The diffusion of architectural innovations

Modelling social networks in the ancient building trade

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4. The diffusion of architectural innovations: Modelling social networks in the ancient building trade

Henrik Gerding and Per Östborn

Abstract: *Within the project LATERES COCTILES early fired bricks have been the object of a multifaceted investigation. One aim has been to elucidate the mechanisms behind the diffusion of this innovation. An inventory of Hellenistic and early Roman fired bricks around the Mediterranean resulted in an archaeological database comprising 276 brick contexts. Network analysis was applied to these data using a two-fold strategy: First, general similarity networks were generated, representing likely causal relationships between the contexts. Exploratory and statistical analysis of these networks enabled a data-based characterisation of the diffusion process. Then a theoretical model of this process was developed with the aim of simulating the observed data. By comparing model simulations with observed data, the model could be improved step by step. The starting point for constructing the model was the assumption that different categories of people contributed differently to the diffusion process. In this paper the underlying principles and main results of the modelling will be presented, together with a possible interpretation of these results. It is argued that a shift in decision-making within building industry and a greater reliance on technical expertise might have had a key role in promoting the diffusion of some architectural innovations.*

Keywords: Fired bricks; diffusion of innovations; similarity networks; social modelling; ancient building trade
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Introduction

In this paper we present the main results of an attempt to simulate a historical diffusion process with a network-based social model. After a short summary of our previous investigations, which form the basis for this endeavour, we lay out the underlying principles as well as the main outcome of the model. For the technical details of the model and the simulation procedure, we refer to another publication.[1] A significant part of the paper is devoted to one possible interpretation of the simulation results, concerning the configuration of the ancient building industry.

The diffusion of fired bricks: a network approach

This study is part of a larger investigation on the early use and spread of Hellenistic fired bricks, where network analysis is one of several approaches to a diverse but largely neglected material.[2] One of our main objectives has been to investigate how this innovation spread across the Graeco-Roman world, from its introduction in the mid-fourth century BC, until its final breakthrough at the turn of the Common Era.[3] To this end we strove to collect all published reports on Hellenistic fired bricks, concentrating on the European part of the Hellenised world. All total, we gathered information on 276 brick contexts from 131 sites, located in ten different countries. Although far from complete, this material was deemed to constitute a representative data set. Depending on the quality of the reports we could extract information on the appearance of the bricks, their structural use and function, as well as the architectural context of each find, sometimes corrected or augmented by personal observations. The information was compiled in a database, basically forming an attribute table. To enable comparison we used eighteen attributes to describe each brick context. However, these attributes were of different kinds: some represented numerical values, others intervals; most of them were categorical.

Figure 4.1. Hellenistic fired bricks (Tauromenion, Pompeii, Rhegion, Soloeis). Photos by H. Gerding.

Hellenistic bricks differ from Roman imperial bricks in several ways (Fig. 4.1). Most importantly it should be noted that, while fired bricks constituted a standard building material in most parts of the Roman empire, the use of Hellenistic fired bricks was both limited and sporadic for a very long time.

Fired bricks were used in Mesopotamia from the beginning of the fourth millennium BC, reaching a peak in the Neo-Babylonian period. As a result of this long brick tradition, there were also occasional uptakes of fired bricks in adjacent areas: Anatolia, the Levant, and even Egypt. However, based on current evidence, the innovation was not adopted in the Greek world until the very end of the Classical period. This may seem strange, particularly considering the much earlier use of roof tiles. Terracotta roof tiles were introduced in central Greece before the mid-seventh century BC;[4] the earliest securely dated attestations of brick masonry derive from Thasos around 340 BC.[5] During the following period of tentative spread, lasting for over 300 years, the innovation was obviously transmitted over long distances, sometimes in a very short time, but rarely to densely urbanised areas. However, just before the turn of the era the diffusion process reached a point of take-off towards breakthrough (Fig. 4.2), followed by widespread acceptance of the innovation. Thus, we can outline different stages of the process: periods of rapid spread, discontinuance, re-invention and breakthrough. All this makes fired bricks particularly well suited for an investigation into the mechanisms behind diffusion in antiquity.

