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Leonardo's civil bridges

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Abstract

Within both aesthetic and history fields, civil engineering occupies a privileged place among arts whose manifestations are based on drawing. In this work, Leonardo's creativity concerned with civil bridges proyects, have been studied. Leonardo designed ten bridges: eight of them intended for military porposes and only two were purely planned for civil functionaly - "Ponte sul corno d'oro", infolio 66, manuscript L; and "Ponte a due piani", represented in the Manuscript B at the Institute of France, infolio 23. There can be no doubt about Leonardo's intentions when he started on designing these two bridges: his genious for creativy focused on providing both singulary and functionaly to the structures: they should be admired and utilized at the same time, a monument for civil society to be used.The work presented here attemps to make an scientist-historical trip along these Leonardo's bridges, highlighting their technical, geometrical and aesthetic characteristics, as well as emphasizing Leonardo's human, scientist and artistic nature.

Introduction

However not being a prolific painter, Leonardo was a productive draughtsman, keeping in diaries numerous small drafts and detailed drawings, which documented every possible thing that got his attention. Besides his diaries, there can be found many studies about his paintings, some of them can be identified as being precursors of some of the Leonardo's pieces of art.

The 5fh of August 1473, Leonardo dated his first certain work: a Landscape of Arno Valley, which shows with great detail the river, the mountains, Montelupo Castle and the farms in the background. Nowadays, that piece of art can be admired in The Uffizi Gallery.

Leonardo was not a cultured man in his time: he did not learn latin and was not the archetypal of humanist, being called by himself as "*a man with no arts*". He was, therefore, often ignored by his contemporary scholars. Neither he was an expert on Algebra, since it seems a bit excessive to consider him as a mathematician. However, even today one can be wonderred at his works on Engineering, birds' flights and other areas that arosed his insatiable curiosity.

It is appropiate to mention here that in 1496 a deep change is produced in Leonardo's activity. In that year, he strengthened friendship with the Franciscan priest Luca Pacioli who, frequenting the same milanesa court, stimulated Leonardo's interes on Maths and, especially, on Geometry through studying Euclides. The meeting between Leonardo and Maths is not a novelty itself, due to the fact that Maths are the foundations of perspective – the painter's science – whose rules constituted a learning subject at Renaissance workshops. This fashion is given by the application of a kind of superior consciousness - particularly intense during the following period - a deeper intimate understanding of creation, that carries him to a more profound analysis of every of his creations.

Leonardo registered with great attention to detail his lucubrations about technical and scientist subjects. He beautifully combined arts and science, in order to represent the materialization of his ideas in the best possible way. With a sense of eagerness to criticize, as if he was not keen to totally reveal his discoveries, left-handed Leonardo wrote everything in his diaries using the so called mirror writing - from right to left. Reading his writings requires, if one is not used to it, the use of a mirror.

Fig. 1 Leonardo da Vinci. Self-portrait.

Despite his great capacity for observation, his approximation to science never excelled from his theoretical explanations nor from his experiments; however, in order to understand the phenomena, he used to describe and even draw, in great detail, the nature phenomenology, intending to make an encyclopedia based on those drawings of almost everything. Nevertheles, there were barely several designs that were built during the author's life.

Leonardo never published nor distributed the contents of his manuscripts, which kept unknown until the XIX century, when his contributions to the technical-scientist development finally came to light. For this reason, L. Sprague de Camp considers Leonardo not as the first

modern engineer, but as the only and the latest engineer in antiquity, pointing out that the publication of Leonardo's scientist discoveries occurred after Leonardo's time. His contributions to other arts - like sculture - and sciences – like ingeneering, mechanics, physics, biology, architecture, anatomy, geology and maths – which he himself believes to be the essence of his nature -, were decisive. Despite his work on this field is not considered to have enough scientist rigor and the results were not fully conclusive at that time, it can not be omitted that his exceptional intuitions – particulary those related to geometry – play an important role in the history of mathematical thought. Some of those intuitions became realities in subsequent centuries.

Therefore, the myth of Leonardo as brilliant prophet of every discovery or invention of our time, has probably its origen at his very mysterious figure and also - as it is understandable - at the first spontaneous consideration given by anyone who comes across any of his technological designs. The advertisement on "*Italian Genius*" made for the exhibition about Leonardo, in Milan 1939, definately contributed to the mith, as long as the the recent elaboration of a comercial brand that has being extremely sucessful among the general public.

