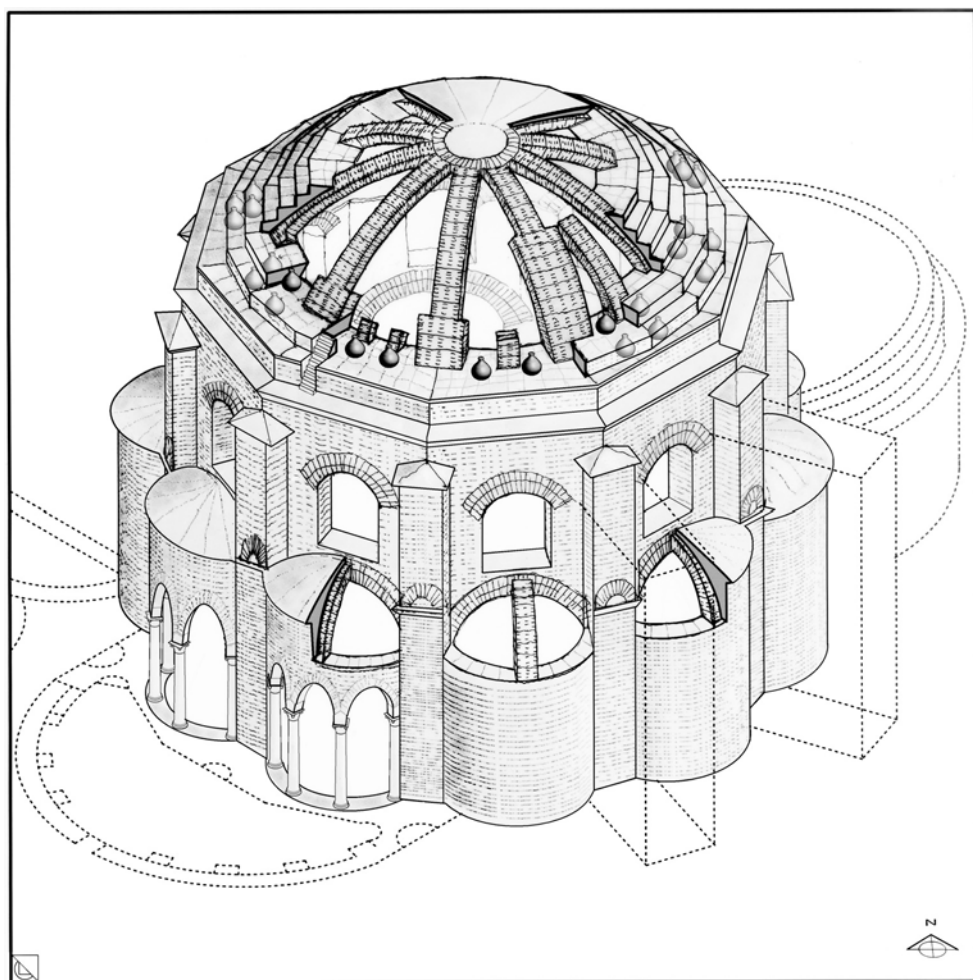


## CONCRETE VAULTED CONSTRUCTION IN IMPERIAL ROME

*Concrete Vaulted Construction in Imperial Rome* examines the methods and techniques that enabled builders to construct some of the most imposing monuments of ancient Rome. Focusing on structurally innovative vaulting and the factors that influenced its advancement, Lynne Lancaster also explores a range of related practices, including lightweight pumice as aggregate, amphoras in vaults, vaulting ribs, metal tie bars, and various techniques of buttressing. She provides the geological background of the local building stones and applies mineralogical analysis to determine material provenance, which in turn relates to trading patterns and land use. Lancaster also examines construction techniques in relation to the social, economic, and political contexts of Rome, in an effort to draw connections between changes in the building industry and the events that shaped Roman society from the early empire to late antiquity.

Lynne C. Lancaster is assistant professor of classics at Ohio University. An architect and archaeologist, she is a Fellow of the American Academy in Rome and has published in a variety of journals, including *American Journal of Archaeology*, *Journal of Roman Archaeology*, and *Römische Mitteilungen*.



