Zeitschrift: IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen

Band: 36 (1981)

Artikel: History of construction in different geographical environments

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DOI: https://doi.org/10.5169/seals-28280

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History of construction in different geographical environments

L'histoire de la construction dans les environnements géographiques différents

Geschicte der Tragwerke in verschiedenen geographischen Umgebungen

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SUMMARY
This paper is divided into three parts. The first discusses the huts of primitive civilizations. These were built before the classical periods in Egypt, Greece and China, and they are still constructed in various parts of the world, for example in Papua New Guinea. The second part deals with the more monumental buildings of the classical civilizations, prior to the development of iron and reinforced concrete structures. The final section examines some geographical influences on modern architecture, which has often been described as uniformly and monotonously international.

RESUME
Le rapport est divisé en trois parties. La première partie discute des huttes des civilisations primitives. Celles-ci ont été construites avant les périodes classiques en Egypte, en Grèce et en Chine, et elles sont toujours construites dans diverses régions du monde, par exemple en Papouasie. La deuxième partie s'occupe des bâtiments plus monumentaux des civilisations classiques, avant le développement de l'acier et des structures en acier et en béton armé. La dernière partie examine les influences géographiques sur l'architecture moderne, laquelle a souvent été décrite comme internationale, uniforme et monotone.

ZUSAMMENFASSUNG
Die Abhandlung ist in drei Teile aufgeteilt. Der erste bespricht die Hütten der primitiven Zivilisaitionen. Diese wurden vor der klassischen Zeit in Aegypten, Griechenland und China gebaut, und sie werden auch heute in verschiedenen Gebieten der Welt noch errichtet, zum Beispiel in Papua, Neuguinea. Der zweite Teil behandelt monumentale Gebäude der klassischen Zivilisationen, bevor Strukturen aus Eisen oder aus Stahlbeton entstanden. Der letzte Abschnitt untersucht den Einfluss der Geographie auf die moderne Architektur, die oft als international einheitlich und monoton bezeichnet wird.

Primitive Buildings

Lest I be accused of condescension, may I quote the Oxford English Dictionary, which defines primitive, *inter alia,* as "original, from which some construction begins, from which another is derived". The buildings of primitive civilizations are small and simple, compared with those of the classical period, because there is not yet any demand for great religious buildings or for palaces for powerful rulers.

Most primitive buildings leave no ruins, so that we have only limited information about the structures of the pre-classical civilizations, but they were probably not unlike those of present-day primitive societies. Until the late 19th century there were numerous tribes whose construction procedures had not been affected by the iron age. There are some people in the New Guinea Highlands whose first contact with the outside world was made within living memory, and whose buildings are therefore of particular interest. Apart from the use of steel tools for cutting the materials, they have not changed significantly since that time (Fig. 1).

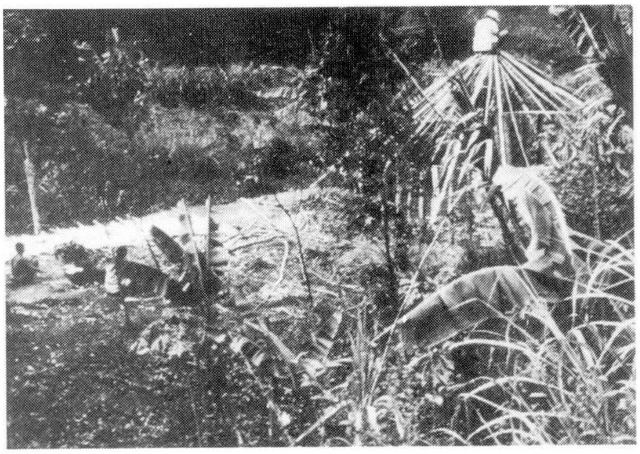

Fig.1 Circular hut in the New Guinea Highlands under construction. Once the materials have been assembled the hut can be easily be erected by two people in one day. The structure consists of bamboo tied with vegetable fibres. The walls are plaited mats.

