The Engineer’s Aesthetics – Interrelations between Structural Engineering, Architecture and Art

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ABSTRACT: Engineering structures are said to represent a specific aesthetics based on principles such as material efficiency and flow of forces. This paper wants to take a closer look at this aesthetics. By the examples of steel and concrete bridges, it aims at tracing back its origins and by taking into account also examples from other disciplines it wants to reveal interrelations between structural engineering, architecture and art. Besides showing how profoundly these disciplines were influenced by what was and still is called the “engineer’s aesthetics”, this paper also wants to raise the question, if and in how far current proclamations of this aesthetics seem reasonable.

INTRODUCTION

In his manifesto Towards a New Architecture (first published in 1923) Le Corbusier opened the first chapter by stating: “The Engineer, inspired by law of Economy and governed by mathematical calculation, puts us in accord with universal law. He achieves harmony.” (Le Corbusier 1946, pp. 7, 16) A few pages further, he continues: “The engineer therefore has his own aesthetic, for he must, in making his calculations, qualify some of the terms of his equation; and there it is that taste intervenes.” (p. 19). Until today, there is general agreement that in contrast to traditional architecture the engineer’s aesthetics is characterised by a calculated optimum utilisation of materials as well as by the illustration of the flow of forces within the structures (e.g. Leonhard 1982, Menn 2003, pp. ix, 67f, Bühler 2004). Regarding the conception of engineering structures three factors are to be identified: Technical and scientific basis, construction technology, shaping and design.

In order to increase the social recognition of their professional discipline, engineers in recent years have claimed a far-reaching cultural influence of this aesthetics and have placed it on one level with art and architecture (Lorenz 2007, p. 162). In this context, however, certain questions have hardly ever been raised: Where and when did the idea of an engineer’s aesthetics originate? What did it imply in the past and what does it imply today?

The disciplines that are called for, when questions of aesthetics and cultural significance are raised – art history and cultural history – have so far broadly neglected such questions as a promising field of study. By tracing back the concept of the “engineer’s aesthetics” this paper, written by an art historian and a structural engineer, wants to make a first attempt towards the topic. With the help of examples of bridges and works of art it wants to point out circumstances under which the idea of this aesthetics came up, how it became popular amongst architects and artists and that – due to the technical development, to fashions in forms and materials as well as to a changing status of engineering structures – throughout the 20th century it was subject to a shift of focus and to successive changes, respectively.

BETWEEN TRADITION AND MODERNITY

As is well known, the industrial revolution resulted in fundamental novelties in almost any field of social life. In the building sector industrially produced materials (iron, steel and concrete) became predominant, new pro-
duction methods (mass production and on-site assembly) were applied, new building tasks were to be fulfilled (e.g. railways and appropriate stations, bridges, tunnels) and the academic discipline of the sector was split up into the traditional branch of architecture and the new, primarily technically based branch of civil engineering (Straub 1992, pp. 16–17, Heymann pp. 42ff). Parallel to this, another shift became apparent: The newly erected buildings along with their constructors became subject of highest scientific, artistic and also public attention. In magazines such as The Builder (founded in 1843) they were discussed as representatives of the progressive industry and new technologies, in poetry they were praised, in works of fine art their aesthetic and cultural impact was visualised. This significance of the new structures was also demonstrated at the buildings themselves, where a whole range of aesthetic means, which were sure to be understood by anybody, evoked venerable traditions (Segeberg 1987, p. 119): Being expensive and time-consuming, however, these means (e.g. forms, attributes and architectural quotes) (Fig. 1), sometimes clashed with the ever more pressing requirement of reduced costs and building time – an invention of the 19th century (Peters 1981) – as well as with the wish to openly demonstrate the technical qualities of the gigantic structures.

An example of this ‘clash’ is the Brooklyn Bridge, at the opening on the 24th of May 1883 the biggest building on the American continent and longest suspension bridge in the world. As shown in Fig. 2, already from a distance its granite pylons announced a bridge of sheer incredible size. As distinct from buildings like the brick-built Britannia Bridge (Fig. 1) the Brooklyn Bridge openly demonstrated the technical achievements of its constructors Johann and Washington A. Roebling, who with the help of newly developed steel cables, had managed to span the immense length of 487 m and reached a total length of 1 833 m. The gigantic suspension bridge demonstrated an unparalleled technological achievement. In addition, it incorporated a remarkable municipal consensus between New York and Brooklyn, until then two politically, culturally and socially separated cities. “After the ravages of the Civil War, the dislocations of the troubled post-war economy, the political malfeasance of Tammany Hall, the conflicts occasioned by new mass immigration, the bridge seemed to unite the two cities’ diverse people and heal their open wounds.” (Haw 2005, p. 15).

