

INNOVAZIONE TECNICA E PROGRESSO ECONOMICO NEL MONDO ROMANO

Atti degli Incontri capresi di storia dell'economia antica
(Capri 13-16 aprile 2003)

a cura di
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ESTRATTO - OFF PRINT



EDIPUGLIA
Bari 2006

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THE ECONOMIC IMPACT OF TECHNOLOGICAL ADVANCES IN THE ROMAN CONSTRUCTION INDUSTRY*

How do we measure the economic impact of a technology in the ancient world? Perhaps by looking not only at what happens when that technology is adopted, but also what occurs when, in some cases, a technology ceases to be used. I have already dealt with some of the more advanced technologies of antiquity in my paper on *Machines, Power and the Ancient Economy* in the *Journal of Roman Studies* 2002¹. In this paper I want to examine some much more basic technologies, to show that the adoption – and loss – of these also had far-reaching economic consequences. I shall focus principally on the impact of certain building techniques that were widely used in the Roman period.

Faced with a lack of statistics from the ancient world, historians of ancient economies are forced to seek proxy indicators of economic performance. Chief among these are pottery and coin finds, each with their own peculiar problems of interpretation. It is surprising, though, that the construction industry, so often used today as a barometer of the economic climate, is so little exploited for such ends by historians of the ancient world. After all, it is an industry which can be studied through standing remains and building inscriptions, and is a visible expression of both public and private capacity and willingness to spend considerable sums of money. The potential is illustrated by Janet DeLaine's landmark studies on the economics of building the Baths of Caracalla, and of the building trade at Ostia², but the

* I am very grateful to Elio Lo Cascio for the invitation to contribute this paper, to Janet DeLaine for reading it at the conference which I was unable to attend in person; and to Bryan Ward-Perkins, Paul Bennett, Chris Wickham and Helena Hamerow for helpful comments on an earlier draft.

¹ Wilson 2002.

² DeLaine 1996; 1998; 2000.

construction industry (as opposed to the practice of euergetism) remains conspicuously absent from synthetic treatments of the Roman economy as a whole.

There was considerable building activity, both public and private, in and around the city of Rome under the late Republic, and throughout the Roman empire from the Augustan period onwards, fuelled by the foundation of overseas colonies, increasing urbanisation on the Roman model in the western Mediterranean and north-west Europe, and the utilisation by the emperor and by local élites of prestige building projects for political ends. The Roman world has left some of the most spectacular and grandiose physical remains from any period of pre-industrial history, and also some of the most numerous. The absolute level of expenditure on building projects must have been enormous, and one is led to suspect that it should have constituted no negligible proportion of economic activity, in spite of the relative lack of attention paid to the construction industry in modern discussions of the Roman economy.

My purpose here is not to attempt to quantify the size of the building industry in Rome or across the empire, but to show how certain advances in the technology of construction enabled the growth of the industry, both in terms of manpower engaged in construction projects, and in the scale of what the industry was able to achieve. I shall focus not only on some well-known advances in materials (brick, concrete), but also on conceptual improvements, and in particular on standardisation and modularity.

Materials

It is a commonplace in the history of Roman architecture that the introduction of concrete and the widespread adoption of techniques of arcading and vaulting were major catalysts that enabled Roman architecture to develop a new aesthetic and a conception of scale quite unlike the Classical and Hellenistic tradition of trabeated architecture that preceded it. Indeed, Sir Mortimer Wheeler identified buildings on a massive scale as a defining feature of Roman architecture³. Perhaps less commonly appreciated is that the new materials offered not only new possibilities in terms of what structural engineering could achieve, but also new ways of

³ 'Size and Baalbek', in Wheeler 1966.

organising workforces and supply chains, with far-reaching socio-economic effects.