In the twentieth century primitive societies have been confined to the hottest and coldest parts of the earth's surface. The former may be divided into hot-humid and hot-arid zones, of which the hot-humid is the more hospitable. It produces an ample supply of readily worked structural material in the form of bamboo, reed, and tree saplings. These can be cut at leisure. When there is an adequate supply of structural materials of the right length, a house can be built easily in one day.

The resulting house is not entirely weatherproof, it becomes infested with vermin, and it is easily destroyed by fire. However, it does not cost much to build, even in terms of the resources of a primitive society, and it is easily replaced. Indeed, in many regions it is treated as a disposable building, to be abandoned or destroyed when it no longer meets the sanitary standard of its owners. It is interesting to note that in the 1960's, when the consumer-oriented society was at its most fashionable, a disposable house was regarded as a desirable modern objective.

The construction is environmentally suited to the climate. It provides ventilation in a hot-humid climate; insulation would be of little value when the difference between the daily maximum and minimum temperature is small.

The type of building illustrated in Fig. 1 is still erected in many of parts the Pacific region, even in islands, such as American Samoa or Fiji, which have been greatly influenced by European-American concepts. There are regional differences, notably the use of two vertical poles and a ridge beam to produce a large hut (Fig.2). There are modern improvements, such as the use of concrete floors in Samoa. The tradiational method has been totally abandoned in some islands, for example Rarotonga, where timber-framed huts with iron roofs have acquired the characteristics of an indigenous architecture.

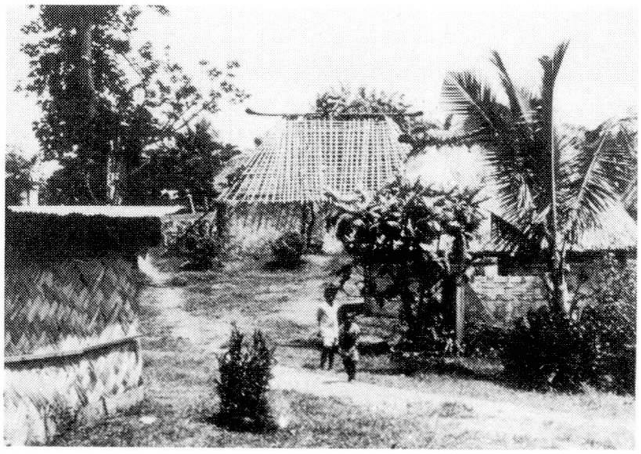

Fig. 2 A large bamboo hut in Fiji, which has two vertical poles and a ridge beam.

The primitive architecture commonly associated with hot-arid regions has thick walls of local materials, such as mud, mud-brick or stone which provide good insulation and thermal inertia. The real structural problem is the construction of the roof. One common solution is a curved roof, but the attainable span is usually very small in primitive buildings and the interior space is limited accordingly. Another solution is a timber roof, where timber is available. A roof of light materials largely negates the insulation and thermal storage of massive walls; however, in some parts of the world with great temperature variations, notably in the Middle East, timber roofs are covered with a thick layer of soil, and sometimes also with grass, to provide the roof with the necessary thermal insulation and heat storage capacity.

In the 1930's, and again in the 1960's, it was fashionable to proclaim vernacular architecture as the true guide to the correct use of local materials in conformity with the local climate. Primitive man, if given many centuries to experiment, would unerringly discover solutions in conformity with the best modern precepts of building science. Looking at the surviving methods of vernacular construction, there is much evidence in support of this thesis. However, the keyword may be "surviving". When a primitive society comes into contact with another that has a higher technology it naturally adopts many of its techniques. The old methods are more likely to survive if they perform satisfactorily.

Even with that proviso there are a number of vernacular structures which are not well suited to their geographical region. Central Ghana may serve as an example. The northern part of the country is hot-arid, and the southern part is hot-humid and has ample resources of timber and reed. However, the people of a large part of the forest country live in mud-huts which are ill-suited to the climate. It may be that these people migrated from the arid north, but this would have happened several centuries ago. Attempts by various foreign experts to persuade the forest people to use the readily available timber for more comfortable buildings have not, as far as I know, been successful. This emphasizes the role played by tradition.