We have chosen to regard diffusion in line with modern Diffusion of Innovation Theory (DIT), that is, as the result of social interaction between individuals, involving at least one user and one

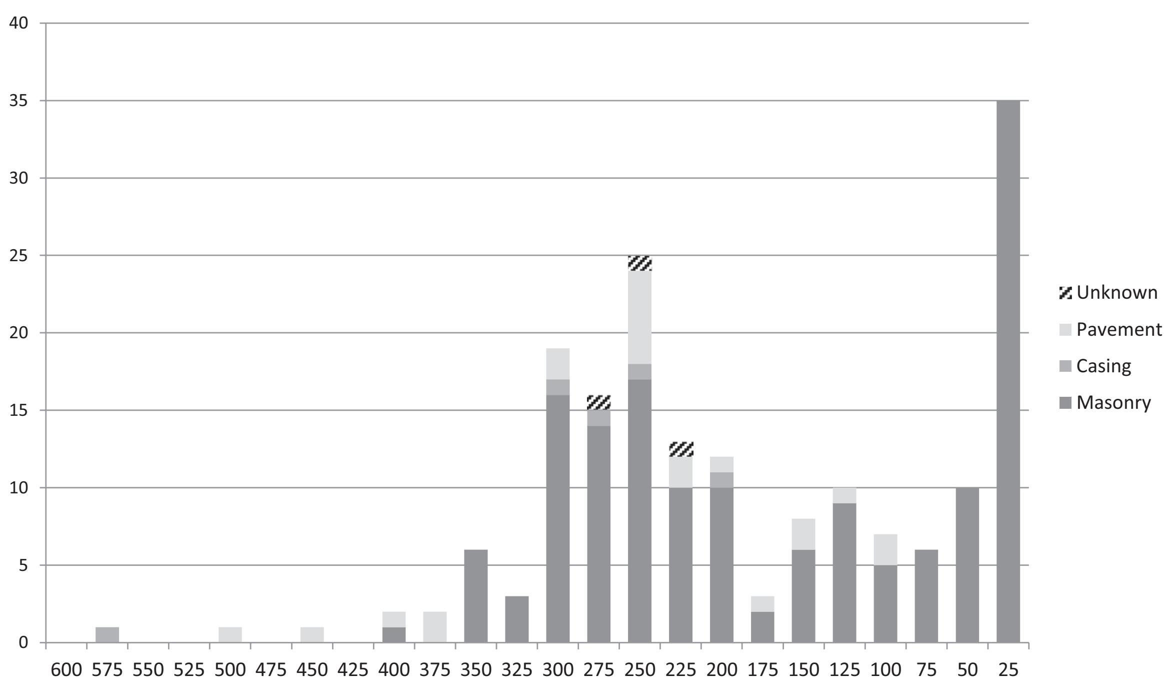

Figure 4.2. Temporal distribution of fired bricks (600–1 BC), divided by structural use.

potential adopter. This is a social process in which information about, and from, other users is more important than information on the innovation itself. Thus, what is often perceived as a diffusion of an artefact or a technology is actually a diffusion of behaviour.[6] The concept is also described by the so-called innovation-decision model, formulated by Everett Rogers.[7] He divided this process into several steps, the first three of which are:

1. Knowledge: stressing that awareness of an innovation does not automatically lead to adoption;
2. Persuasion: a phase where the potential adopter weighs perceived relative advantages against perceived costs and risks;
3. Decision: the crucial step, where the adopter has to overcome the uncertainty that is felt towards the innovation.

Adoption is more likely to occur if the information about the innovation is provided by a user who is closely related, affiliated or similar to the potential adopter; likewise if the user is a role model, an authority or a trusted person. Furthermore, the number of users and non-users among the potential adopter's acquaintances will also have an impact, manifested for example as group pressure. The diffusion process is the sum of all individual decisions regarding the innovation. The contacts between users and potential adopters constitute a social network, and the structure of these relationships will have an effect on the outcome. In other words, the diffusion process takes place within the boundaries of an underlying social network and can be seen as a subset of this network. Thus, the advantage of a network approach is not only that causal relationships between various brick contexts can be visualised, but also that formal network analysis can be used to explore the diffusion process and the structural properties of the underlying social network.

In a previous study we introduced the concept of general similarity networks.[8] This concept is based on the assumption that similarity between two contexts may indicate a causal relationship, which can be graphically represented by an edge connecting two nodes. A set of nodes linked to each other in this way makes up a similarity network. The use of similarity networks as an analytical tool is not a new idea. What we propose is that the network approach is particularly appropriate if we want to study some kind of complex evolution, such as a diffusion process. Normally similarity between different contexts is based on a single type of attribute, for example, the co-presence of a certain artefact or the abundance of a certain find. Most contexts, however, are best described by a large set of attributes, represented by different kinds of values: numerical values (e.g. thickness of bricks), intervals (e.g. date range), incidence (e.g. presence of plaster), and categories (e.g. structural use). In order to detect relationships effectively, we wanted to allow any kind of similarity relation as a criterion for connection, where different kinds of attributes could be mixed. A similarity relation could then be expressed as a general criterion: 'connect all contexts that share at least ten attributes and overlap in time.' A general approach made it possible to test different conditions for similarity in search of likely causal relationships.

