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Does an(y) order exist within the Structural Art

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Abstract. Many authors have treated the beauty and aesthetics from the social and philosophic point of view [Kant, Plato], whereas very few of them have meditated within the domain of Architecture let alone Structural Engineering [1]. The Beautiful is beautiful, and the Ugly is ugly, but subjectivity apart, is any mean of defining a way or some Principles which can be of Guide for the designer. Is there any mathematics within the beauty, i.e., can the beauty be described in a mathematical way? It is a simple, yet a very difficult question answering, since both the beauty and aesthetics falls into the domain of feelings, whereas each human doesn't feel the same when seeing an object created by another human. This Paper is representing a modest temptation to prove that it can be done.

Keywords: Structural Art., Beauty, Aesthetics

Introduction

Since the dawn of civilizations, structures have been an integral part of any symbol within societies. Be it a column, a cornerstone, a vault or an obelisk; all of them has been consciously or unconsciously used to express the will of people, their desire to submit other people to their wishes of a grandiosity and power. Since approximately the middle of the 19th century, architecture has become a profession "apart", whilst the structure, although being a crucial part of it, has fallen into "*l'oubli*". Nowadays, there is hardly to be found a building, an edifice and let alone a bridge, where the structure doesn't reign supreme as a powerful architectural element. If a tower has been classified as "beautiful", then take a close look at his structure, since, its most powerful element would be: a super-column, a super-shear wall or a combination of both of them. Unfortunately, the structure has often been misused, and in some cases even used abusively, by the so called "star architects", which go as far as to speculate as of "how they built" them. Let just take as an example, an arche bridge whose main structural element, i.e. the arch himself, runs parallel to the river flow, that is normal to the traffic or the flow of people. It represents a direct conflict with the bridge's main purpose – to serve people, not the river.

Now the principal question this paper aims answering is this: is it possible to define some guiding principles in order to create symbols (since the structure is a symbol) that are loved by people, since they do serve people, not the egos of Designers, which for the sake of their ambitions often create structural aberrations in contradiction with the law of physics itself. Since the discourse enters deep into the domain of aesthetics, and as we know, aesthetical values of an artefact are an object of subjective cognition, someone might say that this is impossible.

In this paper, I will attempt to demystify it. I am profoundly convinced that, a structural element as a part or as a whole of an architectural ensemble cannot be neither efficient mechanically (and this can be proven) nor beautiful if it breaks the elementary Newtonian laws of gravitations.

On basic principles in the art of structures

Urban clusters and civilizations are formed around certain symbols in a completely spongy manner. As noted above, these symbols, in the vast majority of cases, feature engineering works with many different destinies, such as cult, entertainment, gathering arenas, etc. When these are projected on the basis of the mechanical efficiency of the materials used, within the resources that the society possesses, while respecting the aesthetic criteria, then the same ones are transformed into artwork. With the creation of works of art (French: oeuvres d'art) in the three-dimensional environment, structural engineering, architect and sculptor are engaged. Namely, while the former creates forms based primarily on scientific rules; the second creates based more on the social dimension; while the latter creates artwork of a symbolic nature whose main purpose is to preserve the memory of a person or personality.

The happiness of the human being, among other things, also depends on the aesthetic quality of the environment where he lives and operates [1], [4]. In a democracy whose basic derivative is individual freedom and productive creativity, these symbols cannot in any way avoid the objective criticisms and concerns expressed by its citizens. This important fact must be treated with the designer's deserved seriousness if he wants his work to be accepted within the community.

The goal of a designer of a structure should be to generate a new value for the environment where engraving is planned. To achieve this, the designer needs to have profound knowledge of the relevant field. Most of the cases begin with the conception of forms inspired by original ideas, which arise from nature itself; then, using the principles and the scientific (mathematical) apparatus, they should be analysed, dimensioned and finally realized. The inspiration is wide-ranging, and the ideas can be based on an oak tree, a spider web, a nautilus shell (see Chapter 2 above), a soap bubble, etc., etc. But inspiration is not self-sufficient. Designers will need certain skills such as: artistic inspiration, mathematical bases, creativity, originality, presentation skills (drawing) etc. When his ability has reached the appropriate level, he will have achieved the initial idea to raise and develop it to the desired degree – an artwork. With such a stir and battle, must have faced engineers like Thomas Telford, Gustav Eiffel, Robert Maillart, Fritz Leonhardt, Heinz Isler, Pier Luigi Nervi, Sergio Musmeci, Christian Menn, Jörg Schlaich and more recently Santiago Calatrava, whose structures are certainly worthwhile to be enjoyed in different museums around the world.