Classical Timber Structures

The influence of tradition is shown particularly clearly by Ancient Egyptian architecture which copied timber structures in stone for more than two thousand years with only minor variations in the structural concepts.

The emphasis on stone as the material for important Egyptian buildings is probably due to the importance attached to life after death, and thus to permanence of construction. In primitive civilizations durability is generally not a major consideration in the design of buildings; indeed, disposability may be considered desirable for reasons of hygiene.

We therefore enter the era of conflict between simple and economical long-span structures using timber, and durable structure using stone or brick, which could be made to bridge long spans only with difficulty and at great expense. We know very little of the, possibly long-span, timber structures of the early classical period, except in East Asia. The remains of the great masonry structures survive, and are well-known.

The Japanese had a interesting solution to the lack of durability of timber structures; they re-built important structures at regular intervals. Thus the present Ise shrine is allegedly an exact copy, the 59th copy, of the original shrine built in the 7th century (Ref. 1).

This interest in timber structures possibly accounts for the development of an ingenious structure for sloping roofs used in China and in Japan (Fig. 3). As far as I am aware this structure which consists of a series of beams of increasing length has never been used in the Middle East or Europe, nor has the triangulated roof truss been used in East Asia until introduced from Europe.

It is likely that the Romans understood the advantages of triangulation, because a picture of a triangulated truss appears on Trajan's column in Rome. It shows a bridge in Roumania across the Danube, by any strandards a big river. In medieval times the advantages of triangulating trusses were not understood in Europe, but they were rediscovered in the 16th century, probably by Andrea Palladio (Fig. 4).

The Japanese type of roof structure uses more timber, probably not scarce at that time in either Japan or Europe, but it requires far less labour for cutting the joints.

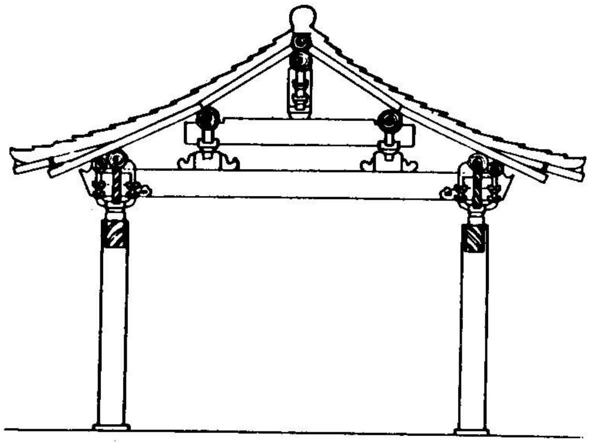

Fig. 3 Framing of traditional timber roofs in China and in Japan.

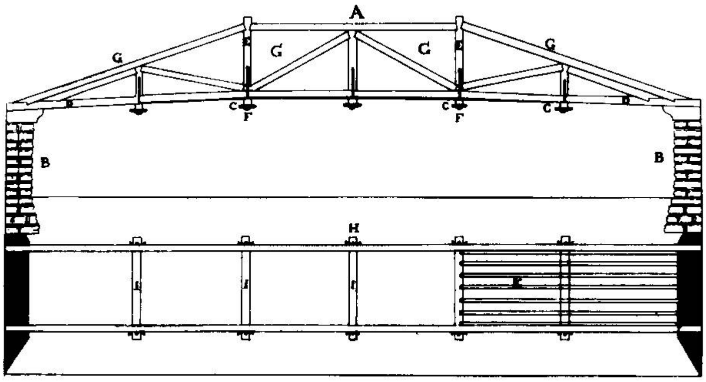

Fig. 4 Andrea Palladio's bridge over the River Cimone, with a span of about 30 m that was large for the 16th century. In his *Four Books of Architecture* (Ref. 2 p. 65) he explains the structure:- "A, The flank of the Bridge. B, The pilasters that are on the banks. C, The heads of the beams that form the breadth. D, The beams that form the sides. E, The colonelli, F, The heads of the cramps, with the iron bolts. G. are the arms, which bearing contrary to each other, support the whole work..." Evidently Palladio recognized the importance of the diagonal members.

