The conception of building in ancient architecture and the “rules of art”

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Abstract

The ancients identified with their native territory, and builders had a profound knowledge of the environment in which they operated. Their constructions, which have survived unchanged for centuries in their natural setting, are an unequivocal demonstration of their expertise concerning the various hazards associated with the territory. A profound knowledge of building materials combined with a spatial conception of natural forms, producing exemplary construction prototypes, was passed down over the centuries in a practical tradition comprising the “rules of the art of building”.

The basic difference between historical and modern building can be summed up in the antithesis “construction/structure”. A construction is a unitary spatial organism which meets its volumetric, structural and environmental requisites without any functional differentiation. It was conceived to last forever: by modern parameters it possesses extremely high safety coefficients with respect to standard conditions. A construction was built according to rules of the art which guided all the phases of its production. A structure, on the contrary, is an organism which has been designed and realised merely to satisfy static functions.

This investigation starts by considering a few exemplary prototypes of ancient building and goes on to identify some rules of the art, adopting modern structural calculation to show how they corroborate the buildings’ static soundness. It focuses on Roman substructions as the basic spatial construction element used to erect amphiteatres, bridges and massive supporting structures. It focuses also on exemplary prototypes of the 19^{th} century.
Keywords: conception of building in ancient architecture, rules of art.

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1 Constructive conservation of the built heritage

Over the last century conservation of the built heritage, in both its constructive and structural aspects, has invariably been incongruous and invasive, violating the ancient constructive conception.

With the advent of the modern science of construction and industrial materials, this is part of the price architecture has paid for the technological revolution.

Modern technical and scientific culture has come to view historical constructions as an archaeological entity with their own, unfamiliar constructive conception, while the extraordinary resources of traditional materials and ancient constructive techniques, which over the millennia had seen the creation of the world architectonic heritage, were lost to view.

This led to the widespread recourse to consolidation, introducing into the ancient constructive fabric a chaotic cementification and the expedients of the new construction technique. Over the decades this practice has brought about damage which is often irreversible, on behalf of an illusory security.

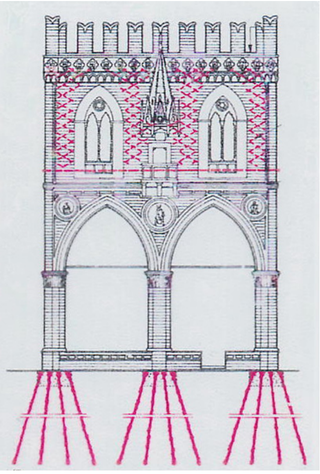

Figure 1: Scheme of the consolidation intervention carried out using *reticulated cementing* and subfoundations with *root shafts* in Palazzo della Mercanzia (16th C) in Bologna, 1978/79.

A greater awareness developed in Italy during the 1980s following the earthquakes in Friuli and Irpinia, thanks to the National Committee for the Protection of the Monumental Heritage from Seismic Risk, set up by the Ministero per i Beni Culturali and the Protezione Civile. It produced important documents and promoted an extensive research project [1] favouring a more informed conception of the conservation of our historical and monumental heritage.

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Unfortunately this conception has not made much headway in the academic world, which prefers to consider it as a theoretical framework to which to refer, without going on to formulate regulations and specific conditions for drawing up projects. The whole situation is conditioned by a crude attitude on the part of building contractors, for whom consolidation represents easy profits.

Nonetheless, some interventions carried out on the archaeological and monumental heritage by the Soprintendenze of the Ministero per i Beni e le Attività Culturali and the Istituto Centrale del Restauro have mapped out a strategy in which the chief objective is to gain knowledge of the site so as to intervene by "repristinating" and "improving" the conditions of equilibrium which had been lost or altered. The complexity of the construction phases is the key to understanding the dynamics of instability; this requires an interdisciplinary approach to the monument, together with evaluations of merit which have nothing to do with simplistic, pre-packaged calculations.

Figure 2: Rome, the round temple in the Foro Boario [2].