Roman concrete consisted of a sand and lime mortar mix into which was dumped rubble aggregate to give it body and bulk. Mortared rubble of this kind differed from earlier mortared masonry construction by forming a relatively homogeneous mass that could be laid over wooden formwork to create arches and vaults; the wooden centring was removed once the mix had dried and set hard. By the second century BC, if not before, it had been discovered that adding pozzolana, a volcanic sand from the Puteoli region containing naturally occurring alumino-silicates, to the mix produced a concrete that did not need to shed water to set. This enabled faster construction, and also allowed the use of concrete for underwater structures such as harbour works and bridge pier footings. The massive advantage of concrete over masonry construction, of course, is that it was faster, cheaper and required less skilled labour. Concrete walls were faced initially with irregular small blocks (*opus incertum*), but in the late second century BC a new facing style was introduced, *opus reticulatum*, in which the blocks were squared to a uniform size and laid diagonally. Filippo Coarelli has made the point that the standardisation of the facing elements used in *opus reticulatum* made it easier to construct, enabling the employment of less skilled workers, and suggests the introduction of *opus reticulatum* may be seen as one of the building industry's responses to an increase in building activity fuelled by population growth at Rome in the late second century B.C.⁴ Similarly, fired bricks came into general use during the Augustan period in place of sun dried bricks; they are more durable, with greater load-bearing capacity, and were also used as facing for concrete walls. A study by Janet DeLaine of different types of wall facing techniques used at Ostia shows that in general the labour requirements for building the same amount of walling in brick or *opus reticulatum* were substantially less than for *opus incertum*⁵.

Huge quantities of bricks were required for imperial and other building projects, especially in and around Rome, where high population density generated intense building activity, and brick-faced concrete construction was employed to meet the demand for buildings to serve all sectors of society. To the prestige imperial projects we must add the innumerable apartment blocks (*insulae*), smaller baths, shops, houses, warehouses,

⁴ Coarelli 1977, 16-18.

⁵ DeLaine 2000.

tombs and even temples built of brick-faced concrete – Ostia, and like it Rome, were largely built of brick. Elsewhere in Italy, brick is common and tile ubiquitous, even on small rural sites found in surface surveys. The brick producing industry was consequently massive, and in the Tiber Valley at least it came increasingly under senatorial and then imperial control. By the later second century most of the major *figlinae* in the Tiber Valley were concentrated in the hands of the emperor and his close family. Bricks were produced to standard sizes, as indeed mud bricks had been in the ancient Mesopotamian world. Standardised sizes enabled contractors to diversify suppliers, a key consideration in the speedy completion of vast projects like the construction of aqueducts or public baths where the quantities required could not be produced by a single brickyard. In effect, brick production removed a potential supply bottleneck inherent in masonry construction, where rates of quarry extraction and stone-dressing are often the limiting factor on speed of completion. Whereas a building constructed in ashlar masonry usually depended on a single quarry, whose extraction rates therefore determined the supply of material and controlled the rate of construction, projects building in brick could mix and match products from a multiplicity of suppliers, reducing construction time⁶.

For the suppliers of bricks, standardised sizes meant that they could produce for the market, knowing that so long as construction activity continued on a large aggregate scale, their products could find a buyer; they did not *have to* produce only to order for specific projects, although some may have done so. The scale of the industry, and of demand, is illustrated by the fact that bricks from the Rome and Tiber Valley brickyards, and even from Salerno in Campania, were exported to North Africa⁷. Indeed, all the major African ports from Cartennae (Ténès) in Mauretania Caesariensis along to Lepcis Magna in Tripolitania have yielded examples of stamped bricks from the Tiber Valley, while fabric analysis of fired bricks from Carthage shows that numerous unstamped examples were also imported from Italy⁸. Occasionally Italian bricks are found at inland sites, such as Bulla Regia in Tunisia. Perhaps some of these bricks arrived in Africa as saleable ballast or return cargoes, but some were probably imported for specific

⁶ Examples of buildings constructed with bricks from different brickyards are numerous, even normal, at Rome and Ostia, see e.g. Bloch 1938-1939.

⁷ Wilson 2001.

⁸ Tomber 1987.

projects – they occur principally in public baths, and in large cistern complexes.