In reality, it can not be stated that every machine and Leonardo's "invention", is the product of his original and fertil genius. To confirm this, suffice it to read Roger Bacon's writings in the far England of XIII century*: "… it is possible to make means to sail without rowers, in a way that those enormous ships can cross rivers or oceans driven by only one pilot, faster than were they full of men. It is too possible to build carts that move with no horse, thanks to a wonderful strength. I believe that the former kind were made of those carts used by ancient men to fight against each other. It is possible ti contruct machines that can fly, made in such a way that being the man in the centre of the machine, drives it with a mechanism that prints bird movement to its wings, made as similar as bird wings. And in the same way, it is possible to build a winch of small size which lifts small weights and brings down almost infinite ones… it is too possible to construct artefacts for walking on the sea and rivers, and to even touch the bottom with no risk. Undoubtedly, Alexander the Great used instruments of this type to explore the sea bed, as there narrates the astronomer Etico. It is undoubted that the above mentioned instruments were already constructed in the antiquity and they are constructed also today, with the only exception of the flying machine - neither I nor no other person that I know have never seen. Nevertheless, I know a wise person who tried to make also this instrument. Of these devices we can construct an almost infinite quantity: for example, bridges that are stretched on the rivers without need of props or supports of any species, besides machines and inventions till now unknown"*[1].

All the machines, all the "inventions" attributed to the genius of Leonardo are described in this writing as belonging to a tradition that lasted for centuries. That tradition was kept still alive and active - surely, during the second half of Four hundred, as indicates the new brunelleschiana tradition - in expert engineers like Taccola, Buonaccorso, Ghiberti and Francesco di Giorgio Martin. The military agreements as well as the notes on technical and mechanical knowledge that the mentioned engineeres were writing - adding coarse but effective illustrations - had great demand and were circulating in surely bigger number than it has come up to us; Leonardo had copied and studied them, since some notes and memories of the artist demonstrate.

It should be assumed, so, that Leonardo's technical designs often depend on the reading book and manuscripts written by others and, especially, on the observation of the activity that was developing in the workshops or from the exchange of ideas with scholars and technical personnel of his time. However, it is necessary to admit once again that his work as mechanic and engineer is, for his extension and depth of experience, really unique and sometimes precursor; and that we are speaking about one of the biggest figures that the humanity has given; but it is not, by no means, a solitary fruit matured in the desert since it seems that someone may claim.

2 Bridge and Engineering as an aesthetic concept

The bridge is so ancient as the humanity, or even previous to it. The early man used trully the natural gangplanks that he found to his disposition. In this way, a trunk fallen by chance on a creek, a liana between two trees placed in both shores, stones that avoid a water course without preventing it to flow, or an arch excavated by the erosion.. they can be the models provided by nature.

Over the centuries, bridges of all kinds have been built, and rarely the engineer has neglected the aesthetic aspect, though not always he has managed to perform quality works in this respect. Sometimes, in the search of the singularity, the author has emphasized the decorative aspects and big structures, or has masked the metallic structures with more noble materials.

Aesthetic judgment is always subjective, but it is possible to establish some general shared criterion. Le Corbusier wrote: " false and bombastic are very little of benefit to art, while beauty can arise without searching it, from the spontaneity of the engineer constructions, which are created according to the laws of the nature and, in this way, they can reach harmony"[2].

As other infrastructures, a bridge can stimulate a new urban accession, or favor the development of a new peripheral area of the city.

Beside being present in space, a bridge has also a presence in time. On space and time history travels, the great history, made of battles, triumphal incomings and symbolic meetings, but also that small history of those who live in the proximities of a bridge. Urban bridges, especially, represent a pole of attraction for the community; from infancy, the inhabitants of the zone familiarize themselves and get fond of the bridge, and end

[1] *Bacon, R. Opus Maius, sixth part. Samuel Jebb's edition. London, 1733*

[2] *Le Corbusier. Les tendances de l'architecture rationaliste en rapport avec la peinture et la sculpture, Rome, 1937.*

up feeling it as something they own, something that shapes his own environment.

Men like Leonardo considered perspective as a method for the objective representation of space, that is to say, as instrument, but also as the basic component in the new linear conception of space, consequence of a certain historical situation provoked by reversion of figurative taste.

The artists of the Renaissance understood that good representation at perspective not only was precise and realistic, but also beautiful and agreeable at sight, up to the point of which, under the influence of the theory and of the practice of the Renaissance perspective, for a long time the representations of other cultures, or of other centuries, in which these rules were not observed, have been considered to be primitive, awkward or even ugly.

