LOAD-BEARING STRUCTURE, ENCLOSING FORM AND SPATIAL INTERPENETRATION: ON TECTONIC CONSTRUCTION AND ITS RELATION TO THE BUILDING OF SPACE

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Tectonics and philosophy: Architectonics

As space and spatial design became the new paradigm of architectural theory at the turn of the twentieth century, tectonics disappeared as an architectural-aesthetic concept. Since its rediscovery, tectonics has been discussed as if it were detached from the design of space, rather than in relation to it. Quite admittedly, it is not self-evident to relate tectonics to space and spatial design. In thinking about tectonics, we think initially about matter, not space; we are concerned with its physical structure and not its spatial shape and configuration. However, we can relate tectonics to spatial design, especially if we understand 'tectonics' as tectonic construction, and construction as a means of spatial design. In undertaking just such an analysis, the paper explores the meaning of tectonics for the making of space.

'Tectonics' as Tectonic Construction

Concerning the understanding of tectonics, Eduard F. Sekler argued:

When a structural concept has found its implementation through construction, the visual result will affect us through certain expressive qualities, which clearly have something to do with the play of forces and corresponding arrangement of parts in the building, yet cannot be described in terms of construction and structure alone. For these qualities, which are expressive of a relation of form and forces, the term tectonic should be reserved (1965: 89).

Similarly, in the contemporary discourse, i.e. since the late 20th century, tectonics is conceived generally as an architectural realm dealing with the aesthetic expression of material, structure and construction in the architectonic built form. For example, Fritz Neumeyer argues that the core of the concept of tectonics:

refers to the mystic relationship between the quality of the joining and the visible expression of things and affects the correlation between the order of a built and the structure of our perception (1993: 55).

Although both definitions describe tectonics in relation to structure and construction, they tend to locate the essence of tectonics in the realm of aesthetic expression.

However, as soon as we regard 'tectonics' as tectonic construction, tectonics is not first and foremost the aesthetic expression of a structural concept and its construction. Construction and structural concept themselves become tectonic. Hence, tectonics is conceived as both the structure's identity, as well as its aesthetic representation; it is the material basis, as well as its ideal expression and perception.

Referring to Gottfried Semper and his understanding of tectonics, Kenneth Frampton's (1995) theory of 'Tectonic Culture', contains a reference to 'tectonics' as tectonic construction. Tectonics is discussed as both the poetics of construction, and as a specific mode of construction: the tectonic frame. Following the theory of Semper, and by discussing it as part of cultural practice and as a means of its representation, Frampton focuses also on the aspect of its aesthetic expression.

Without wishing to question the aspect of poetic expression and the understanding of tectonic construction as part of a cultural practice, the present paper attempts to relate tectonic construction to spatial design by focusing on its structural identity. Here, spatial design is confined to the building of space, that is to say, to the part of spatial design that comprises the immediate shaping and structuring of space. Accordingly, the paper makes, with regard to tectonic construction, indeed reference to Gottfried Semper, but draws primarily on the theory of Karl Bötticher (1852).

After an explanation of the term tectonic construction, the paper follows an architecture-theoretical conception, which has strongly influenced the understanding of the relation of tectonic construction and the building of space: the contradistinction between bearing and enclosing, formulated already in Hegel's ([1842] 1984: 55-56) distinction between column and wall as a respectively bearing and enclosing element.

In twentieth century, enclosing remained a central aspect of the building of space. Yet, it was discussed rather in relation to the other central concept concerning space and spatial design: spatial interpenetration.

Based on this and with a reference to the socio-spatial understanding of space as place, the paper argues in favor for the understanding of the building of space as a synthesis of enclosing and interpenetration. Such synthesis allows to relate tectonic construction to the building of space in an immediate way, resulting in an interplay of load-bearing structure,

enclosing form and spatial interpenetration.
With the focus on the space-building quality of the respective tectonic construction, this conception is illustrated by an analysis of three different principles of tectonic construction: the modern skeleton frame, grid tube constructions, both from steel or reinforced concrete, and the, so to say, pre-modern 'tectonic wall' of stone.