# CONCRETE VAULTED CONSTRUCTION IN IMPERIAL ROME

## INNOVATIONS IN CONTEXT

LYNNE C. LANCASTER

Ohio University



**CAMBRIDGE**  
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS  
 Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press  
 40 West 20th Street, New York, NY 10011-4211, USA  
[www.cambridge.org](http://www.cambridge.org)  
 Information on this title: [www.cambridge.org/9780521842020](http://www.cambridge.org/9780521842020)

© Lynne C. Lancaster 2005

This book is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2005

Printed in Hong Kong at Golden Cup

*A catalog record for this publication is available from the British Library.*

*Library of Congress Cataloging in Publication Data*

Lancaster, Lynne C.  
 Concrete vaulted construction in Imperial Rome : innovations in context /  
 Lynne C. Lancaster.  
 p. cm.

Includes bibliographical references and index.

ISBN 0-521-84202-6 (hardcover)

1. Vaults (Architecture) – Rome – Design and construction – History – to 1500.
2. Concrete domes – Rome – Design and construction – History – to 1500.
3. Rome – Antiquities. I. Title.

TH16.L364 2005

690'.143'09376 – dc22 2004029473

ISBN-13 978-0-521-84202-0 hardback

ISBN-10 0-521-84202-6 hardback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party Internet Web sites referred to in this book and does not guarantee that any content on such Web sites is, or will remain, accurate or appropriate.

Cambridge University Press  
0521842026 - Concrete Vaulted Construction in Imperial Rome: Innovations in Context  
Lynne C. Lancaster  
Frontmatter  
[More information](#)

---

*For Tom*

I believe that in architecture, as in all art, the artist instinctively keeps the marks  
which reveal how a thing was done.

– Louis I. Kahn

## CONTENTS

<i>List of Illustrations and Tables</i>	<i>page</i> xiii
<i>Preface</i>	xix
1 INTRODUCTION	I
A Note on Monuments and Previous Scholarship	2
How to Use this Book	2
The Nature of Roman Concrete	3
Concrete Vaulting during the Republic	3
Structural Behavior of Concrete Vaults	6
Roman Mathematical and Analytical Background	10
Materials, Transport, and Production	12
The Building Industry in Rome	18
The Innovations	21
2 CENTERING AND FORMWORK	22
Assembling the Centering	22
Removing the Centering and Formwork	26
The Use of Brick Linings on the Intrados of Vaults	29
Evidence for Centering Arrangements	32
Barrel Vaults, 32 • Cross Vaults, 34 • Domes and Semidomes, 40	
Conclusions	48
3 INGREDIENTS: MORTAR AND CAEMENTA	51
Mortar	51
Lime, 53 • Pozzolana, 54 • <i>Cocciopesto</i> , 58	

## CONTENTS

<i>Caementa</i>	59
Provenance of <i>Caementa</i> , 64	
Conclusions	65
4 AMPHORAS IN VAULTS	68
Types of Amphoras Used	69
Early Examples of Amphoras in Vaults	69
Examples of Amphoras in Late Antique Vaults	75
Conclusions	81
5 VAULTING RIBS	86
Early Development of Vaulting Ribs and Relieving Arches	86
The Vaulting Ribs at the Colosseum	88
The Use of Solid Brick ( <i>Bipedalis</i> ) Ribbing	91
Ladder and Lattice Ribs in Barrel Vaults	98
Ladder and Lattice Ribs in Cross Vaults	106
Ribbing in Domes	108
Conclusions	111
6 METAL CLAMPS AND TIE BARS	113
The Earliest Use of Tie Bars	115
Tie Bars in the Imperial Thermae	116
Tie Bars at the Forum of Trajan	118
Spacing of Tie Bars	125
The Use of Tie Bars with Lightweight <i>Caementa</i>	126
Iron Architrave Bars and Impost Blocks at Hadrian's Villa	126
Conclusions	127
7 VAULT BEHAVIOR AND BUTTRESSING	130
Arches and Barrel Vaults	132
Cross Vaults	134
Domes and Semidomes	138
Conclusions	146
8 STRUCTURAL ANALYSIS: HISTORY AND CASE STUDIES	149
Historical Development	149
Basilica Ulpia	156
"Temple of Mercury" at Baiae	156
Pantheon	158



