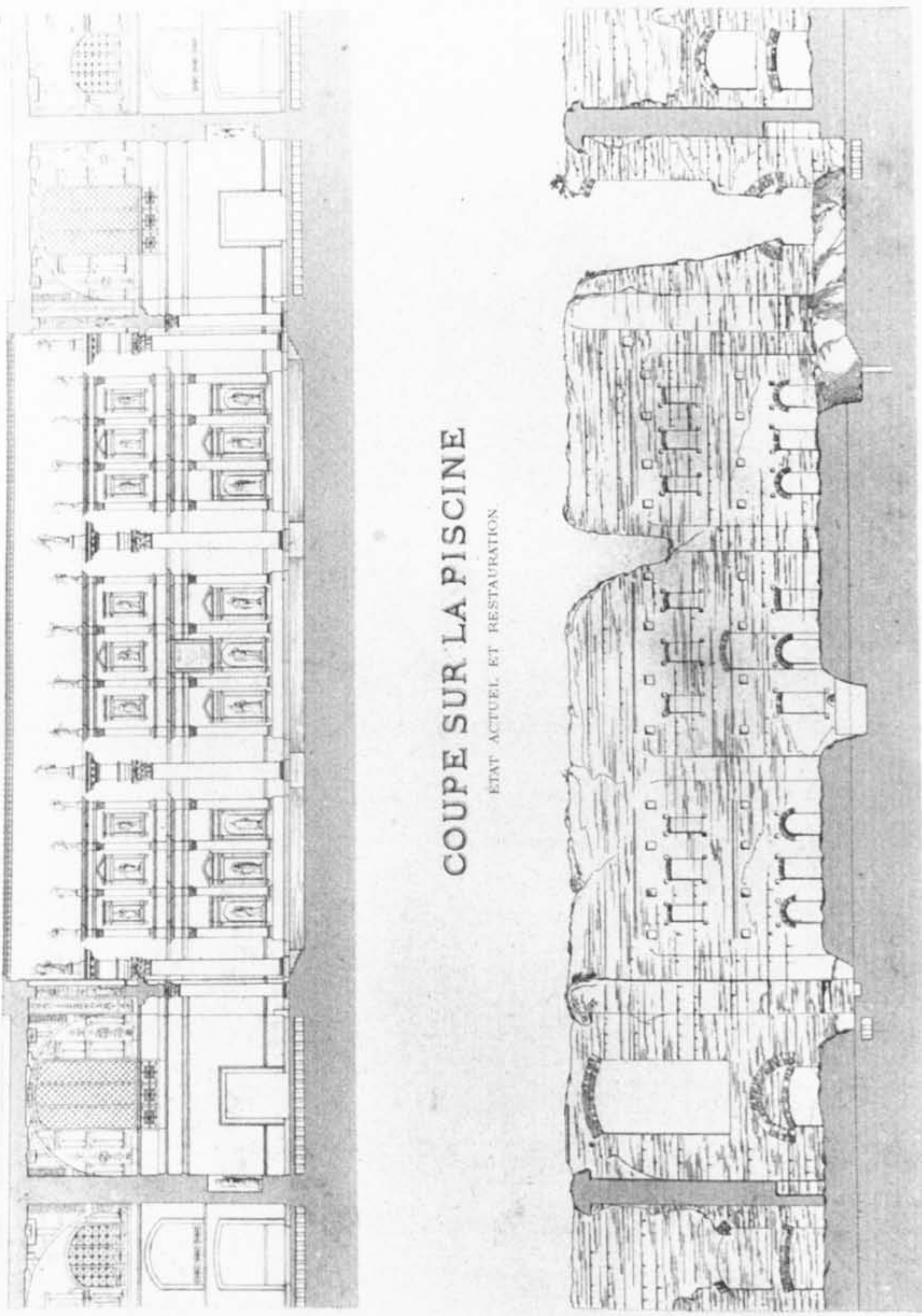
(b)



(c)

Fig. 125: Baths of Caracalla, central block, Renaissance sketches of *natatio* N facade. (a) Palladio, (b) Abaco, (c) Sangallo.

Figure 126



Baths of Caracalla, central block, N <u>natatio</u> facade, elevation and reconstruction by Blouet 1828, Pl. X.

Fig. 127: Baths of Caracalla, central block, Rm 17E, ? holes for fixing window frames.

Fig. 128: Rome, Piazza Farnese, granite basin from Rm 14 of central block.

Fig. 129: Baths of Caracalla, sketch by Palladio of a porphyry basin found in central block.

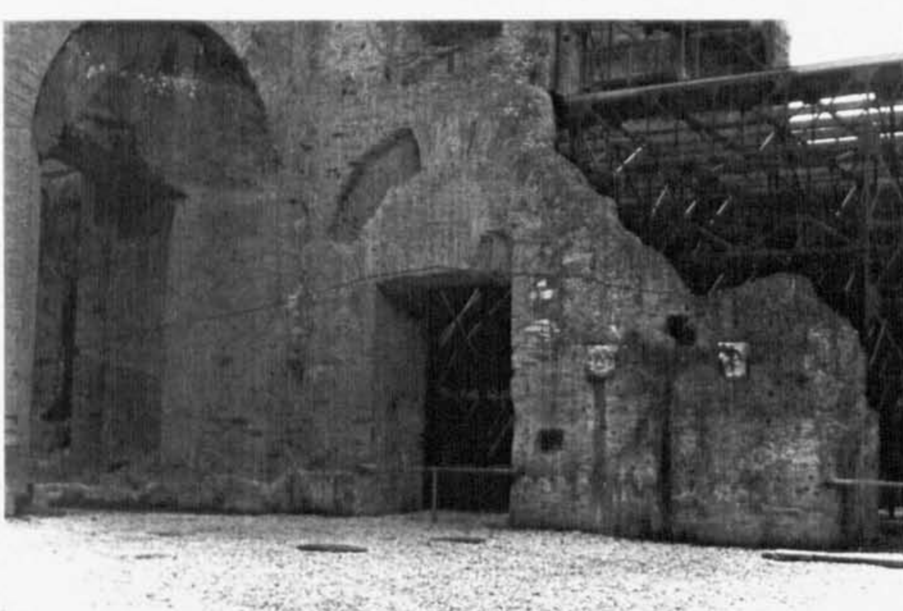


Fig. 130: Baths of Caracalla, central block, frigidiarium, central bay of S side, niche with cutting for water pipe.

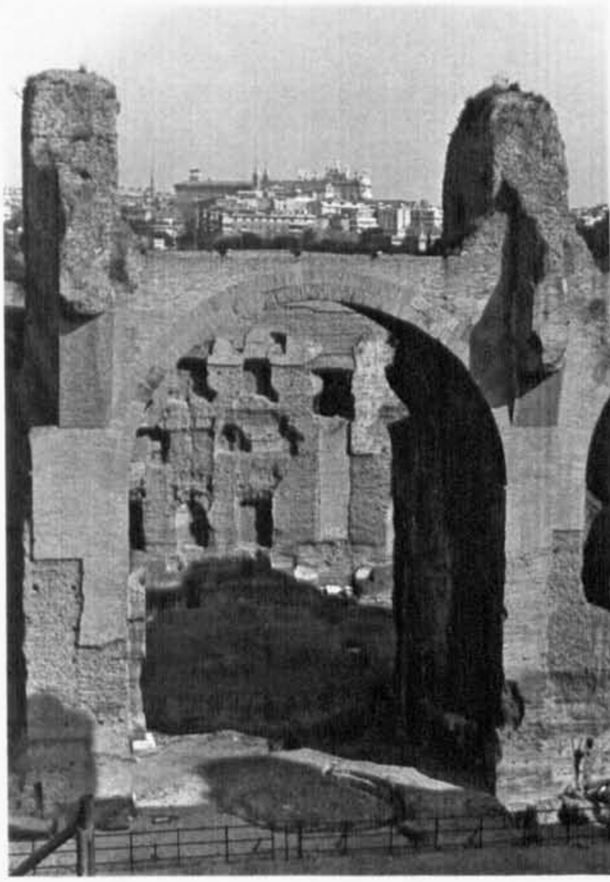


Fig. 131: Baths of Caracalla, central block, frigidarium, N side with circular pool.

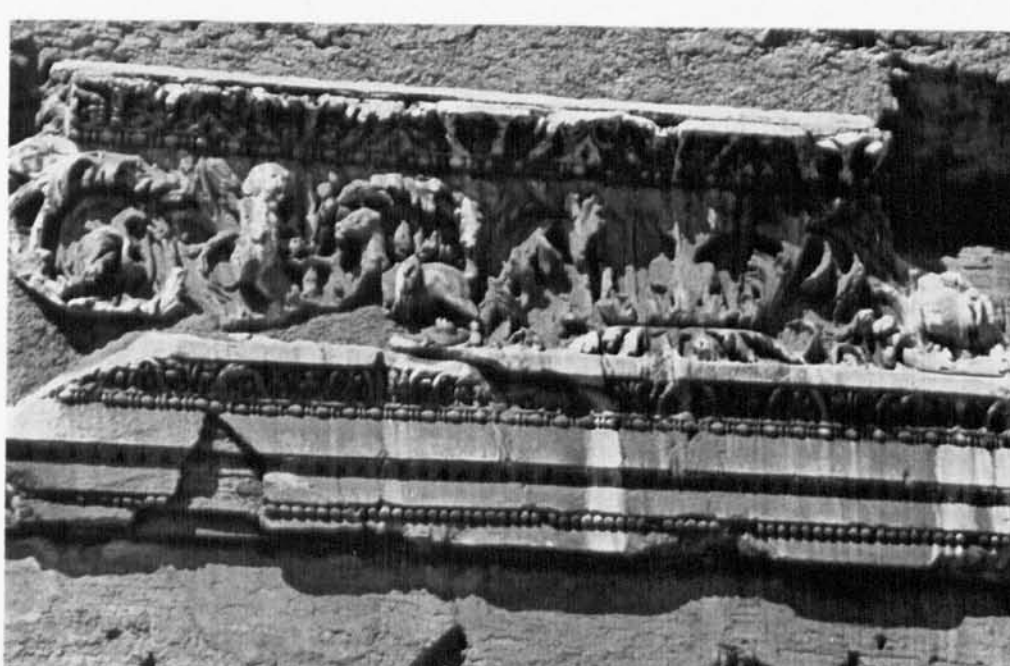


Fig. 132: Baths of Caracalla, central block, Rm 12E, architectural veneer from portico wall.

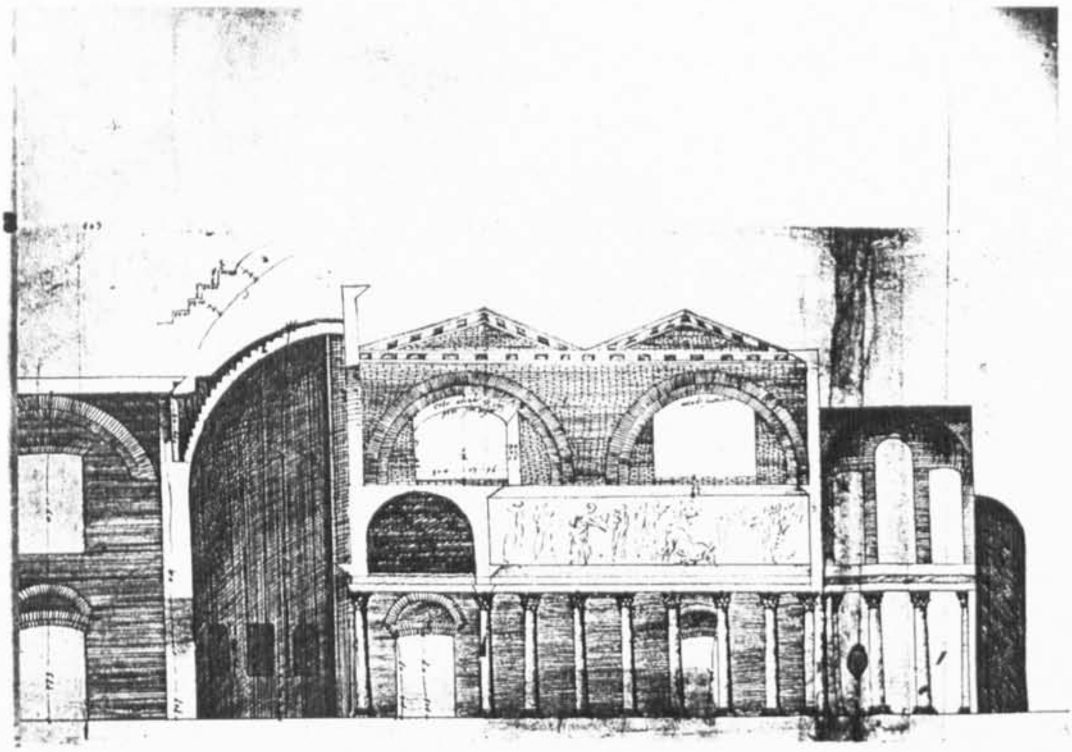


Fig. 133: Baths of Caracalla, central block, section through Rm 12W from the collection of the Anonymous Destailleur, Bl. 27v.

Fig. 134: Baths of Caracalla, central block, section of weapon frieze.

Fig. 135: Baths of Caracalla, central block, Corinthian capital of palaestra order.

Fig. 136: Baths of Caracalla, central block, figured Composite capital now in natatio.

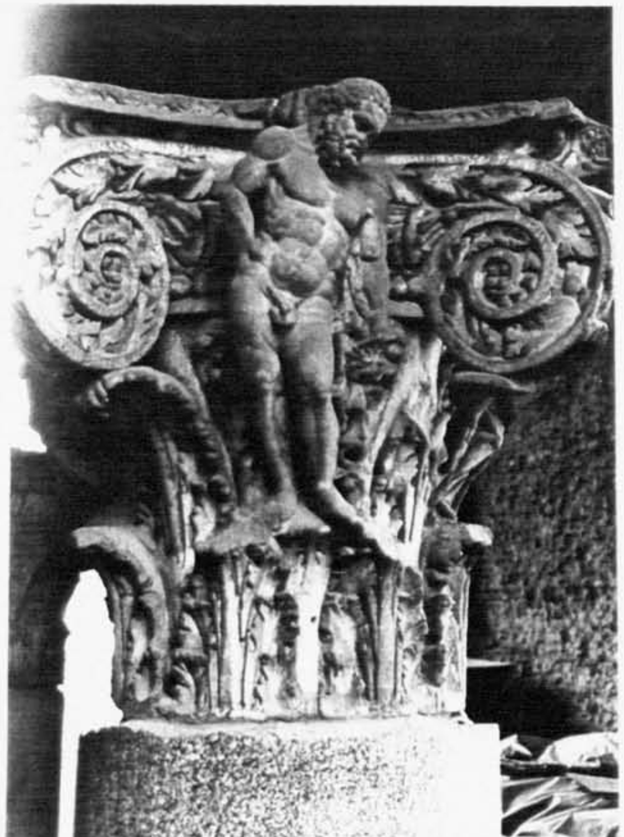


Fig. 137: Baths of Caracalla, central block "Hercules" capital from frigidarium pool.

Fig. 138: Baths of Caracalla, central block "Mars" capital from frigidarium pool.

Fig. 139: Baths of Caracalla, central block, Composite capital shown in Fig. 136, side view.