With its amazing size and high cultural significance the Brooklyn Bridge, however, pointed even beyond itself and the general connotation of bridges as “the architecture of connection” (Blakstad 2002). It also represented the significance bridges gained in the 19th century as symbols of the new mobility and finally the widespread hopes in a technically based future. Newspaper articles on the opening day, when 1 800 vehicles and 150 300 people passed the bridge, give an impression of this significance: “This splendid structure thrown across the river”, wrote the Brooklyn Daily Eagle, “is not only good in itself but a sure promise of immeasurably greater good to come.” (Haw 2005, p. 15).

The cultural significance of the Brooklyn Bridge, gained from both its technical and social achievements function, is clearly expressed by its aesthetic means. The massive stone pylons, which support the strong steel cables, have pointed arches. Together with the rhythmic both vertical and translucent bracing of the cables they evoke the tradition of a gothic cathedral. The Russian poet Vladimir Majakowski beautifully described this in a poem from 1925 (Blackstad 2002, p. 91). An equally high cultural claim is evoked by the pylons’ material: granite, a type of stone that due to its durability since early Egyptian dynasties and then particularly in the 19th century was favoured for representative monuments (Fuhrmeister 2002, pp. 126f). In the context of the bridge, the granite, thus, functions in both technical and cultural terms. In retrospect, the Brooklyn Bridge marks a transition; with its somehow bizarre juxtaposition of the massive granite pylons and a transparent steel construction, it leads from traditional architectural concepts towards a new, so called engineer’s aesthetics – which was first critically discussed, but soon celebrated as the only acceptable aesthetics of modern times.
DEMONSTRATING TECHNICALITY

In contrast to the Brooklyn Bridge, which still referred to and relied on familiar architectural concepts, other bridges of the time already demonstrated this radically new aesthetics. Examples of this are the collapsed Firth of Forth Bridge as well as constructions by the French engineer Gustave Eiffel. Although structures like the Maria-Pia-Brücke (1875–77) and the Garabit Viaduct (1881–84) are based on one of the oldest bridge types (both are arch bridges), this type now appears as sheer construction.

The parabolic steel arches of the Garabit Viaduct (Fig. 3) demonstrate the structure's technical nature. It has no cladding; instead, even in the smallest detail it shows the exactness of its industrial production and on-site assembly (Fig. 4). In addition to functioning as the load carrying structure, the steel components of the Garabit Viaduct represent the actual construction. This construction shows a new space-mass-relationship: The massive body of a stone bridge resolves into an 'air framing' steel skeleton, which rises above the riverbeds in an almost immaterial way. The technical character of the structure, thus, predominates the building both in respect to its construction and its aesthetic appearance. In this context, the technical achievement of the gigantic bridge along with its representation of modern technology is transformed into an aesthetic value: the aesthetic value of sublimity, which is described in contemporary reports of this bridge and similar structures (Segeberg 1987, p. 147). Unlike Edmund Burke's 18th century concept of sublimity, however, in which nature itself suggests the sublime (Burke 1989), this effect is now evoked by the control of nature and its transformation into a manmade, triumphal and virtually horrific object of technology (Herding 2002, p. 11).

Whilst this aspect of the bridge and other structures of the 19th century was of central interest to contemporaries, it lost some of its importance in the following decades. To Le Corbusier, who in 1923 referred to the bridge as an outstanding example of the engineer's aesthetics (Fig. 4), production, form and the social connotation of this aesthetics were of far more interest. The Swiss art historian Siegfried Giedion, another leading figure in the propaganda of the engineer's aesthetics, simply wrote that "a likewise grand expression of floating balance" was never surpassed in bridge building (Giedion 1992, first published in 1941, p. 196).

In spite of this fascination, the structures from the very beginning also aroused harsh criticism (Döhmer 1976, p. 112ff, Segeberg 1987, p. 133). Comments in the vivant discussion amongst engineers, architects, theorists and laymen involved scepticism on the side of Karl Bötticher (Wömer 1979, p. 75), Gottfried Semper (Semper 1884, p. 485, Quitzsch 1997, p. 178ff) and later Eugène Viollet-le-Duc (Pevsner 1969, pp. 16ff) up to damning criticism by John Ruskin (Ruskin 1894, p. 102; also Fritsch 1890, p. 23ff). To their mind the new structures appeared too technical, too cool, crude and quasi dead. Their typical filigree character was accused of being invisible, hardly inspiring confidence and by no means offering an aesthetic value. These accuses resulted in the conviction that the more technically optimised the less pleasing to the eye the construction would be:

Until today, wrote the publicist Heinrich Pudor in 1902, iron architecture is solely of technical, mechanical nature. [...] If in stone architecture we only find architectural knowledge and use obsolete style forms, in iron architecture we do not even try to apply the laws of art. There the art-knowledge rules, here the technical knowledge. (Pudor 1902, p. 1, translated by the authors)

Until the early 20th century, art historians and architectural theorists, even if in favour of the new structures, criticised their lack of artistic appeal (Meyer 1907, Muthesius 1913, Streiter 1913, pp. 110ff). However, they agreed that a revolutionary shift in architecture was taking place, a shift that – no matter how it was judged at the moment – would radically change the aesthetic values of their own and forthcoming times (Gurlitt 1899, p. 463). In fact, the adaptation of the new aesthetics soon turned out to be the only way to keep up with modernity. As Le Corbusier put it in 1923 when quoting from the Programme de l’Esprit Nouveau (1920): “Nobody nowadays denies the aesthetic which derives from modern industry’s creations.” (Le Corbusier 1946, p. 83)
TECHNICALITY AS A LEITMOTIV OF MODERN ARTS

By the 1920s the new aesthetics along with the vivid debate about it had also entered the arts. As a Leitmotive it shaped an intentional and deliberately modern aesthetics, of which the Deutsche Werkbund or the Bauhaus are prominent examples. Already in 1913 Walter Gropius declared:

"The new time demands its own sense: Exact forms, bare of any coincidence, clear contrasts, the organising of elements, the sequencing of similar parts and unity of form and colour will be the aesthetic qualifications of the modern architect in accordance with the energy and economy of our public life. (Gropius 1913, pp. 19f, translated by the authors)"

In Space, Time, Architecture, Siegfried Giedion gives plenty of examples for the transfer of such ideas into other fields of art. Many more could be mentioned, in particular amongst photographers, who like Albert Renger-Patzsch regarded their medium as a constructive one (Janzien 2001), and the Constructivists, who like Naum Gabo thoroughly discussed room-space relations in joined, almost immaterial sculptures (Fig. 8). The preconditions for this transfer of engineering methods and their constructive character into the arts were to a great extend of a visionary kind. With a view to scientific improvements as well as the tremendous development of new technologies the issue of a new world and a better future had become a matter of emphatic concern to modern artists. In this context, the engineer was held up as a shining example (Fig. 5). Jan Tschichold, co-founder of the so-called New Typography, for instance regarded the engineer as a new type of human being, who unquestionably called for a new design:

"Tradition is nowadays faced by those works, which, unloaded by the past, had a determining influence on primary occurrences, on the face of our time: automobile airplane telephone radio light advertising New York! These things designed with no consideration for aesthetic prejudices were created by a new type of human being: the engineer // The engineer is the designer of our age. Typical characteristics of his works: economy, precision, generation out of pure, constructive forms, which correspond with the function of the object. (Tschichold 1928, p. 11, translated by the authors)"

In accordance with the “new type” Tschichold developed a typography, which was predominantly based on norm and standards. A basic element or module reappears as the form-giving factor; norms were to be applied by the use of standardised DIN-formats for paper (Petri 2009, p. 44).

As for this standardised, technical aesthetics no predecessor within the arts could be made out, it was also regarded as the perfect counter part to bourgeois connoted fine art, architecture and literature. The engineer, thus, did not only become the prototype for aesthetic ideals but also for modern political utopias, which particularly influenced Russian Constructivism.

The most famous symbol of this movement is the extravagant tower, which the Russian artist Vladimir Tatlin designed between 1917 and 1920 (Fig. 6). The so-called Monument to the Third International, which – apart from a wooden model – was never realised, was supposed to be erected in Petrograd after the Bolshevik Revolution. With a height of 400 m the rotating steel-glass construction, which was planned to function as headquarter and monument of the Comintern, was supposed to surpass the great symbol of bourgeois modernity, the Eiffel Tower, by approx. 100 m (Schart 1995, p. 161, Hammer; Lodder 2000, pp. 86ff).

This reference to the Eiffel Tower and similar girder constructions at the same time perfectly fit into the Constructivists’ belief that in order to meet the revolutionary ‘Zeitgeist’ „the artist or, better, the creative designer should take his place alongside the scientist and engineer.” (Schart 1995, p. 161). The use of steel, though, was to imply more than this. With the metal representing the epitome of the industrial, constructive and utilitarian material, it was also intended to embody political aims. Its aesthetic use was meant to indicate the working
class and was, thus, regarded as a stupendous declaration of faith in a communist society. Such political connotations of the engineer’s aesthetics, were, of course, bound to the radical political changes in the first decades of the 20th century. Nowadays they are hardly common any more. The situation, however, is different if one looks at another characteristic aspect of the engineer’s aesthetics: the demand for truth to the material and the embodiment of the flow of forces.