Exploratory analysis was performed and supplemented with statistical analysis of the observed network patterns.[9] The analyses suggest that there was indeed a diffusion process, as opposed to random, independent appearances of fired bricks. This diffusion seems to have taken place in a small-world social network of builders and decision makers, where the innovation was more likely to be transmitted over short distances, but where long-range connections were also present. The data seemingly exclude a scale-free network, in which the diffusion is governed by a few dominant hubs. Furthermore, brick usage can be separated into cultural clusters, distinguished by similar attributes, but also by spatial and temporal proximity.

Modelling the diffusion process

As a final step in the network analysis, we set out to model the diffusion process in order to recreate the observed patterns in the collected material. The aim of the modelling was to find the smallest and simplest set of mechanisms within the model framework that are able to reproduce the known aspects of the diffusion of fired bricks. The details of the model and the simulations are presented elsewhere.[10] This paper will focus on the basic principles and the possible interpretations of the results.

Instead of attempting to encapsulate all aspects of the diffusion process, we aimed at as simple a model as possible. Our starting point was the assumption that different groups of people contributed in different ways to the diffusion process. This assumption is supported, on the one hand, by earlier studies in the field of diffusion of innovation,[11] and on the other by our knowledge of the building trade in Antiquity.[12] Therefore, slightly arbitrarily, we stipulated the existence of three actor groups. These can be interpreted as different professional or social groups, within or between which the innovation might have spread.

In order to differentiate between the groups in the model, they had to be given different characteristics. We used two defining features: (1) the capacity to make decisions about the use of fired bricks; (2) the ability to transmit the innovation over long distances (Fig. 4.3). The first distinguishing feature is essential for adoption to occur; the second was implied by our data. In

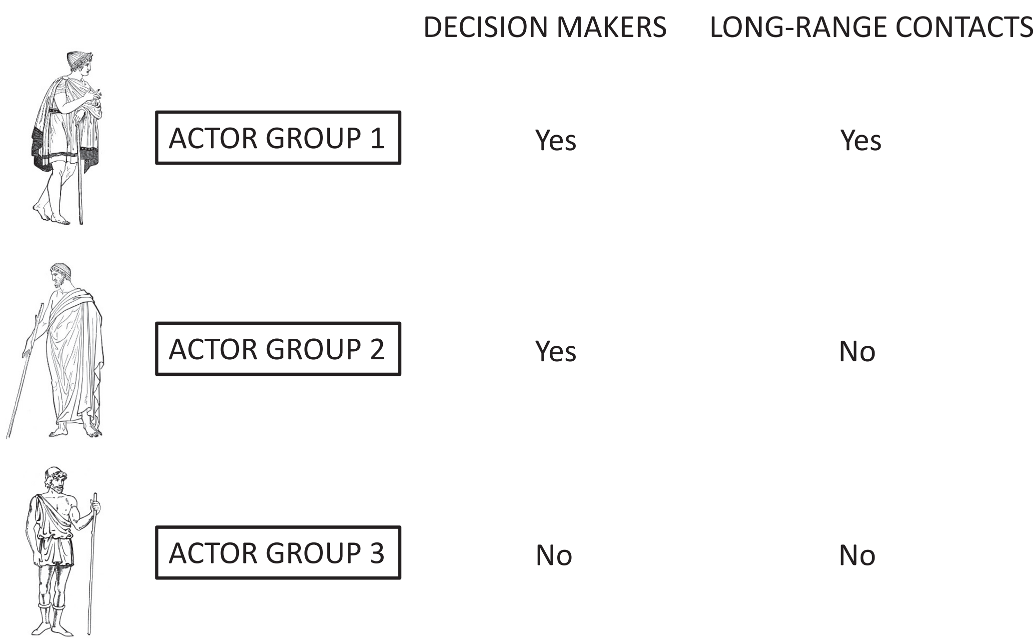

Figure 4.3. Definition of the three actor groups in the model.

the analysis of the similarity networks we found an irregularity in the cumulative distribution of edge lengths.[13] Normally the curve would fall off smoothly, but in our case a significant shift was observed at edge lengths between 200 and 300 km. This indicates that short- and long-range connections represent two qualitatively different phenomena, and that there was an upper limit to the short-range activities at about 250 km. The two phenomena can be interpreted as different modes of diffusion, or different actor groups.