An engineering-artwork structure consists of a conglomerate of all structural elements, the shape and size of which makes the definition of its silhouette. Since structural engineer is precisely the main responsible person for their relative, but also "absolute" size and degree, he/she cannot avoid the "responsibility" that, in addition to the mechanical and economic efficiency aspects also possess their artistic and aesthetic aspects. Since structural engineer is a central figure for "engraving" a form, it can be freely said that this "craft" has already been erected where it has its place - in the *art of structures*.

As in the Middle Ages, the Renaissance, and even today, various authors have tried to give relatively scientific definitions to beauty. A consensus has been reached that it is not possible to give quantitative criteria on the aesthetic values of an artwork. One of the authors who has gone this far, of course, is Fritz Leonhardt with his book "*Brücken*" written in 1982 [1].

The underlying question, which is set out here, is: is it possible to set at least some basic principles that could be considered as basic prerequisites that would have to be fulfilled to be able to create an artwork – a structure?

We definitively say yes. While below we will try to list them one by one, adding the relevant arguments. Bearing in mind that the human being, as the most important phenomenon, is at the core of all the ventures that relate to the creation of these works, we will begin with the principle of objectivity, which is also the "entrance door" for in the beautiful human adventure called creativity.

Principle of objectivity

This principle is about attitude, judgment, appreciation and decision-making for all that coincides with the design of an artwork. This is the wider and most important principle for the whole process of human creativity. This principle lies in a close connection with human personality and dignity. The principle of objectivity should be manifested in every area of human activity, in each country and at any time, regardless of the circumstances in which it is acted upon. From the principle of objectivity derive, among other things, justice to others, and the critical attitude towards oneself (self-knowledge) - to the renunciation of individual ego [4]. On the basis of the principle of objectivity there are noble motivations, the source of which is human love itself. Human-based creation based on this principle can bring excellent results, elegant, clean forms and economic solutions-creative man becomes productive. Ambition can be constructive, but its motivations can be inflexible and often even completely unproductive. It pushes to work but at the same time draws the personality in the foreground, and not the society and the general interest, and thus pushes the fulfilment of the unproductive character of the creator of an artwork [4].

Ambition can only be useful when it does not serve exclusively to personal interests or when it does not appear (naturally) as a result of a personality with spiritual disorder, which sometimes takes on the dimensions of creative sadomasochism (otherwise how can one explain some artwork created with little taste, without character, "unhappy" in the surroundings where they have been engraved?).

Even when it (ambition) does not contradict the interests of the majority, it must be "suppressed": mainly through the cultural depth, the desire to be honest, self-criticism and love for man, the environment, and society

Principle of functionality

This principle has to do with the need to meet the basic requirement, the need for which an artwork (bridge, tunnel, tower, etc.) is designed and then constructed. An art work can be illustrated as a typical example of the application of the general law of biology, according to which "the need urges the body". In the present case, "the need" is the communication of people and goods, the need for rally, fun; while "the organ" is the work of art, whose main task is to fulfil the predetermined social role.

The design elements of a bridge, for example, when it comes to the principle of functionality, must contain all traffic conditions: in front of the bridge, over the bridge and underneath it, both during and after completion, even for the entire lifespan of it. For as far as these conditions are considered and studied, as far as these are specified and fulfilled, as well as the requirements relating to the functionality of this artwork, both during construction and exploitation, have also been met. An important component of the functional aspect of an artwork is maintenance during its exploitation - this must be the vital component of the project. Environmental sustainability and recycling are an integral part of this principle.

Principle of stability

It is one of the basic principles which the designer should pay more attention to. It is a bad thing, however, that this principle is presented as the underlying criterion on which today the construction engineering faculties are based. Here, the engineer feels, so to say, "on his/her own ground", being equipped with the scientific apparatus gained during the study period. The principle of stability has nothing to do with the primary structure, but it needs to be further expanded, i.e., with the stability of everything that has to do with changing the state of the structure, such as intended and desired to be, whereby by the state is meant the projected structure, but other aspects included as well, such as durability, appearance, etc. (in terms of Eurocode, *ULS, SLS*).

The concept of stability is therefore closely interlinked not only with the concept of equilibrium, stability, structural fatigue, but also with the concept of predictable utilization of an artwork.