The introduction of concrete construction, and especially of brick-faced concrete, enabled some de-skilling of the workforce – unskilled or semi-skilled labourers could put the core of a building together under the supervision of skilled foremen, while the removal of supply bottlenecks meant that the workforce could work in larger and more numerous gangs than could skilled masons dressing and laying ashlar blocks. Brick-laying is of course a skilled task, but less so than dressing ashlar blocks and fitting them together. Masons and marble workers were still of course used, but increasingly for veneer and detailing, while the main bulk of a building was put up in brick-faced concrete. The increasing use of less skilled labour for large projects was one of the factors facilitating the political use of massive building programmes as a means of employing the urban poor at Rome.

Modularity

Other construction elements also became standardised – marble column shafts and blocks for veneer were often produced to standard sizes⁹. But hand-in-hand with the standardisation of components went a standardisation of larger units of design within an individual project. Roman buildings were to a considerable extent composed of repeated elements – aqueducts, theatres, amphitheatres, shops and warehouses frequently incorporated arcades or vaulted chambers of the same size which allowed the re-use of the same wooden centring or formwork, which could simply be moved from one unit to the next as construction proceeded, without having to dismantle and rebuild it. Evidence for this sort of practice has been identified in the aqueduct of Pompeii, where by studying the impressions of formwork timbers in the underside of the channel vault, Christoph Ohlig has shown that a limited number of wooden formwork units were employed and moved along the channel as construction progressed¹⁰. Such repeated modularity in arcading and vaulting was not motivated solely by symmetry and aesthetics, but also by simplicity of construction. It facilitated the multiplication of simultaneous work points, reducing bottlenecks.

⁹ Ward-Perkins 1992, 25; Dodge 1991, 36-8.

¹⁰ Ohlig 2001, 118-21.

Roman and medieval building

The effect of the introduction of these techniques can be gauged by comparing the construction times of large-scale Roman building projects with large-scale medieval ones. The central block of the Baths of Caracalla in Rome was erected between AD 211 and 216, with the outer enclosure completed under Alexander Severus. During the five years in which the central block was constructed the aqueduct branch (the Aqua Antoniniana) and the vast cisterns holding c. 10,000 m³ must also have been constructed, as without them the baths could not have functioned on their opening in 216. The complexities of the project management challenges involved are well brought out by DeLaine's study of the economics of the construction of the Baths of Caracalla¹¹. The Baths of Diocletian show a comparable speed of construction – the entire complex was built in under eight years. By contrast, a medieval cathedral such as Laon or Salisbury might take 50 or 100 years to build¹², while the rebuilding of York Minster went on virtually continuously for 250 years (1220-1470), dependent on a master mason and a relatively limited gang of craftsmen. Henry III's rebuilding of Westminster Abbey lasted from 1245 until his death in 1272, hampered by frequent shortages of money; the accounts for 1253 show the employment of between 100 and 428 craftsmen and labourers on the project at any one time¹³. While the greater scale and lavishness (in terms of marble veneer, mosaics and sculpture) of the Roman baths are explicable in terms of the greater resources available to Roman emperors than to medieval English or French kings, the greater speed of construction is not, or not entirely. It was due principally to the semi-industrialised nature of Roman construction, using standardised components assembled by relatively unskilled labourers in repeatable, modular fashions, with materials sourced from a multitude of suppliers producing to similar standards. It was the use of semi-skilled labour which encouraged the employment of the poorer sectors of society and also which enabled the employment of literally thousands of people at a time – DeLaine estimates that 9,000 people worked on the Baths of Caracalla, of whom a large proportion were not skilled artisans. Indeed, the creation of a casual labour market for the urban poor seems to have been a

¹¹ DeLaine 1998.

¹² E.g.: Laon (1160-1225); Notre Dame, Paris (c. 1163-1250); Notre Dame, Chartres (1194-1250 or 1145-1220?); Salisbury Cathedral (1220-1310).

¹³ Colvin 1963, 130-59.

significant factor in imperial building projects¹⁴. The wealth and sophistication of Rome required an enormous amount of building activity, prestige and otherwise, with pressures for quick completion; this prompted developments in building technology which enabled the growth of the construction sector, which in turn facilitated larger and more numerous projects.

