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Evolution of architectural forms of historic buildings

R.F. Borges
Penn State University, USA

Abstract

This paper examines the evolution of architectural forms of historic masonry buildings up to the Middle Ages. Consideration is given to those building forms or structures that contributed most to the stability, aesthetics and topology of the monument. It also discusses how this development brought about structural concepts and methods of construction employed in architectural heritage. The thesis proposed in this paper emphasizes the important role played by the development of architectural forms in defining structural aspects of historic buildings.

1 Introduction

The analysis of architectural forms provides an insight into past cultures and eras. Behind each of these forms and styles lies neither a casual trend nor a vogue, but a period of serious and urgent experimentation directed toward answering the needs of a specific way of life. Climate, methods of construction, available materials, and economy of means all impose their dictates. Each of the most significant architectural forms has been aided by the discovery of new construction methods. Once developed, a method survives tenaciously, giving way only when social changes or new building techniques have reduced it.

This process is exemplified by the evolution of architectural forms of historic masonry buildings.

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Three important developments, in the form of structural systems, contributed to the determination of building forms: the post-and-lintel, or trabeated, system; the arch (vaulting) system, either the cohesive type, employing plastic materials hardening into a homogeneous mass, or the thrust type, in which the loads are received and counterbalanced at definite points; and the Gothic-skeletal system, in which the basic building components are combined to form an organic structural unity.

In the following discussion, a brief account of the development of architectural form is given considering these basic structural systems to be determinant in the evolution of architectural forms.

2 Evolution of architectural forms

2.1 Historical notes

Since ancient times, available building materials and tools have determined or modified architectural forms. Methods of construction and structural considerations also contributed to the evolution of architectural form. From the Walls of Jericho (8000 BC) to the Gothic cathedrals of the XIII century, this evolution of building forms or structures can be seen as a continuous development of structural elements whose basic function is to support loads (columns, pillars, walls) and those elements that perform principally a spanning function (beams, arches, vaults and domes).

The practice of architecture and building construction was based on craft tradition dating back to antiquity. The "stacking system" prevailed with the ziggurats of Mesopotamia, Fig. 1, and the pyramids of Egypt, Fig. 2.

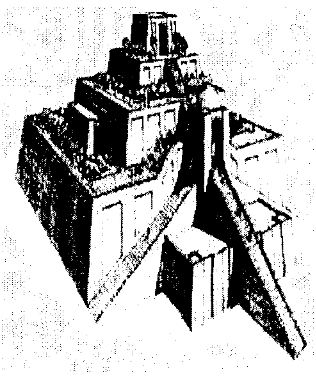

Figure 1: Ziggurat, Mesopotamia

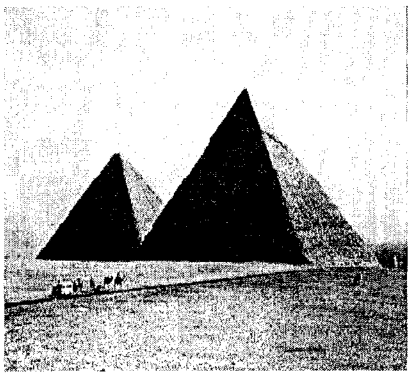

Figure 2: Pyramids, Egypt

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In Egyptian architecture, the earliest extant structures (erected by 3000 BC), to be called architecture consisted of the post-and-lintel system, Fig. 3. This trabeated system was employed exclusively and produced the earliest stone columnar buildings in history. Later, after generations of experimentation with buildings of limited variety, the Greeks gave to the simple post-and-lintel system the purest, perfect expression it was to attain as in the Parthenon, Fig. 6.

For a long time, the classical Greek system of the "orders" became the most visible contents of architectural form emphasizing composition and the concepts of proportion and harmony, thus representing the formal characteristics of architectural tradition. These orders: Doric, Ionic and Corinthian, were purely ornamental in nature and did not perform a structural function. The tradition of Greek architecture was preserved but the recognition that the orders were nothing but ornament encouraged architects to take liberties in their designs. Architraves could be interrupted, curved or bent upwards into arches.

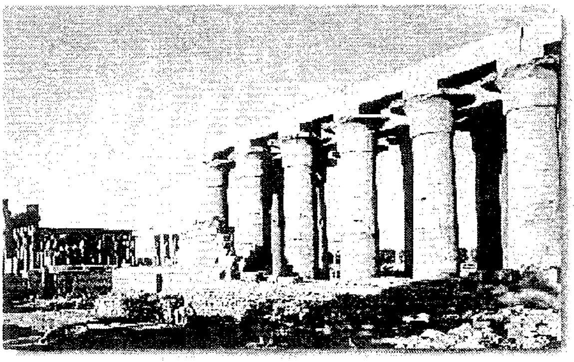

Figure 3: Post and Lintel, Egypt

Arches have been built since prehistoric times. The Egyptians, Babylonians, and Greeks used the arch and the corbel, generally for secular structures, such as storerooms and sewers. Roman architecture, borrowing from the Etruscans and combining the columns of Greece and the arches of Asia, produced a wide variety of monumental buildings throughout the Western world. Their momentous invention of concrete enabled the imperial builders to exploit successfully the vault construction of Asia and to cover vast floor spaces with great vaults and domes, as in the Pantheon.