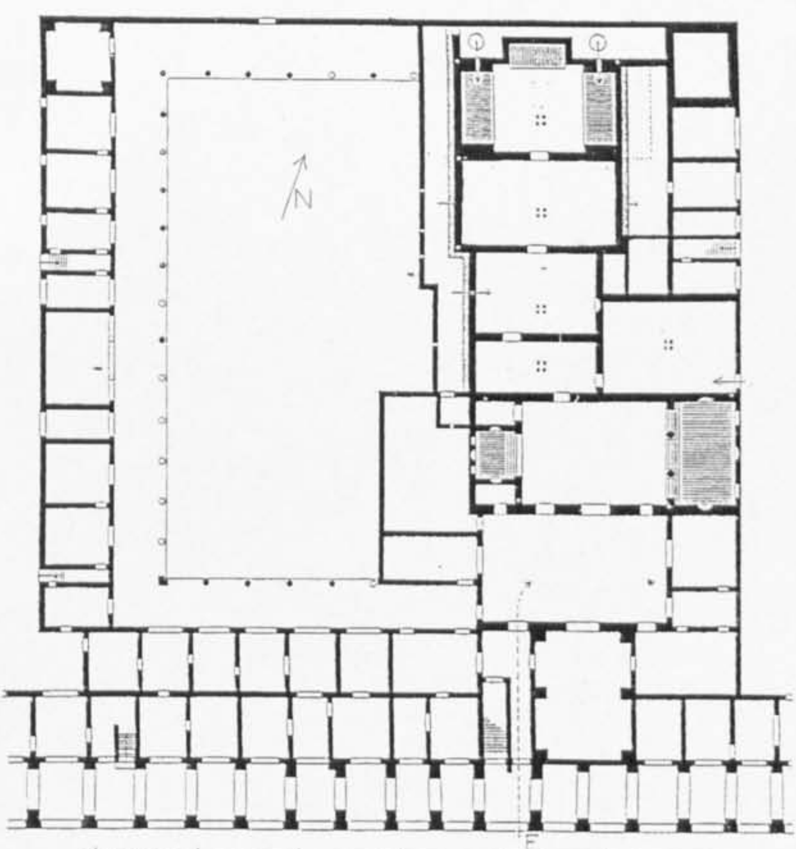
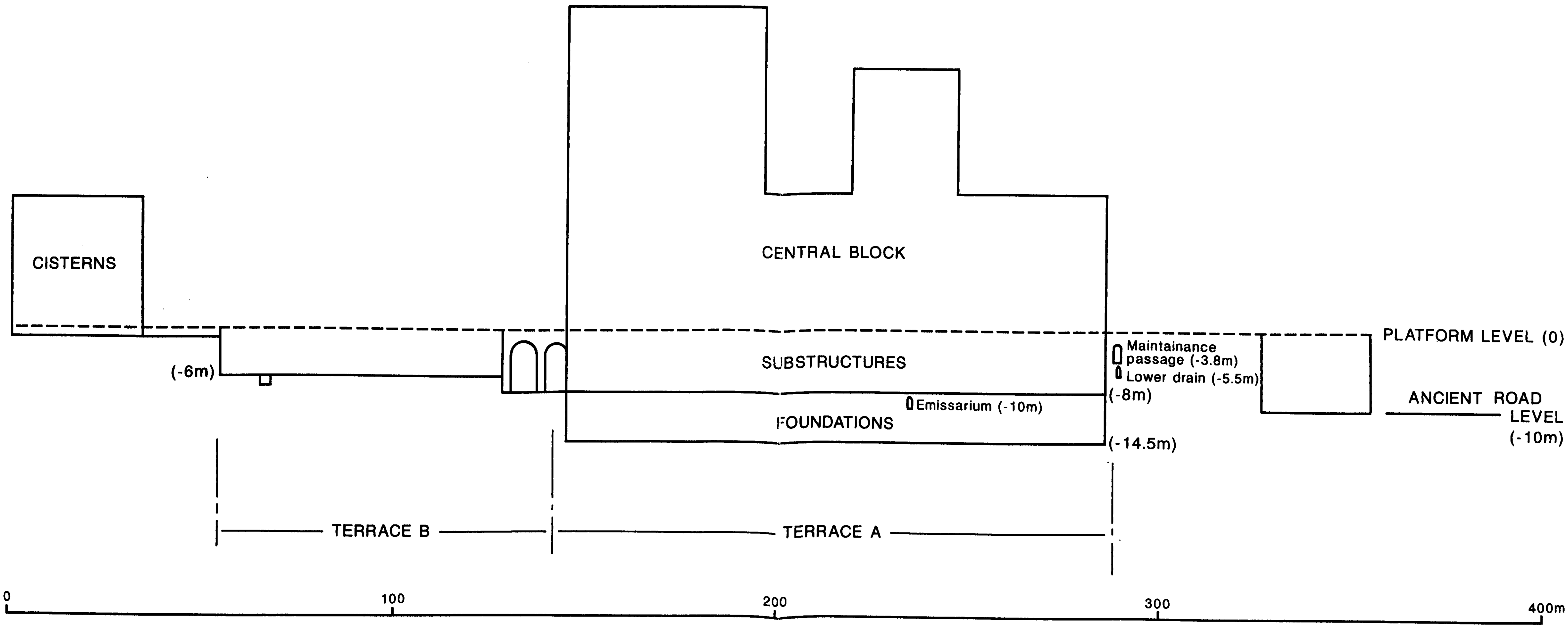
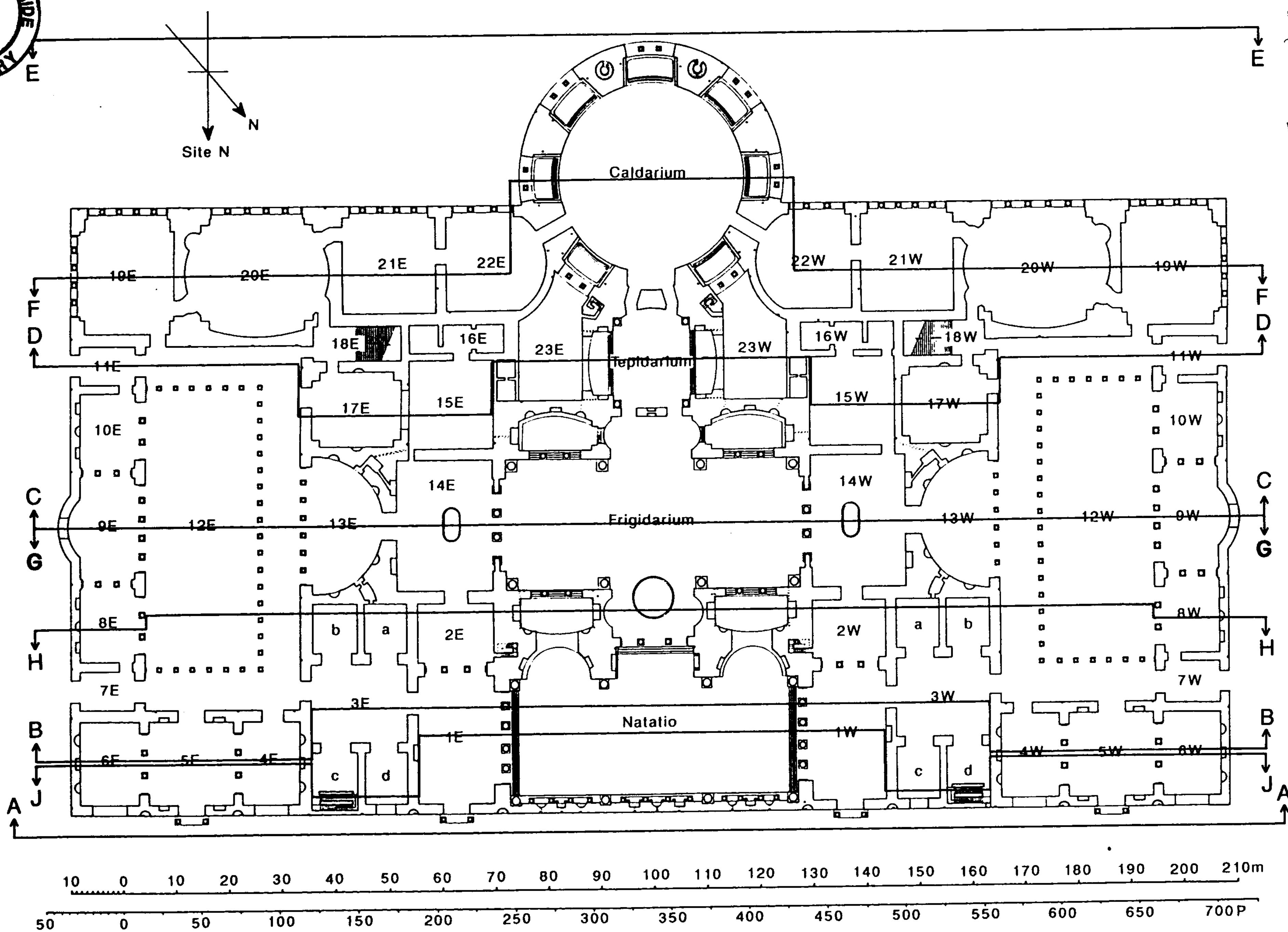


Fig. 140: Ostia, Baths of Neptune, plan.

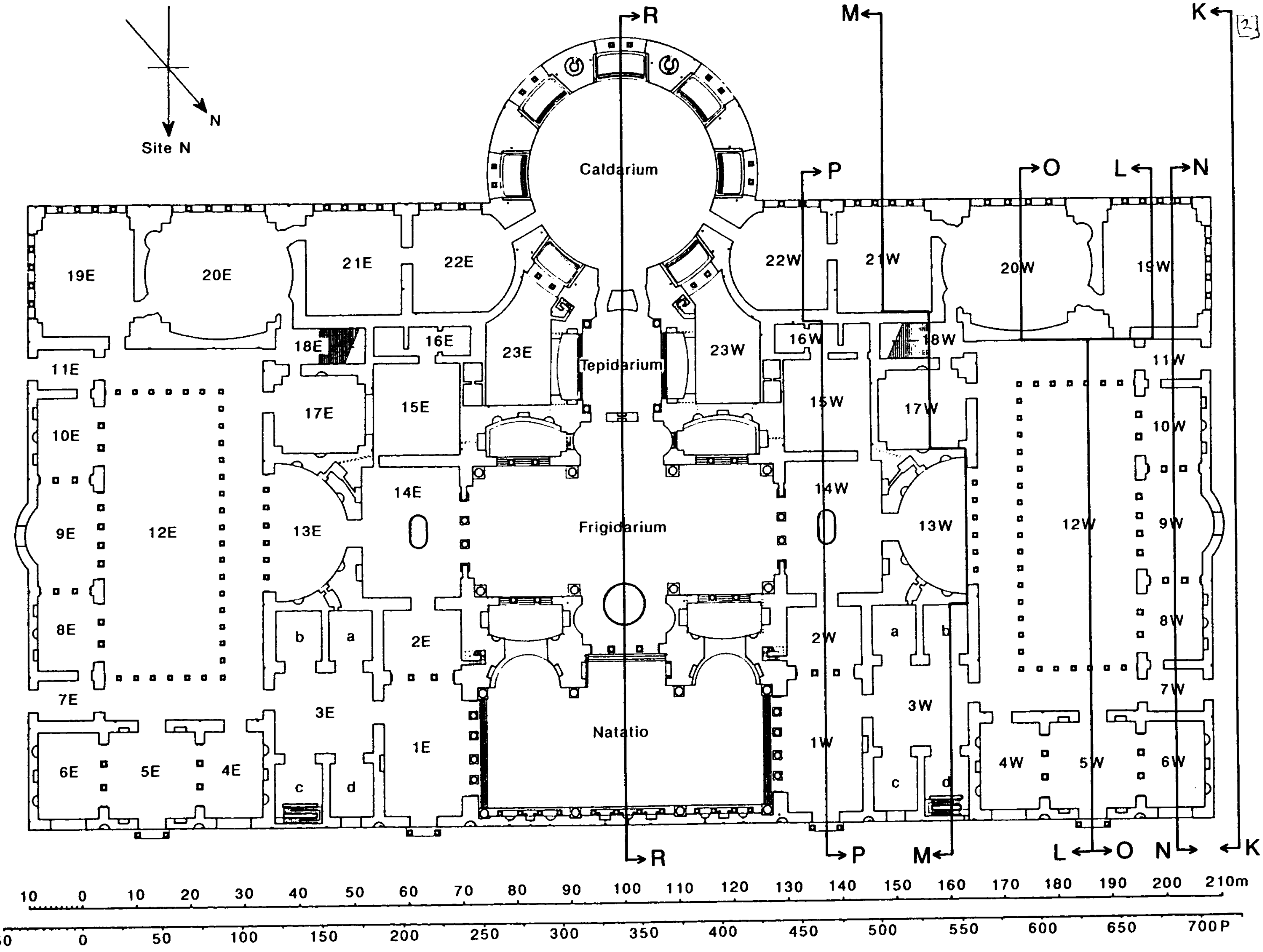
SHEET 9

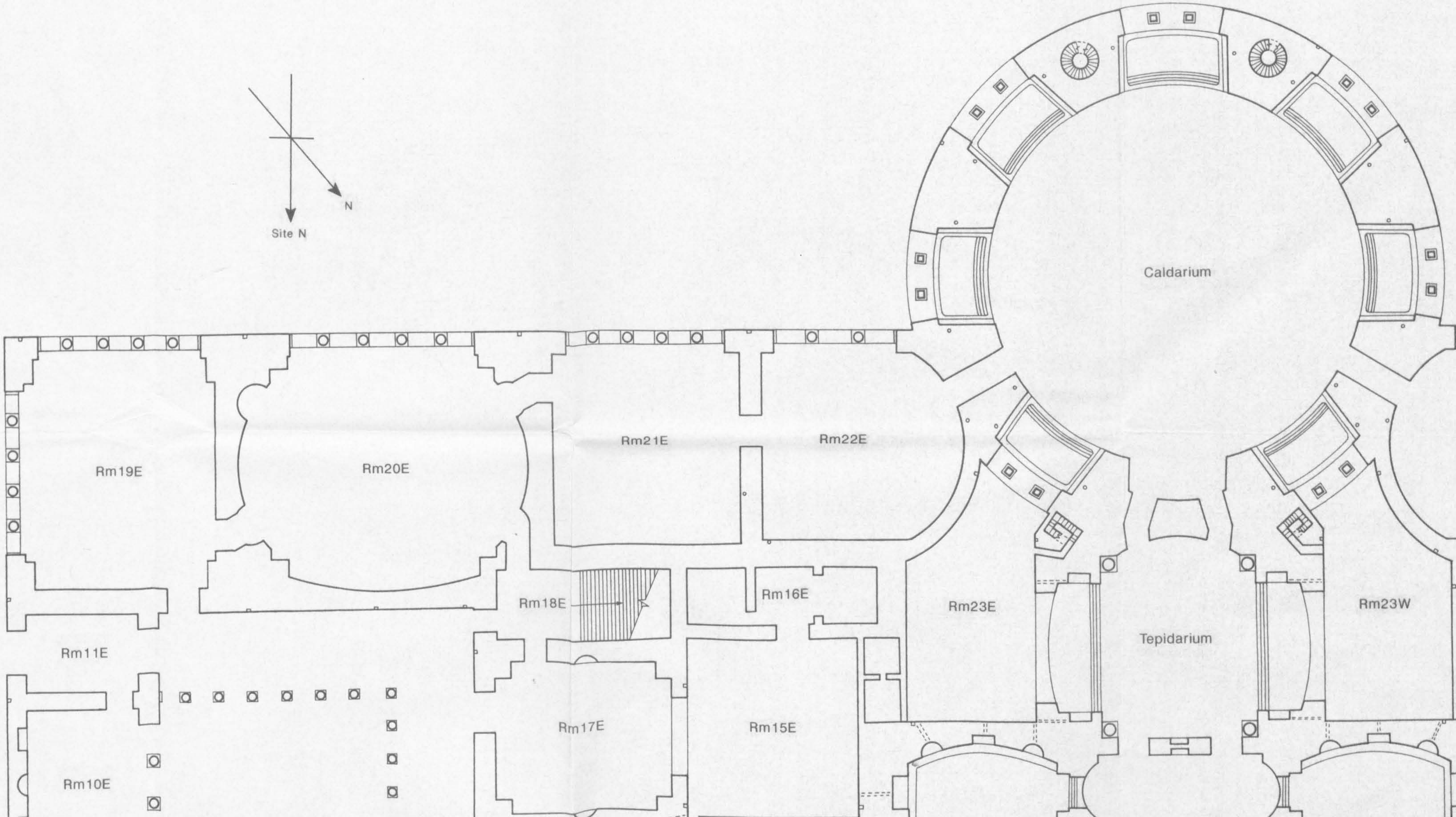

CISTERNS
CENTRAL BLOCK
SUBSTRUCTURES
FOUNDATIONS
PLATFORM LEVEL (0)
Maintainance passage (-3.8m)
Lower drain (-5.5m)
Emissarium (-10m)
(-6m)
(-8m)
(-14.5m)
ANCIENT ROAD LEVEL (-10m)
TERRACE B
TERRACE A
0
100
200
300
400m

BATHS OF CARACALLA: SECTION KEY. SHEETS 2, 3, 4.