The model allows transmission of the innovation from one site to another, both within and between the three actor groups, based on probability rates which can be altered. The huge number of hypothetical interactions was reduced to a bare minimum, from which all possibilities could be re-combined (Fig. 4.4). This means that all external and internal factors that affect the diffusion process in one way or another are reduced to a single probability rate, but we still retain the possibility to differentiate between their combined effects on various actor groups. It should be stressed that we are only interested in the relative importance of the actor groups, not the absolute figures for the probability rates.

Instead of trying to reconstruct an underlying social network, for which very little historical evidence exists, we allowed potential diffusion between all sites, but let the probability rate drop with the distance, in accordance with the findings from our previous network analysis. The brick attributes were reduced to a set of binary variables, which changed slightly through random 'mutations' at every transmission, thus simulating the continuous development of the innovation.

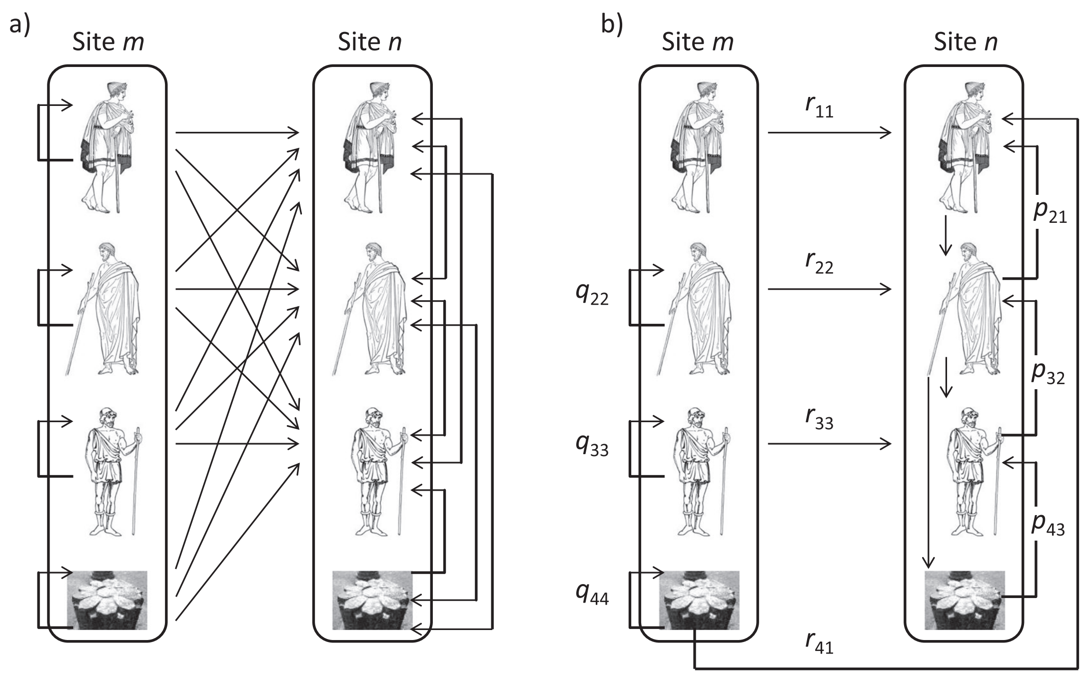

Figure 4.4. Flow charts showing possible interactions between members of different actor groups in the model: (a) All possibilities; (b) Simplified model.

This way we could construct a versatile model without losing ourselves in a wealth of parameters. However, in order for the simulations to have any explanatory value, these abstract entities have to be interpreted historically. We would like to argue that actor group 1 best corresponds to elite commissioners of buildings, whereas actor group 2 is closer to architects and master builders, the difference then being the range of their social contacts. We feel confident in assuming that elite individuals managed to maintain social contacts over longer distances than non-elite individuals did, although most of their contacts probably were short-range as well. Architects and skilled craftsmen did travel to some extent, but they rarely went outside their own region.[14] The third actor group can be interpreted as brick makers, craftsmen and builders, who might have been familiar with the innovation, but generally did not have the authority to implement it.