The relationship between the uses of brick-faced concrete and the scale of the construction industry (and indeed the economy as a whole) is well illustrated by looking at what happens in late antiquity and the early middle ages. Large brick constructions were still erected in the early fourth century AD at Rome (Basilica of Maxentius), and Trier (Basilica of Constantine), and continued in the east after the split of the empire, with brick remaining an important material in Byzantine architecture. In the west, however, large-scale brick projects were limited to Rome (and became rarer there) and Ravenna. Honorius' heightening of the Aurelian Walls in the early fifth century is perhaps the latest really large project at Rome. It is of course no coincidence that the biggest early sixth-century project, S. Vitale at Ravenna, is to be found in the new Byzantine capital of Italy. Increasingly these works used reclaimed bricks. In Italy, production of new bricks in Campania stopped in the fifth or perhaps the early sixth century, and at Rome, where brick production continued into the eighth century, it was on a very much reduced scale from the fourth century onwards. The brick buildings of early medieval Rome were built entirely, or almost entirely, of re-used and disparate Roman bricks. After the seventh century brick production is not attested on any large scale at Rome until perhaps the fourteenth, or more certainly, the fifteenth century¹⁵.

North of the Alps construction in mortared rubble, concrete or fired brick appears to have ceased by the late fourth or early fifth century AD. In Britain, no fired bricks or even clay roof tiles seem to have been produced between the early fifth century and the Norman period, when Coggeshall bricks make an appearance in Essex in the first half of the twelfth century. During the Saxon period Roman bricks and tiles were reused in churches, but new bricks were not produced; in flint buildings they were employed as quoins or for window mouldings and door jambs (e.g. St Botolph's, Colchester). At St Albans almost the entire tower and transepts of the late eleventh-century cathedral were built of re-used Roman brick quarried from

¹⁴ E.g. Suetonius, *Vespasian* 18, and discussion in Wilson 2002, 4.

¹⁵ Parenti 1994, 30.

the adjacent buildings of Verulamium, including the theatre. Indeed, the appearance of Coggeshall bricks in the twelfth century was a response to the drying up of supplies of Roman brick for recycling as quoins and door jambs in flint buildings¹⁶. The Coggeshall brick industry lasted until c. 1230, when the technology was again lost in Britain until the reintroduction of brick-making from Flanders in the fourteenth century, apparently centring on Hull, which in the fourteenth and fifteenth centuries became the only brick-built medieval town in Britain. A brickyard is first recorded at Hull in 1303, and Hull also has the earliest large-scale brick building in England, Holy Trinity church (early fourteenth century), whose transepts and choir are built of brick.¹⁷ In southern England brick construction is rather later, one of the earliest examples being Bell Harry Tower of Canterbury Cathedral, where the inner lining of the upper lift of tower was built in brick under Prior Goldstone 1st, after 1405. Large secular projects are later still, and even then are chiefly defensive – e.g. Sandown Gate, Sandwich, or Tattershall Castle (both mid fifteenth-century), although the Roper Gate, Canterbury (1450) is an early domestic example. In western England, bricks were only introduced into the Severn Valley area in the late fifteenth or early sixteenth century¹⁸. Although floor and decorative wall tiles are known from the late Saxon period onward, the earliest roof tiles are not found until the later twelfth century. There is therefore a long gap, of several centuries, between the cessation of brick production in Roman Britain and the reintroduction of the technology in the middle ages; and when it was reintroduced it was for large-scale religious and defensive projects. The delay in the renewed uptake of brick technology in medieval England, with a lag of perhaps two centuries between its (second) re-introduction and its generalised uptake, suggests that special factors are required to sustain a brick-making industry on a substantial scale. Arguably, these are related to the size and scale of the construction industry as a whole.

How do we explain the loss of such a basic technology as fired brick and tile in early medieval northern Europe? The obvious answer, in the light of what I have just been saying about the advantages of brick-faced concrete construction in the Roman building industry, is that the cessation of brick and concrete construction in northern Europe is a reflection of

¹⁶ Anon. 1996; Potter 2001.

¹⁷ Brooks 1939.