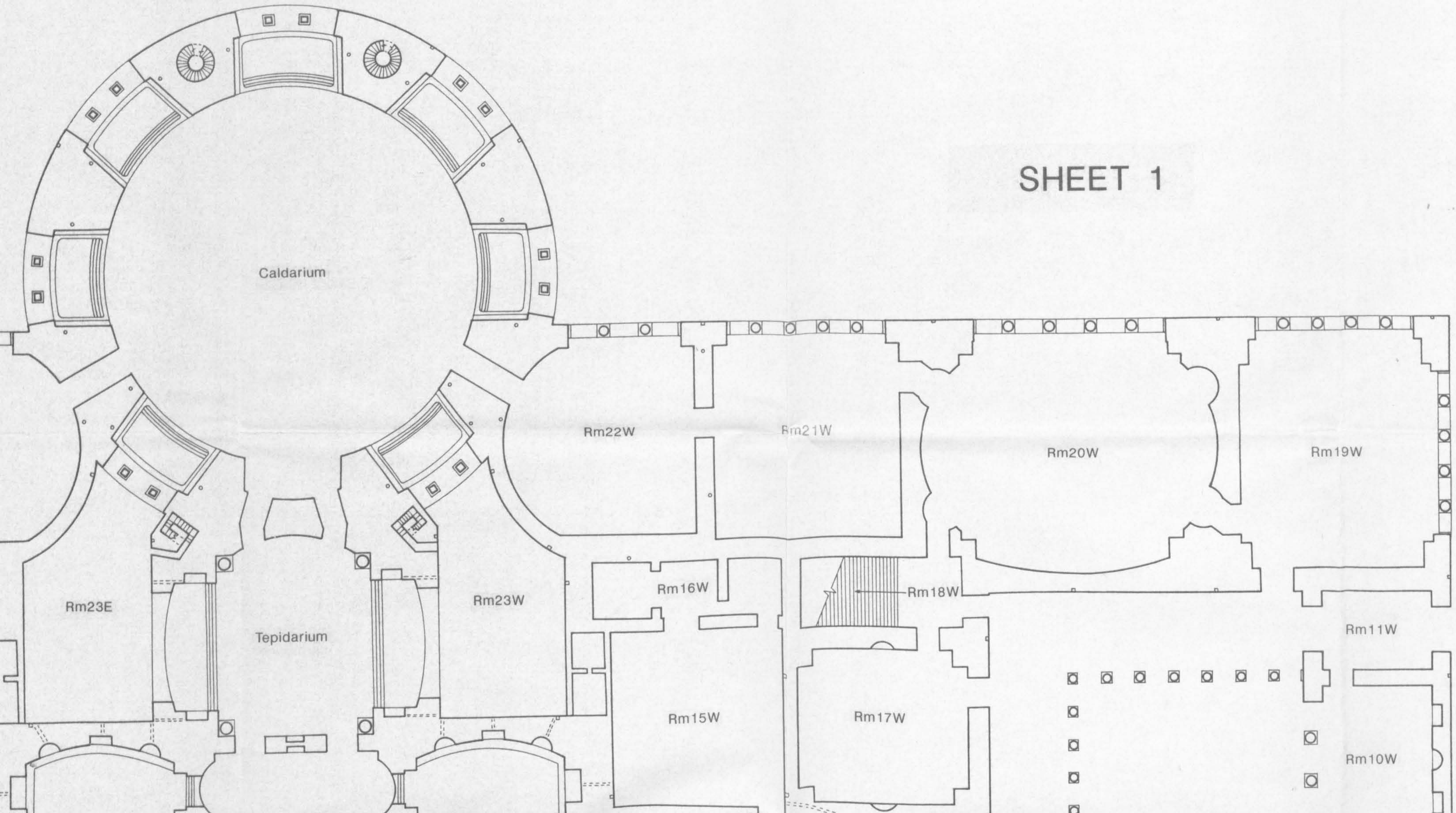


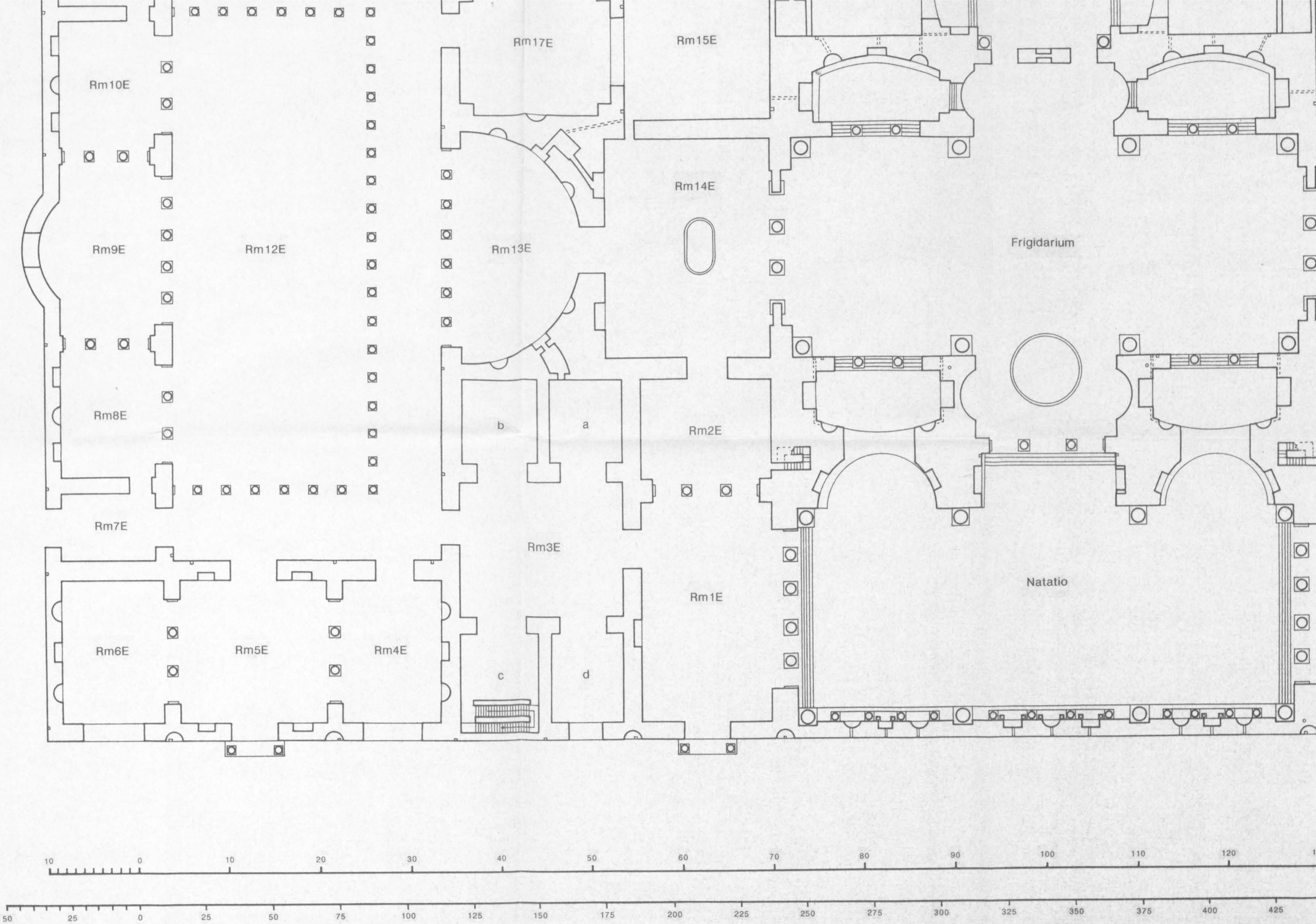
BATHS OF CARACALLA: SECTION KEY. SHEETS 5, 6, 7.

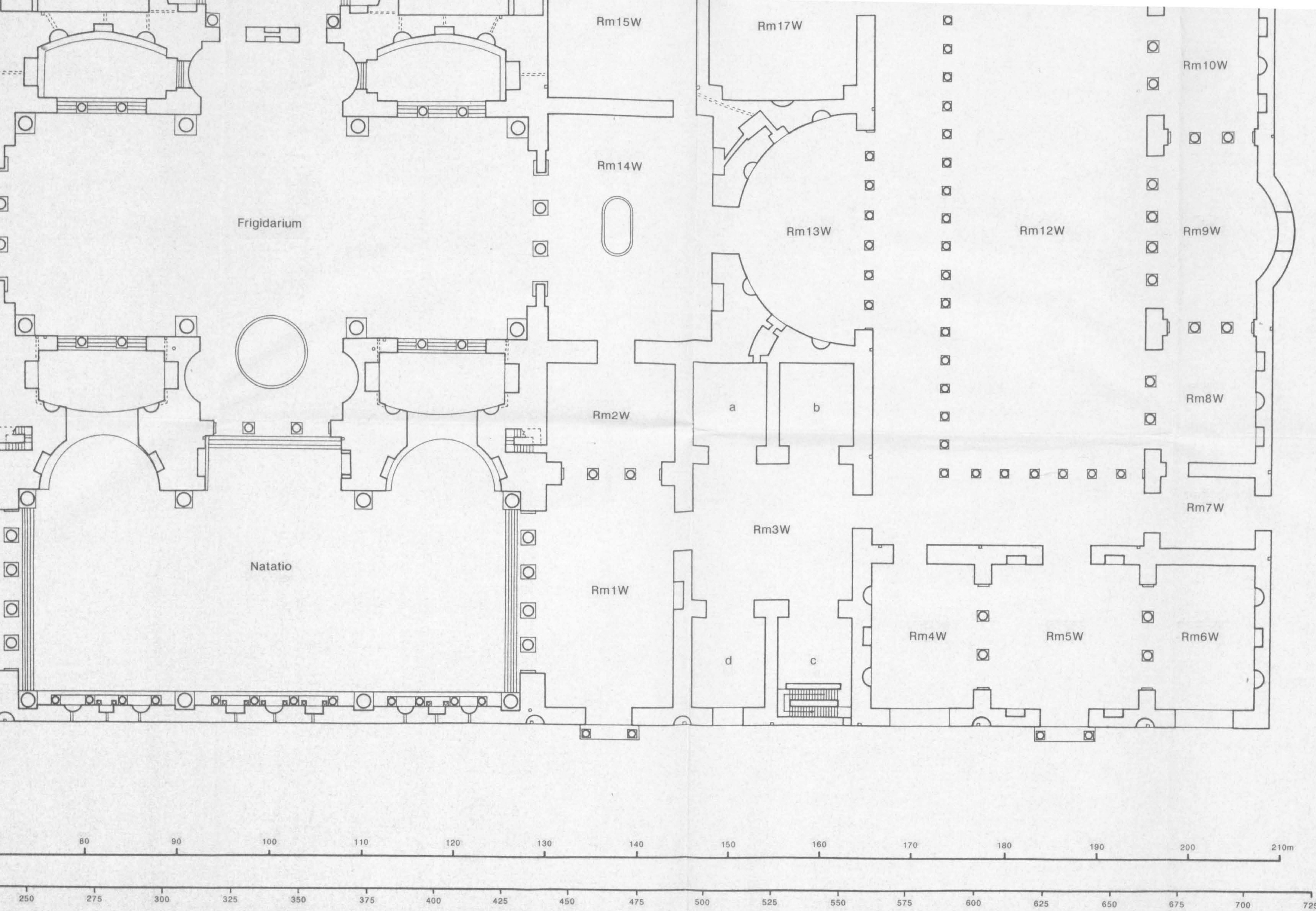



Site N
N
Caldarium
Rm21E
Rm22E
Rm19E
Rm20E
Rm18E
Rm16E
Rm23E
Rm23W
Tepidarium
Rm11E
Rm17E
Rm15E
Rm10E

SHEET 1


Caldarium
Rm22W
Rm21W
Rm20W
Rm19W
Rm16W
Rm18W
Rm23E
Tepidarium
Rm23W
Rm11W
Rm15W
Rm17W
Rm10W


Rm17E
Rm15E
Rm10E
Rm14E
Rm9E
Rm12E
Rm13E
Frigidarium
Rm8E
b
a
Rm2E
Rm7E
Rm3E
Natatio
Rm1E
Rm6E
Rm5E
Rm4E
c
d
10 0 10 20 30 40 50 60 70 80 90 100 110 120
50 25 0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425


Rm15W
Rm17W
Rm10W
Rm14W
Frigidarium
Rm13W
Rm12W
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b
Rm8W
Rm7W
Rm3W
Natatio
Rm1W
Rm4W
Rm5W
Rm6W
d
c
80
90
100
110
120
130
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150
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170
180
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210m
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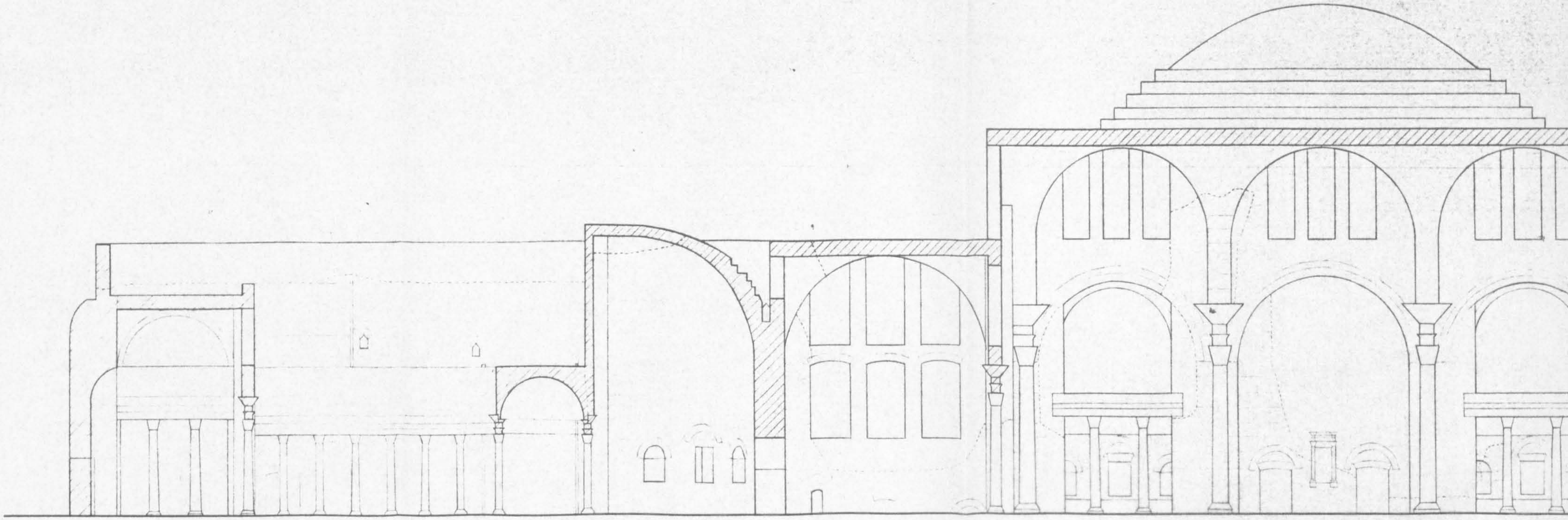
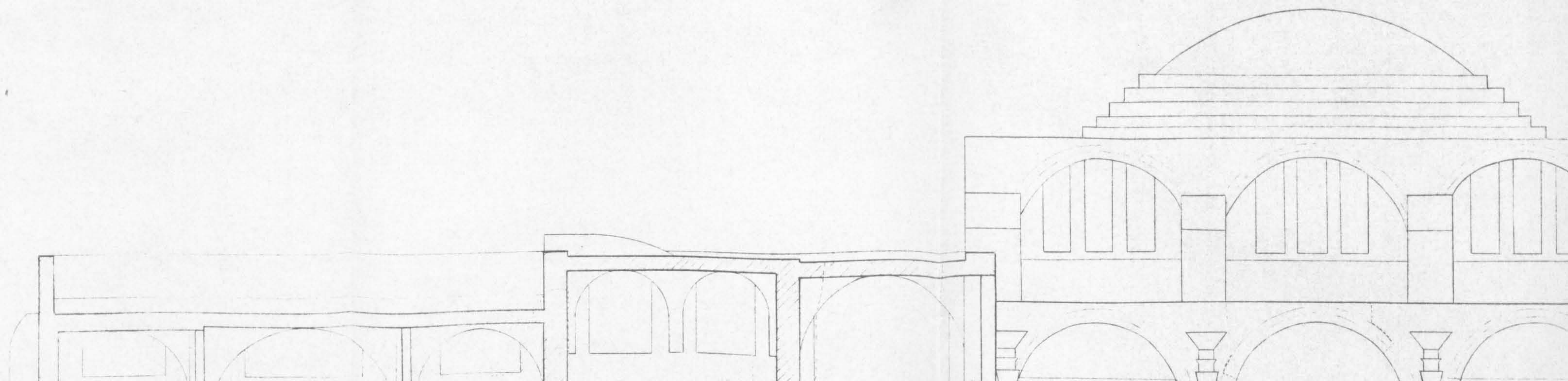
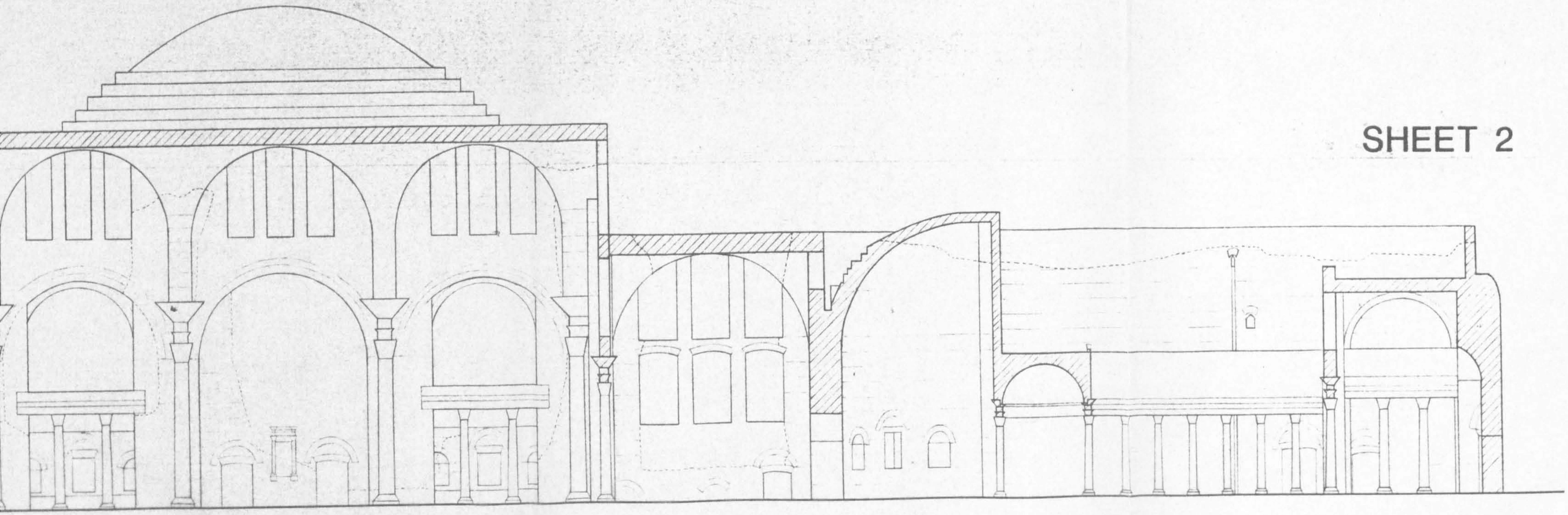
725P