By adjusting the probability parameters and introducing additional mechanisms to the model, we tried to recreate the diffusion process as closely as possible. The results of the simulations were tested against the temporal and geographical distribution of the collected material, as well as the structural properties of the similarity networks. Five features can be identified as the most important characteristics of the diffusion process:

1. Hesitant and fluctuating diffusion before take-off (temporal distribution);
2. Diffusion in the 'periphery' of Hellenistic Europe (geographical distribution);
3. Mainly short-range diffusion (network properties);
4. High degree of 'cultural clustering' (network properties);
5. A small world without dominant hubs (network properties).

When we adjusted the model to fit the data, the strategy was to start with the simplest possible models, and add complexity only if needed. The hesitant diffusion and the correct edge length distribution could be attained merely by calibrating the relative importance of the different actor groups. However, in every simulation run, the diffusion process tended to take hold quickly in densely urbanised areas and spread rapidly there. This was an undesired effect of the inverse dependence between transmission probability rates and distance in the basic model, which indicated that an additional mechanism had to be introduced.

It must not be forgotten that some of the factors that benefit the diffusion of an innovation, such as group pressure, also work against it. Just as a large number of adopters within a group may affect the decisions of other members of the group, the number of non-adopters may also exert influence, especially if there are existing alternatives to the innovation. In other words, as long as most of your acquaintances stick to the old ways of doing things, you are less likely to try something new yourself. We called this the 'conservatism factor' and incorporated it in our model.

Even if the 'conservatism factor' is reasonable *per se*, it goes against the intuition that there was a stronger incentive to adopt new technologies in densely urbanised areas, due to a higher level of competition. However, the apparent absence of this mechanism may be due to the fact that the technical, economic and social benefits from fired bricks were perceived as marginal. Other innovations with more obvious benefits might have been attracted to urban centres for this reason. What we can say is that within the framework of the core model we had to include a mechanism that repelled the innovation from large urban centres, in order to make the simulated diffusion process resemble the real one. The addition of the 'conservatism factor' had a huge effect in making the simulations more realistic, in that it delayed the introduction of the innovation in the most densely urbanised areas, including Rome and Athens.

The final model was able to mimic the real temporal and geographical distribution and the resulting similarity networks in considerable detail, with one exception. The model could not be made to reproduce a slow and hesitant diffusion, followed by a steep take-off. Since the former state is a distinctive trait for the period in question, it was highly prioritised in the simulations. The main results can be summarised as follows:

1. Actor group 1 must be more influential than actor group 2 in terms of 'transmission power.'
2. Actor group 3 has to be active. This latent diffusion can be seen as spread of knowledge about the innovation.
3. There has to be a 'conservatism factor,' inhibiting rapid spread of the innovation to densely urbanised regions.
4. There must be an element of re-invention, significantly altering the way bricks were used. Minor adjustments, accumulating step-by-step as the knowledge of bricks spread, cannot account for the observed 'cultural clustering.'
5. The take-off towards breakthrough cannot be reproduced in an otherwise well-calibrated model.

These results can now form the basis for different explanatory interpretations.

Implications of simulation results

The outcome of the model indicates general conditions for the diffusion of fired bricks, some of which may be interpreted in terms of historical circumstances:

1. Actor group 1, interpreted by us as elite commissioners, must have played an important role, compared with actor group 2 (architects and master builders).
2. Adoption probabilities in general, but particularly those for actor group 2, seem to have been of a low order. In other words, the conditions for diffusion were for a long time so difficult that they precluded breakthrough.
3. This 'weak' diffusion process, however, must have been supplemented by a more stable spread of latent knowledge/acceptance, which could spawn adoption indirectly and keep the process alive.

These results are only relevant within the framework of the proposed model. Since the model in question only constitutes one possible representation of reality, and a very limited one, they must be treated as indications rather than firm conclusions. Moreover, some of the results can be seen as trivial in the sense that they were to be expected, given what we already knew about the diffusion process. However, the important point to be made is that all significant traits of the diffusion process can be accounted for by a relatively simple model, with one exception; the model failed to reproduce a steep take-off, preceded by a long period of slow and hesitant diffusion. This provides us with a clue as to what parts of the process may be related to internal dynamics, and what parts are likely to be a result of changes in the historical circumstances. Thus, we do not necessarily have to assume some major historical cause for the apparent drop in brick use in the early second century BC (Fig. 4.2), but are probably correct in looking for an explanation for the sudden take-off in the first century BC.

As the proposed model does not contain sufficient mechanisms to explain the final breakthrough of the innovation, we must turn to exterior causes. Unfortunately, there is a wide range of factors which offer a reasonable explanation for the development at hand. The following list summarises the main categories:

1. Changes in the innovation content;
2. Changes in the general conditions (social, economic etc.);
3. Changes in the structure of the underlying social network;
4. Changes in the behaviour of actor groups (as they are defined in the model).