Art is the creation of beauty for man. The science of the theory of art , gives a series objective principles which serve as a guide for the artist in his labor of creating beauty. The knowledge of those principles, founded on the direct investigation of the nature of art and on the systematic estudio of the masterpieces of our ancestors, grants the artist with the faculty to straightly criticize the works of the others, with full knowledge of reason and good orientation, at the same time as he avoids serious reefs.

Aesthetics is the science of beauty. From it we know and feel this property of things.

The idea of beauty is innate and undefinable; it answers to a spiritual need. Beautiful is, therefore, that that produces the pleasure of the feeling.

Does beauty exist within the objects or it is in ourselves?, Schiller has said " *the reality of things is within them, but its manisfestation is in us"*[3].

There is no point that things are beautiful if the one that sees them is not provided with the necessary feeling to estimate this property that makes us love them and unfuses us with spiritual delight.

Man as spectator of beauty is the manager of judging the kindness of the work, of its aesthetics and of its beauty. In epochs of general culture and of unification of ideas, like in the Greece of the 5th century or in the Florence of Leonardo, the best critic was the ignorant public, who was judging, not for individual feeling, but according to a collective opinion.

Entering already into nature, the objective and art of the civil engineering highlight three aspects, intimately tied, that do not appear together in other arts: scientific, useful and beautiful. Three aspects that have not only to exist at the same time, but to be mutually completed.

Engineering uses material as practical way for its mission. This material comes in every element, limited by a form that must assemble certain conditions in order that its stability and permanency remain guaranteed; and mechanics gives these conditions, in agreement with the nature of the material and with the forces that act on the element. There is, so, a scientific connection.
As well as the form of every element of the work harmonizes with the function that the above mentioned element recovers, the form of the whole is tied by the immediate end of convenience to which the work must be destined. The engineering, unlike other arts, which are completely disinterested, fulfills always with an end of usefulness, *material* most of the times, or simply *moral* others.

Engineering is constituted beautiful art through two elements: idea and form, so intimately related that the second one is capable and sufficient to express the first one; otherwise the idea would not go out of the soul of the artist to go into the spectator's. It is, certainly, what happens in all arts.
In aesthetic field, since in historical one, civil engineering occupies a place of privilege between arts that take the drawing as the foundantions of its manifestation.

Any work of civil engineering has three fundamental conditions: solidity, convenience and beauty. To them, economy might be also added.

The realized work must be not only solid, this is, of calculated dimensions to assure the stability (real solidity), but it also has to look like that (apparent solidity). From this appearance it is born precisely what is known by the name of proportion.

Perhaps, we should speak here, though briefly, about proportion, which is the relationship between dimensions; relationship between the whole and each part of it: logical, necessary relationships, in such a way that they satisfy reason and sight of the spectator at the same time.

Proportion is not dimension. Dimensions indicate simply heights, widths and surfaces; while proportions are the relative connections between these parts following a law. Proportions are established, certainly, by engineering, on the laws of stability, which derive from geometry. A triangle is an entirely complete, perfect figure, in what it gives the most convincing idea of stability. From triangle they departed: Egyptians and Greeks, and later architects and engineers of the Middle Ages. Neither should proportion be mistaken with symmetry.

Even the most vulgar artist can follow, without any effort, a symmetrical way: he only has to repeat to the right what it has been done to the left side. On the contrary, it is indispensable to proceed to a slightly more delicate study to establish a system of proportions in a bridge.

Symmetry dominates nature, which gives us the model. To establish order, symmetry is an excellent procedure. It consists of the repetition of elements according with the distance to another geometric element, which can be a point (radial symmetry) or an axis (axial symmetry).

Today, it worries more weighting than symmetry, this is: an apparent symmetry achieved by the balance of the masses.

The geometric theory subordinates the general proportions to certain geometric simple forms. This theory is probably more important and certainly the most general.

[3] *Schiller, F. Über die ästhetische Erziehung des Menschen . Weimar, 1795.*

Egypt, Greece, the Persia Sasanid, Rome, the Latin and medieval styles, the Renaissance, used the geometric theory.

A geometric or arithmetical system that serves to establish the laws of proportions, far from being a hobble, is, on the contrary, an invaluable help.