Section CC



SHEET 2



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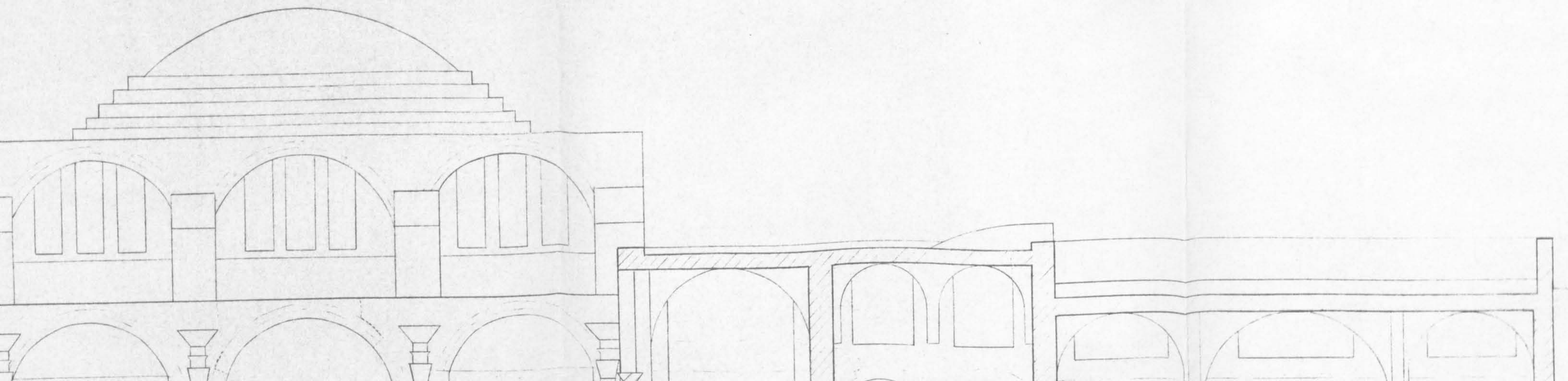

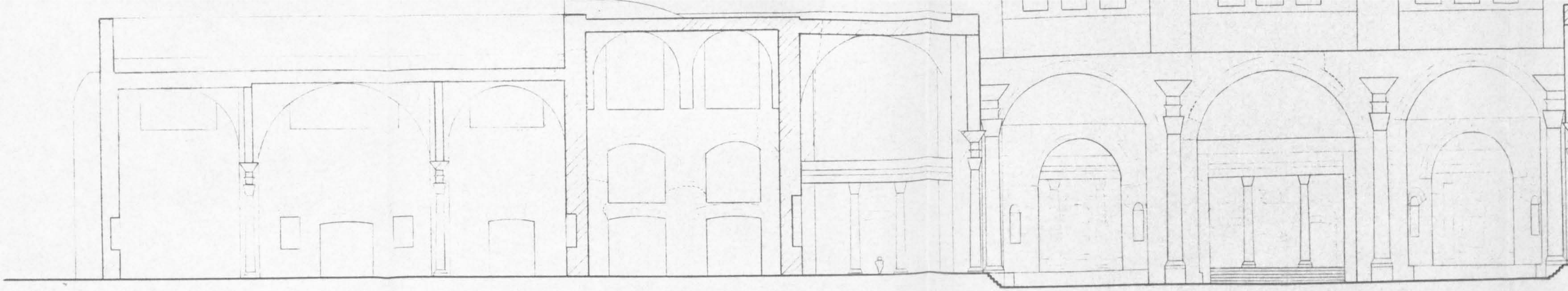

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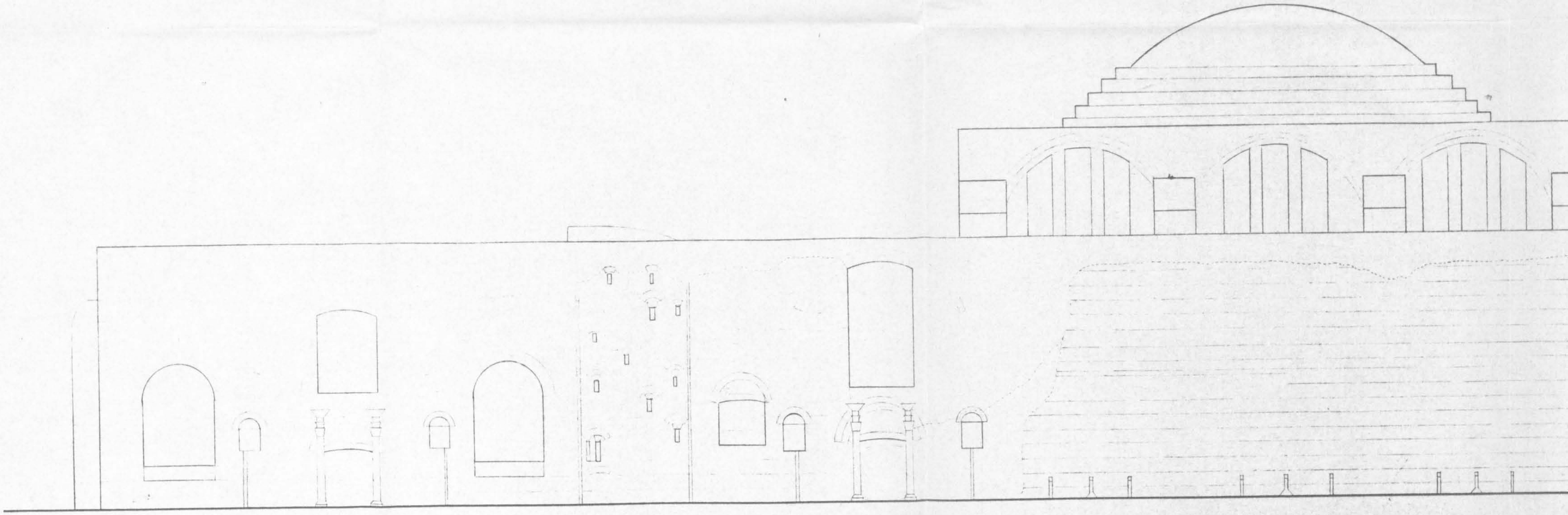

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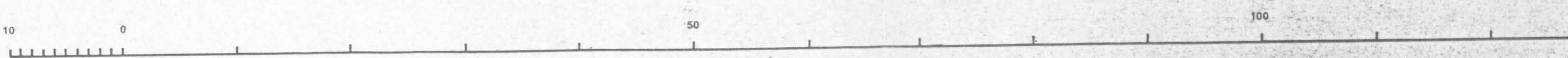

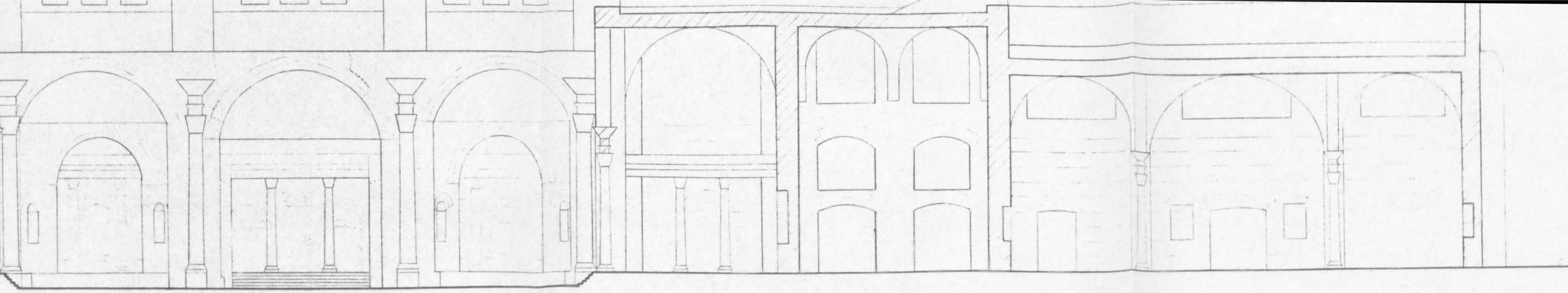

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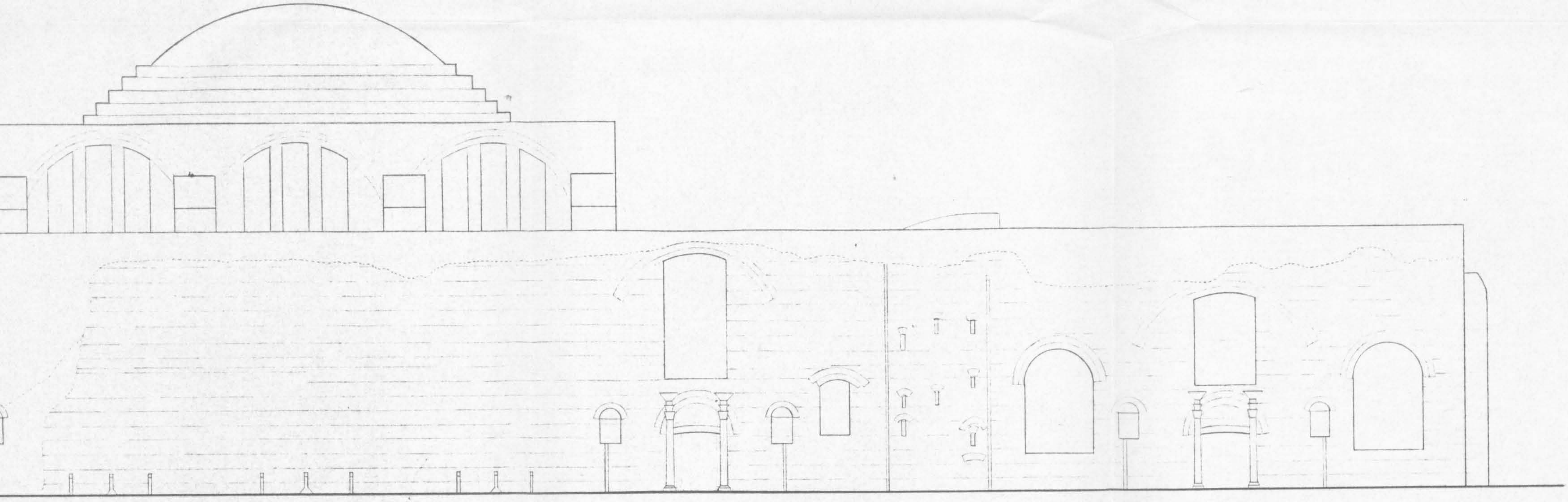

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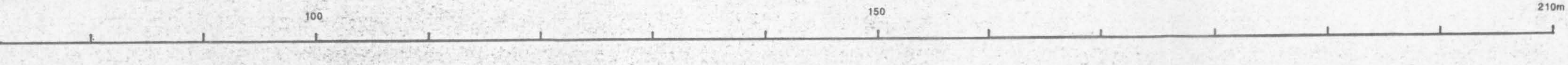

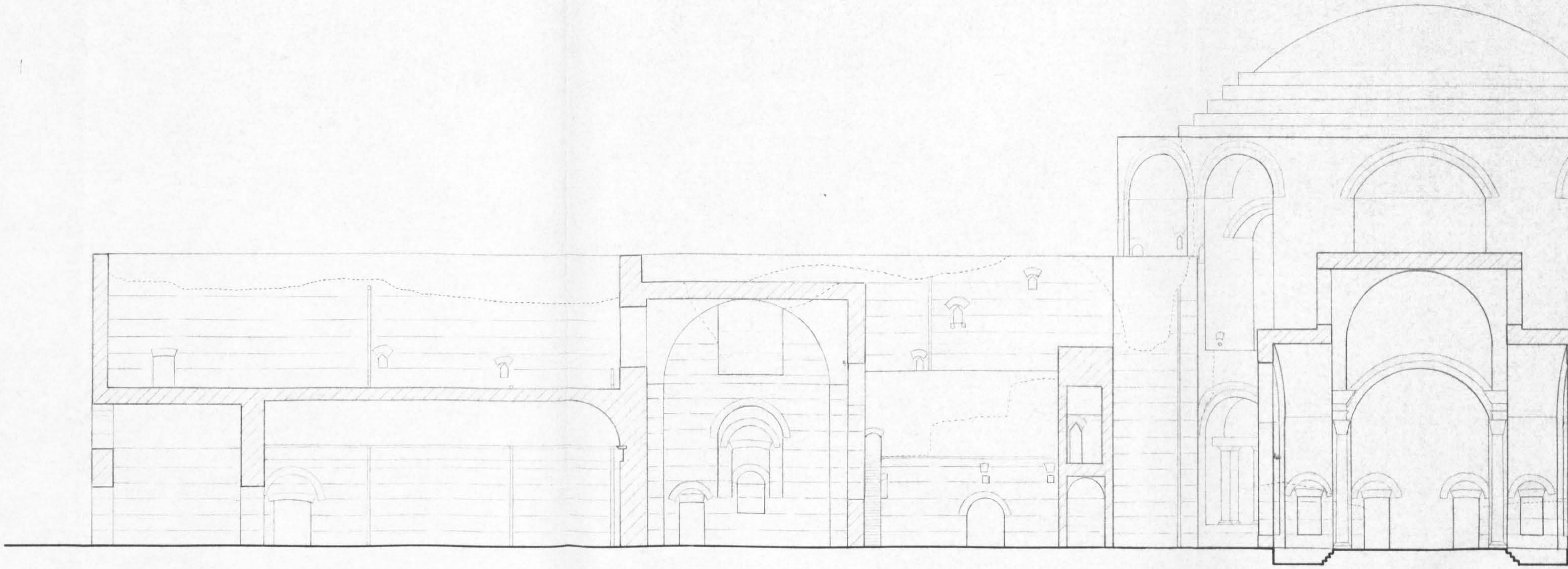

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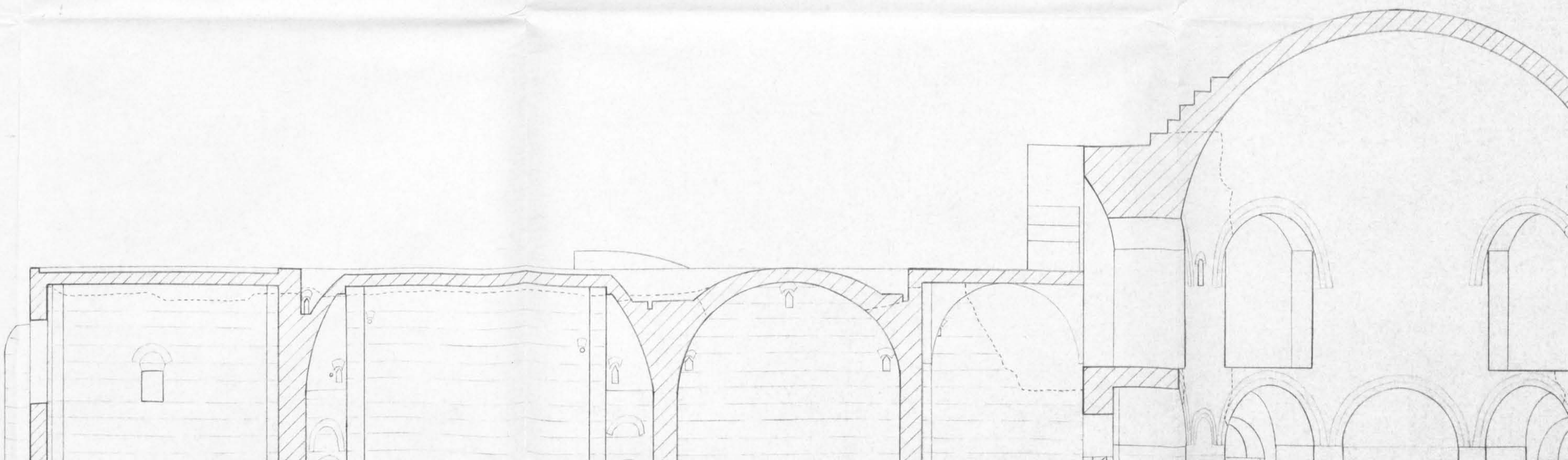

