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The Artistic Vanguards and the Bridges: Innovation and Transversality of Engineering and Other Arts

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ABSTRACT

This article critically reviews the development of painting art and the engineering of bridges in the first half of the 20th century. It shows that the expression of thought is directed towards innovation at a certain historical moment and non-imitation as a professional ethos. The vision is articulated through a multilevel perspective, including the social shaping of technology. The different milestones are chronologically compared following the Artistic Vanguards. It is shown that there was an accumulation of radical, disruptive innovation in the period between the World Wars. New tools to develop creativity were sought, and new figurative solutions and materials, such as concrete for bridge construction, began to be employed. The impressionist Monet and Eiffel and the cubist Picasso and Ribera deeply comprehended the previous techniques and dared to challenge them. The transversality of art and engineering is key to the innovation process.

Keywords: Art, artistic vanguards, bridges, concrete, engineering, innovation

INTRODUCTION

Today we live in a knowledge-based society (Drucker, 1969). However, it is increasingly compartmentalized, and the professions are its clear exponents. Of course, it can be understood that each artisan produces his piece, but it seems worrying that they do not know what they make, how, and why the artisan next door does it.

An encapsulated knowledge loses the enrichment of the environment and

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hardens, following the specialization rules exclusively. On the other hand, the meeting of several fields gives rise to osmosis and creativity. In knowledge, it is explained by the idea of cross-pollination (Boutang, 2011).

With this idea, two disciplines are analyzed, the art of the so-called Artistic Vanguards in painting and bridge engineering, at a given historical moment, specifically, during the first part of the 20th century when the expression of thought was directed towards non-imitation, giving rise to disruptive innovations.

Artistic movements in painting, such as Cubism, which developed around 1910, proposed forms of expression destined to break with the figurative modes bequeathed by tradition, and they redefined what was understood as art. In bridge engineering, the discoveries of new materials such as steel and concrete were supposed to be great advances and led to the spectacular development of structures, compared to those of stone and wood, in use until then.

First, it is necessary to underpin the concept of innovation and draft the theoretical framework that allows the affirmation that said innovation took place. The innovation object of this study is a disruptive innovation (Bower & Christensen, 1995), radical, and not an incremental advancement, hence the choice of art according to the so-called Artistic Vanguards in painting and parallel bridge engineering.

The multilevel perspective is the theoretical framework that justifies and articulates innovation in art and engineering, which studies the innovation process through three levels: niche, sociotechnical regime, and sociotechnical landscape (Geels, 2010). The niche is divergent, and it is where disruptive innovation mostly arises. The regime demarcates the operation level of the industry, production, and infrastructures and regulates the application of technology in the economy. Finally, the sociotechnical landscape corresponds to art and culture, more generally to the sociotechnical mindset.

The innovation in art is seen through the change of this mindset itself, in the evolution of reality perception and expression, expanding what was understood till now as art. Hence, the arts are placed at the landscape level. from where it transcends to fields such as engineering. From the perspective of engineering as a work of art (Manterola, 2010), depriving things of their utility transforms them, and they become works of art, as Duchamp did by exhibiting a now-famous urinal in a museum.

In bridge engineering, we attribute innovation to the development of structural engineering technology (Billington, 1985) in its typological and aesthetic evolution within Europe, which has shaped most of its global theoretical and constructive guidelines. Engineering is primarily located at the regime level because it constitutes the infrastructure of productive capacities of society in transport and construction.

The innovation unfolding during the Artistic Vanguards is staged through the theoretical framework of the multilevel perspective. The innovation articulation and its permeability among levels are also highlighted through the social construction or shaping of the technology/innovation approach (Klein & Kleinman, 2002; Pinch & Bijker, 1984; Winner, 1993). This concept reinforces the importance of transversality between disciplines. Technological innovation is not seen as a finite product that arises in a divergent and pioneering niche and afterward is scaled up and applied, impacting society and other levels. The interpretative flexibility of innovation implies that it is a product of interaction between the actors and levels.

Engineering evolution is analyzed in comparison with art according to historical sequencing. It implies not only the technology that engineering and art entail but also the shape, lines, structures, color reasoning, the emotion. Aristotle (2000) distinguished three dimensions of intelligence: episteme (logic), techne (practice), and phronesis (wisdom, incorporating context). Metis (Kumar, 2021; Mulgan, 2018) or improvisation is also recently added and relevant. Both in art and bridge engineering, all four dimensions apply.

During the 19th century, it is challenging to find antecedents that follow a convincing theoretical framework that allows a coherent conceptual *bridging* between art and engineering. As a result, they become too distant in their approach to reality and its transformation. However, innovation is a common transversal phenomenon, and its outlook is considered an inspiring stronghold for study coherence.