Another important element is the grandeur - the effect of magnitude-. It is obtained by the repetition of the same element, by perspective, by elements of comparison to the natural scale. This third way of obtaining the grandeur suggests the question of the " natural scale " and of the scale of proportion.

In classic art, a small monument is something like the reduction of the big one: slightly sensitive fault in the Greek monuments whose dimensions do not sin of being exaggerated; but in the classic Roman works this fault grows in importance, since it generates works which magnitude is not noticed.

In the engineering of the Middle Ages, there are established elements of comparison of natural size, favorable to the grand effect. The Roman props, arches, etc, can have the same dimension in a work in a small villa than in a great imperial city, because nature, invariable, is the unit to these elements. There it takes root the secret of the grandeur of the Roman monuments.

It is important the Influence of the visuality and perspective effects. The visual effects due to the superposed colors and to the situation of the eye of the observer, can make proportion change.

A work of engineering is composed, clearly, of several parts. If there characterizes each of these component parts by using a form that corresponds to its idea, the whole will remain evidently characterized.

Material characterizes the work of engineering in diverse ways: by its color, its hardness, its polish, etc.

A hard material always expresses well the idea of permanency.

Any work made by the human brain, so in the field of letters as in arts, cannot live if it does not possess what is called style. This belongs to man and is independent from the object. In poetry, for example, the thought, the impression exists. The way of expressing them, of making them penetrate in the soul of the audience, is the style.

In engineering, style has double character: of science and of art. It is a system of construction as well as a manifestation of beauty, which when united they give a geometric - aesthetic form.

Finally, we can conclude that, though it is not always easy to join the concepts of engineering, in all its scientific expression, with beauty as aesthetic expression: an aesthetic component really exists in civil engineering and we might feel that it is its essence. As said in some occasion the architect, mathematician and engineer Richard Buckminster Fuller (1895-1983): *" when I work with a problem, I never think about beauty. I just think of how to solv it. But when I have finished, if the solution is not beautiful, I do know the result is bad"*[4].

It is very probable that in Leonardo's drawings and, especially, in his proposals of engineering, he was always very aware of this very idea, along with other considerations expressed in the present epigraph.

3 Leonardo and his bridges

It has been written greatly about Leonardo's painting, about his sculpture, his wit, his machines …, about his aspect, especially, of mechanical and military engineer: However, it can not be left apart another Leonardo's creative aspect related to the project of bridges, tunnels, urbanism, etc. Because of this, this time we would like to concentrate on Leonardo the designer of bridges, approaching to the two of them that do not have military character.

3.1 Military bridges

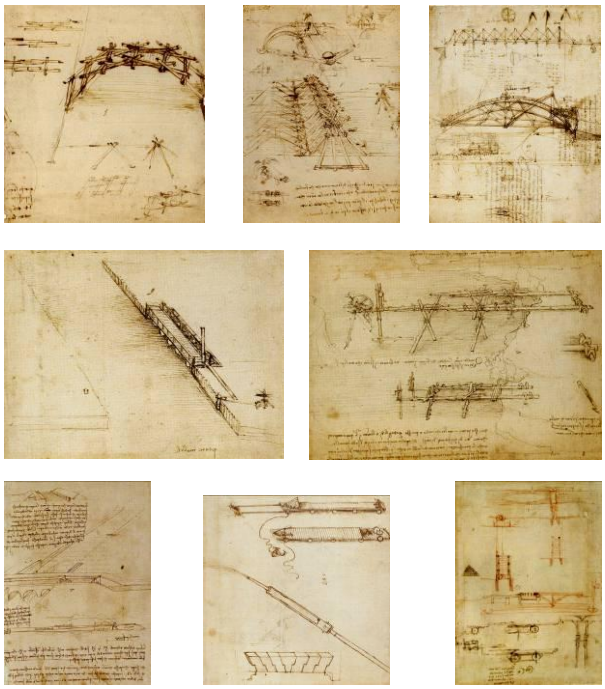


Figure. 2 The military bridges designed by Leonardo. All of them are included in the Atlantic Codex

Ten are the bridges that Leonardo designs, of which eight have military character and only two have a civil function. The military bridges represented in Fig. 2, are not the objective of our study, just to mention, however, their aim for functionality, rapidity of construction and portability:

From left side to right and top to bottom, the autoamble bridge (Atlantic Codex , infolio 69ar and 71v); bridge in double row (Atlantic Codex, infolio 57v); swing bridge (Atlantic Codex, infolio 855r); pontoone bridge (Atlantic Codex, infolio 857r); bridge over trestles (Atlantic Codex, infolio 55r); channel bridge (Atlantic Codex, infolio 126v); bridge of assault (Atlantic Codex, infolio 1074r); retractable bridge (Atlantic Codex, infolio 238r).