Tectonic Construction
What distinguishes a structural concept and a construction as being tectonic? As a concept of archeological and aesthetic theory, tectonics refers to structure in two different ways. First, it refers to structure in its general understanding of system and order. Essentially, though, it references structure as constructional structure. In this sense, it relates to a system and order of a structural concept that deals with the static interaction of load and support under the conditions of interrelated working forces such as gravity and thrust. Also in relation to construction, tectonics makes reference to the sense of system and order and, in difference to structure, to the

1: The big mosque

sense of joining, and thus to the field of physical production. Though any material construction is exposed to the static interaction of load and support, a tectonic construction is the articulation of it. It articulates it by arranging the support of load and the corresponding working forces in a systematic way. A tectonic construction is therefore characterized as being differentiated and being distinguished from the building as a whole of load-bearing and non-bearing elements. Without any differentiation a visual expression of a structural, thus tectonic concept does not exist, as in the case of a monolithic wall. Correspondingly, any tectonic construction tends to be a skeletal construction. Here, the skeleton as an entirely independent load-bearing structure is the extreme. Likewise, a cross vault is a tectonic construction.

As such, tectonics was discussed in the archeological and aesthetic theory of the 19th century. In particular the architect and theoretician Karl Bötticher (1852) linked tectonics to structure, as well as to a skeletal mode of construction. In his well-known scheme of core form and art form ("*Kernform*" and "*Kunstform*"), the former is the physical manifestation of a tectonic concept that finds its artistic implementation in the tectonic art form. Werner Oechslin points out, that in Bötticher's idea *"inner coherence and truth were regarded as a yardstick for a complete architectural concept"* (1994: 53). He emphasizes that Bötticher was concerned with the mutual relation of core- and artistic form, in the sense of an organic connection or entity of content and form. Bötticher conceived the core form as a built of limbs ("Gliederbau"), and it was realized in two ways: as a whole of a system of various structural elements, and as the joining ("Junktur") between these elements. Concerning the skeletal character of the "*Gliederbau*", for Bötticher its archetype was the pavilion roof

2: Settlement, Rio Santa Cruz

construction, representing *"the pure existence of the concept of a free structure."*
For Gottfried Semper (1851, 1860-63), tectonic construction was a craftwork rather than a structural concept and its artistic implementation. Although he discussed tectonics not in terms of a structural concept, for him tectonics was also bound up with a skeletal mode of construction. According to Semper, such construction developed as a specific handicraft and by the application of the material wood. In the course of an evolution of the cultural practice of building - and as one of its four basic elements, out of which this practice has been developed - the pre-architectural tectonic craftwork found its application in architecture, and at a certain stage of this application, it found its architecture-aesthetic sublimation: based on the principle of dressing ("*Bekleidungsprinzip*") that Semper conceived as the general basis of the cultural praxis of building, tectonic construction found this sublimation in the symbol-like integration, in the, so to say, dressing art form.
Concerning Bötticher's scheme of core form and art form, we could argue that Semper did not understand core form and art form as an aesthetic system of content and form. The art form itself was for him the real and only constitutive element of architectural aesthetics; the so to speak aesthetic content, as such. As a constructional system, tectonics remained for him outside the realm of aesthetics.
Herewith, he separated the architecture-aesthetic quality of tectonics from the physical level of structure and construction. In the subsequent art-theoretical discourse on architecture, tectonics and construction became more and more separated. For Heinrich Wölfflin (1886), as well as August Schmarsow (1894, 1905), tectonics already meant tectonic shapes. Schmarsow, who was first to define the essence of architecture as the art of spatial design, even had the opinion that we are the happiest in our homes: *"when we are not bothered with the question of stability and a real conflict of load and support"* (1905: 164). Finally, he questioned the value of

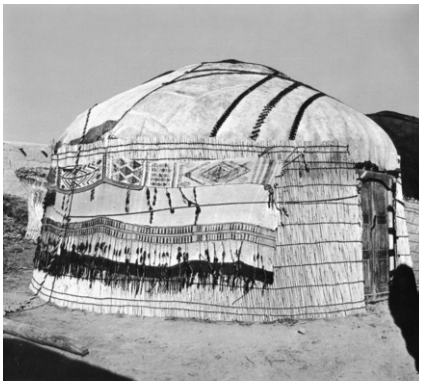
tectonics as a fundamental term for aesthetic theory, at all. Accordingly, tectonics disappeared from the stage of modern architectural theory, in terms of tectonic construction but also as a basic architecture-aesthetic concept (Bornbein, 1982: 100).