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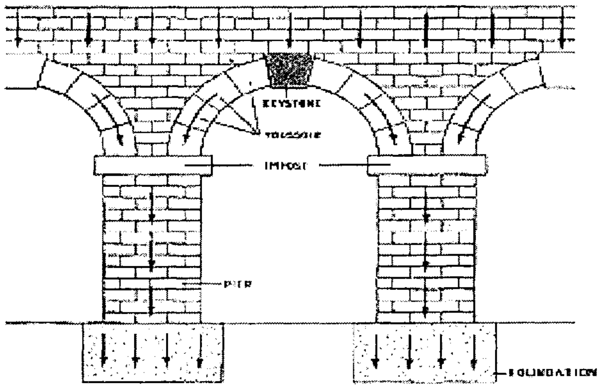

Figure 4: Roman Arch

The Romans were the first to develop the arch, Fig. 4, on a massive scale. They realized the structural potential of the arch and its derivatives, the vault and the dome, by incorporating these elements into their constructions.

Byzantine architects experimented with new vaulting principles and developed the pendentive, Fig. 5, used brilliantly in the VI century for the Church of Hagia Sophia in Constantinopla.

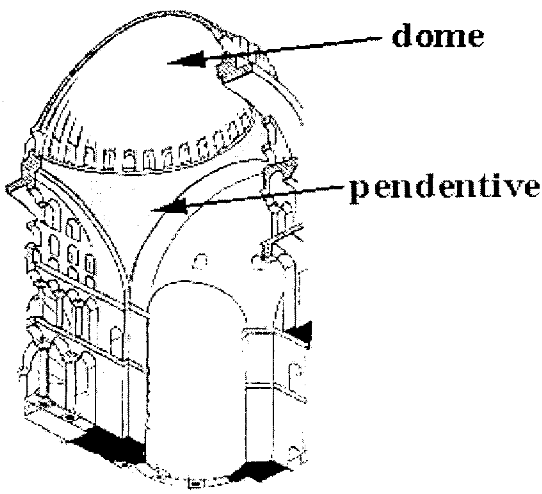

Figure 5: Dome, Pendentive

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The Romanesque architecture of the early Middle Ages was notable for strong, simple, massive forms and vaults executed in cut stone. In Lombard Romanesque (XI cent.) the Byzantine concentration of vault thrusts was improved by the device of ribs and of piers to support them. The idea of an organic supporting and buttressing skeleton of masonry, here appearing in embryo, became the vitalizing aim of the medieval builders. In Gothic architecture it emerged in perfected form, as in the nave of Notre Dame, Fig. 7.

The birth of Renaissance architecture (XV cent.) inaugurated a period during which the multiple and complex buildings of the modern world began to emerge, while at the same time no new and compelling structural conceptions appeared.

Nevertheless, the Renaissance brought about a new interest in the accomplishments of antiquity, especially in Italy. Ancient works of art and buildings became objects of study, prompting a search for writings on architectural theory and building construction. Structural mechanics began to develop largely because of the increasing demand for a rational analysis connected with the building of masonry stone vaults. The main motivation for the early development of structural theory was to understand and control the fracture of materials as evidenced by Leonardo DaVinci's studies and later by Galilee's experiments. These developments undoubtedly contributed to the creation of modern structural theory.

2. 1.1 Stone architecture

The period running from the Paleolithic era to the Middle Ages is characterized by the use of masonry, and in particular, stone in architecture, heralding future uses of the material. For example the horizontal stone in dolmens (chamber tombs walled and roofed with megaliths) would later form the basis for the lintel principle used so magnificently by the Egyptians and the Greeks.

Following the era of megalithic monuments, there was a move towards a more elaborate form of architecture with a religious function. As previously mentioned, stone architecture began with a "stacking" system, of which the Egyptian pyramids are typical examples. The Romans brought about developments in stone construction through a rational use of the arch principle and through the construction of domical vaults made of stone.

Romanesque architecture in the Middle Ages went on to draw from Roman experience and made few changes to the basic principles. The feat of conquering verticality, intended as an expression of religious fervor, led cathedral builders of the Gothic period to develop the pointed arch and to discover the flying buttresses system that they made great use of from an aesthetic as well as a structural point of view.