[4] *Buckminster Fuller, R., New Views on R. Buckminster Fuller. Edited by Hsiao-Yun Chu and Roberto G. Trujillo. 2008*

3.2 Civil bridges

Two are the civil bridges that Leonardo projects: Ponte sul On Corno D'Oro, infolio 66, manuscriptly L; and ponte a due piani, represented in the Manuscript B of the Institute of France, infolio 23.

There is no doubt that when Leonardo thinks about both bridges object of our study, his creative genius admits, from the beginning, that a bridge represents a singular monument, which not only can be admired, but it must be used: a monument put to the service of society, and little or very much, used by all.

"I, your modest servant ... I will construct for you a mill that does not need water, since it will be enough to propel the mere force of the wind "or God, praised His name, He has granted me to design a system that allows to extract

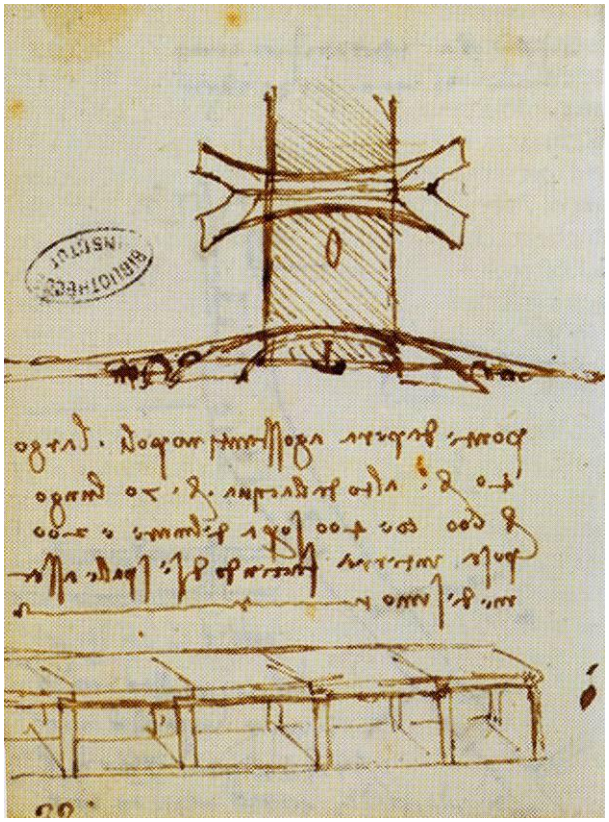


Figure 3. Ponte sul Corno D'oro. infolio 66, manuscript L. Institute of France

the water from the ships without need of ropes or cables, just by using a hydraulic self-propelled machine."

This is the way it began the letter found in the State Files of Topkaki's Museum, in which Leonardo offers his services as Engineer to the Sultan of Constantinople, Bayaceto II.

The drawing, realized about 1502-1503, shows the plant and one perspective almost in the elevation of the bridge, with a great ship of unfurled sails passing by below.

" It has come to ears of your modest servant that you have the intention of raising a bridge from Istanbul up to Gálata, but that you could not have biult till now because you have not found a man capable of doing it. I, your modest servant, know how to make it. I would construct it so highly as a building, so that, due to its height, nobody could exceed it...

The bridge had to save 420 meters, connecting the ends of the Golden Horn, a tightening in the river Bosporus that separates Europe of Asia. To do that, Leonardo re-designed the classical keystone bridge, reducing it in the center and expanding it in the stirrups that connected it with both shores, going forward 300 years to the theoretical principles that allow to calculate this type of structures. The width should be 24 meters, 360 meters of span and 40 meters of height over the level of the high tide.

...I will do it in such a way that a ship could pass under him even having all its sails unfurled... We would arrange

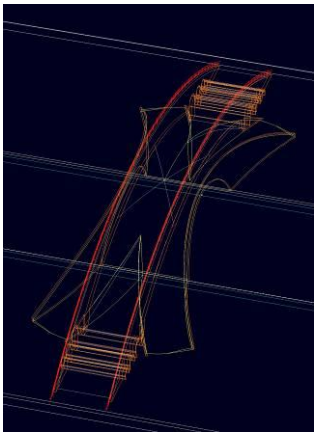
Figure 4. Model of Leonardo's bridge in the Museum of the Science of Valencia

too a drawbridge in order one could go on to Anatolia's coast... Want God that you believe my words and you take into accounts this one, your servant, who stays always to your entire disposal."