Fulfilment of one of the requirements regarding the global stability of an artwork does not automatically mean fulfilment of the demand for its normal use. For instance, an example can be given when a substantial relocation of the supporter to (a statically defined) structure occurs; displacement, which may not endanger the global stability of the structure, but that this seriously violates the aspect of normal use of the work of art (appearance, level, cracking, shaking, etc.) However, both states (the so-called borderline with the language of modern codes) may occur either separately or at the same time, where failure to fulfil one may lead vice-versa to the failure of the other.

Finally, it should be noted that from the level of fulfilment of this principle, it will depend not only the economic aspect but also the life itself of an artwork. An elaboration and, above all, a correct implementation of the component details of an artwork is the greatest guarantee of a design working life and relatively limited maintenance costs.

Great engineers of the last century (like Maillart, Leonhardt, Freyssinet, Nervi, Menn) were (some are still alive, fortunately) not only extremely resourceful in the use of new materials and technologies, but the same in fulfilling this fundamental principle, managed to realize works worthy of exhibitions in the art museums, precisely respecting other principles in addition to their stability.

Principle of Rationality

The meaning of rationality relates not only to the structure of an artwork, but also to its neighbourhood, its connecting points (its extreme points), as well as the implications that arise as a result of this interaction, either economically or aesthetically. Prices resulting from this interaction should serve as an extremely important criterion when it comes to choosing between variants, for example. The comfort and security of users (automotive, railroad or pedestrian traffic), exploitation and maintenance costs for the projected life expectancy of the work of art are narrowly related to the sense of rationality.

The decision on the choice of a variant from metal, reinforced concrete or precast concrete should only be taken after having analysed in depth all the parameters relating to the manner of execution, durability, exploitation, maintenance and finally demolition and eventually, recycling. Another very important parameter that relates to rationality is that of the resources it possesses both at the level of materials used and the workforce, and not to mention at all - the available budget.

Lately, mainly due to the lack of objectivity (see the principle of objectivity above), lack of relevant knowledge about the principle of stability, ideas are being thrown around the world and less rational projects are being designed, contrary not only to the flow of forces but often contrary to the flow of public (the normal arc in the circular flow?!). Ignorant politicians, in need of promoting their ideas through creation of symbols, engage "star architects" who, in violation of the principles elaborated here, project works that can be called much more of a speculation than artwork.

The principle of authenticity

This principle is closely linked to creative human skills. Creative innovation rests within that work of art that derives from the creative ability of the designer (structuralist), considering elements such as: location, context, environment, etc. A work of art (bridge), such as the one of Salginatöbelbrücke (R. Maillart), stands with all its greatness in its context (Schiers, CH), but it would seem meaningless if it were to be located in the plains of Fushë Kosovë, for instance. The desire for originality is closely linked to the principle of objectivity. Often, and especially recently, the desire for more originality [5] has led to the extreme empowerment of the ego and the misuse of the basic principles of science on structures and mechanics. Likewise, the desire for affirmation has also inspired the appetites of the so-called "star architects" [6] to put in place most bizarre solutions (and with the help of authorities, unfortunately, make them real) and often

(with the help of irresponsible constructors) to create works that severely violate not only the basic aspects of the laws of physics but that are also conflicting with aesthetic laws [2]. This principle is closely related to the development of technology and the use of new materials, escape from "standard works" and conventional boundaries of the period. However, the expression of individuality is welcomed and necessary to mark the designer's style. Authentic designers have left their indelible traces precisely through authenticity, creativity and advanced awareness of the materials used and the context coupled with a profound analysis of environmental incorporation and resource abilities. This has continuously led them to be admired, whether by the common observer or by their good connoisseur.

The principle of aesthetics

Understanding the notion of aesthetics is the *Holy Grail* of art on structures. This principle is especially valuable for bridges as synonymous to works of art. Aesthetically, a structure is largely dependent on the very nature of its conception, the unity of the composition of structural elements, the degree of preservation of rhythm and the repetition of structural elements, its elegance, its simplicity, its transparency, its global scale, harmony, the colour and texture of the constituent elements, as well as the level of exposure to light and shadow [7]. Figure further below, presents the Craigellachie Bridge in Scotland, a work designed by the notorious engineer Thomas Telford and realized in between 1812 - 1814. This artwork, at the time of its construction, was considered a great achievement in the field of bridge constructions (from cast iron).