## CONTENTS

“Temple of Minerva Medica”	161
Conclusions	164
9 INNOVATIONS IN CONTEXT	166
Accumulated Knowledge	166
Evident Need	168
Economic Ability	170
Social/Cultural/Political Acceptability	172
APPENDIX 1. CATALOGUE OF MAJOR MONUMENTS	183
APPENDIX 2. CATALOGUES OF BUILDING TECHNIQUES	205
A. Formwork Imprints on Barrel Vaults	205
B. Formwork Imprints on Domes	206
C. Formwork Imprints on Semidomes	206
D. Brick Linings on the Intrados of Vaults	207
E. Uses of <i>Cocciopesto</i> to Protect the Extrados of Vaults	211
F. Lightweight <i>Caementa</i>	213
G. Amphoras in Vaults	215
H. Vaulting Ribs	216
I. Blocks with Tie Bar Cuttings	221
APPENDIX 3. SCORIA ANALYSIS	222
APPENDIX 4. THRUST LINE ANALYSIS	225
<i>Notes</i>	231
<i>Glossary</i>	245
<i>Works Cited</i>	251
<i>Index</i>	265

## LIST OF ILLUSTRATIONS AND TABLES

*Frontispiece.* “Temple of Minerva Medica” in the Horti Liciniani.

### FIGURES

1. Sanctuary of Jupiter Anxur. Terracina.	<i>page</i> 5
2. Diagram of principal parts of an arch.	6
3. Diagram of stress patterns in a beam.	7
4. Section D at Baths of Trajan. Rome.	8
5. Diagram of deformation of vault due to creep.	9
6. Sanctuary of Fortuna Primigenia. Palestrina.	9
7. Sketches of the Sanctuary of Fortuna Primigenia. Palestrina.	11
8. Reconstruction of wooden centering for concrete barrel vault.	23
9. Wooden trusses at San Pietro and San Paolo Fuori le Mura. Rome.	23
10. Marble panel with depiction of wooden amphitheater.	24
11. Detail of plaster cast from Trajan’s Column. Italic, Spain.	24
12. Scarf joints.	25
13. Frame saws.	26
14. Wooden centering. Olympia, Greece.	27
15. Detail of Blackfriar’s Bridge. G. B. Piranesi.	28
16. Diagram of method of lowering the centering of vaults.	29
17. Reconstruction of centering using brick linings.	29
18. Detail of vault built using brick linings. Case a giardino, Ostia.	30
19. Heliocaminus Baths at Hadrian’s Villa. Tivoli.	31
20. Pons Fabricius. Rome.	32
21. Pons Cestius. Rome.	33
22. Engravings of Pons Cestius. G. B. Piranesi.	33
23. Reconstruction of centering frames at Pont du Gard. A. Leger.	34
24. Barrel vaulted room under San Clemente. Rome.	35
25. Common deformation pattern for centering frames.	36
26. Basilica of Maxentius. Rome.	36
27. Basilica of Maxentius. Rome.	37
28. Reconstructions of formwork for a pavilion vault and a cross vault.	38