FLOW OF FORCES AND TRUTH TO THE MATERIAL

Already Heinrich Pudor remarked that besides making visible the constructive and static laws, engineering structures should also obey to “the highest artistic law”: the development of forms out of the material’s inner character and the revealing of this character (including the inner flow of forces) (Pudor, 1902, p. 4). These criterions, which nowadays seem rather natural to engineers, entered the discipline in the early 20th century. Together with the demand for an efficient use of material, modern construction techniques and low costs they were particularly well embodied in bridges by the Swiss structural engineer Robert Maillart. A quite elaborate example is his Salignatoble Bridge from 1930 (Fig. 7), which has not forfeited its aesthetic and technical value until today (Sigrist 2006). In 1991 it was designated as an International Historic Civil Engineering Landmark by the American Society of Civil Engineers. The bridge has a total length of 133 m, crossing a valley with a three-hinged arch and a distance between the supports of 90 m. The arch has a box cross-section, firstly open and subsequently closed as the arch merges with the deck slab. The bridge carries a roadway with a width of 3.5 m that is supported on reinforced concrete walls.

Instead of treating the concrete as a substitute for stone, Maillart managed to make use of the material’s specific qualities. By refining his ideas for earlier projects, e.g. the Tavanasa-Bridge of 1904, Maillart created an entirely new structural system, which stood in contrast to the established notions of bridge engineering: The variable depth of arch reflects the profile of the bending moments due to traffic loads, unnecessary constructional elements of any kind are removed, and the possibilities of shaping forms made from concrete are perfectly used. By developing the form on the basis of the flow of forces (structural analysis and design) Maillart gave to concrete both new technical options and a new aesthetic appeal. Moreover, geometry, size and proportions of his bridges seem to be carefully chosen, proving that he put special care on these aspects (Maillart 1936 (reprint), p. 121).

Maillart gained wide recognition not only in the engineering society. However, in appraisals, his structures were often seen as mainly technical works, ignoring that the factors construction technology (including cost efficiency) and shaping equally influenced the conception (Gauvreau 2006). This perception highlights one of Maillart’s contributions to structural engineering: He developed a new and independent vocabulary of forms for concrete structures, which had emancipated from forms of traditional steel or timber structures. The predominating idea of creating forms that reflect the flow of forces is important until today; despite the fact that it guarantees material efficiency it conveys a plausible implicitness. This idea also demonstrates Maillart’s affiliation to the specific mentality-historical moment of the 1920s and 1930s. As Siegfried Giedion and the artist Max Bill, both admirers of Maillart’s work, pointed out, his structures are best compared with modern works of art (Fig. 8), in which material is transformed by the application of rational construction (Giedion 1992, pp. 194–297; Bill 1949, pp. 27–33). “The development of a sculpture”, Naum Gabo explained in 1937, “is dominated by its material. The material is the emotional basis of a sculpture; it gives the basic accent to it and sets the limits of its aesthetic effect.” (Trier 1999, p. 61, transl. by the authors)

Figure 7 (left): Robert Maillart, Salignatobel-Bridge, Switzerland; (Billington 1990, without p.)
Figure 8 (right): Naum Gabo, Construction in Space: Arch, 1937; (Hammer; Lodder 2000, p. 254)

At this point it shall be added that although common amongst modern artists and architects and still crucial for the engineer’s aesthetics, this conviction in the 20th century was by no means new. In fact, it goes back to the 19th century, when a discussion provoked by the technical revolution came up. This discussion was based on the desire for “truth” of expression, a value, which as a consequence of the increasing mass production and the circulation of new materials seemed to be in danger (Bandmann 1971, p. 140). The central point of the debate was the notion that architects and artists – despite all skillfulness – should only work within the frame set by the nature of the chosen material. This idea was articulated in the demand for openly shown, “true” and
“honest” materials and finally lead to the appeal that the inner character of a material should be awakened and increased by the artist (Raff 1994, p. 28). Subsumed under the term “truth to the material” (Bandmann 1971, p. 138) it became one of the leading principles of modern architecture and art (e.g. Wingler 1968, pp. 151f; Wagner 2001). Even if differently motivated, the underlying principles of Maillart’s structures find its direct equivalents in artistic concepts of the time and their materialisations in works of art and architecture.