Classical Masonry Structures

The history of the architecture surviving in the Middle East and Europe as distinct from that of Japan, is mainly a masonry buildings, and the roof structures of the most important buildings, since the time of Ancient Rome, were built of stone, brick or concrete. In some buildings, for example in most Gothic cathedrals, the masonry vault was surmounted by a timber roof. The masonry vault protected the interior of the cathedral from fire, and the timber roof kept the rain off a thin masonry vault that, in many cases, could not drain the water because it consisted of a number of curved structures with several low points. Before the age of lighting conductors, invented in the 18th century by Benjamin Franklin, a very tall building was liable to attract lighting, and its timber roof was thus at risk. In addition fire from military action was a constant problem throughout most of Europe's history. The importance of masonry vaults for fire protection was recognized at an early time:-

> "I am entirely for having the roofs of temples arched, as well because it gives them greater dignity, as because it makes them more durable. And indeed I know not how it happens that we shall hardly meet any temple whatsoever that has not fallen into the calamity of fire .... Caesar owned that Alexandria escaped being burned, when he himself took it, because its roofs were vaulted." (Ref. 3, p. 150).

Once the structural designer was committed to build a long-spanning roof with timber, and before the age of iron structures, he had to devise a geometry which took the greatest advantage of the compressive strength of masonry materials, and minimized their low tensile strength.

We know today that a cable hanging under its own weight, that is, a pure tension structure, assumes a mathematical curve

$$y = a \cosh \frac{x}{a}$$

where x and y are the horizontal and vertical coordinates, and a is a constant.

We call this a catenary, and it is similar in shape to a parabola. Evidently if a structure is to be in pure compression, it must have the exactly opposite shape, that is, an upturned catenary.

I do not know who first suggested that this theory was discovered in Mesopotamia 1500 to 1800 years ago, but it may have been James Waller. Certainly it is mentioned in a paper of which he is the co-author (Ref. 4), and a modern thin reinforced concrete catenary vault was named by him "Ctesiphon vault", after the 6th century vault on the outskirts of modern Baghdad.

Elongated arches resembling catenaries were used in Iran and Eastern Turkey in medieval times, and pointed arches existed in the Holy Land at the time of the First Crusade (1096-99), and were copied in the Gothic cathedrals.

The need for a correct solution would be greatest where the tensile strength of the masonry materials was lowest, and the Mesopotamia of the 6th century relied on lightly burned brick as a major building material because of shortages of natural stone, timber and fuel.

It is conceivable that this solution could have been discovered during the Hellenistic era (which made more profound innovations), and used in the Middle East for the construction of arches, vaults and domes. I found the argument sufficiently convincing to reproduce it in a book (Ref. 5, p.104).

I later developed doubt about its validity for two reasons. The catenary concept was discovered in the 17th century. David Gregory, Professor of Astronomy at Oxford University, published it 1697 (Ref. 6), but it was probably known to Robert Hooke several years earlier (Ref. 7, p. 50). It may even have been the idea of Sir Christopher Wren, who preceded Gregory in the chair of astronomy and used a structure resembling a catenary in the dome of St. Paul's Cathedral in London (Ref. 5, p. 180). From the 17th to the early 20th century designers used chain or string models to determine the line of thrust of arches vaults and domes (Ref. 5, p. 196-7 and Ref. 8, p. 87). There is no mention of the use of such models in earlier ages.