## LIST OF ILLUSTRATIONS AND TABLES

29. Detail of cross vault from the Colosseum. Rome.	38
30. Reconstruction of the centering scheme for the Aula at Trajan's Markets. Rome.	39
31. Comparison of centering schemes (same scale) for cross vaults at Trajan's Markets and the Baths of Caracalla. Rome.	39
32. Diagram of domes showing formwork layouts.	40
33. Reconstruction of the centering at the "Temple of Mercury." Baiae.	41
34. Formwork impressions on the octagonal dome at the Domus Aurea. Rome.	42
35. Geometry of centering for the octagonal dome at the Domus Aurea. Rome.	43
36. Pantheon section. Rome.	44
37. Reconstruction of Pantheon centering. M. Viollet-le-Duc.	45
38. Reconstruction of formwork for segmental domes.	47
39. Excavation photo of the Serapeum at Hadrian's Villa. Tivoli.	47
40. Diagram showing the cycle of chemical changes in lime mortar production.	53
41. Quicklime at the Casa del Sacello Iliaco. Pompeii.	54
42. Section of Mausoleum of Helena. Rome.	57
43. Detail of vault covering from the Basilica Argentaria. Rome.	59
44. Reconstruction of <i>horti pensiles</i> at the Domus Tiberiana. Rome.	60
45. Vesuvian scoria at the Forum of Caesar. Rome.	61
46. Section of the Pantheon showing distribution of materials. Rome.	62
47. Mausoleum of Helena with amphoras in dome. Rome.	69
48. Amphora types found in vaults in Rome.	70
49. Cross vault with amphoras. Magazzini "Traianei," Ostia.	72
50. Plan of the Villa alla Vignaccia. Rome.	72
51. Villa alla Vignaccia with amphoras in walls and vaults. Rome.	73
52. Fallen vault from the Casa de la Exedra. Italica, Spain.	73
53. Diagrams showing uses of amphoras for land reclamation projects.	74
54. Wall containing amphoras. Pompeii.	75
55. Balcony vault of the "Casa di Via Giulio Romano" with amphoras. Rome.	76
56. Circus at the Villa of Maxentius with amphoras in vaults. Rome.	77
57. Sketch of dome of the "Temple of Minerva Medica." Rome.	78
58. Octagonal Hall at the "Villa of the Gordians." Rome.	79
59. Semidome at Santa Maura with amphoras. Rome.	83
60. Plan and section of St. Jerome. Cologne, Germany.	84
61. Acropolis gate at Alatri, Italy.	87
62. Porta Rosa in city walls of Velia, Italy.	87
63. Theater of Marcellus. Rome.	88
64. Sanctuary of Hercules Victor. Tivoli.	89
65. Drawing of the Theater of Marcellus. Rome.	89
66. Section through the Theater of Marcellus. Rome.	90
67. Four types of vaulting ribs at the Colosseum. Rome.	90
68. Drawing of travertine ribs at the Colosseum. Rome.	91
69. Section and partial plan of the Colosseum showing location of ribs. Rome.	92
70. Sketch section at bay 34 of the Colosseum. Rome.	93
71. Detail of Flavian ladder rib at the Colosseum. Rome.	93
72. Axon of the Domitianic Vestibule. Rome.	94
73. Plan of lower level of the Domus Augustana. Rome.	95