Tectonic Construction and the Building of Space
As explained above, any tectonic construction tends to be a skeletal construction. Also concerning the building of space, the contradistinction between the skeletal construction and the built form tends to result in at least a relative differentiation of the tectonic construction from the built form, which forms the space-building entity as a whole of load-bearing and non-bearing elements. But how can tectonic constructions be related to the building of space?

Interestingly enough, already Bötticher (1852) and Semper (1860-63) discussed tectonic construction in relation to the building of space. For Bötticher the origin of a structural, thus tectonic, principle lay in the way it covers a space. Here, he distinguished between two basic possibilities: the horizontal and trabeated roof or floor construction and the curved vault construction. The first results in the tectonic construction of beams and columns, representing the structural system of vertical support of the horizontal load. It finds its aesthetic perfection in the Doric temple. (see illustration 8)
The second possibility results in the tectonic construction of cross vault and buttress, representing the structural system of the vertical and horizontal support of thrust producing loads. It finds its aesthetic perfection in the Gothic cathedral. (see illustration 9)
As Bötticher related tectonic construction to the covering of space, he opposed it to its enclosing. Here, he followed Hegels mentioned distinction between the wall as a primary space enclosing and the column as an exclusively load-bearing element.

Semper made also such a distinction, though without referring to Hegel's aesthetic theory, but rather arguing from a materialistic point of view. Different to Bötticher, he did not make a distinction between enclosing and covering. Semper, as later Berlage ([1904] 1991:51-79), referred to the building of space in the general understanding of spatial enclosing. Within his classification of four basic crafts, he related the building of space exclusively to the textile, i.e. to the woven and 2-dimensional enclosure of space. He argued that the building of space began with a woven separation of the home from the outer life:
Scaffolds that served to hold, secure, or support this spatial enclosure had nothing directly to do with space or the division of space.... They were used for fortification and defense, for ensuring a durable enclosure, or for supporting the spatial enclosure above them, as well as for supplies or other loads - in short, for reason foreign to the original idea, namely that of enclosing space.
Semper conceived textile as the original architectural element, not only in terms of material culture and its visual representation, but also in terms of the building of space. For him, the textile shapes space by its screen-like enclosure and its definition as a place within the surrounding space.

Semper opposed tectonic construction, and construction in general to the building of space, at a time when the paradigm of architecture focusing on the design of space still had to be developed. As long as designing of space was still first and foremost understood as the enclosing of space, it was developed by following Semper's opposition between space and construction. Adolf Loos (1898) also agreed explicitly with Semper's principle of dressing in separation from a mere technical understanding of construction:
The task of an architect is to create a warm and homelike space.


3: Turkmen house, North of Afganistan

Carpets are warm and homelike. Therefore, he decides to unfold a carpet on the floor and to hang up four, in order to build the walls. But it is not possible to build a house with carpets alone. Both the carpet on the floor and the tapestrys need a constrcutional scaffold that keeps them in the right position. To invent this scaffold is the second task of an architect. ([1898] 1962: 105)

In his publication "Building in France, Building in Iron, Building in Ferroconcrete", Siegfried Giedion (1928) connected construction with spatial design in an immediate way. But consequently he connected construction not with the enclosing of space but with its opposition, namely spatial interpenetration. In difference to other contemporaries of the modern movement, also focusing on space in terms of spatial interpenetration, including the connection of space with movement and a corresponding fourth dimension, Giedion connected this conception of space with an rather programmatic understandning of architecture as a societal and socio-economic practice, including the conrete developments in the field of construction. He recognized spatial interpenetration as an aesthetic phenomenon of modern architecture, beginning with the lightweight and filigree iron constructions of the nineteenth century and finding its architectural culmination in the application on the modern housing production, especially in the reinforced concrete architecture of Le Corbusier.
Like no one before him," Giedion argues, "Corbusier had the ability to make resonate the ferroconcrete skeleton... Out of the possibility of hanging the whole weight of a building on a few ferroconcrete pillars, of omitting the enclosing wall wherever one so desires, Corbusier created the eternally open house.... Cubes of air within, cubes of air without... Corbusier's houses are neither spatial nor plastic: air flows through them! Air becomes a constituent factor! Neither space nor plastic form counts, only RELATION and INTERPENETRATION. There is only a single, indivisible space. The shells fall away between interior and exterior. ([1928] 1995: 168-69)