This approach was taken, albeit with only partial success, in the reconstruction interventions in the wake of seismic events which affected Umbria and the Marche. There is comprehensive documentation of the interventions of static restoration carried out in Italy in the proceedings of the national conferences of the Association for the Rehabilitation of the Historical Built Heritage [3].

It must be said that the culture of architectonic restoration has always ignored material history, focusing almost exclusively on the purely visual aspects. All too often the historical built heritage is treated as "artificial nature" where interventions must necessarily leave an apparent imprint. Whereas in fact the ancient constructive conception should be of interest to all the numerous professional disciplines which are involved, each in its own specific manner, with the historical built heritage: archaeologist, historians of art and architecture, restorers, architects, engineers, geologists, and so on.

For in fact, this heritage constitutes an archive of material history whose principles of design and implementation must be investigated so as to identify the fundamental features for what they can teach us concerning its conservation.

2 The ancient constructive conception

The ancient constructive conception is characterised by certain typical features. First of all its sources were nature, originally, and then geometry, since civilization took a significant step forward when humankind succeeded in rationalising the natural forms through the science of geometry.

The materials used were entirely natural, often with a considerable specific weight, and were adopted so that gravity itself ensured impressive conditions of stability and durability. These materials, fundamentally anisotropic, possess mechanical characteristics which were bound to influence the constructive project.

As a rule, the foundations of ancient constructions are continuous and direct, and often deep, lowering the overall centre of gravity.

The elevation is characterised by a spatial conception and functional coherence which makes the modern dichotomy between structure and façade irrelevant. In fact the fundamental distinction between historical and modern building can be summed up in the duality construction/structure.

A construction is a unitary spatial organism which meets its volumetric, structural and environmental requisites without any functional differentiation. Since it was conceived for a limitless durability, it possesses extremely high safety coefficients (to talk in modern terms) with respect to standard conditions. (One example can suffice: the Roman bridge at Porto Torres, subjected to the loads of modern road transport, presents compression tensions of 3-4 daN/cm^2 and traction equivalent to practically zero.) It was built according to rules of the art which guided all the phases of its production.

A structure, on the other hand, is designed according to the models of structural mechanics to satisfy static functions. It is a material organism to which all the “free floating” parts of the building are attached, and depends increasingly on the assemblage of industrial components. Thus modern building has definitively lost the handcrafted nature of historic building, and is more and more the product of industrialised construction.

Finally the techniques adopted for historical building are those of handicrafts, with stratifications stretching back over thousands of years. They directly influence constructive performance, while the durability of the constructions is conceived in terms of a timespan stretching over centuries. When a construction is affected by collapse it undergoes a fragile breakage manifested by a network of cracks which determines kinematic mechanisms. On the contrary, the behaviour of a structure responds to elastic analysis.

The fundamental principles of constructive conservation, with a broad consensus in the most progressive historical and scientific culture, were recently formulated as follows:

- Respect for the ancient constructive conception;
- Homogeneity of materials and techniques;
- Principle of minimal intervention, to be programmed in a spirit of improvement and possible reversibility;
- Programmed maintenance.

The homogeneity of materials and techniques is necessary so as not to alter the mechanical and physical-chemical behaviour of the construction, not to modify the original distribution of the states of stress, and not to induce phenomena of deterioration owing to incompatibility between the materials employed.

The principle of minimal intervention, programmed in a spirit of improvement and possible reversibility, is based on the premise that the monuments which have come down to us across many centuries of wear and tear were conceived as everlasting constructions able to stand up successfully to material vulnerabilities. All too often they have been violated, mutilated and transformed by human violence. Thus the principle of minimal intervention tends to the repristination as far as possible of the original constructive conception through interventions of static *improvement* [4], performed whenever possible using materials and techniques conforming to the original ones, and conceived in a spirit of reversibility, since future research may come up with a more appropriate form of refurbishing. Modern materials and techniques must first and foremost guarantee a durability measured in terms of centuries, and also favour a lexical and structural compatibility with the ancient conception. The principle of programmed maintenance keeps the monument monitored, eliminating any incipient degradation. In this way the construction will be ready to face up to crises even of an exceptional entity, such as recurring seismic events, with only limited damage.