There are antecedents regarding the study of non-imitation in bridges by Billington, who described the steps of the evolution of the great structural artists, comprising three stages: imitation (not always present), innovation, and inspiration (Billington, 2003). He also contextualizes the 'Structural art timeline' (Billington, 1985), recording the most representative engineers, works, and advances. The density and concentration of references around the avant-garde period, i.e., the end of the 19th century and the beginning of the 20th, are noticeable. It is pointed out how, after the first and second industrial revolutions till the 60s, the courage of old constructions has been replaced by monotony and shyness (Schlaich, 2001).

Few works focus on the importance of a cross-disciplinary approach. A spirit of collaboration that encourages the crossing of knowledge works as a "Transversal Culture" (Laiglesia et al., 2010), which shows that success can be understood as innovation based on the transversality of knowledge and the complementarity of diversity, particularizing the Art-Science-Technology triangle. Following these terms, a visual tool called CATI is applied to analyze the positioning of the New European Bauhaus (Rosado-García et al., 2021) as an approach to transversality. The abbreviation CATI is Spanish and stands for Ciencia (science), Arte (art), Tecnología (technology), and Innovación (innovation); these concepts are the backbones of sustainable engineering and industry. It highlights the importance of science, opening spaces where possibilities and uncertainties do not need an empirical justification and where intuition and art become an important way of searching for answers and solutions. For example, the Historical Bauhaus was considered an inclusive educative space. Maximum efficiency and spatial logic orchestrated the dispositions of relationships (Carra, 2009) with the revision of the values and methods applied in education in general and art in particular; members of the school were taught to 'unleash participants' creative forces' through spontaneity and intuition (Ballantyne, 2004).

Today, interest in other transversal aspects, such as aesthetics, seems to reappear. Nowadays, an approximation of the concepts of engineering and art is required since they are more than modes of expression with which the engineer, like the artist, becomes a maker of the form (Rosado-García, 2022). Bridge engineering of the twentieth century underwent the transformation that brought the potential of new materials, with the consequent technical achievements, functional gains, and the "reconquest" of aesthetic values claimed by great engineers such as Fernández-Casado or, more recently, Billington, Manterola, or Rice. The latter is an example of creative engineering and transversality between disciplines such as engineering and architecture (Rice, 1994). Knowledge of structural mechanisms cannot and should not be unrelated to the rest of the disciplines, whether technical or humanistic (Arenas, 2002). Everything that requires a commitment to composition, balance, and the accumulation of sensations is art. Faced with a painting like "The Scream" by Munch, it must also exist in the sensory experience of a bridge (Sanz-Balduz, 2004).

The objective is to humanize the way of seeing engineering, inspire engineering education to guide teaching in the humanities, and promote engineering ethics (Billington, 2006). A comparative analysis in studies of disciplines so apparently different pretends to positively affect the actors, inducing reflection, enriching, and inciting their interest in why, how, and what can be done to foster future innovation.

Ethical engineering supports a noble cause because it favors life, culture, and the most authentic human values. Hence, a relevant aim of this study is to bring engineering closer to society. Moreover, engineering and ethical engineering not only satisfy intrinsic conditions such as functionality or economy. "Ethics and Aesthetics can never be absent from the work of the engineer" (Arenas, 1990).

Science, transposed to technology, technique, and art, are considered the main sources of inspiration and impulse toward innovation. However, art also can influence the level of the sociotechnical landscape, understood as a mindset, common sense, and social aspirations.

This article conducts a qualitative critical review of the case study of innovation in art and engineering in the interwar period in Europe, following the common thread of the so-called Artistic Vanguards.

The objective of the work is to demonstrate that, at a certain historical moment, in the presence of the industrial revolution, innovation permeates different levels. The expression of human thought is directed towards non-imitation, taking a parallel course both in art and in bridge engineering, with the development of concrete and following, in this particular case, a sequence of "isms": Fauvism, Cubism, Futurism, Expressionism, Dada, and Surrealism.

LITERATURE REVIEW

The art-engineering bionomy was considered; thus, it is worth defining what we understand by each concept and analyzing these concepts' evolution throughout history. In traditional terms, technology was understood as an art and craft (Klein & Kleinman, 2002). However, since the beginning of the 19th century, it has evolved, mainly with the spread of engineering schools toward technological invention. Art is a human activity that aims at creating cultural works but also implies a set of skills, techniques, or principles necessary to carry it out.