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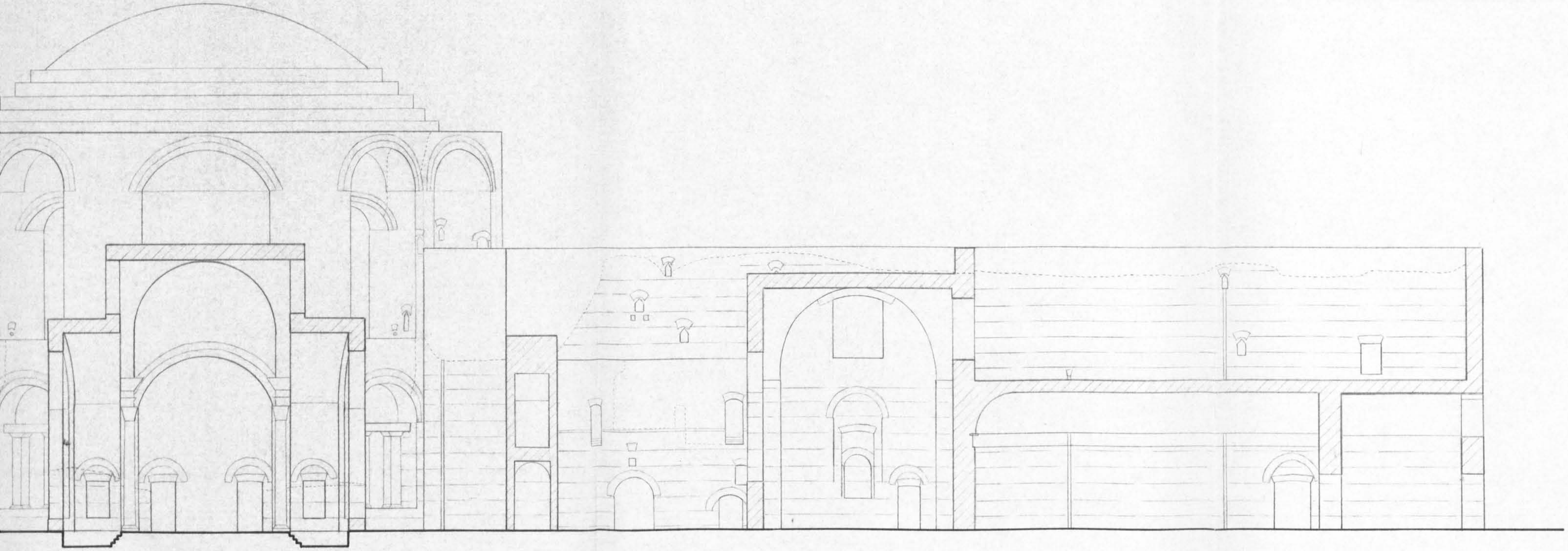

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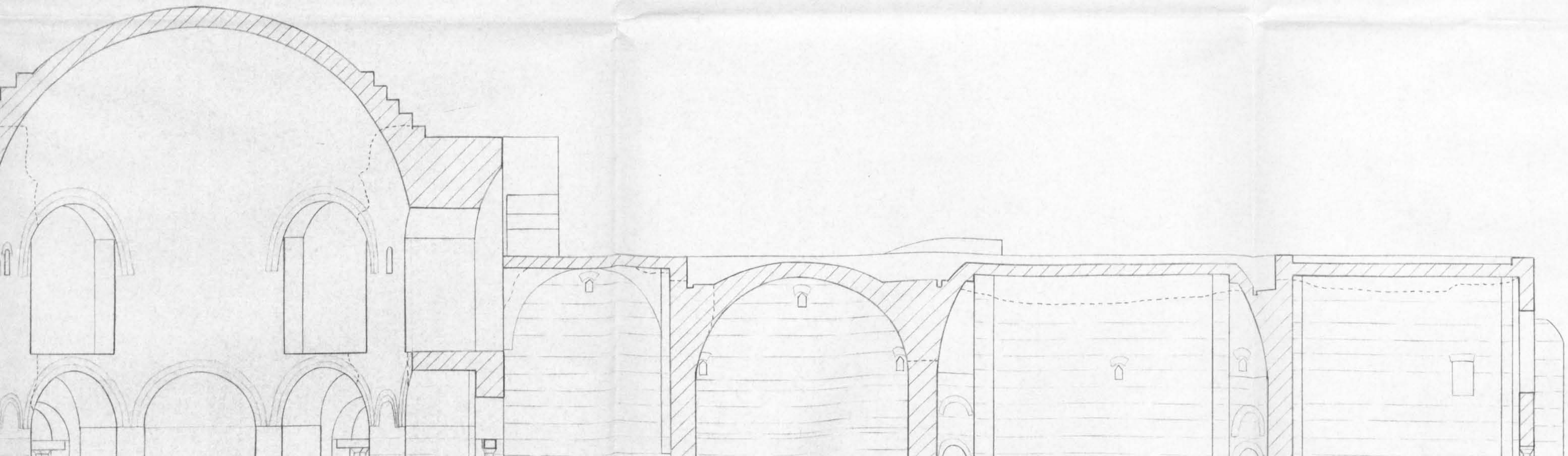

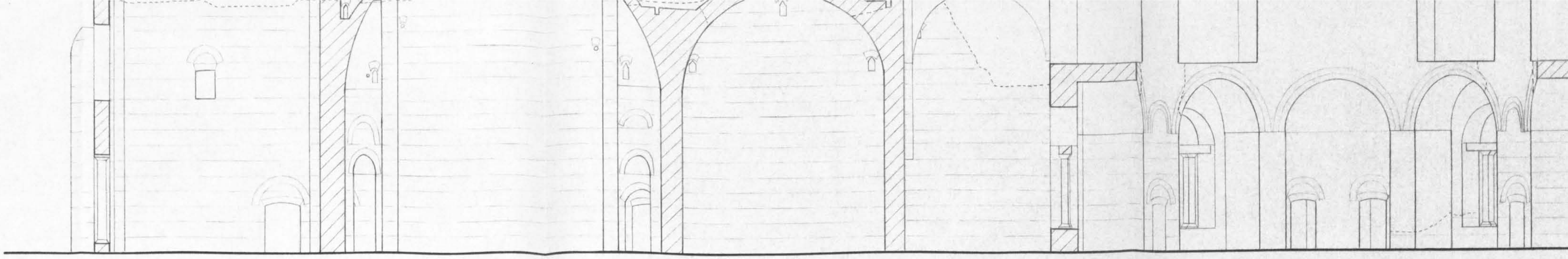

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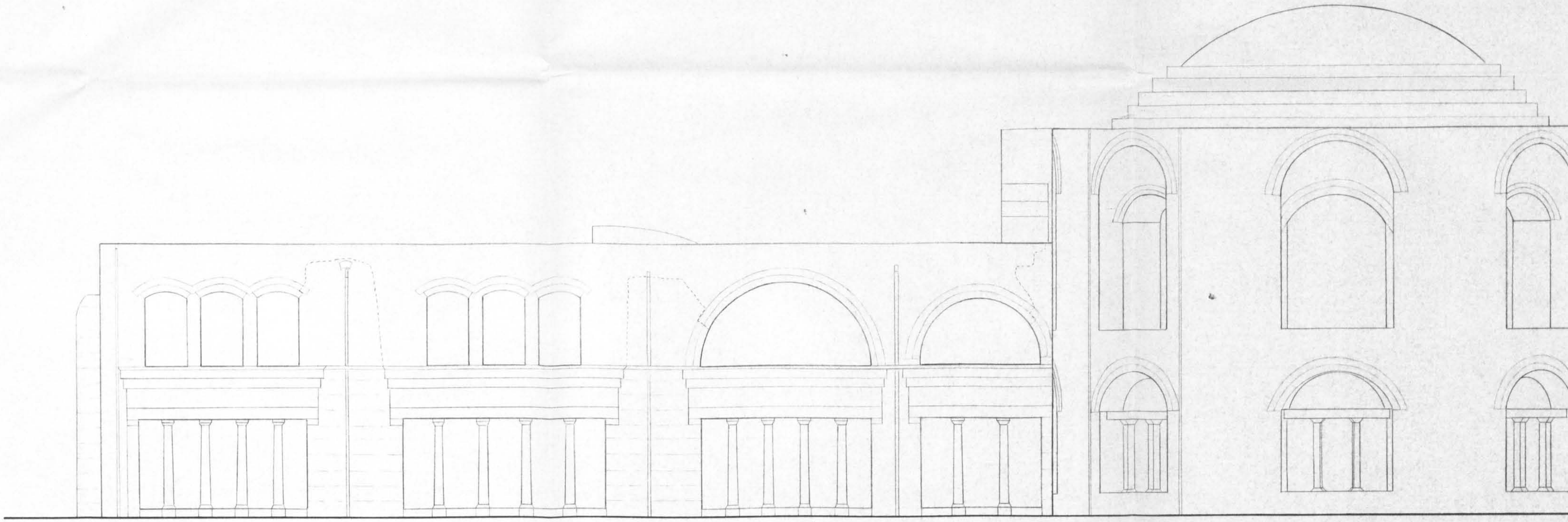

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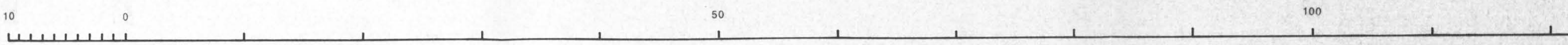

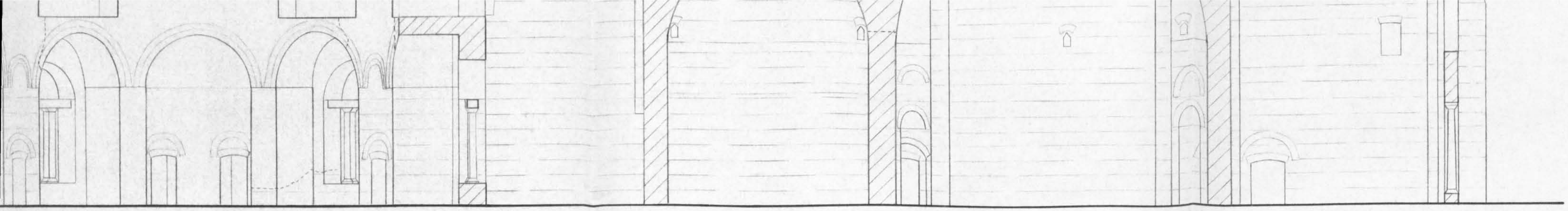

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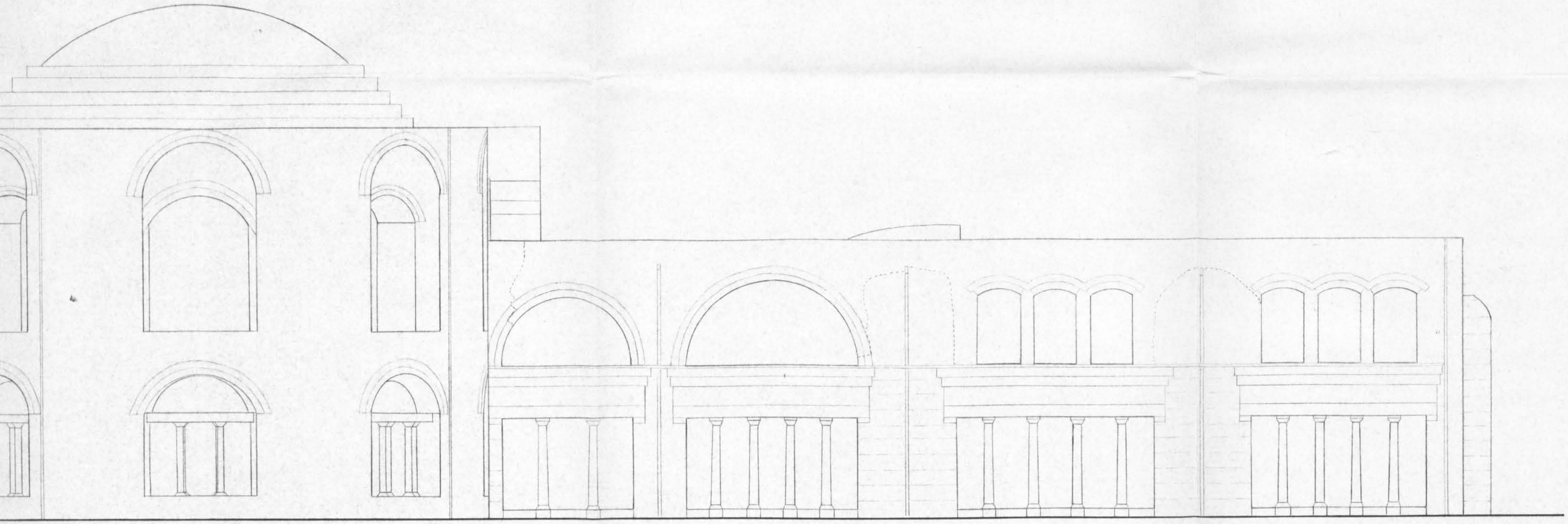

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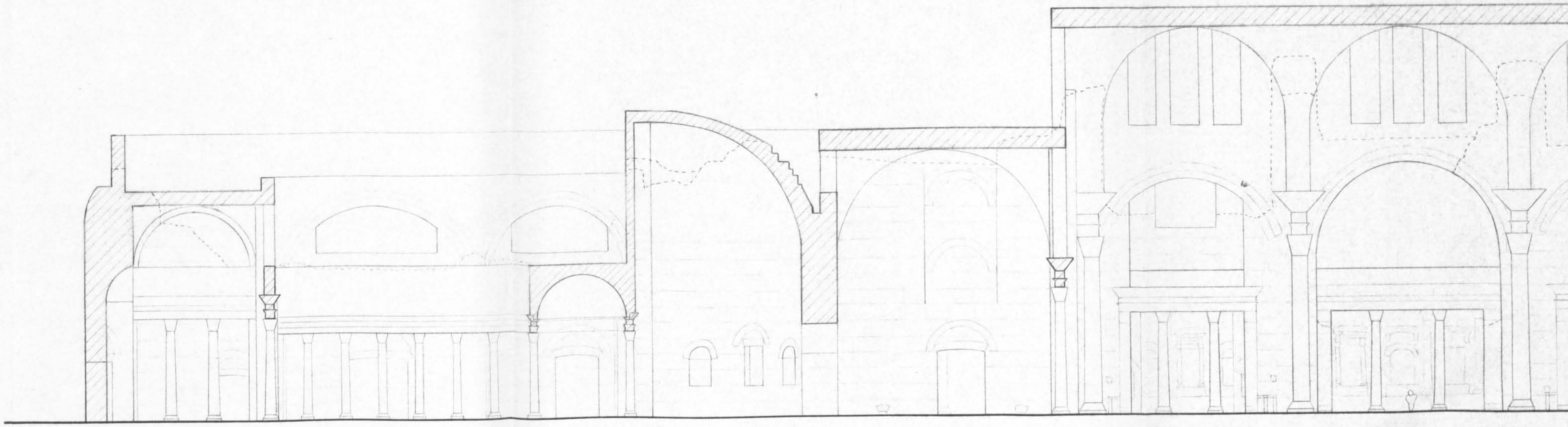

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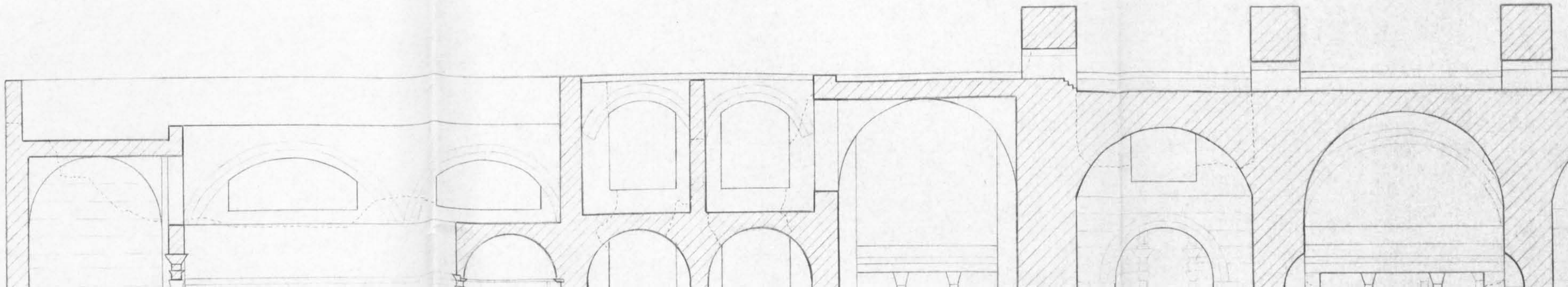