Building of space: between enclosing and interpenetration
In the architectural theory of the second half of the twenthieth century building of space was still identified with the enclosing of space. As Bruno Zevi put it:„Architecture, however, is like a big hollow shape, in whose interior man enters, in which he stays and moves." (Zevi 1957 in Boudon 1991: 27). Yet, as a result of the modernist idea of space, spatial enclosing was discussed also in relation to the outside space (Zevi 1957, van der Laan [1977] 2003) and explicitly in terms of spatial interpenetration (Giedion 1969).
Parallel, space has increasingly been discussed in terms of its social and cultural meaning. In this respect, it has been connected to the concept of place, representing the idea of meaningfull space (Martin Heidegger 1951, Aldo van Eyck 1960, Norberg-Schulz 1980, Kenneth Frampton [1981]

2002, Herman Hertzberger 1991). In Heidegger's conception of space, which is essential for the general dicussion of place as it has taken place in postmodern architectural theory, a place is defined by limiting and distinguishing it from the mere geometrical continuum of space. Just thereby, it gains its meaning.

Christian Norberg-Schulz connects this concept of place explicitly with the enclosing of space:
Whereas landscapes are distinguished by a varied, but basically continous extension, settlements are enclosed entities. (...) Any enclosing is defined by a boundary (...) The enclosing properties of a boundary are determined by its openings, as was poetically intuited by Trakl when using the images of window, door and treshold. In general the boundary, and in particular the wall, makes the spatial structure visible as continuous or discontinuous extension, direction and rhythm (1980:12-13)
Although Norberg-Schulz conceives a place as being opened to the space around, its spatial, thus socio-spatial identity he defines rather in contrast to spatial extension than in interrelation to it.

Opposed to this, we can argue that any limiting and distinguishing of space as place exist just in relation to the continuum of space, from which it has been distinguished. In this sense, to the identity of any place belongs also its relation to the continuum of space, as to it belong the relation to other places.

Building of Space as Interplay of Load-bearing Structure, Enclosing Form and Spatial Interpenetration
On the basis of this architecture-theoretical conception of space and place, building of space can also not be discussed merely in terms of spatial enclosing. On the one side, it is bound up with the necessity of spatial separation with a plane enclosing and covering of space. In this respect, the enclosing of space refers to the concept of place. But on the other side, and in order to create a socio-spatial quality, any built space should be connected to the outside space. In this respect the opening of the enclosing form and the corresponding interpenetration of inside and outside space refers to the connection of the place with the continuum of space, as well as with other places. In this respect, we can conceive the building of space only as a synthesis or interrelation of both spatial enclosure and spatial interpenetration.

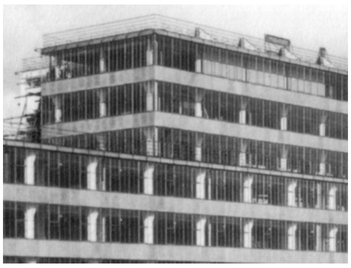
As soon as we understand the building of space as such a synthesis of enclosure and interpenetration, tectonic construction can also be related to the enclosing of space. By so doing, the synthesis of enclosure and interpenetration becomes an interplay of tectonic construction, enclosing form and spatial interpenetration.
But what is the specific space-building quality of tectonic constrcution within this interplay?