Secondly, the shape of the Ctesiphon vault could have developed from that of a timber vault. Reeds can be bent elastically to an arch shape which resembles a parabola or catenary (Fig. 5). A recent book published in East Germany shows a photograph of contemporary vernacular Iraqi roof built from reeds bents into arches (Ref. 9, p. 196). Vitruvius described vaulted roofs built from a structure of reeds bent into arches as a common form of construction in Roman times (Ref. 10, pp. 205-6).

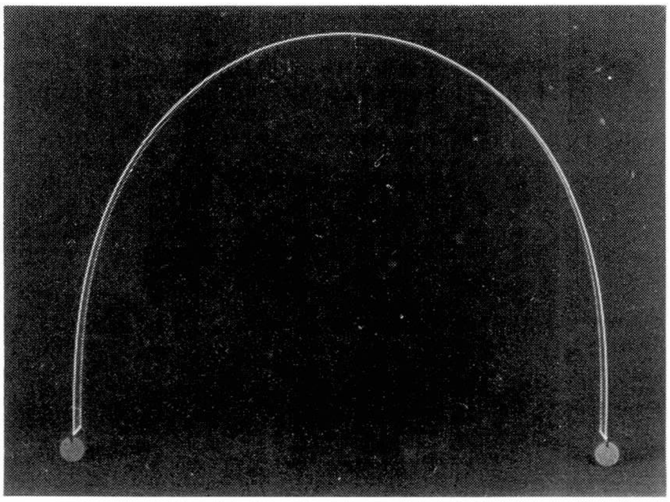

Fig. 5 Piece of perspex bent elastically to form an arch.

The timber column turned into stone persisted in Greek and Roman architecture, for centuries. It is therefore likely that the shape of the elastically bent timber arch would also have been used in masonry. The fact that it is relatively close to the catenary makes it a structurally efficient form, and this accounts for the fact that the Ctesiphon vault, with the large span of 25m, could be built in a weak material and could survive maltreatment for more than a thousand years. It would also account for the relative efficiency of the Gothic arch as compared with the Roman semi-circular arch. The elongated domes of the Renaissance and the Baroque which are much lighter than comparable Roman structures may also derive from the same source.

Modern Structures

In recent times geography was probably a factor in the development of the steel-framed building in the 1880's. Iron was first used for the construction of fireproof floors and roofs in the first decade of the 19th century in the industrial regions of the English Midlands (Ref. 5, p. 25). Until it attracted world-wide attention with the construction of the Crystal Palace, there had been general agreement that utilitarian iron structures were often masterpieces of engineering, but that they were not architecture. Iron might be used to support the masonry of a monumental building, so long as it was not visible.

After the success of the Crystal Palace, some architects began to think otherwise, and this drew a rejoinder in 1872 from Charles Eastlake, at that time the Secretary of the Royal Institute of British Architects:-

"One architect at least .... did not hesitate to avow his conviction that Mr. Paxton, guided by the light of 'his native sagacity', had achieved a success which proved incontrovertibly how mistaken we had been in endeavouring to copy from ancient examples; that the architecture of the future should be the architecture of common sense; and that if the same principles which had inspired the designer of the Exhibition building had been applied to the Houses of Parliament, to the British Museum, and to the new churches in course of erection, millions of money would have been saved and a better class of art secured.

"Sanguine converts to the new faith began to talk as if glass and iron would form an admirable substitute for bricks and mortar, and wondrous changes were predicted as to the future of our streets and squares ....

"It did not take many years to dissipate the dreams of universal philanthropy to which the Exhibition scheme had given rise, and with these dreams to charming visitors of a glass-and-iron architecture may also be siad to have vanished. If the structural details of the Crystal Palace teach us any lesson, it is that they are strictly limited in application to the purpose for which that building was erected". (Ref.11., pp. 281-282).

The prevailing opinion in New York was similar, but Chicago was too remote at the time of the Great Fire of 1871 to be concerned about such matters of taste. The rapid reconstruction of the city, using only fireproof structures, was the urgent priority. It was probably this geographical isolation which caused W.B. Jenney to design the first building with a complete skeleton frame (the Home Insurance Building, Chicago) in 1885, more than 70 years after the first use of iron beams in buildings. Once the economy and efficiency of the skeleton frame had been demonstrated, New York quickly adopted it, followed by Europe and Australia.