## LIST OF ILLUSTRATIONS AND TABLES

74. Sketch plan of cryptoporticus at the Villa of Domitian. Castelgandolfo.	95
75. Cryptoporticus at the Villa of Domitian with ribs. Castelgandolfo.	96
76. Cryptoporticus at the Villa of Domitian with ribs and coffers. Castelgandolfo.	97
77. Section E at the Baths of Trajan. Rome.	97
78. Drawing of the Trajanic latrine in reconstructed part of the Forum of Caesar. Rome.	98
79. Trajanic latrine at the Forum of Caesar with travertine impost blocks. Rome.	99
80. Drawing of the Pantheon with its ribbing system. Rome.	100
81. Exterior of the Pantheon. Rome.	101
82. Plan of the Villa di Sette Bassi. Rome.	102
83. Ladder rib in the cryptoporticus of the Villa di Sette Bassi. Rome.	102
84. Ladder rib at the Villa di Sette Bassi. Rome.	103
85. Plan of the Severan Baths and the Baths of Maxentius on the Palatine. Rome.	103
86. Lattice ribs at the Severan Baths on the Palatine. Rome.	104
87. Nymphaeum Alexandri “Trophies of Marius.” Rome.	104
88. Detail of rib in outer ambulatory of the Colosseum. Rome.	105
89. Detail of lattice ribbing at the Baths of Maxentius on the Palatine. Rome.	105
90. Detail of nave façade of the Basilica of Maxentius. Rome.	106
91. Detail of ladder rib in cross vault at the Villa di Sette Bassi. Rome.	107
92. Lattice ribs in the cross vaults of the Maxentian substructures on the Palatine. Rome.	107
93. Dome at the Baths of Agrippa with lattice ribbing. Rome.	108
94. Plans of domes showing restored rib patterns.	109
95. Section of “Temple of Minerva Medica.” Rome.	111
96. Architrave block from the Forum of Trajan with remains of iron tie bar. Rome.	114
97. Reconstructed section of the Horrea Agrippiana. Rome.	115
98. Cornice block with tie bar cutting from the Horrea Agrippiana. Rome.	116
99. Reconstruction of the portico fronting the Basilica Aemilia. Rome.	117
100. Measured sketch of <i>bucranium</i> block from the portico fronting the Basilica Aemilia. Rome.	117
101. <i>Bucranium</i> block from the portico fronting the Basilica Aemilia. Rome.	118
102. Section H at Trajan’s Baths showing holes for anchor blocks for tie bars. Rome.	119
103. West palaestra of the Baths of Caracalla. Rome.	120
104. East palaestra of the Baths of Diocletian. Rome.	120
105. Generic reconstruction of the palaestra portico from an imperial bath showing tie bar and anchor block.	121
106. Cornice blocks from Trajan’s Forum. Rome.	121
107. Comparison of proposals by C. M. Amici and J. Packer for reconstruction of the Column Portico at Trajan’s Forum. Rome.	122
108. Comparison of proposals by C. M. Amici and J. Packer for reconstruction of the Basilica Ulpia. Rome.	122
109. Plan of the Basilica Ulpia. Rome.	123

## LIST OF ILLUSTRATIONS AND TABLES

110. Reconstruction of lintel construction at the Hall of the Doric Pilasters at Hadrian's Villa. Tivoli.	124
111. Hall of the Doric Pilasters at Hadrian's Villa. Tivoli.	125
112. Arcuated lintels at Santa Costanza. Rome.	127
113. Diagram of two proposed design schemes used at the Pantheon. Rome.	131
114. Diagram showing failure patterns of arched structures.	132
115. Diagram showing four factors that affect the stability of an arched structure.	133
116. Drawing showing vaulting configurations at the Market at Ferentino, the Market at Tivoli, the Domus Aurea, and Trajan's Markets at Rome.	134
117. Diagram showing the lines of compressive force in a cross vault.	135
118. View of the Aula at Trajan's Markets. Rome.	136
119. Gallery overlooking the central hall of the Aula at Trajan's Markets. Rome.	136
120. Frigidarium of the Baths of Caracalla. Rome.	137
121. Aerial view of the Basilica of Maxentius. Rome.	138
122. Plan and section of the Basilica of Maxentius. Rome.	139
123. Diagram of construction of dome built of stone voussoirs and diagram of stress patterns in an uncracked concrete dome.	139
124. Deformation patterns in a cracked dome and a semidome.	140
125. Step-rings on the Pantheon dome. Rome.	141
126. Large semidome at Trajan's Markets. Rome.	141
127. Stairs on dome of the "Temple of Mercury." Baiae.	142
128. Buttressing walls at the "Temple of Mercury." Baiae.	143
129. Plan of dome of the "Temple of Mercury." Baiae.	144
130. Drawing of the buttresses of the octagonal dome at the Domus Aurea. Rome.	144
131. Drawing of the "Temple of Venus and Cupid" in the Sessorian palace. Rome.	145
132. Buttress at the "Temple of Venus and Cupid" in the Sessorian palace. Rome.	145
133. Diagram demonstrating the concept of the vector.	150
134. Diagram demonstrating the concept of moment.	151
135. Diagram of stable three-hinge arch and of collapsing four-hinge arch.	151
136. Diagram showing the concept of Hooke's hanging line.	152
137. Example of a funicular polygon diagram.	153
138. Thrust line diagrams for three reconstruction proposals of the Basilica Ulpia. Rome.	157
139. Thrust line through dome of the "Temple of Mercury." Baiae.	158
140. Definition of the Rankine safety factor.	159
141. Thrust line diagram of the Pantheon dome under different conditions.	159
142. Thrust line diagram of the "Temple of Minerva Medica" under different conditions.	162
143. Drawing of the "Temple of Minerva Medica." Franz Innocenz Kobell.	163
144. Dome of the "Temple of Diana." Baiae.	164
145. Drawing demonstrating the steps in making a funicular polygon analysis of an arch.	226