Leonardo's design consisted of two arches of granite that were supporting a top pedestrian alley. The stone supports well the pushes of the arch, for what it is possible to actually construct such a slender bridge. The arches measure only 0,65 meters in the narrowest part and expand up to 4,50 meters in the ends, measuring the base of anchorage 14 meters.

In Leonardo's bridge model kept in the Museum of the Science of Valencia, it is possible to estimate how the stirrups of the bridge contain as well small bridges that lighten the whole and allow the transverse step. The design of the bridge is a combination of elliptical arch for the intrados and segmental for the exterior surface, being the forces of compression transmitted directly against the soil.

In a long bridge, this can mean too much pressure on the last keystones of the stirrups. Leonardo solves the problem increasing the surface of contact of the stirrups, which allows to disperse and to distribute the pressures on a much bigger area.



In the photo of the take-offs we see as the arch appears really as a vault,

Figure 5. Infography of Leonardo's bridge performed with MicroStation

on which the bridge rests. This gets lighter by a few round arches.

The curvature of the vault allows to stabilize the structure opposite to eventual lateral movements.

A few years ago, Vebjorn Sand, a Norwegian painter, visits an exhibition of drawings of engineering and Leonardo's architecture. Immediately he gets fascinated by the bridge and in 2001 in Aas, Norway, a footbridge is inaugurated by a design based on Leonardo's, stimulated by the painter.

Finally, Aas's design was climbed to a span of 100 meters and a total length of 135 meters. After studying two designs (in stone and in wood) it was decided to construct it of laminated wood, decision rested on the idea of using materials and technologies of the region, it turns out to be seemingly disappointing for not having used stone. Nevertheless, the decision is not bad, if we bear in mind that Leonardo's stone bridge was never intended to suffer months of low temperatures and ice that might affect its structural behavior.

The other Leonardo's civil bridge is the one presented in the Manuscript B; which is closely relationed with the urban development study " cittá design him to due livelli ", performed between 1487 and 1489, and that was conceived to be able to separate the zone reserved to the

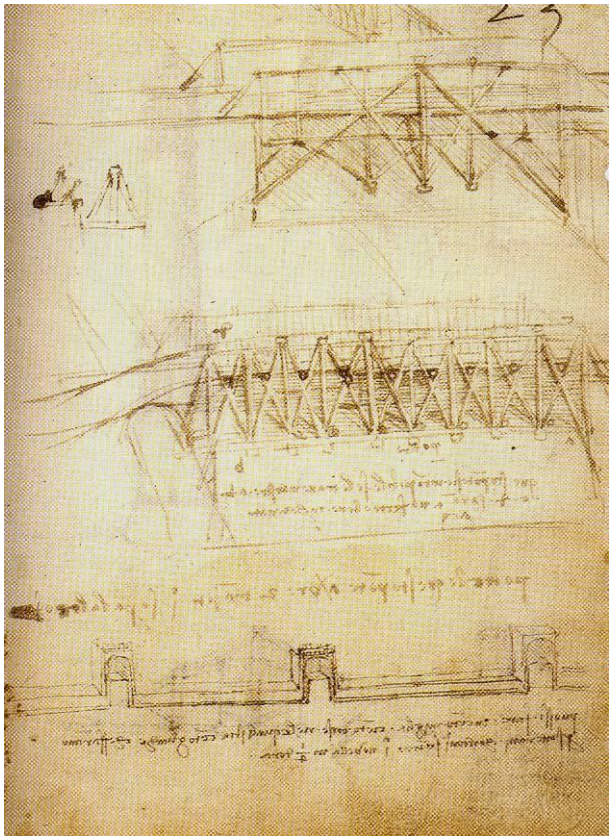


Figure 6. Ponte a due piani (Manuscript B, infolio 23r), Institute of France

work and to the trade from the area destined the citizens leisure time.

Inside the mentioned study, "ponte to due piani " would make possible cross a water course by two levels, which would allow to separate, on the one hand the traffic of entry and exit of the city and, in the other hand, to be able to destine the upper platform of the bridge for the traffic of persons, being lower one for vehicles and animals.