VARIATIONS OF THE ENGINEER’S AESTHETICS

Throughout the 20th century, a lot of engineers enhanced the task of developing forms from structural analysis and design. If one looks at the bridges more carefully, however, it becomes obvious that they often also answered to fashions in forms and aesthetic preferences of their time. Due to the possibility of a rather flexible usage of concrete for instance bridges with organic forms were developed with the technical character of the structures being deliberately reduced. The Kennedy Bridge in Hamburg, erected in 1963 as a road-bridge above the Alster, is a good example of this (Fig. 9). Although built with respect to the principles of structural engineering it shows a strong affiliation to the form-vocabulary of the late 1950s, as for instance found in the well known kidney shaped tables of the time. This form makes the bridge appear like a bridging link between technology and nature instead of embodying a technical contrast to its surrounding.

Despite such formal adaptions, also and in particular economic demands had to be met. In the 1960s, the rapid growth of infrastructure and the increased demand for bridges resulted in a high pressure to minimise costs. This was when the factor construction technology became more and more dominant and industry was looking for optimised construction methods (Sigrist; Bäurich 2006). As a result, the diversity of forms decreased whereas standardised structural elements began to prevail. Fritz Leonhardt’s publication on the aesthetics of bridges, respectively the lack of it in 1982 has to be read against this background.

In recent years, for special building tasks the shaping and design of the structures gained particular importance. One of the exponents of this approach is the architect and engineer Santiago Calatrava. His structures are based neither on considerations of the flow of forces nor on construction technology or cost efficiency, but arise from a sound sensation of forms and quite often refer to analogies from nature. Calatrava’s structures strongly exhibit a sculptural character and adopt the attitude of landmarks. Many of the structures are built for public demands, e.g. train stations, airports or urban bridges (Fig. 10), and are designed as attractions for sites or events.

This postmodern engineer’s aesthetics, which in the case of Calatrava profoundly deviates from its modern principles, gives to the engineer a new artistic freedom. Instead of an underlying constructive logic, the function and social significance (e.g. as architectures of connection) come here to the fore. At the same time, this development reveals a profound change in the cultural significance of the structures and demonstrates a common attitude of today: Up-to-date methods of structural analysis and construction technology, nowadays supported by computer programs, are displayed and/or a progressive design is achieved; bridges and buildings are understood as sculptures or objects that decorate their environments. Whilst their social function is still extremely high (Blakstad 2002), the structures – despite almost infinite technical possibilities – have to a great part lost their significance as symbols of technical progress and models for other cultural spheres. Electronic media and an according “aesthetics of virtuality” have for a long time challenged their position.

The task of constructing well and appealingly remains nonetheless. As a prerequisite, the principles of the engineer’s aesthetics have to be subtly differentiated and should be expanded beyond technicality in the original sense. In analysing the process of the conception of an engineering structure one can generally identify three influencing factors and levels of examination; these are:

- technical and scientific basis
- construction technology
- shaping and design
Technical and scientific basis comprises structural analysis, mechanics of materials as well as related structural design theories. Construction technology refers to all processes of the execution of structures and buildings and shall also include economic aspects. The third factor, shaping and design, implies all geometrical definitions as well as the choice of size, proportions and materials. Of course, there are no strict boundaries between these factors but rather smooth transitions and partial overlaps.

Whilst these factors already affected the construction of the Brooklyn Bridge, the Garabit Viadukt, the Salginatobel Bridge and many more approved structures, they can and should nowadays also be applied to new tasks such as buildings for regenerative energies, water supply or irrigation. At the same time, new technologies (e.g. adaptive textile covers for buildings (Holzbach 2009)) enter the field of structural engineering and challenge well-worn notions of structures and buildings. In the long run, these inventions may have as revolutionary consequences for the discipline and its aesthetics as the industrial revolution and the development of construction technology in the 19th century.

CONCLUSION

As shown in this paper, the engineer's aesthetics cannot be comprehended as an absolute one. Instead, it has to be regarded as a historical construct, which was and still is subject to changes. Emerged from a nowadays almost inconceivable social impact of engineering structures in the 19th and early 20th century, its underlying principles such as construction methods, material efficiency or the idea of creating forms that reflect the flow of forces had a strong impact on modern arts and architecture. At the same time, engineering structures adopted fashions of forms from these branches and in this context sometimes even diverged from other constructive demands. Rather often, however, a prevailing construction technology and use of standardised structural elements interfered with a satisfying shaping.

Today, the awareness of the necessity for considering all three factors: technical and scientific basis, construction technology, shaping and design is still important and should be continuously claimed amongst structural engineers. In addition, these factors should be transferred upon new building tasks. Moreover, after giving impulses to the arts and equally taking impulses from them, engineers nowadays may and should draw a profit from new scientific fields and their specific aesthetics.

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