These causes can be seen as exterior, not only with regard to the dynamics of the diffusion process, but also in relation to the model, as they all imply a sudden change to the relevant parameters or even the basic premises. It is reasonable to assume, for example, that an improvement in the innovation would affect the perceived relative advantage of the innovation, corresponding to an increase of the adoption probabilities. The same goes for a sudden improvement of communication between potential adopters, represented by additional (or strengthened) edges between nodes. John Bintliff has pointed to an important shift in the configuration of the non-elite urban population in the latter part of the Hellenistic period, with far-reaching social and economic implications.[15] It is also possible that the uptake of the innovation in the Roman capital triggered a qualitative change in the process, significantly enhancing the diffusion rate. However, the data at hand does not allow us to say whether the introduction of fired bricks in Rome was the cause of the final breakthrough or merely a consequence of a breakthrough that was already coming about.

In line with the 'minimalistic' approach, outlined above, we will here focus on possible changes in the behaviour of the different actor groups. More specifically, we will put forward an explanation that adheres to one of the key features of the model: the capacity to make decisions regarding the use of bricks. This explanation goes hand in hand with the overall historical interpretation of the model, thereby offering an integrated narrative. Such an explanation is not necessarily more likely than any other but has the merit of coherency.

A tentative historical interpretation

One possible interpretation of the suggested model would be that the diffusion process for a long time depended on a relatively small group of elite commissioners making one-off decisions and communicating these decisions to each other. This sparse network constituted a small world, allowing a swift and far-reaching diffusion, but one which constantly lingered close to extinction. Unlike most commissioners, architects and builders would have had the advantage of being involved in several construction projects during their lifetimes, maintaining contacts with other experts, and having the technical competence to assess new innovations. All this would have promoted the diffusion of fired bricks among this group, provided that they had the capacity to make critical decisions regarding the choice of building materials. As the model indicates, relatively few artisans seem to have had that authority. However, the familiarity and appreciation of the innovation would still have spread among craftsmen and architects, and occasionally facilitated the adoption of the idea by actual decision makers. This latent background knowledge, represented in the model by actor group 3, was shown in the simulations to be crucial for the long-term survival of the diffusion process.

The importance of decision making is of course a direct effect of how we chose to construct the model. However, this notion is founded not only on modern diffusion theory but also on ancient literary and epigraphic evidence. To begin with, we have the testimony of Vitruvius (6.8.9): "*in domini est potestate, utrum latericio an caementico an saxo quadrato velit aedificare*."[16] In other words, the commissioner chooses the building material, the architect makes the design, and the artisan executes the work. Rather than accepting this statement at face value, we treat it primarily as a confirmation of the significance of decision making in the building process.

The failure of the model to simulate a steep take-off towards breakthrough induces us to look for signs of change in decision making over time. The suggested development can be illustrated by two temporally differentiated configurations of interaction, presented here as ideal types.

Early configuration

At the top, we have the commissioner, who could be a private citizen, a magistrate or a public committee (Fig. 4.5). The commissioner worked out specifications and a framework for the design, which sometimes was rather detailed, as shown for example by the Puteoli inscription.[17] If it was a