## LIST OF ILLUSTRATIONS AND TABLES

## MAPS

1. Map of Rome and environs locating major monuments discussed in the text.	4
2. Map of Italy showing major volcanic districts.	13
3. Geological map of Rome and environs showing locations of major building materials used in concrete vaulting.	14
4. Map of Italy showing locations of major sources of timber and limestone.	15
5. Map of the Bay of Naples showing the air fall distribution of the A.D. 79 eruption and the pre-79 eruption of Mt. Vesuvius.	63

## TABLES

1. Recommended Mortar Mix Proportions	55
2. Amounts of Scoria in Vaults in Rome	67
3. Physical Characteristics of Dressel 20 and Dressel 23 Amphoras	71
4. Blocks from Trajan's Forum with Cuttings for Tie Bars	123
5. Proportions of Barrel Vaults	133
6. Proportions of Cross Vaults on Exterior Walls	135
7. Proportions of Freestanding Domes	140
8. Scoria Analysis	223

## COLOR PLATES

*Color plates follow page 154.*

I. Major local building stones used in vaulted structures around Rome.
II. Detail of <i>opus caementicium</i> vault from the Porticus Aemilia. Rome.
III. Four types of pozzolana.
IV. Abandoned pozzolana quarry on via Nesazio. Rome.
V. Detail of mortar with white pumice from the Colosseum. Rome.
VI. Plan of the Baths of Trajan. Rome.
VII. Section H at the Baths of Trajan. Rome.
VIII. Scoria and <i>tufo giallo della via Tiberina</i> at Section E at the Baths of Trajan. Rome.
IX. West palaestra at the Baths of Caracalla. Rome.
X. East palaestra vault from the Baths of Diocletian. Rome.
XI. Dome at the "Temple of Minerva Medica." Rome.
XII. Tor de'Schiavi. Detail of painting by Henrik van Lint and reconstruction drawing.
XIII. Plans of the Baths of Caracalla and the Baths of Diocletian showing vaulting ribs. Rome.

## PREFACE

AS A STUDENT OF ARCHITECTURE AT VIRGINIA TECH traveling in Italy in 1985, I became fascinated with the ancient brick walls that had obviously inspired one of my favorite architects, Louis Kahn. He had visited Rome as a Resident at the American Academy in 1950, and later much of his work was designed around themes of brick arches. The arches in Roman architecture, and particularly the relieving arches inserted into solid walls, captured my imagination. I wondered what secret reasons the Romans had for scattering these elements throughout their buildings. At the time, I was inspired by what I saw as the Roman “honesty” in their use of materials, though I now realize they were probably not remotely interested in this modernist concept. (I have also come to admit that I like most Roman buildings as ruins much better than I would have liked them in their original state.) On my return from the study abroad program, I convinced my architecture professor, Dennis Kilper, to supervise an independent study project on Roman concrete construction, the final product of which would be an illustrated paper. In the end, it was based largely (if not exclusively) on information from Vitruvius and M. E. Blake, and the illustrations were never completed. In the present work, I hope to have remedied the shortcomings of that first project begun two decades ago.

I have been fortunate to work with people who have provided the intellectual grounding to tackle the problems that interest me. After graduating and then working as an architect for a couple of years, I decided to get a Master’s degree in classical archaeology. I went to Oxford University to study with Jim Coulton, whose sharpness of mind and interest in problem solving always enabled him to ask just the right question to guide me where I needed to go. As a bonus, two other scholars interested in architecture happened to be at Oxford at the time on postdoctoral fellowships, Janet DeLaine and Hazel Dodge. Margareta Steinby then came to All Souls for a year, and the architect, Sheila Gibson, who worked with John Ward-Perkins for many years, lived in Oxford. With this core group and others, we all presented our work at a series of architecture seminars where I had the benefit of studying with an intense group of scholars in my formative years. This was also a time when I was spending months at a time at the British School at Rome where I came to know Amanda Claridge, who has always both inspired and humbled me with her intimate knowledge of ancient Rome, and Andrew Wallace-Hadrill, who has been a constant supporter of my work. John Lloyd, a pottery and field survey expert, came to Oxford when I did and became a

## PREFACE

great influence on my archaeological education. His unexpected and much too early death was a blow, and to his memory I have dedicated Chapter 4 on amphoras.