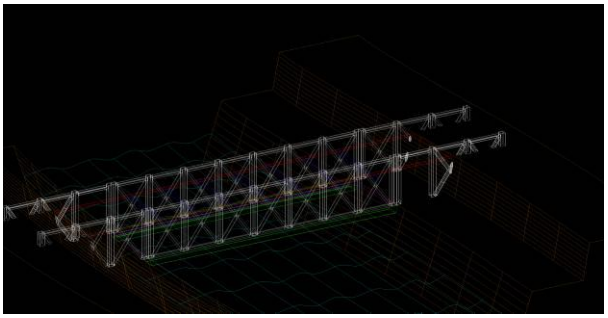


Figure 7. Infography of "Ponte a due piani "

Figure 8. Detail of the "Craigavon Bridge" placed in Londonderry (Northern Ireland) over the river Foyle.

This bridge, provided with a inclined gangplank, with access in its low part, was designed as a robust reticulated studding of wood, provided with important cerchas and arriostramientos to support the great weight of the double traffic.

Unfortunately, this bridge project did not improve more than being a sketch, and it was never built in Leonardo's life.

It was at the beginning of the 20th century when a bridge of two very similar floors to that of Leonardo was projected, so called "Craigavon Bridge" and placed in Londonderry (Northern Ireland) over the river Foyle.

This bridge, designed in 1929, by Mott, Is and Anderson, was a metallic bridge of steel structure. It was constructed by the company Dormon Long between 1930 and 1933, needing for its construction 6.500 cubic meters of

concrete and 5.000 tons of steel, and it cost 255.000 pounds.

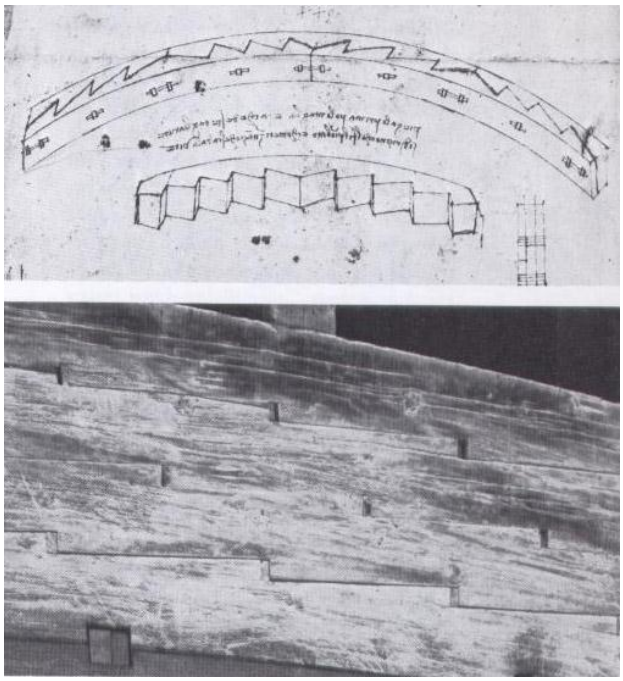


Figure 9. Upper: Detail of the figure that appears in the Codex Atlanticus, infolio 344 verse a.; lower: Detail that shows the assembly of the curled jagged girders in one of the supports.

This bridge has a length of 390 meters and a width of 18 meters, with a section constituted by 12 meters of causeway and two sidewalks of 3 meters each. The low level was destined for the railway traffic and the Superior for the traffic of vehicles and pedestrians.

Figure 10. Sight of the wooden bridge constructed in 1839 in Signau (Berne), over the river Emme.

In 1968, as a consequence of the closing of the company Railroads of the North of Ireland, the lower route, destined for the railway traffic, turned into road of double circulation.

In 1984 and due to the congestion of traffic in the bridge "Craigavon Bridge", a new concrete bridge was built, so called "Foyle Bridge", placed 2 kilometres downstream from the previous one.

There are some other Leonardo's contributions about bridges. For example, in the Codex Atlanticus, infolio 344 verse a, it is shown how the cuts have to be made in order to the girder not splinter, when the aim is obtaining the curled of the girders forming arches, like it happenend 300 years later in the Swiss wooden bridges. The wooden bridge of the photography below, constructed in 1839 in Signau (Berne), has two arches of support realized exactly like Leonardo proposed. This bridge has more than 45 m. length, it crosses the river Emme and can support more than 40 tons. This kind of bridges, unknown until XIXth century, represent another modern application of Leonardo's thought.