It is certain that it has not lost anything of her beauty yet. We can distinguish the following basic features of it: *refinement, order, harmony, transparency, environmental incorporation and highly artistic configuration*. A structure which in itself contains all the above-mentioned features results in a high degree of tranquillity and environmental incorporation and in stimulating emotions at its observer. Of course, experience and judgment by the ordinary observer is a function of the degree of self-esteem and emancipation, but also of other social circumstances which do not have their source in the aesthetic quality of the structure, but in the personality of the observer. The main faults that have been made, which are still present nowadays, are the lack of transparency, refinement and artistic formation - as the fundamental components of the elegance of an engineering work.



Figure 3.13 Craigellachie bridge, Thomas Telford, Craigellachie, Scotland, 1812 - 1814, $l = 50\text{m}$ [3] - a masterpiece of art.

Certainly, foundations of aesthetics are: general culture, increased level of knowledge on visual arts, individual creativity, love and dedication to the chosen profession, acquired experience,

professional ethics and ultimately (but not least) desire and sacrifice to go to the end, unconditionally and uncompromisingly, without neglecting anyone and nothing on this journey.

Discussion

As Fritz Leonhardt wrote [1], nature's beauty is one of the most powerful sources for human health and for the soul of a human being (German: "*Die Schönheit der Natur ist geradezu der stärkste Kraftquell für die Empfindsame Seele des Menschen*"). Indeed, the structures created by nature - the biostructures contain almost all of the elements mentioned above and should serve as an invaluable source of inspiration to the designers of the structures, not just from an aesthetic but also mechanical point of view.

A small number of authors have studied the aesthetic principles of engineering works; among the most renowned ones are Fritz Leonhardt, Christian Menn, David Billington, Jörg Schlaich and Michel Virlogeux. The one who has gone the furthest in this aspect is obviously Fritz Leonhardt, who in his book "*Brücken-Bridges*" [1] has tried to formulate canons that are related to the definition of the fundamental characteristics' *sine qua non*, which an artwork in the field of structural engineering should possess so that it can be considered to have met the principles of aesthetics:

- fulfilling the purpose-function criteria (German: *Zweckerfüllung*),
- proportions,
- order (German: *Ordnung*),
- symmetry,
- repetition,
- refinement of the form (German: *Verfeinerung der Form*),
- integration (amalgamation) in the environment (German: *Einpassung in die Umwelt*),
- surface texture (German: *Oberflächentextur*),
- colours (German: *Farben*),
- character (German: *Charakter*),
- complexity - stimulation through varieties (German: *Komplexität - Reize durch verschiedenartigkeit*),
- inclusion of nature (German: *Einbeziehen der Natur*).

Thus, in the given context, it can be acknowledged that: an art work which contradicts the fundamental principles under which nature creates cannot be either technically or aesthetically accomplished. An art work, designed to violate the above stated principles, has no other fate but going to the basket of forgetfulness - it is judged to "die" - even before it is "born".

And with regard to the beauty of art, aesthetics, and even in the context of our paper, for a constructive conclusion, we would also be able to utilise these thoughts of the well-known aesthetes, namely Benedetto Croce and Nasho Jorgaqi: "*The problem of the origin of art, ... is united to that of the emergence of human civilization on earth*" [8], except: "*Moreover, not all men perceive with the same easiness the beauty in those forms that it appears...*", however [9]] "*...sublime aesthetic releases man from the smallness and the usual preoccupations...*" [9].

However, if the aesthetic sublimates, as a judgment and taste, or as an enjoyment, liberates man from the smallness, in terms of the level of professional duty, we think that the creator (the architect or the structural engineer) is glorified to the magnificence of the complexity of the work

as a whole by details, with serious implications also for all experts of certain fields involved, in this case, in an architectural work.

Summary

There cannot be architecture without structure. Structure is an integral part of any architectural work, and this can be seen in almost any of existing edifices or buildings – it is omnipresent. The tendency, nowadays, is the promotion of vanguard architectural ideas through spectacular structures, therefore one could ask the question: which one is more important within the fabric of the “final product” architecture or structure. Unfortunately, lately on, structural art is often misunderstood, and abusive ideas are taking place everywhere, mainly by the so called “star architects”, often helped by structural engineers, be it for the sake of opportunism or both unproductive personal ambitions and ego.

To be clear: one cannot obtain a “*plus-value*” in an architectural work, if its structure breaks the physic’ elementary laws. Therefore, it is an imperative to impose some kind of a Guiding Principles as how one should approach the design process as a whole.

This article, far from trying to impose itself as a general rule, takes a modest step in this direction, and proposes some guiding principles in order to obtain what is “the holy grail” in architecture – the beautiful.

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