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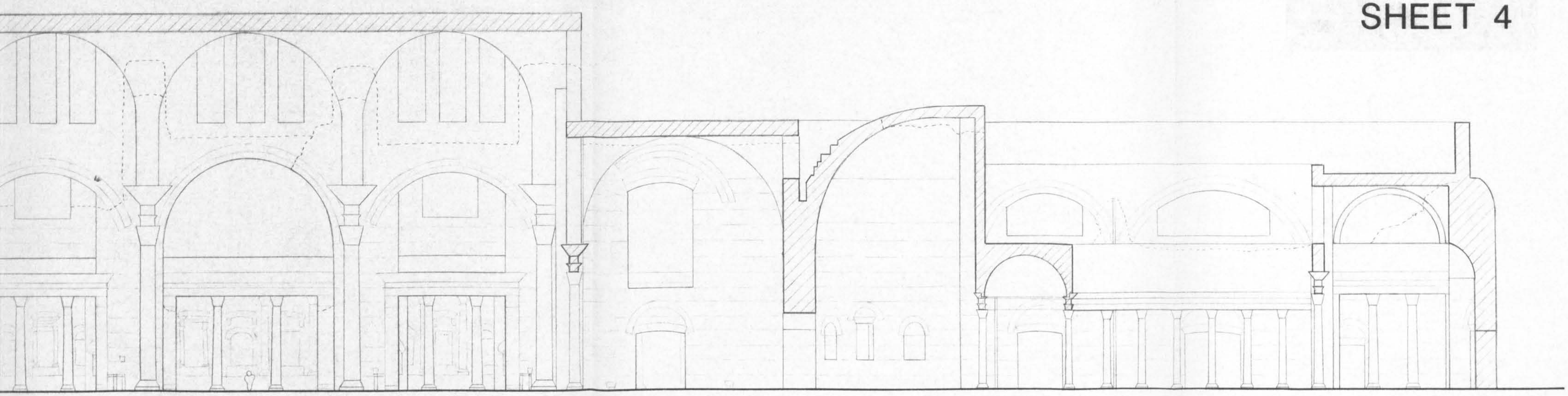

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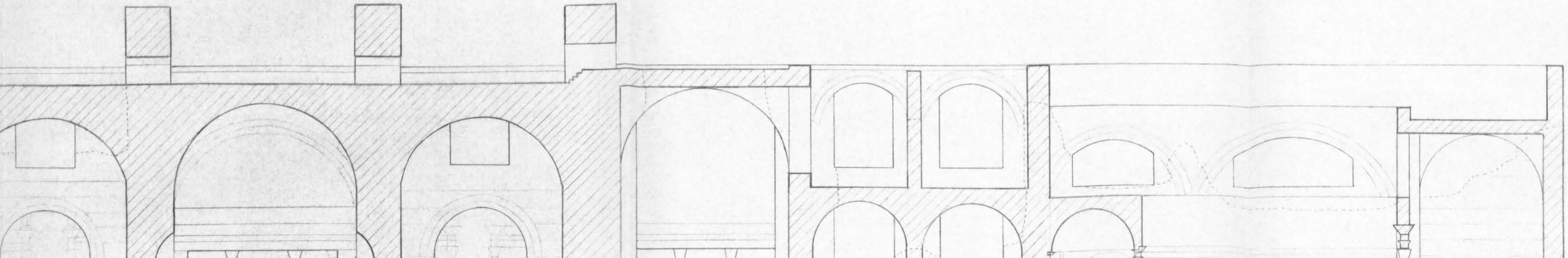

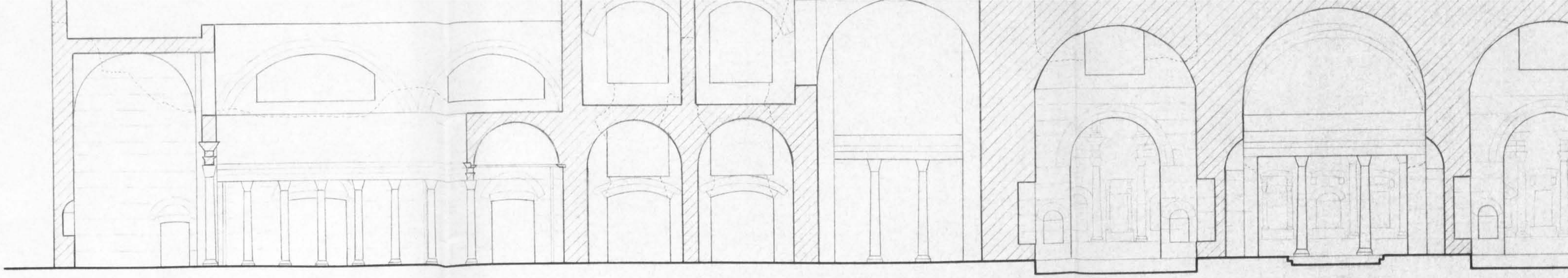

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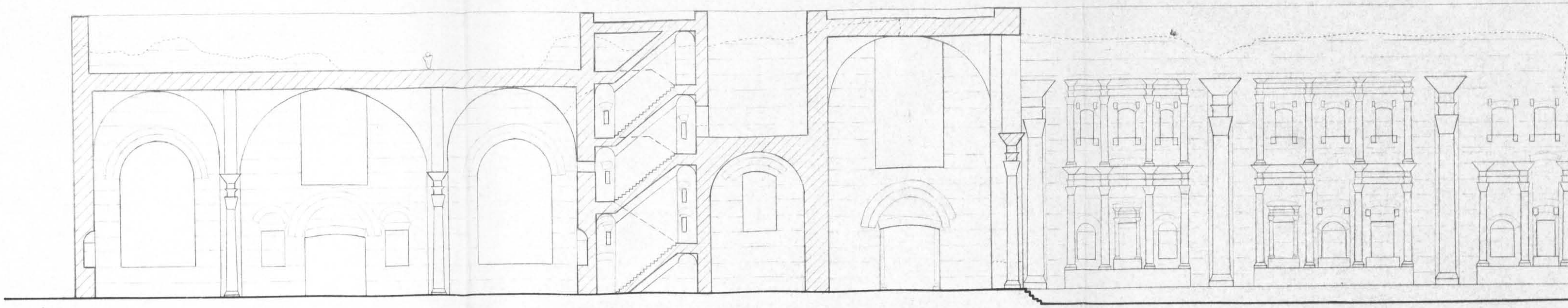

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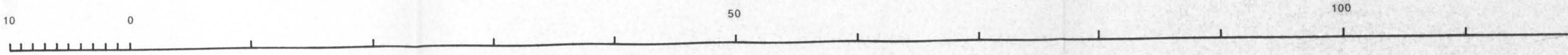

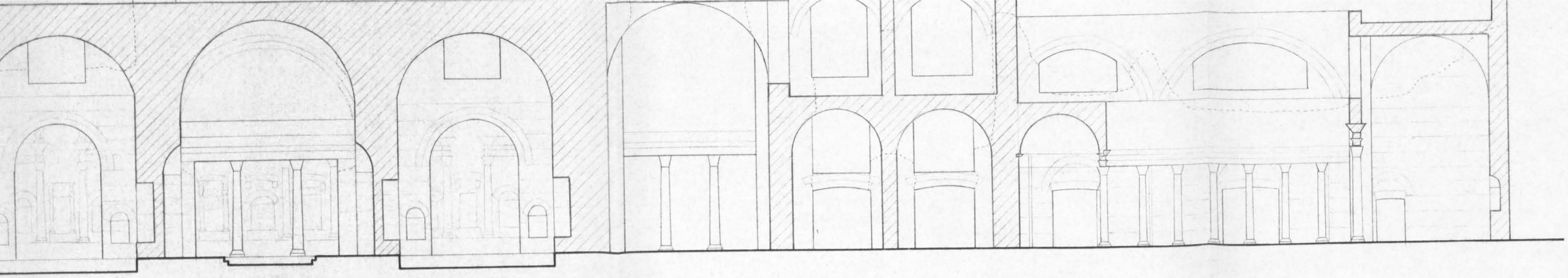

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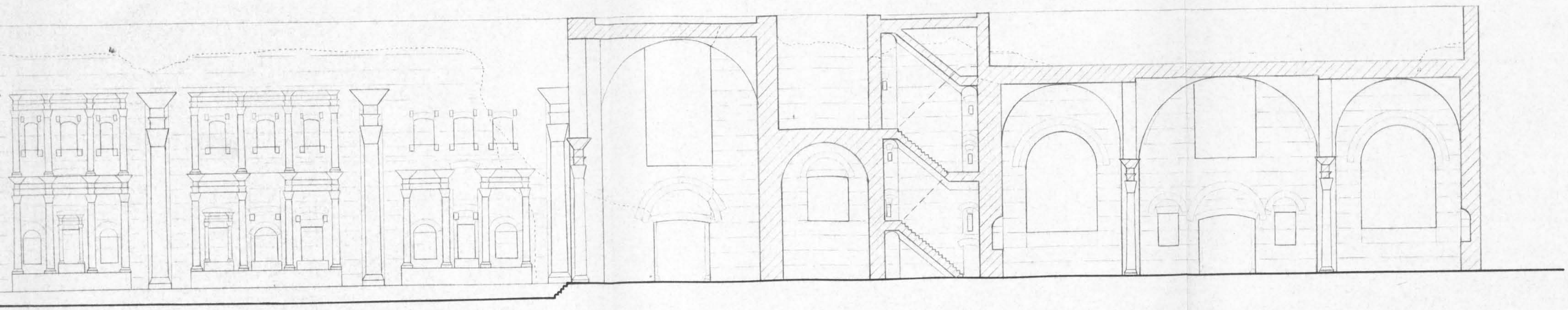

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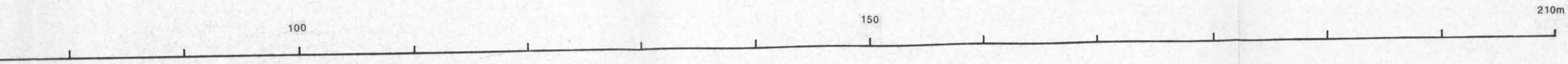

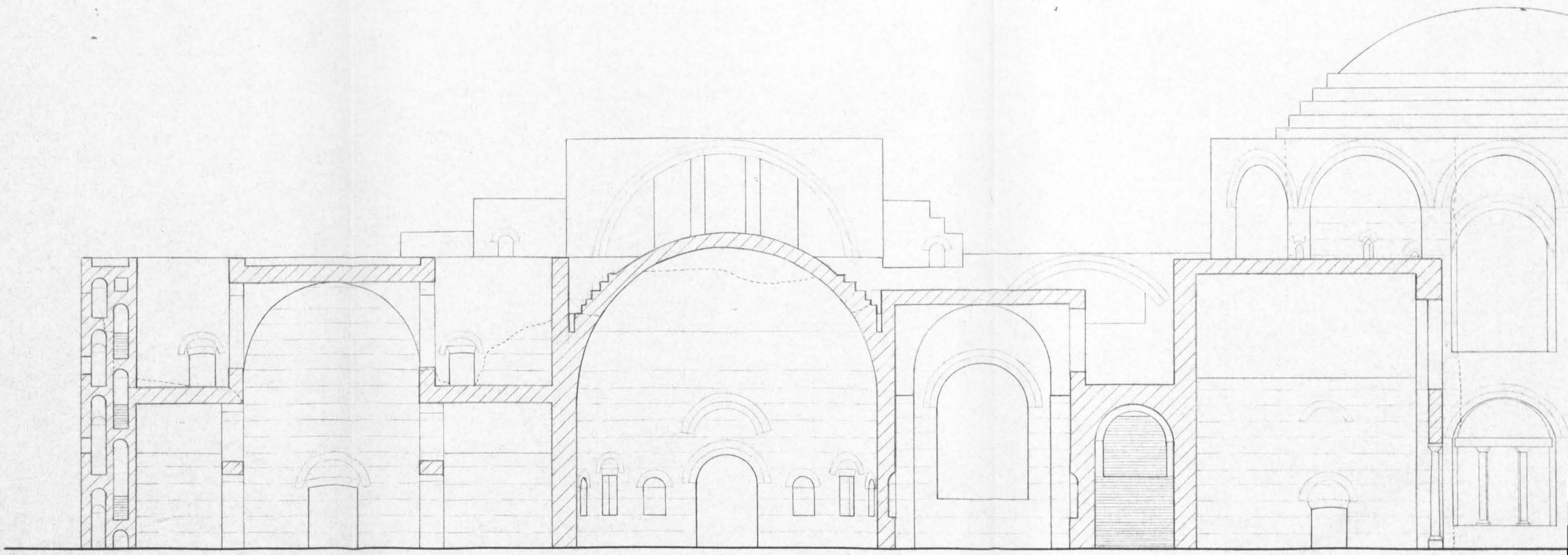

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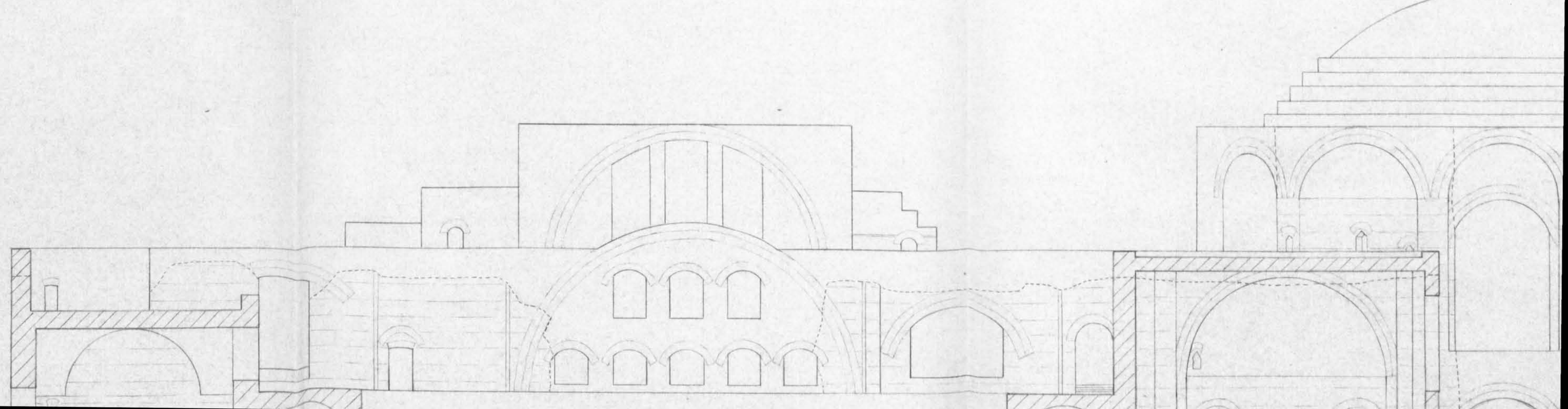