3 The long march of ancient architecture: material know how and rules of the art

The ancients were rooted in their native territory, and builders had a profound knowledge of the environment in which they operated. Their constructions, which have survived unchanged for centuries in their natural setting, are the best possible demonstration of their expertise concerning the various hazards associated with the territory.

A profound material know how combined with a spatial conception of natural forms, producing exemplary construction prototypes, was passed down over the centuries in a practical tradition comprising the “rules of the art of building”. In fact “rules of the art” have always characterised human behaviour. This was true in agriculture, and over the millennia in the art of building; and it is still the case today in most aspects of technological evolution.

In the course of time the art of building accumulated knowledge concerning the territory, raw materials in the first place, and subsequently binding agents, which were adopted and implemented according to an accurate and informed experimentation. Of course this process knew its failures, but these too served to establish a heritage of shared knowledge known as the “rules of the art”.

Very different is the case of structural calculus, based on rational mechanics, involving a theoretical conception of nature which uses simplified models that have been formulated analytically. This has become an instrument of great specialisation, regulated by binding normative prescriptions, effectively distancing the designer from the hands-on experience of the worksite.

These two approaches are epistemologically distant and, as things stand, irreconcilable; so much so that structural engineering tends to reinterpret ancient building according to its own schematic elaborations. Only recently, with the development of calculus based on finite elements and the advent of extremely powerful calculators, has it become possible to identify with any accuracy the static performance of ancient constructions in their entirety.

4 Some emblematic typologies

On the subject of seismic vulnerability we should go into a series of elements and construction details which play an evident role in seismic safeguarding. These include bridging arches between buildings, bands of stonework to reinforce the corners, added thickness in the load-bearing walls and limited height in buildings. All these features, in a more refined and complex form, were part of the rules of the art which informed the construction of the major monuments in ancient times.

Figure 3: Rome, view of the complex of the Domus Tiberiana from the Roman Forum.

One emblematic case is the Roman “substruction”. It is a fundamental element in the most interesting compositional and constructive processes in Roman architecture [5]. Taken by itself, it looks deceptively simple, comprising a spatial system made from two walls, often parallel to one another, connected by a vault with circular intrados and flat extrados. In reality the substruction is used in complex systems which are laid out side by side and piled up one on top of the other. By composing multiple combinations of this simple module, Roman

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architects created such prestigious monuments as the Sanctuary of Palestrina and Domus Tiberiana, amphitheatres, warehouses on the Tiber, and the elaborate buildings in spa resorts. The substruction can also serve as a containing wall, withstanding great pressure from terrain.

A reconstruction of a possible geometric scheme for an individual substruction exemplifies the proportions used in its creation. It has been shown to have a remarkable static resistance, and also that incidental loads have little or no incidence on its tensional state. Clearly, the practice of assembling several substructions alongside or on top of one another leads, within certain limits, to a superior static regime.

Figure 4 shows the cross-section of a substruction and the modular measurements of its various parts, based on a sample of actual examples.

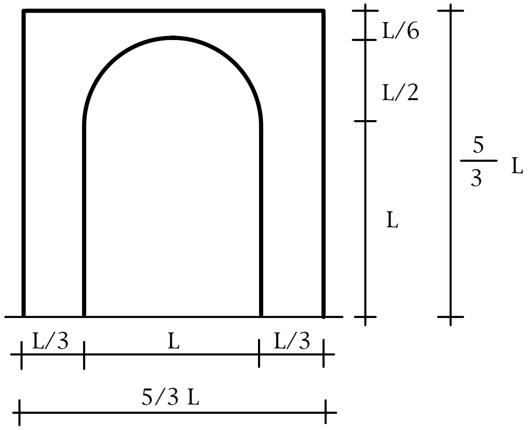

Figure 4: Construction proportions of the substruction, in cross-section.

(a)

(b)

Figure 5: (a) The Colosseum (75/80 BC), example of a building using the technique of *substruction*. (b) Porto Torres, Sardinia, Roman bridge.