Though Giedion (1928) discussed tectonic construction without to conceive it in terms of tectonics - sinds his focus was that of the surmounting of materiality instead of its representation - he described a specific space-building potential of tectonic construction. It lies in the ability to enable the opening of the enclosing form and to enable a spatial interpenetration of the separated spaces. This specific potential is the consequence of the systematic arrangement of the support of load and the corresponding working forces and the skeletal configuration of tectonic constructions.
Their actual space-building quality is determined by the transformation of this space-building potential. How this transformation takes place, and is implemented in different ways and with different results, poses the core of the following analysises.

Thereby, the respective space-building quality of the three principles of tectonic construction I explore in two ways: Firstly, is the skeletal structure differentiated from or integrated into the space enclosing and covering form? Secondly, in which way does it take part in the implementation and expression of the opening of the enclosing form and the spatial interpenetration? Here, the correlation between the aspects of bearing, enclosure and interpenetration, and the three dimensions of space -height, width and depth - are of central importance. In order to simplify matters, I confine myself to horizontal interpenetration between the inside and outside space of a building.

Three Principles of Tectonic Construction
On the basis of well-known buildings, all three principles represent a distinct implementation and expression of the space building quality of the respective tectonic construction principle. These include the skeleton frame of steel reinforced concrete, grid (geodetic) constructions of the same materials in the shape of tubes, and the 'tectonic wall' of stone.
The Skeleton Frame

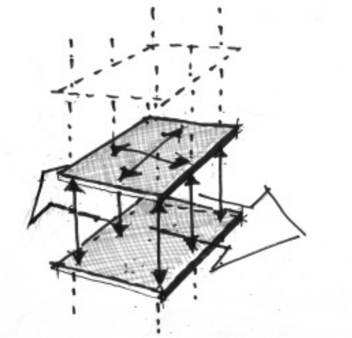
4: Musée des Traveaux Publics



5: Van Nelle Factory

The skeleton frame is bound up with the paradigm of structure and skin and the idea of the *plan libre*. In contrast to the massive wall of stone or bricks, the skeleton frame has allowed previously unknown flexibility in the design of built space and form. As being expressed in Le Corbusier's scheme of the Domino house, the load-bearing construction is, in principle, completely separated from the space-enclosing form or skin. The design of the facades has become entirely free, up to a completely glazed envelope. The reduction of the bearing structure to a set of columns and beams with large distances in-between allows a far-reaching free arrangement of the inside spaces, both in horizontal, as well as in vertical direction.

Due to a twofold dualism, the skeleton frame is, so to speak, the maximal possible distinction between a tectonic construction and a space building form: on the one side a 3-dimensional bearing structure of linear elements, and on the other side 2-dimensional non-bearing planes, enclosing in the shape of vertical facades and covering in the shape of horizontal slabs. As long as it stays respectively outside or inside of the vertical planes of the outer skin, the bearing construction remains in an absolute dualism to the enclosing of space. This changes as soon as the skeleton frame is directly connected to or even integrated into the space-enclosing form. In the shape of a stabilizing and spatial matrix it gains a certain space building quality, which remains however rather marginal, depending on the spatial distance inbetween the skeleton's limbs and the corresponding filegree appearance of the tectonic frame.



6: Scheme Skeleton Frame

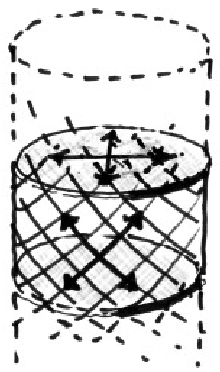
The essential relation to the building of space lies rather in the function of supporting the covering slab or roof. Here, it is principally opposed to them in spatial direction - vertical support versus horizontal covering above and horizontal separation below. The result is a rather indirect relation to the space-covering element. This contrast also does not change in the case that the beams are visible and function as a connecting element between the vertical bearing structure and the horizontally covered space. The predominant relation remains that of horizontal covering and vertical support.
Concerning the interrelation between covering and interpenetration, the plane of covering is parallel to the orientation of interpenetration. In connection with its filigree appearance, the essential aesthetic quality of the skeleton frame is therefore, that of absolute openness and horizontal spatial interpenetration.