4 Criteria of aesthetic valuation and elements for its measure

When considering aesthetics in Civil Engineering, and focusing especially on bridges, visual quality of the work turns out to be as important as aesthetic quality.

Searching of rules that might lead to the beauty, is a Utopia longed by every man along history: golden section, Fibonacci's succession, etc. However, a fundamental quality of the essence of arts is to defy existing ideas and, therefore, to defy dogmatic notions of how to creat pieces of art with "good taste". Leonardo in the antiquity and, more nowadays, Maillart, Roebling, Fernandez Casado, Fernandez Ordóñez, Manterola and other masters at bridges design, demonstrate that designers need to be free of such restrictions of doubtful foundation, in order to create works of artistic significance.

The systematic application of a few rules should not necessary be pursuiting. The reason is that aesthetics belongs to the domains of philosophy, physiology and psychology, and therefore it cannot be understood completely from critical and logical reasoning, without the consideration of senses. Judgment on the aesthetic qualities belongs to the area of feelings, or sensory sensations, which are different in every individual, according to his experiences, impressions from his environment, etc. Hence, judgment on the aesthetic qualities of an object will be different in every observer.

Aesthetic quality is a subjective appraisal of the observer upon a certain scene. It is therefore useless to objectify aesthetics, although it is certainly possible to describe:

- Visually integrated (harmony) / visual impact.
- Slender / heavy.
- Transparent / opaque.
- Arranged / disarranged.
- Proportioned / disproportioned.
- Efficient / structurally inefficient

5 Composition, function and shape

Proportions, arrangement and scale according with the environment, play an essential role in the aesthetic behaviour of a work.

The meaning of composition here consists of the process of organizing a few elements by means of a few criteria or design basis. These principles are concepts that can help the designer to communicate the dominant topic of his

composition. They can be applied to every element of the design or to the whole composition. In graphical design, however, equilibrio, contrast, emphasis, rhythm and unity can be considered to be more used. In case of a general public work, and in bridges especially, there is no reason for its design not to share some principles with its graphical design, due to the fact that the infrastructures simply are shapes, volumes within a landscape.

The function that an object has to fulfill is its guide of design. There are famous phrases in the matter: " the logic of the shape " by Eduardo Torroja or " shape follws function " by Sullivan. In structures, the most evident function is to withstand actions (appart from the functionality that the whole system provides). For this reason, shapes that coincide with the flow of forces, that respect the natural laws, are considered to be expressive and beautiful. It is in the arch where the function of a bridge is better expressed: to save an obstacle and to transmit the loads to the ends. Because of its shape, it is considered to be beautiful. The same thing happens with the parabolic shape of the suspension bridges.

Shape has surrendered to the function of resistance, according with man's knowledge of these principles for designing shapes, always aiming to reach efficiency.

Therefore, function has to be made clear. The functional requirements are, for example, use, resistance, durability, expenses and the constructive procedures, but also it is necessary to consider visual functionality as a functional requirement of priority importance.

6 Conclusions

- 2D Drawing is insufficient to represent volumetries.
- The quality of aesthetic is difficult to quantity. It is not possible to objetify, but it is possible to describe.
- The aesthetic quality has to be compatible with the rest of requirements: functionality, economy, durability, safety and environmental respect.
- Beauty is timeless, does not go out of fashion.
- Aesthetics cannot sort out a badly designed structure.
- Something correctly proportioned, is attractive.
- Function includes visual functionality of a public work and, therefore, aesthetics is an integral part of the design.
- Leonardo redesigned the classic keystone bridge, reducing the center and expanding the stirrups that connect the structure with both shores, going 300 years ahead of the theoretical principles that allowed to calculate this type of structures.
- Leonardo goes forward to his time on the conception of the urban mobility, conciving models to be able to separate the zone reserved to work and to trade from the area destined to the citizens leisure. In addition, he is the first one in raising the separation of traffic for exit and entrance in the city, as well as the possibility of destining two levels in some bridges: one for the people traffic and other one for vehicles and animals.
- In the civil engineering that Leonardo projects, three aspects highlight, intimately tied, but rarely appear together in other arts: scientific, useful and beautiful. Three aspects that not only have to co-exist together, but also they have to be mutually completed; such aspects that Leonardo unifies with incredible mastery.
- Leonardo's civil engineering works invite to proportions that are established on the laws of stability, that derive from an ideal geometry that adapts itself to the structural requirements of the projected work.

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