This project on vaulting began at Trajan's Markets. I knew that I wanted to study some aspect of the monument for my Master's thesis, and when I went to meet with Lucrezia Ungaro, the person in charge of the Markets, for the first time in 1989, she suggested that I concentrate on the vaulting. Eventually the Master's thesis was expanded into a doctoral dissertation on concrete vaulted construction from Nero to Trajan, the premise of which was to investigate the fifty-year period leading up to the construction of the Pantheon dome. This book, the proverbial "thesis book," derives from that study, but the scope is much expanded. After completing the dissertation, I realized that some of the most interesting questions were those that dealt with the differences between the construction of the high empire and that of late antiquity. As a publication strategy I decided to concentrate first on publishing the detailed information I had collected on particular monuments, such as the Colosseum and Trajan's Markets, so that I could refer to them later in a more general work on concrete vaulting. During the past decade, the book has been growing in the background as I familiarized myself with the radically different world of late antiquity in an effort to understand how the construction industry changed.

This book is more "interdisciplinary" than the dissertation, and I would not have been able to tackle some of the more technical issues were it not for help from other experts, especially in the fields of geology and structural engineering. In 1996, I attended a lecture in Rome on the rocks of ancient Rome by the geologist Marie Jackson, who has since helped tremendously with my geological education. The emphasis on geology throughout this book, as

can be seen in the color plates, was generated from our early excursions together looking at Roman rocks. However, before long my initial chapter on building materials had grown to twice the length of any other chapter, and I realized that this was the topic of a separate work. The information presented here is a fraction of what I collected, and I hope to present a more detailed analysis of building materials in the future. Later, in 2001, I met another geologist, Fabrizio Marra of the Istituto Nazionale di Geofisica e Vulcanologia in Rome. His help and encouragement with the scoria analysis in Appendix 3 were invaluable, and he acted as my "cicerone," taking me to explore abandoned pozzolana quarries. Finally, in the field of geology, I want to thank a group of scholars with whom I have worked on a mortar dating project and who have inspired me to pursue more actively interdisciplinary projects: John Hale (archaeologist), Jan Heinemier (physicist), Alf Lindroos (geologist), and Asa Ringbom (art historian).

I have long been interested in the engineering aspects of ancient construction and had read structural studies on historical buildings by Robert Mark, Roland Mainstone, and Jacques Heyman. I could perform simple beam analyses from what I had learned in college, but I aspired to do thrust line analyses and discovered that I needed tutoring. In 2002, I received notice of the First International Congress of Construction History in Madrid, where Heyman was billed as the keynote speaker, so I decided to attend. In the end, we met and he very kindly agreed to read an early draft of what is now Chapter 8. He also introduced me to one of his former students who was an organizer of the conference, John Ochsendorf at MIT. With John's help and many exchanges over e-mail and telephone, I learned how to make my own thrust line analysis, and I have presented the basic steps in Appendix 4 for anyone brave enough to have a go at it. Thus, I have been fortunate to meet experts in



## PREFACE

other fields whose broad visions and generous spirits have aided me in answering questions that I might not have otherwise asked.