¹⁸ Vince 1984, ch. 9.

massive economic contraction or even collapse in the fifth century, to the extent that there was insufficient new building activity to require or justify the continued use of a system where producers made relatively standardised products for a construction market. In Britain, indeed, mortared construction, in stone or brick, appears to cease completely from the fifth to early seventh centuries A.D. Just as economic growth in the Roman period led to technological improvements in construction to meet increased demand for building, generating a positive feedback effect by enabling the growth of the construction sector, and so further economic growth, so economic contraction causes a reversal of these processes, with a negative feedback effect.

The explanation of economic collapse would seem to be confirmed by the loss of another, equally basic, technology in Britain in the same period – the potter's wheel. Between the early fifth century and the introduction of Ipswich Ware, now dated *c.* 720¹⁹, *no wheel-thrown pottery at all was produced in the British Isles*. The regional pottery industries producing kitchen wares and table wares in late Roman Britain (e.g. Oxfordshire ware, East Midlands, Severn Valley ware and Hadham ware) disappeared and pottery production continued only on a domestic scale²⁰. The potter's kiln appears to have disappeared as well, and the handmade ware that was produced during this period was fired at a low temperature in clamps or on bonfires. When the first kiln-fired and wheel-thrown pottery, Ipswich Ware, does reappear, it is produced on a hand-turned slow wheel (tournette or turntable), using techniques introduced from Frisia or the Rhineland; the spread of wheel-thrown pottery was gradual, and was limited in the Mid Saxon period to East Anglia and Northumbria. Here the pot is built up using hand forming techniques, and the tournette only used in finishing; the use of the slow wheel may have little or no impact on efficiency²¹. The kick-turned fast wheel, as used by Roman potters, uses centrifugal force to form the pot far quicker than can be done by hand, and this reappears only in the Late Saxon period (ninth or tenth centuries), in pottery copying continental forms.

Population change might be adduced as a possible explanation for the change in technology; the invaders brought their own traditions of carpentry construction, rather than masonry building, and hand-made

¹⁹ Blinkhorn 1999, 8-9.

²⁰ Vince 1984, ch. 11; Dark 1996 for a slightly more optimistic view.

²¹ Vince 1984, ch. 5.

pottery rather than wheel-thrown wares. But this would explain the introduction of new technologies better than the disappearance of long-established, fairly basic techniques such as the potter's wheel. Furthermore, it appears that these technologies disappeared across Britain before invasions occurred on a scale sufficient to cause population replacement; and wheel-thrown pottery disappeared even more completely in the unconquered western parts of Britain²². The loss of brick and tile production, and of the potter's wheel and kiln, are best explained in terms of the collapse of markets and distribution structures. Potters in the fifth to seventh (or even ninth) centuries were not producing for markets sufficiently large to warrant techniques any more costly than those involved in the production of hand-made, low-fired pottery; only churches were built in stone, and only after the Conversion (*c.* 600), and were not large or numerous enough to require a brick industry. The techniques of mass-production which characterised the Roman building and pottery industries are obviously linked to the size of markets, and market size in the Roman world was effectively increased by the existence of frequent and well-used long-distance trade links enabling producers to reach markets overseas. The cessation of production of bricks and wheel-thrown pottery is a reflection of early medieval Britain's removal and isolation from the networks of exchange that characterised the Roman economy.

The Mediterranean world retained the tradition of wheel-thrown pottery production, which doubtless reflects the greater persistence of long-distance trade networks there in the early medieval and medieval periods. However, the cessation of fired brick production in the western Mediterranean reflects a progressive contraction of the construction industry that, although more gradual and less total than in northern Europe, was nevertheless marked. The contrast with the eastern Mediterranean, where fired brick continued to be a feature of Byzantine architecture, may in part reflect the role of the state there in continuing to fund large building projects (increasingly defensive or ecclesiastical), sustaining an economic climate in which mass-production of standardised elements by private brick makers continued to be economically viable. The examples of wheel-thrown pottery and of fired brick production illustrate the degree to which mass-production for large, and often geographically distributed markets, was a characteristic feature of the economy of the Roman empire at its height.

²² Ward-Perkins 2000, 528.

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