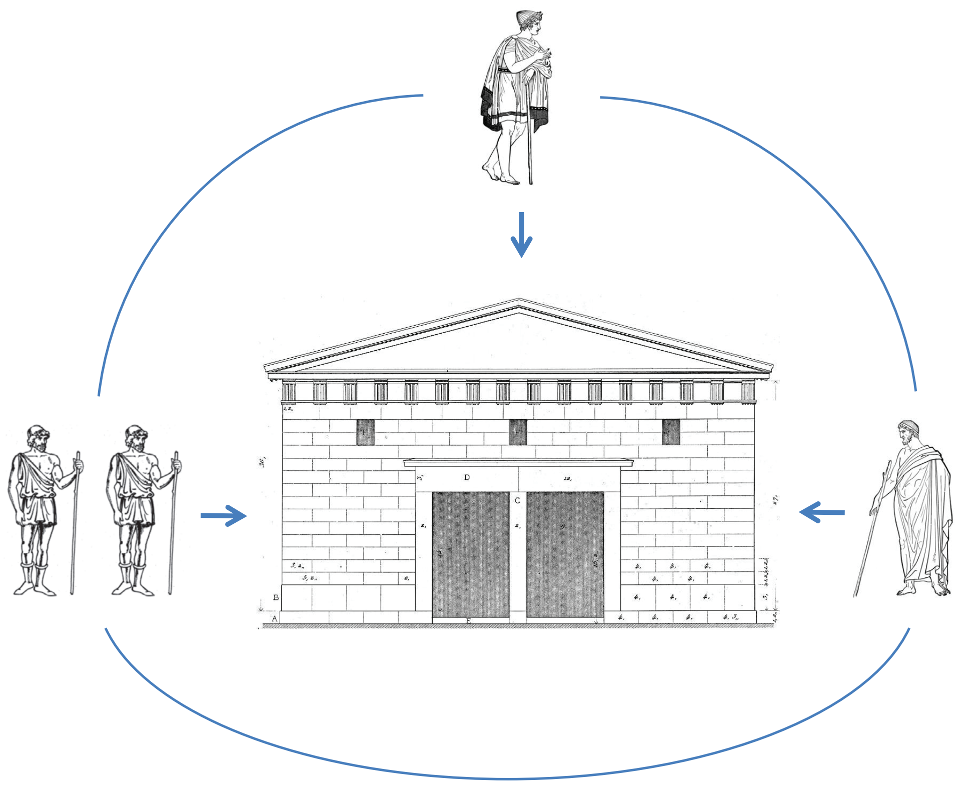

Figure 4.5. Schematic configuration of relationships in the building process in the late Classical period. For an explanation of the relationships, see the text.

major building, an architect or master builder was appointed to elaborate on the design and make refinements, but the commissioner would still be able to intervene at a later stage.

In public projects the architect worked under the close supervision of a building committee, and was paid on a daily basis rather than a long-term contract. In Athens the council would approve and if necessary modify the preliminary design.[18] The commissioner provided the building material, but also recruited the workforce. These could be hired day-labourers, entrusted with specific tasks, or entrepreneurs, taking up piecemeal contracts within the framework of the original design.[19] The execution and quality of the work was overseen by the architect, who might also be responsible for solving certain technical problems. However, building inscriptions show that the role of the architect was often that of a supervisor and administrator of the project,[20] reporting back to the commissioner, who made the final decisions. The fact that architects were often replaced during lengthy projects further illustrates their subordinate role.

Private building would have followed a similar pattern. Although we cannot say for certain that commissioners always made the crucial decisions, it is quite clear that many elite commissioners acted as patrons of architects and master builders,[21] and sometimes also performed the role of an architect.[22] From the beginning of the Hellenistic period, euergetism developed as a self-interested behaviour among elite individuals. These benefactions were often performed by commissioners, who also took responsibility for the construction, as shown by many building inscriptions. Architects were sometimes allowed to figure prominently in these inscriptions, as they were closely linked to the commissioner anyway.[23]

Turning to republican Rome, we have reason to believe that the building industry worked in a similar way, but also that it was governed by patron-client relations, which would further motivate the direct involvement of the commissioner.[24] Providing business opportunities and work to entrepreneurs, craftsmen and day-labourers would be just another kind of *beneficia*.

Contracting of privately commissioned buildings during the Republic is not well documented.[25] In fact, the small legal interest in problems arising from private contracting before the first century AD may indicate the limited extent of the phenomenon. It could be that the precise stipulation of mutual responsibilities was preceded by reliance in the workings of clientage; that is, there was no need to establish a legal contract between a patron and his client. It may also reflect a situation where many private commissioners of both public and private buildings also acted as the actual building entrepreneur, basically giving the contracts to themselves. In summary, public and private commissioners alike were deeply involved in the building process.

Late configuration

In Roman imperial times the relationship between commissioners and builders had transformed (Fig 4.6). Decisions on construction were often delegated to experts. The patron-client relationship within the building trade had partly dissolved, as a result of a changing political landscape, and was replaced by a legal framework, as indicated by judicial texts.[26]

The entire project was now let out to a main contractor, who may have been a master builder or an entrepreneur working closely with an architect.[27] The main contractor provided material and labour, and probably worked out the full design. Alternatively, many smaller building firms joined up to take on the contract. Janet DeLaine has argued that the *collegium* of *fabri tignuarii* played an important role in organising major imperial projects.[28] Based on detailed studies of the building remains of Ostia, DeLaine has also convincingly shown how decisions on material and building techniques can be attributed to individual contractors, master builders or craftsmen. The increasing degree of professionalisation is further illustrated by the fact that the maintenance of public works was directed and executed by a trained and permanent staff (cf. Frontinus).