The use of a skeleton from did not by itself imply the abandonment of the external masonry wall. It continued in use even for "modern" buildings until the 1920's.

The concept of the transparent curtain wall was essentially aesthetic. The load-bearing wall needed to be thick, particulary if the building was tall; but buildings with skeleton frames did not require load-bearing walls. The lightness of the structural frame made possible by the new technology was obscured by the traditional masonry walls.

Some architects in the 1920's,notably Le Corbusier, thought that this was wrong:-

"The Engineer, inspired by the law of Economy and governed by mathematical calculations, puts us in accord with universal law. He achieves harmony ....

"The Engineer's Aesthetic and Architecture - two things that might march together and follow one from the other - one at its full height, the other in an unhappy state of retrogession.

"A question of morality; lack of truth is intolerable, we perish in untruth." (Ref. 12, pp. 1-2).

The glass curtain wall, while not a structural concept as such, was justified because of the emphasis it gave to the newly discovered light skeleton frame. Ludwig Hilbereimer, an associate of Ludwig Mies van der Rohe, first at the Bauhaus and later at the Illinois Institute of Technology, claimed that in Mies' buildings "the disunity between architecture and engineering had been overcome; the engineer, once the servant of the architect, is now his equal."(Ref. 13, p. 21).

This applies, however, only to the structure. The environmental design is clearly subordinate to the visual effect of the metal-and-glass curtain wall, the essential ingredient of the Miesian style.

It is interesting to speculate to what extent the glass curtain wall owes its development to the relatively severe climate of central Europe and the even more severe climate of the Eastern United States. In both countries proper facilities for winter heating are essential. In the Eastern United States summer cooling is also very desirable. By contrast an English architect might satisfy his client with open fireplaces and no summer cooling, and a Sydney architect might satisfy his client with no provision for heating or cooling, other than good attention to sunshading and ventilation. In neither case is a mechanical/electrical plant required.

In the 1950's energy was cheap and plentiful, and the concept made excellent sense in the climate of North-East America which for reasonable comfort demanded in any case a heat engine and a forced-ventilation system. The events since 1973 have changed the emphasis in architectural design, and post-modernism is, in my opinion, in no small part due to the energy crisis of 1973. It is possible that events would have taken a different turn if the avant-garde of modern architects had worked in a different geographical environment.

The time has come to review the relation between structure and environment. We took it for granted that a well-designed structure in primitive architecture and in the architecture of the classical period would help to provide a favourable thermal environment. The complete separation of the structural environmental functions occurred only in the mid-twentieth century. We should take a fresh look at the load-bearing wall, and particularly the load-bearing wall incorporating sunshades (Fig. 5).

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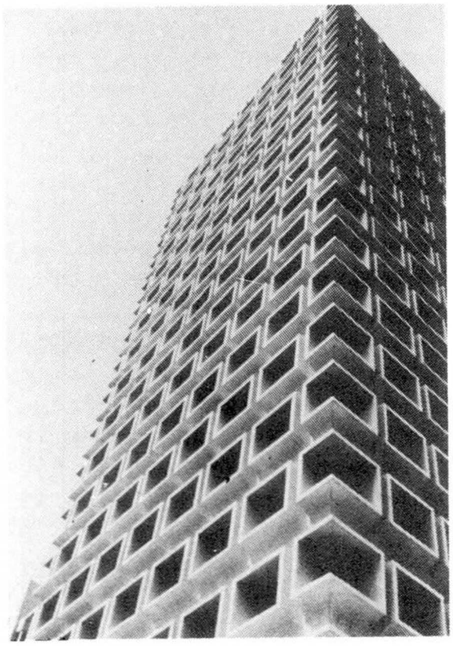

Fig. 6 Sunshades as part of a load-bearing wall (Greater Pacific House, Sydney)