7: Prado Epicenter Store

8: Swiss Re HQ St MaryAxe

Grid Tube Construction
With a grid tube construction the load-bearing capacity of steel and reinforced concrete in relation to structure and skin has been realized in an opposite way: the tectonic construction is not detached from the space-enclosing form. In contrast, the skin itself is changed into a skeletal structure. In terms of design, the tectonic structures exposes itself, as a aesthetic synthesis of both bearing structure and ornament of the skin. As Axel Sowa puts it:
As with basketry, their structure is both support and surface. Their beautiful visible sceletons meet both their static and aesthetic requirements. These high-performance coverings are also load-bearing structures as much as visual ones; that enliven and decorate their external surface: the facades (2007)
The term grid construction comprises a lot of different types of grids: geodetic or not in structure, dome, shell or tube in shape. In recent years, grid constructions are integrated in so-called morphological or morphogenetic design strategies (Testa: 2002; Hensel, Weinstock, Menges, 2004) In order to simplify matters and to facilitate the comparison of the three modes of tectonic construction, I confine myself to grid tube constructions.

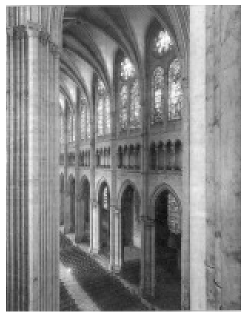
Such grid construction differs from the skeleton frame in two ways. First, it is characterized by an absolute integration of the bearing structure into the space-enclosing form. But, it is not simply integrated into it. Depending on the density and masiveness of the grid, the grid itself shapes and represents the space building envelope, culminating in a fabric-like character and a corresponding screen-like appearance of the grid. Such textile character is the second difference.
In terms of its static principle, the grid's tectonic structure is characterised by at least two, each other neutralizing, vectors that span up the space enclosing fabric. By so doing, the correlation between tectonic construction and the vertical axis of gravitation is disintegrated. The result is an absolute synthesis of bearing structure and space-enclosing. form. The grid supports as a fabric. Therefore, the predominant expression of a grid construction, not only in the shape of a tube, is always the expression of enclosure, however open it may be.



9: Scheme Grid Tube Construction

'Tectonic Wall'

10: Doric temple

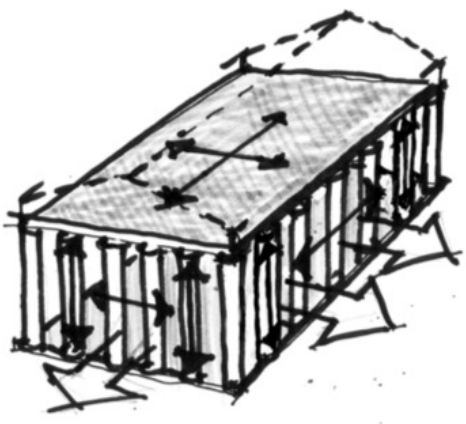


11: Gothic Cathedral

The third principle, with which I want to describe the space-building quality of tectonic construction, is the 'tectonic wall' of stone. By introducing this term I refer to the German term Mauer as it was defined by the theorist of art Max Raphael ([1934] 1976). Refering to ancient Greek, Romanic and Gothic stone architecture, Raphael defines the Mauer in contradistinction to the Wand, that represent for him a monolithic wall. As a result of a historical process, so Raphael's argumentation, the Mauer represents a joining of structural elements. Subsequently, this technique of joining results in a differentiation between load bearing and non-bearing, thus supported elements, naturally connected to the structuring of the built form in open and closed parts. Additionally, this differentiation

is architecturally realised as an articulated differentiation of the bearing structure from the enclosing form. Thus, Raphael conceives, in contrast to Hegel, the Mauer as a space-building construction principle, in which the differentiation between bearing and enclosing remains a relative differentiation.
In this sense, I refer to Raphael's concept of the Mauer as a ‚tectonic wall', representing the articulation of a skeletal structure of stone, as it is to be found in the structural principle of beam and column in a Doric temple, as well as in the shape of cross vault and buttress of a Gothic chathedral.