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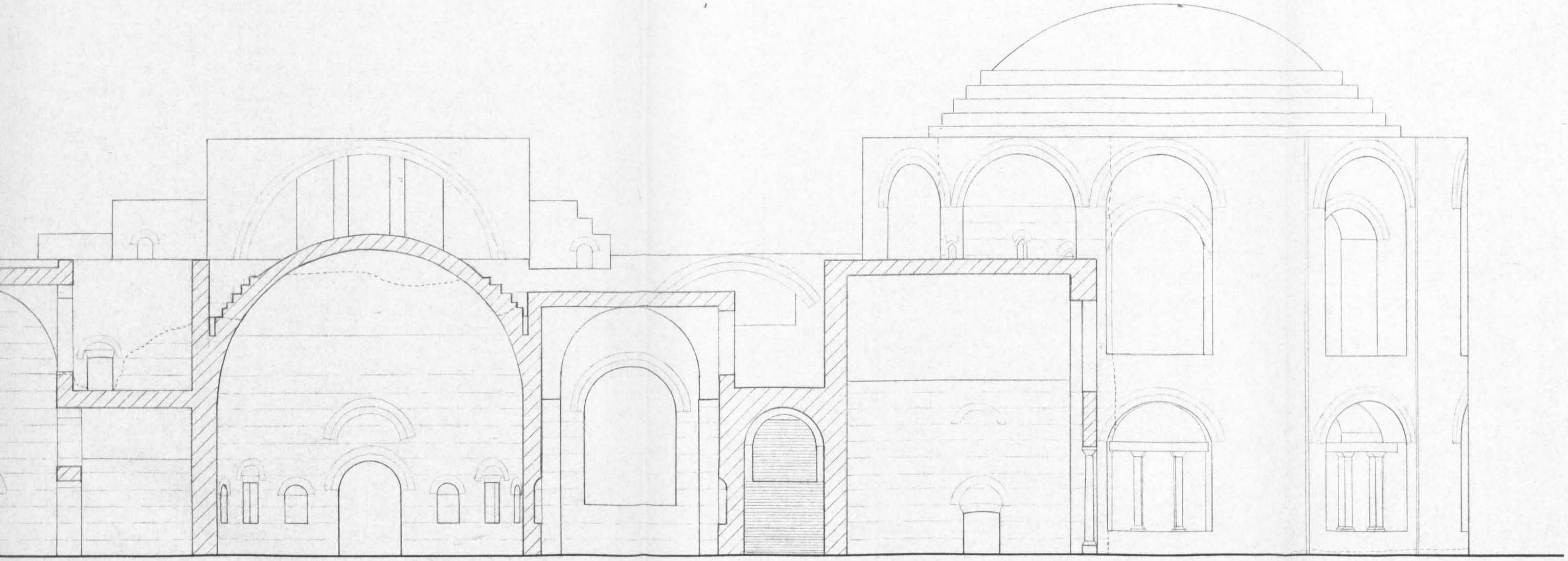

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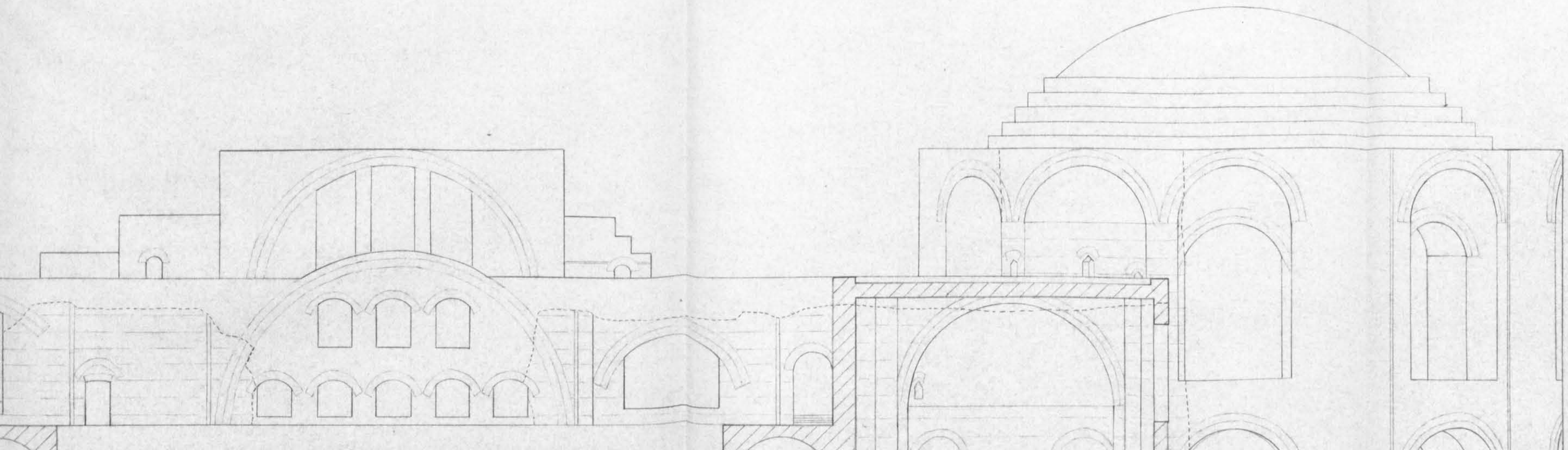

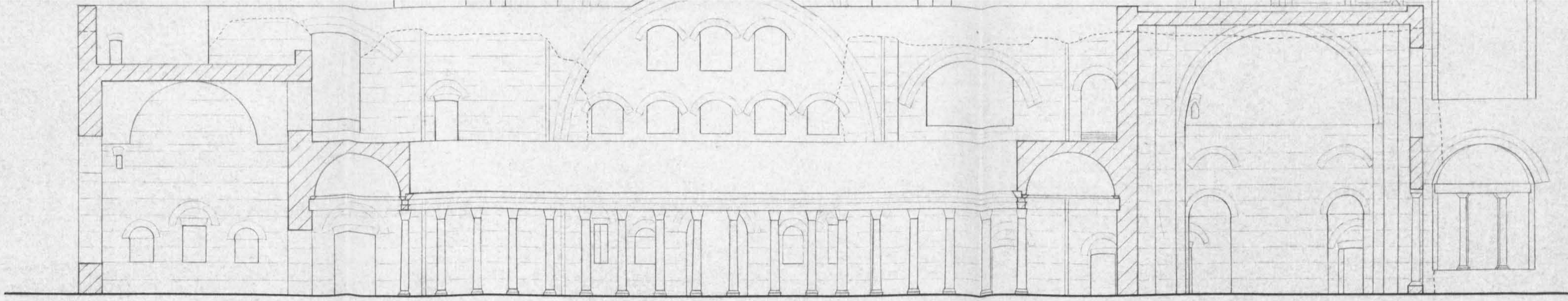

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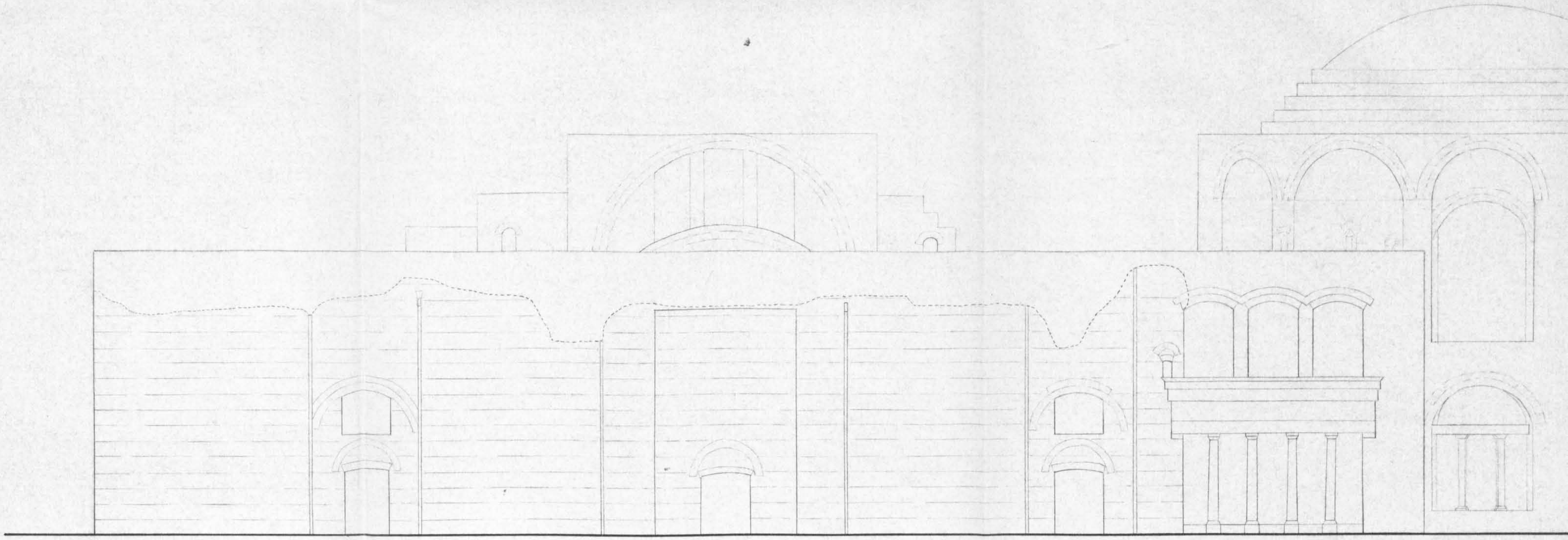

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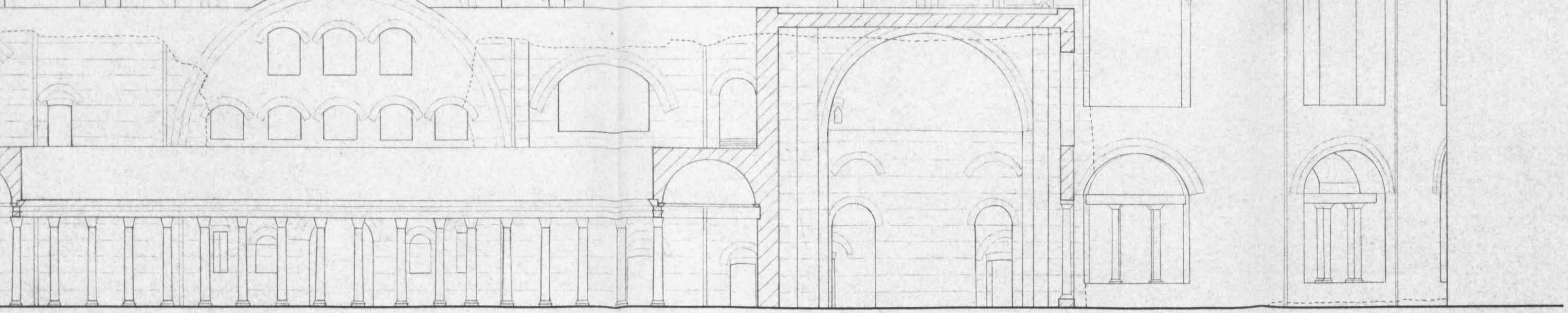

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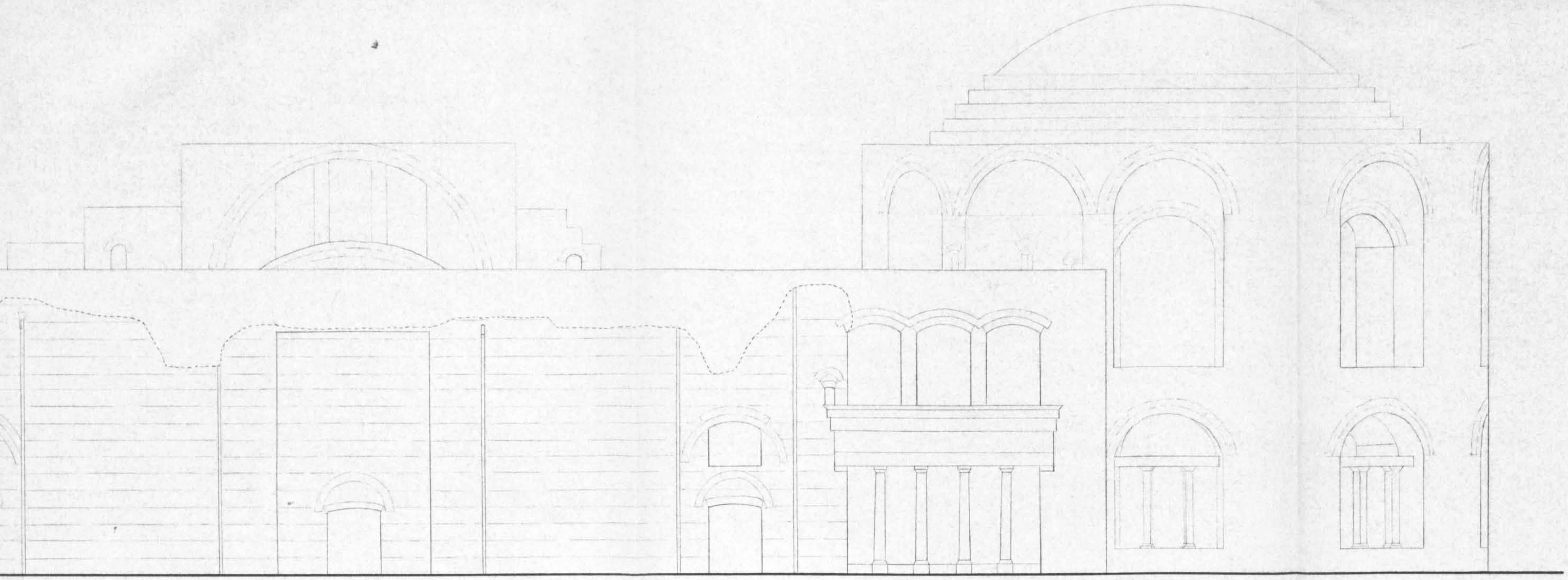

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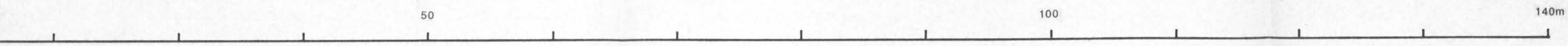

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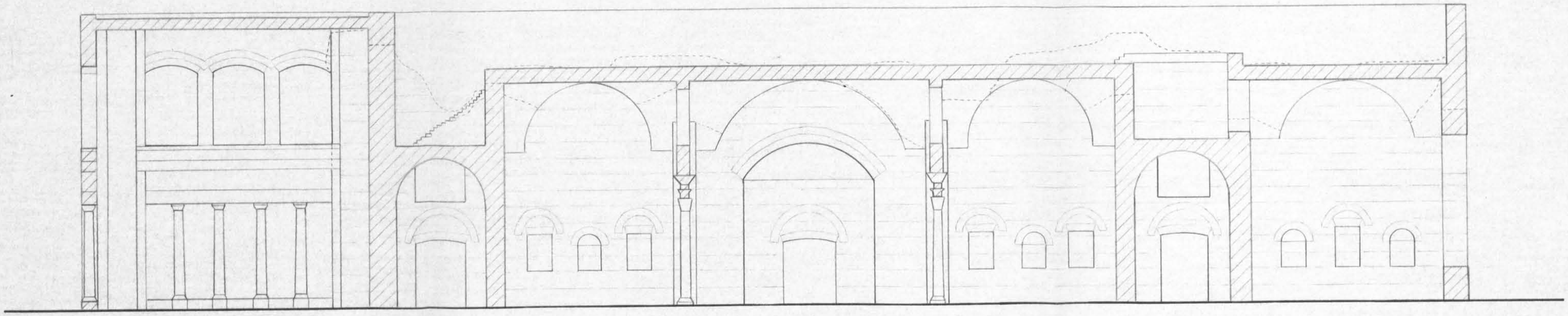

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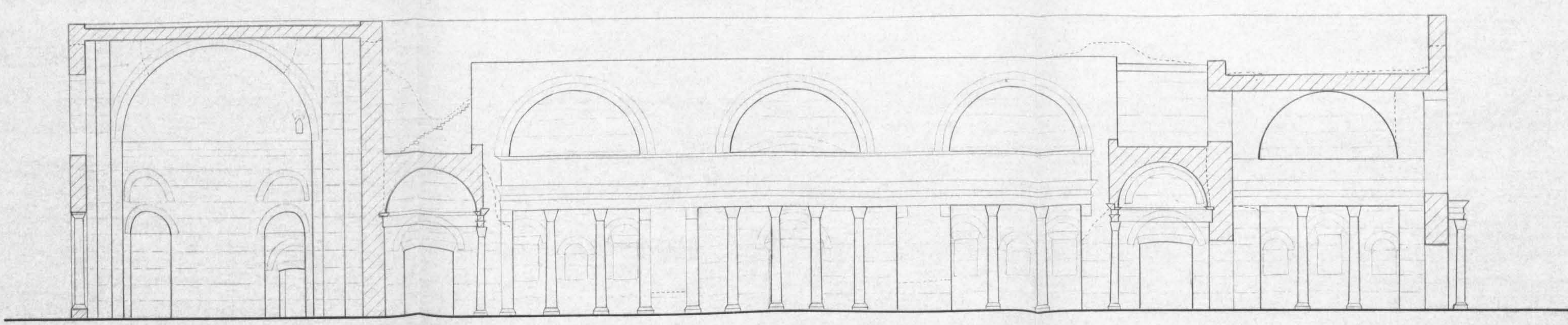

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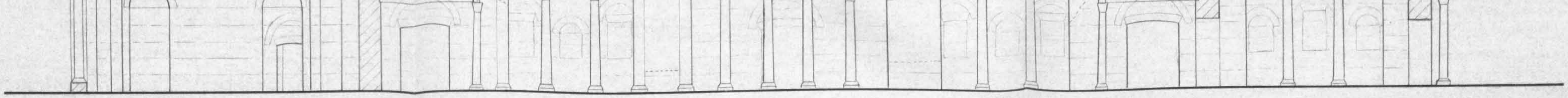