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Vaults were used to span greater lengths of space along the naves and aisles of the cathedrals. With these efforts to "lighten" structures, masonry stone-construction reached the limits of its potential during the Gothic period. The Sainte-Chapelle, built in Paris in 1246, represents the height of achievement in this respect.

2.2 Structural aspects

2.2.1 Function and structural characteristics

Function refers to the specific purpose for which an element is used in a structure. That is, some elements are employed to carry loads while other elements are used principally to span a certain space. Structural characteristics are those referring to strength, stiffness, and stability. The structure must be strong enough to carry loads; it must not deflect unduly; and it must not develop unstable displacements. Strength and stiffness are not conditions of great relevance in the design of masonry, whereas those pertaining to stability are of primary importance, particularly when designing curved-shaped masonry structures. These pictures show how builders of different periods overcame the difficulties of spanning a large ground area, and in the end achieved a logical and efficient construction.

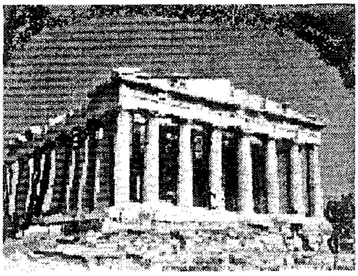

Figure 6: The Parthenon

Figure 7: Notre Dame

The post-and-lintel system of a Greek temple and hence its shape, Fig. 6,were determined by the strength of its material, for the space between any two columns could be no greater than the longest possible (strong enough) stone crossbeam. Thus, the post-and-lintel type of construction limited further development in the topology of the architectural form.

The Gothic builder, on the other hand, solved the spanning problem in a different way by relying on the use of the vault, as illustrated in Fig. 7, by the Nave of Notre Dame, Paris. The master builder also depended on strength but, much

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more so, on the stability of the masonry structure for the shapes and sizes of the building components of the structure.

Masonry vaults constructed of numerous blocks of material pressing against one another exert not only the accumulated downward weight of the material and of any superimposed load but also a lateral thrust, Fig. 8, or tendency to spread outward, Fig. 8b. To avoid collapse due to instability, adequate resistance against this thrust must thus be concentrated at the haunches of the vault.

The resistance may take the form of thickened walls at the haunches, Fig. 8c; or of buttresses placed at points of concentrated thrust as in Romanesque, Fig. 8d, and Gothic architecture using flying buttresses, Fig. 8e. Metal ties, Fig. 8f, can also be used to resist the lateral thrust.

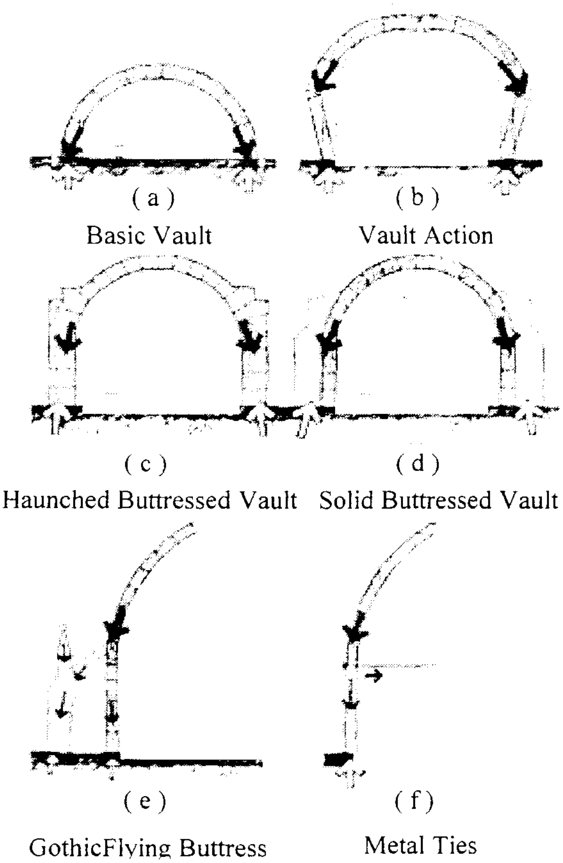

Figure 8: Thrust in Masonry Vaults

This necessity to resist lateral thrust, mainly from the point of view of stability and not of strength, has controlled the evolution of masonry vaulting (composed of separate units of material), and its use in historic buildings. Consequently, the evolution of architectural form is effectively described by the development of masonry vaulting systems that rely on the geometry of its configuration in order to maintain its stability and hence, its structural reliability.

2.2.2 The masonry vault

Roman vaults were the basis on which more complex and varied architectural forms were developed during the Middle Ages. Thus, to better understand the evolution of masonry vaulting and how its effective utilization came about, we most start with the Roman barrel vault, Fig.9, in which large blocks of stone, cut to the right size and shape, supported each other to form a tunnel-like structure.