Many people contributed to my thoughts and ideas about Roman construction through conversations and excursions. Margareta Steinby has been a constant source of information, inspiration, and support over the years. Mark Wilson Jones has offered many insights about the design process and has provided a refreshing counterpoint to my focus on construction. I have benefited greatly from Robert Coates-Stephens's knowledge of ancient and medieval Rome. Peter Rockwell, a sculptor/scholar, taught me to carve a Corinthian capital when I was in Rome in 2001, an invaluable experience that provided me with a different perspective on the construction process. I also have benefited greatly from insights and on-site visits with Jim Packer to the Forum of Trajan and am grateful for his support of this project. Others with whom I have had enlightening conversations include: Jane Aiken, Larry Ball, Heinz Beste, Elisabetta Bianchi, Mario Como, Lucos Cozza, Clayton Fant, Shawn Graham, Michael Heinzelmann, Henner von Hesberg, Shawna Leigh, Giovanni Manieri Elia, Archer Martin, John Oleson, Bob Ousterhout, Betsey Robinson, Rabun Taylor, Bill Wallace, and Roger Wilson.

Two colleagues deserve special thanks for reading substantial portions of the manuscript and for sharing their own (often unpublished) research with me, Carla Amici and Janet DeLaine. I have had the great joy of engaging in many long conversations and on-site visits to monuments with each, and I consider them my closest intellectual companions. I also owe debts of thanks to others outside of my own area of expertise who have taken the time to read and comment on various chapters of early drafts of this manuscript (and are in no way responsible for any mistakes in the final one): Susan Martin on the building

industry and legal issues; Ted Peña on the amphoras and trade; Marie Jackson and Fabrizio Marra on geology; and Jacques Heyman, Robert Mark, and John Ochsendorf on structural analysis. Finally, I am grateful to my former Ohio University student, Mandy White, for her careful reading of and insightful comments on the penultimate draft of this manuscript.

One complication for a project such as this one is the need for numerous *permessi* for various monuments around Rome, and many friends and colleagues have been instrumental making the arrangements. Lucrezia Ungaro, Roberto Meneghini, and Riccardo Santangeli Valenzani of the X Ripartizione AA.BB.AA of the Comune di Roma have been wonderfully supportive colleagues in all my endeavors. I also am indebted to support I have received over the years from those at the Soprintendenza Archeologica di Roma including Irene Jacopi, Giangiacomo Martines, Cinzia Conti, and Maria Letizia Conforto. I owe special thanks to Rossella Rea, who is in charge of the Colosseum, for her encouragement of my work there. With regard to obtaining *permessi*, I am especially grateful to Maria Pia Malvezzi at the British School at Rome for arranging an often complicated schedule of visits and sometimes working her own miracles during the early research stages of this project. I also thank Anne Coulson of the American Academy for help in arranging *permessi* during my Rome Prize year in 2001.

Financial support both for the research and the production of this book came from a variety of sources. The M. Alwyn Cotton Foundation has been generous in funding my year in Rome in 1996–1997 and providing a subvention to pay for the color plates. For my second research year in Rome in 2001–2002, I owe thanks to the American Academy in Rome for awarding me the Phyllis G. Gordan Post-Doctoral Rome Prize Fellowship and to the Graham Foundation for Advanced Studies in the Fine Arts. I also have

## PREFACE

received generous support from the Department of Classics and World Religions, the College of Arts and Sciences, and the Vice President for Research at Ohio University for travel and for book production costs.

At a personal level I am grateful to a number of people who have helped me along the way: to my parents for supporting my education and to my grandmother for her long-term planning; to Charles Knight for giving me a construction job when I was an undergraduate; to Michael and Mariella Stannus, friends in Rome who have always been there for me in sickness and in health; to Bailey van Hook for her encouragement during hard times; and to Brian Rose for companionship in Rome and for hospitality in Cincinnati during research trips to the Blegen Library.

Finally, without my husband, Tom Carpenter, this project and my interest in archaeology would never have happened. From the beginning, he taught me the value of reason, evidence, and the positivistic approach and has been my most profound intellectual model. He has given generously from his own research schedule to help me with mine at every level – measuring, climbing, hauling me out of holes on a rope, reading too many drafts of this manuscript, serving as a sounding board, and at the end even helping me finish the illustrations as my deadline loomed. I also am grateful to his remarkable patience with me during emotionally tumultuous periods and during the past two years when I was married to my keyboard as I completed the text and illustrations. To him I dedicate this book.