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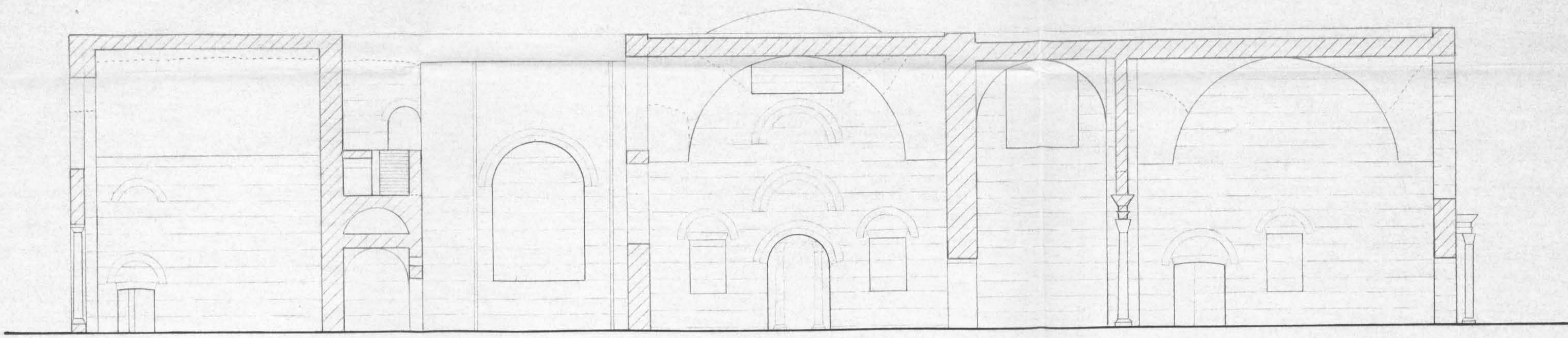

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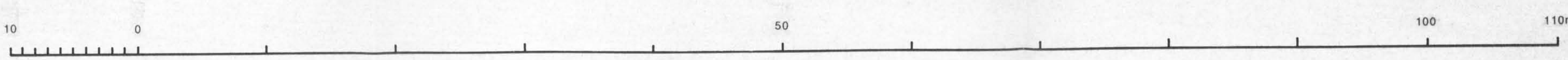

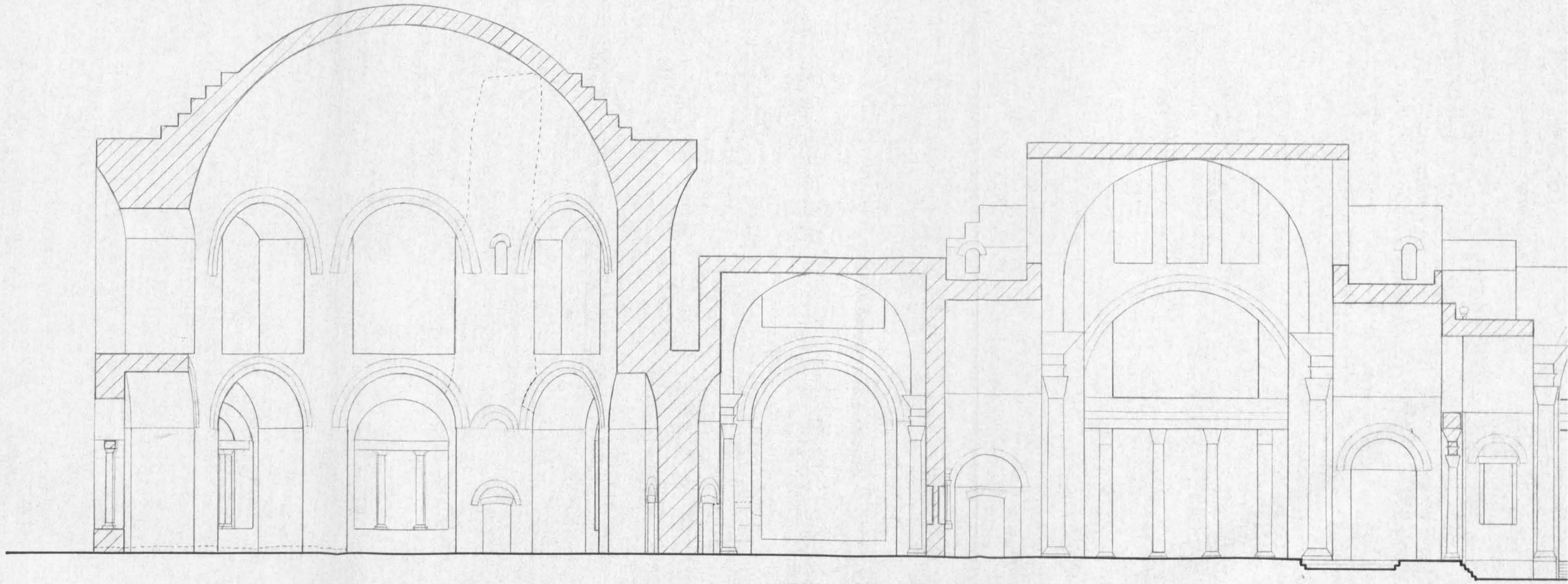

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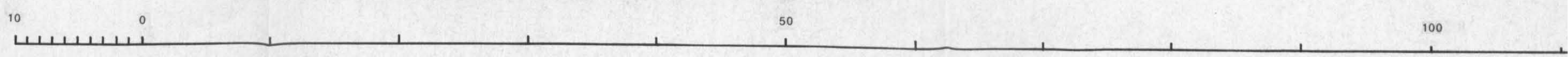

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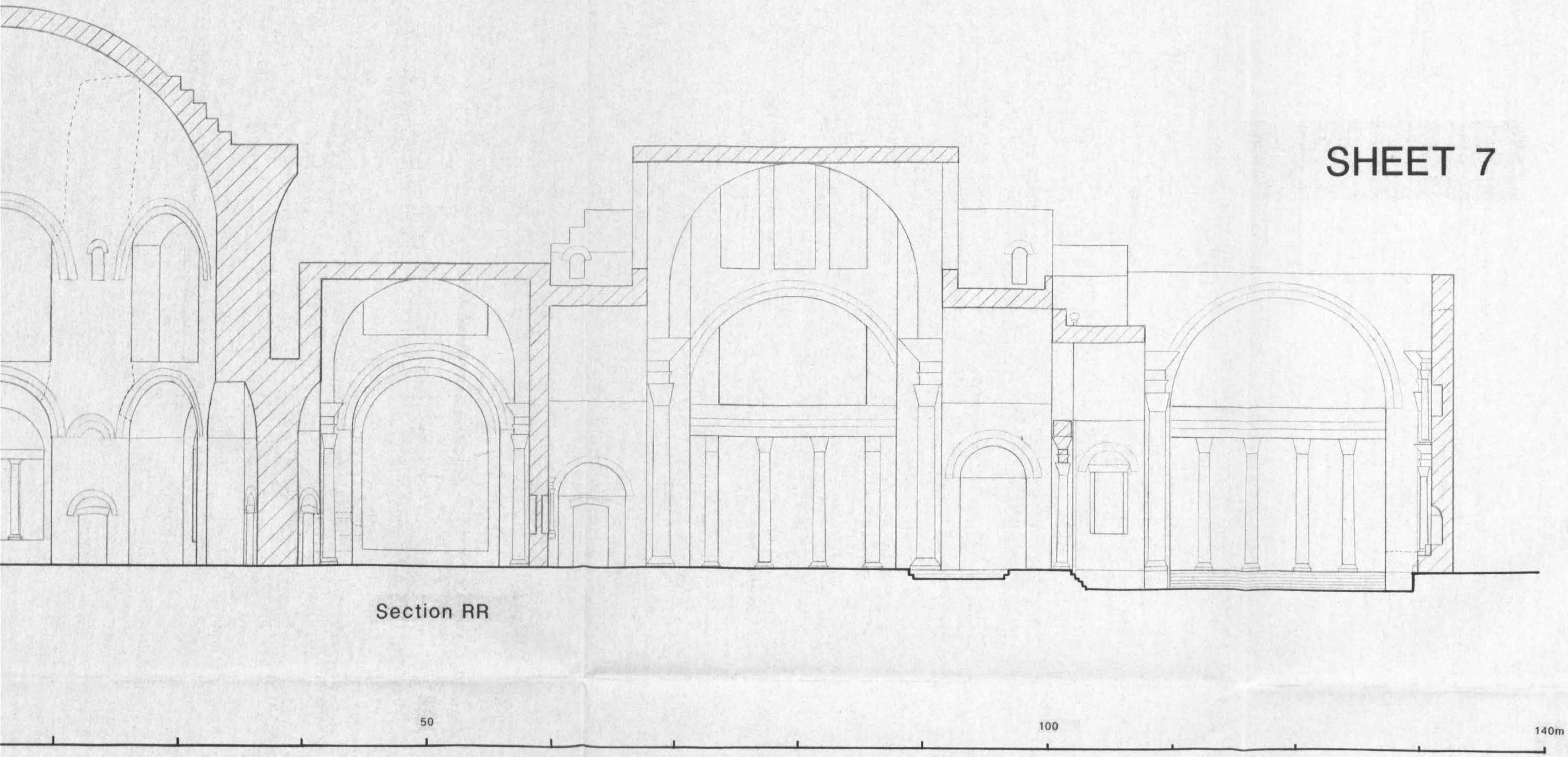

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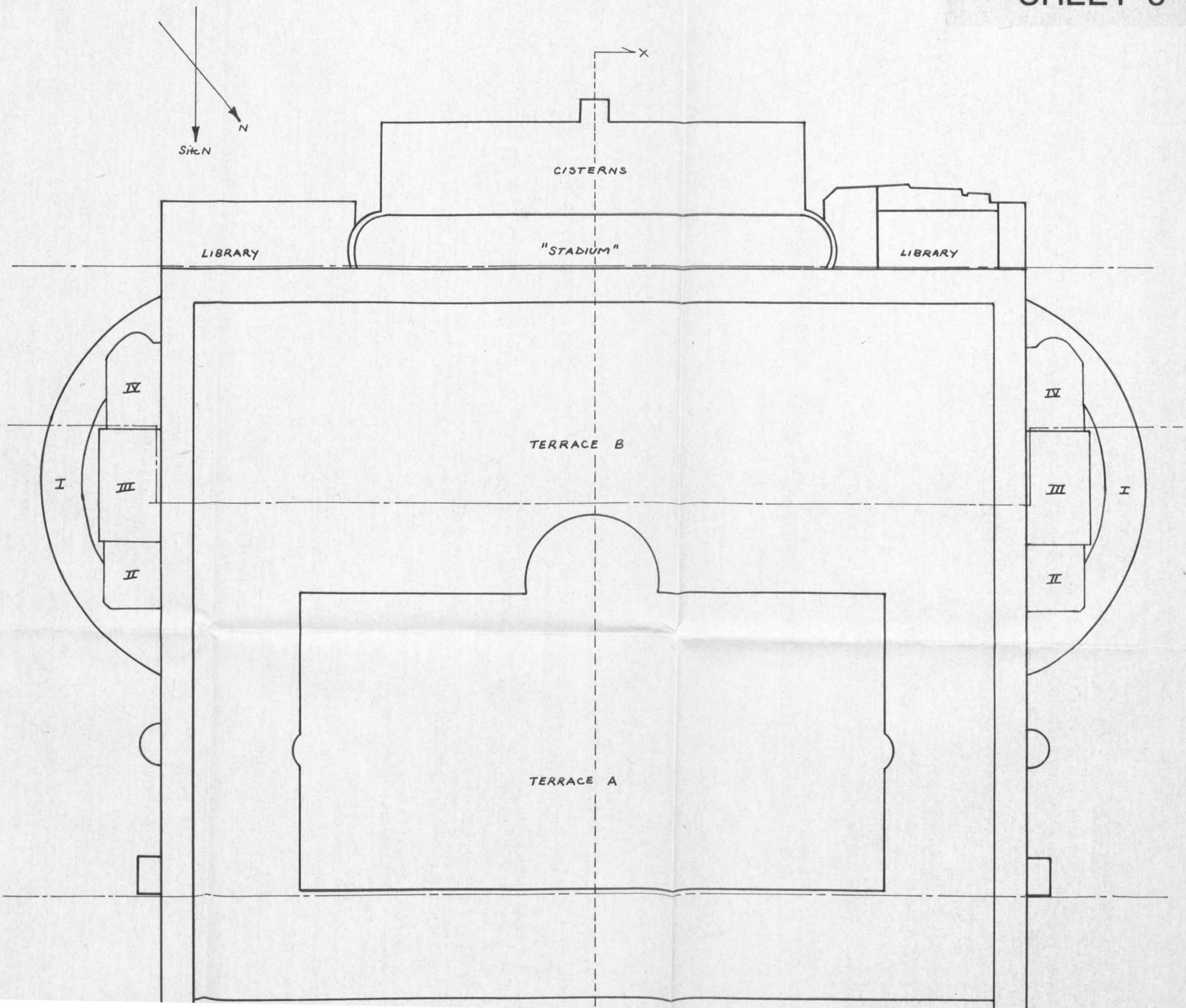
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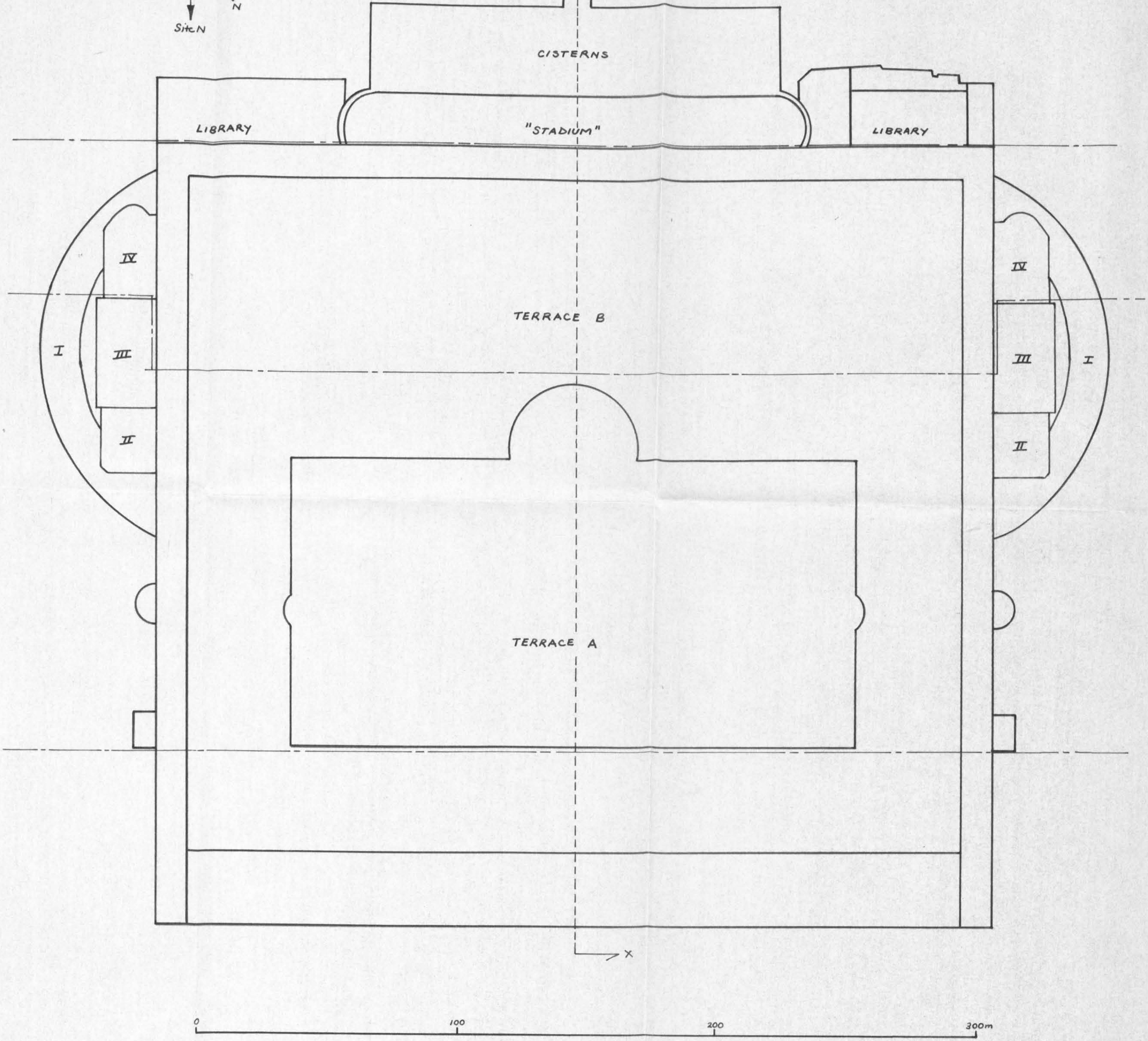
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