Similar to grid constructions also the "tectonic wall" poses a synthesis of bearing structure and space enclosing form, Similar to the skeleton frame, it still has one load-bearing tectonic axis, that of the vertical axis of gravitation. Accordingly, the identity of bearing and enclosing is not as absolute as in the case of the grid. The columns of a Doric temple, for example, support the roof construction, and they enclose the space between the cella and themselves. Similar to grid tube constructions, they are at one and the same time bearing and enclosing. In its spatial direction, however, the function of bearing remains perpendicular to the function of enclosing: vertical versus horizontal.
Since the enclosing shape is a horizontal row of vertical columns, it also gets opened in a vertical, thus to the spatial enclosing perpendicular direction. Therefore, the row of columns encloses and opens the surrounded space, at one and the same time. Here, the proportion between the diameter and circumference of the columns, on the one hand, and their distance to each other, on the other, determines the balance between enclosing and opening.



12: Scheme Tectonic Wall

The "tectonic wall" of a gothic cathedral is also characterized by a synthesis of bearing and enclosing in one plane and the simultaneous distinction in two perpendicular directions: vertical support and horizontal enclosure. In this respect, the perpendicular to the nave positioned buttresses form a vertical element, too.
Also the opening of the in horizontal direction-enclosing wall is vertical. Due to the glass painting, the corresponding spatial interpenetration between inside and outside is not to perceive. The outside space remains an ideal space, represented by the illuminated paintings on the glass. But with regard to the connection between the different naves it is clearly to perceive.

Conclusions
As a result of the given analysis, we can conclude that the interplay of load-bearing structure, enclosing form and spatial interpenetration is designed in different ways, and that it is always also constructionally designed: the skeleton frame allows openess without to enclose, and by so doing, without to immediately build space. As a mixture of a tectonic and a textile construction, grid constructions enclose the space with an open structure. As a change from a stereotomic into a tectonic construction, the tectonic wall opens the enclosing form, tectonically.

In this context, it seems to me very interesting to think about principle relations between the spatial structure of construction and the structure of space. By refering to Semper, Schmarsow (1894) was the first connecting the three dimensions of space with the perception of proportion, symmetry and rythm. In a similar way, we can connect the dimensions of space to the aspect of bearing, enclosing and interpenetration. The way how tectonic construction acts in relation to this, seems to me one determing aspect of its space-building quality.

The paper discussed tectonic construction as a means of spatial design, respectively as a means of the building of space. As such a mean, tectonics gains another architecture-aesthetic quality, next to the aesthetic expression of structure and construction.

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Illustrations

Illustration 1: The Big Mosque (Narthex), Kairuan, Tunisia, 800-836, in John Hoag Islamische Architektur, 1976, p.71.
Illustration 2:Settlement, Rio Santa Cruz, Patagonia, Argentina, in Enrico Guidoni Architektur der primitiven Kulturen, 1976, p.41.
Illustration 3: Turkmen house, North of Afganistan, in Enrico Guidoni Architektur der primitiven Kulturen, 1976, p.77.
Illustration 4: Musée des Traveaux Publics, Auguste Perret, Paris 1936-37, in Kenneth Frampton Studies in Tectonic Cultures, 1995, p. 148.
Illustration 5: Van Nelle Factory, Brinkman en Van der Vlugt, Rotterdam 1931, in Hubert-Jan Henket & Hilde Heynen (eds.), 2002, p.43.
Illustration 6: Scheme Skeleton Frame
Illustration 7: Prada Epicenter Store, Herzog and De Meuron, Tokyo, 2001, in Andreas Deplazes (ed.) Constructing Architectures Materials Processes Structures, 2005, p.119.
Illustration 8: Swiss Re HQ St Mary Axe, Foster & partners, London 1997-2004, in www.archinforum.net (4th Nov 2007)
Illustration 9: Scheme Grid Tube Construction
Illustration 10: Doric temple, Segesta, Italy, 570-560 B.C., in S. Lloyed et.al. Architektur der frühen Hochkulturen, 1975, 340
Illustration 11: Gothic Cathedral, Chartres, France, 12th century, in Angus J MacDonald Structures & Architectures, 2001, p.23.
Illustration 12: Scheme Tectonic Wall