Basing construction on geometry, which presented no problem on a building site, made it possible to produce manufacts in rapid succession, including bridges.

In constructions we rarely find a single substruction, and in systems such as a bridge the substruction at the end of a row features constructive expedients which improve its static conditions. (So we can say that the static benchmark coefficient was calculated giving particular importance to statics, so that the real stresses are even more contained.)

In the Middle Ages new architectonic forms were created, of which cathedrals, castles and towers are the most striking examples. Even in the areas most at seismic risk, such constructions have survived down the centuries. The rules informing their construction were the product of complex experiences evolved by highly specialised teams of workmen.

In the 18th and 19th centuries extensive terraces of buildings were erected using the volcanic tuff stone. They usually comprised a ground floor and four storeys, measuring some four metres from one floor to the next, so that they stood approximately 20 metres above ground level. They were put up quite rapidly on the basis of the following rules of art:

- ceilings first in wood and then in metal, to a maximum height of about 6 metres;
- external walls of 40 cm in width at the fifth floor, with a fixed external façade, while the internal wall facing increases by 5 or 10 cm for each floor according to the internal apertures;
- internal or ridge walls also 40 cm wide at the fifth floor but increasing by 10 cm for each floor, so that at ground level the total thickness measures about 90 cm;
- inclusion of a cellar with barrel vaults so that the foundations lie some 4 metres below ground level, and the thickness of the foundation walls is in excess of 100 cm.

The dimensions given here may vary in different territories on account of the diversity of natural materials used in the masonry. Two centuries on this constructive typology, which does not conform to the recent anti-seismic regulations, is still proving highly efficient.

Figure 6: Naples, Piazza dei Martiri.

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Another 19th century innovation, with the advent of girders in laminated iron, was the widespread use of metal beams and vaulting in stone or brick. Ceilings could be erected easily and rapidly thanks to a simple rule of the art which came to be known as the "bricklayer's rule". Once the planks had been laid about 80 cm apart, the height in centimetres was worked out by multiplying the length of the plank in metres by 3. Now scientific research should investigate these proportions in order to identify all the rules of the art which enabled workmen to create the historical architecture and demonstrate their technical and scientific validity.

5 Architecture for historical building; conclusions and prospects

In facing the issues we have outlined above, the cultural positions of both architecture and engineering are very inadequate. We shall not here go into the relations between ancient construction and restoration, or ancient construction and engineering benchmarks. We shall merely highlight two fundamental aspects.

Regrettably the history of architecture has concentrated on a purely visual approach which totally ignores any reference to material history and hence to the history of constructions. This attitude has characterised the academic formation of architects, resulting in a culture of design which gives more importance to "literary" than "material" considerations.

Engineering, on the other hand, has opted for a role of prime importance but cultural subservience in all the complex aspects of conservation, from structural interventions to technology and plant design. Our hope is that it will not be long before a discipline of "engineering for cultural resources" is able to adopt an approach which is more in line with a properly informed conservation. In this perspective the analysis of the construction conception of the ancients and the pursuit of the "rules of the art" represent two highly significant ways forward. Furthermore, for countries such as Italy which live with a widespread and significant seismic risk, information on the effects of past seismic events provides interesting data concerning the seismic response of historical buildings. To date this knowledge has found little application in the sectors of engineering and restoration, but it could lead to new observations about the historic built heritage, the rules of construction and conservation. Studies have been carried out to identify the seismic damage undergone [6] and, in particular for monumental constructions, we have tried to correlate such damage with the whole construction history [7]. This type of research enriches the "anamnesis" of a monument, and can highlight the significant capacity for resistance to the passage of time and to seismic events of a monumental building. The typology of the damage suffered can indicate some of the critical points in the building's current state.

Once again, our hope is that as people gain a greater knowledge of the ancient constructive conception, this will influence the programming of conservation interventions in terms of both the official regulations and the professional

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formation of architects and engineers, currently based almost entirely on the techniques used in modern constructions. In Italy for the first time regulations have been issued concerning existing buildings in masonry, but it does not deal comprehensively with the question of monumental buildings [8].

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