The commissioner still works out specifications, which are stipulated in a contract. However, this arrangement leaves less scope for continuous involvement and detailed directions. Building inscriptions connected to private euergetism now focus solely on the commissioner, not the architect, which reflects the role of the latter as independent professionals.[29]

Transition from early to late configuration

It is apparent that the first configuration implies a significant scope of active involvement on the part of the commissioner, whereas the second one indicates a more independent role for the architect and master builder, as long as they comply with the contract. It has been suggested by J. J. Coulton that the former arrangement to a large extent relied on adherence to firmly established building conventions.[30] Only in the face of unusual building types and exceptional problems would the architect be required to furnish innovative solutions.

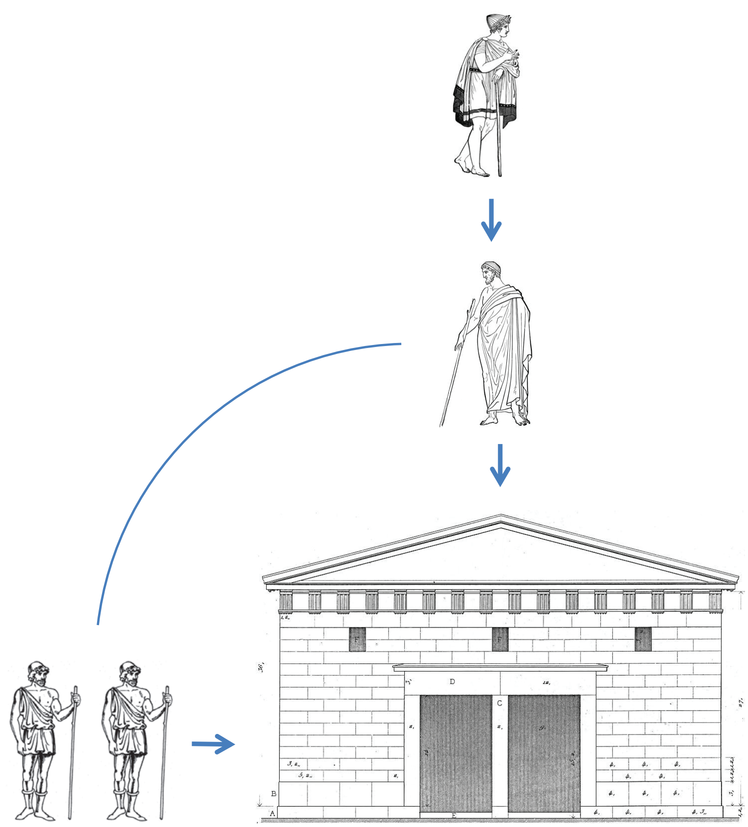

Figure 4.6. Schematic configuration of relationships in the building process in the Roman imperial period. For an explanation of the relationships, see the text.

Overall, these ideal types correspond well with established views on building industry in late classical Greece and the Roman empire respectively. However, very little effort has been made to determine when the significant shift took place, and what consequences it might have had for innovativeness and the diffusion of ideas. Our attempt to simulate the observed diffusion process lends us confidence to suggest that such a shift did occur in the late Hellenistic or Augustan period, and we would like to argue that this hypothesis also finds support from historical evidence. Taken together the sources indicate an increased rate of professionalisation and a transfer of responsibility from commissioners to architects and master builders at this time.[31]

The network-based model suggests that a change in relative strength of 'transmission power,' from long-range actors to short-range actors within the building trade is a possible explanation for the final breakthrough of fired bricks. In the Hellenistic period commissioners, and in particular elite commissioners, had greater 'transmission power' than builders and architects but only due to their dominant role in the building process, effectively suppressing the influence of other agents. When artisans acquired greater independence, along with the professionalisation of the building trade and the emergence of a legal framework, their agency made a significant contribution to the diffusion of fired bricks.

Of course, it has to be remembered that other factors also affected the diffusion process and that we limited ourselves to searching for a *sufficient* explanation for the perceived change. Thus, we suggest that for most of the Hellenistic period lay commissioners were likely to make decisions regarding building materials and other construction details, but that from the late Hellenistic and Augustan period these decisions were increasingly made, or influenced, by professional contractors and trained experts. The latter groups were more prone to understand and adopt new innovations, and to use them repeatedly. Even a small shift in the relationship between commissioners and builders would have had a profound effect on the diffusion of innovations, and could account for the final breakthrough of fired bricks.

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