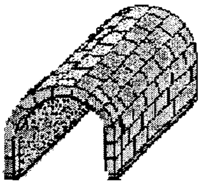

Figure 9: Barrel Vault

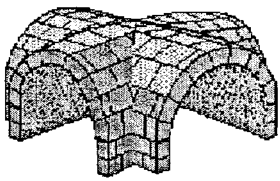

Figure 10: Cross Vault

From the barrel vault, the cross (groined) vault, Fig. 10, is produced by the intersection at right angles of two barrel vaults, creating a surface that has arched openings at its four sides and concentration of load at the four corner points of the square or rectangle. It was found that these cross vaults were much more useful than the barrel vaults, for when risen on pillars to form bays, they could be repeated in order to cover a large area. This allowed for a more spacious and functional structure as was used so effectively in the great Romanesque churches.

Ribs to strengthen the groins and sides of a cross vault were introduced into Romanesque vaulting in the XI century. Further developments created a structural system of using ribs to form a complete organic supporting skeleton thus becoming one of the basic principles of perfected Gothic architecture.

The pointed arch, which was dominant in medieval architecture from the XIII century onward, helped to overcome the difficulties of vaulting oblong compartments exclusively with semicircular sections, as in Roman and Romanesque architecture, and to bring the various ribs of unequal spans to a crown at the same height, Fig. 11. The use of ribs led to increasing complexity in the development of vault forms. The ribs were carried down to the floor as shafts attached to the walls and piers transforming these walls and piers into a glass filled exposed skeleton of arches, columns, and flying buttresses.

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The result was an entirely new structural system in which structure, construction and visually expressive architectural forms were integrated into a new aesthetic, thus producing the Gothic-skeletal system of construction. Refer, for example, to Fig. 7, Fig. 8e, and Fig.11 to appreciate this development.

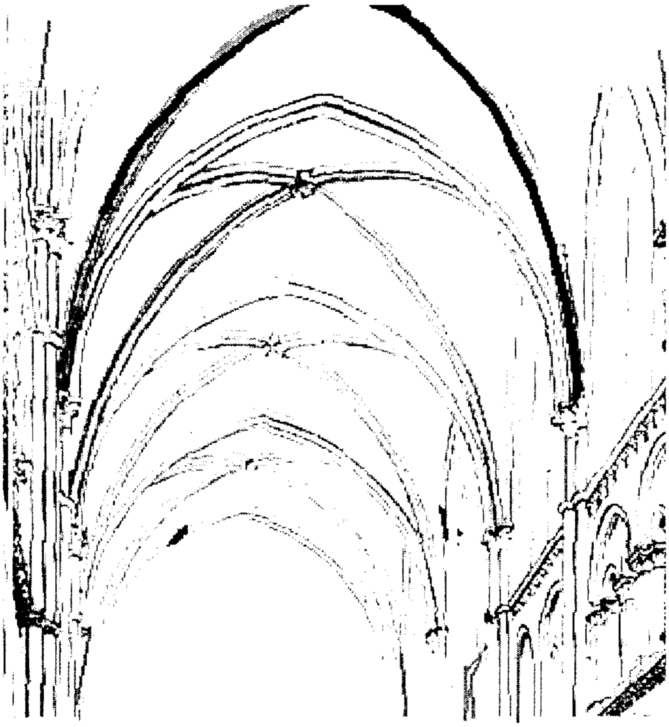

Figure 11: Ribbed Vault

3 Conclusion

The evolution of architectural forms has been dependent upon the development of building components whose basic function is to support loads (post-and-lintel system) and those elements that perform a spanning function (vaulting system).

The post-and-lintel system is limited by the strength of the crossbeam spanning the space between any two columns, and being linear in nature, also restrict additional geometric developments in architectural forms.

Vaulting systems, on the other hand, could be erected over vast spaces creating a diverse dimensionality of space allowing for more complex and varied architectural forms, thus producing impressive and monumental structures. It is this development of curved-shaped structures that is in effect determinant in the continuous evolution of architectural forms.

The development of curved-shaped structural masonry, progressing through the evolution of the vault, brought about significant changes in architectural form and in the structural system of historic buildings. From the invention of the barrel vault to the gradual evolution of (groined) cross -vaulted structures and then, to the creation of the more elaborate ribbed vaulted structures of the Gothic period; vaulting developed in such a mature way so as to control and thus define the architectural forms and structural patterns of construction.

Ribbed vaulting delineated and controlled the Gothic architectural and structural skeletal system of the entire building. All of this structural scheme; consisting of pointed arches, ribs and shafts, piers and buttresses; was designed to support and maintain the stability of the vault. It is then the vaulting system of construction that ultimately produces, and determines the architectural form and structural characteristics of most great historic buildings. This is best exemplified by the Gothic- skeletal system because it is in Gothic that the stone material, function of the elements and the structural behavior of masonry are encountered in their most critical form.

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