Technique and, therefore, engineering and art are considered alive, continuously evolving, and impossible to exhaust in their evolution (Gasset, 1983). Therefore, an engineer or an artist, as a technician, as a 'reifier' of ideas (Calvo-Sotelo, 2003) must be characterized by internal creative impulse.

Traditionally, technology was understood as arts and crafts (Klein & Kleinman, 2002). However, since the beginning of the 19th century, mainly with the spread of engineering schools, it has evolved toward the purpose of the invention.

Scientific knowledge, with its theories regarding the universe's functioning, leads to the technology praxis (with the intermediate points of applied and translational sciences (Perrow & Davy, 2008)). The technique is the knowledge or ability to apply technology (Douglas & Isherwood, 2021; Rip & Kemp, 1998).

Art is conceptualized not only as entertainment and distraction but as a crucial part of the socio-economy, providing mechanisms for developing new ideas in the social context. Creativity is considered the raw material for both cultural and economic development. However, as it is a dynamic part, it often escapes the scope of traditional studies (Potts, 2009). Artist is conceived as a person capable of a creation that provokes the spectator's emotion. It does not seem far from what an engineer achieves with his/her work (Lynch, 1960). Therefore, bridge engineering is understood as an artistic activity (Addis, 1994).

Technology is hereby perceived in transactional terms (Perrow & Davy, 2008) as the material means to achieve an end. The technique, in turn, concerns the processes implied by technology. In modern terms, technology refers to devices and mechanisms and their relationship. They are combined in a system in functional configuration (Rip & Kemp, 1998). Technology becomes part of routines and models of social behavior. As a part of communication within culture, it aims at satisfying needs and achieving objectives (Douglas & Isherwood, 2021). Technology and its artifacts are necessary to make cultural categories visible and stable (Douglas & Isherwood, 2021). The bridge, or the car, are not isolated products but are insignias of the sociotechnical landscape, implying materials, laws (regulatory standards), and culture (value and meaning) of mobility.

Artistic Vanguards

The avant-gardes cover the first half of the 20th century. First, different events between the two World Wars and World War II brought the reactivation of the US economy, making it the cradle of the mass-production model. Then, the Russian Revolution, the Bauhaus in Germany, the happy 1920s, and the New York crash in 1929 unfolded. Finally, it was followed by the Great Depression, the National Socialism of the Third Reich, and the politics of the NEW DEAL for re-energizing the American economy (Cappelli, 1999).

In this context rose the stereotype of an artist who is misunderstood and committed to a series of values opposing the entire convulsed world, prone to miserable developments. Therefore, the economy does not always follow a single upward direction of progress. Instead, it evolves through a meandering movement. It is also true for the processes such as evolution, technological development, or innovation with suboptimal lock-ins (Geels, 2005).

Before World War I, the so-called five Artistic Vanguards were born in this scenario. The 'color revolution' break-in in 1905 with Matisse's Fauvism, inspired by expressionist waves of The Bridge and The Blue Rider groups, abstraction, and realism (Milicua, 1994). Fauvism was born based on the use of intense and unnatural colors. Its main figures are Matisse, Derain, Dufy, and Braque.

The 'revolution of shape' followed in 1910 with Cubism by Picasso and Braque. However, it is not a narrative painting, and as it is undoubtedly not readable, it must be interpreted.

Cubism supposes the definitive establishment of the autonomy of art. It is the multi-perspective, the decomposition of the form. Without a doubt, it invites a reflection on what art itself is. John Golding, one of the greatest writers, appointed it as probably the most important and complete radical artistic revolution since the Renaissance (VV.AA, 2001).

Futurism emerged in 1912 with the manifestos in the plastic arts of Marinetti and the sculptures of Boccioni, Balla, and Gino Severino. Violence, lines, and movement characterized it. It is cubism in movement (Dempsey, 2002). Marinetti's propaganda capacity extolled subversion, and fierce criticism of a series of established values, inciting to break off all ties with the past (Preckler, 2003).

The ideology of Progress of the 19th century and the industrialization of Europe had as a counterpoint the disdain for logic and technique. After World War I, Dada and Surrealism were born. Starting in 1916, Dada was represented by T. Tzara or M. Duchamp, who installed the so-called anti-art. They opposed even the Artistic Vanguards.

With Dada comes the intellectuality, the resignified object. It is rather destructive criticism. Dada is anonymous and collective, seeking to expand and redefine without attending to the object but to ideas (Daix, 2002).

In 1929 Surrealism and the dream worlds by Miró, Ernst, Dalí, Magritte, or Delvaux, led to Metaphysical Painting and a return to the order of rationality to realism (Preckler, 2003). Surrealism sought to decontextualize and produce wonderful associations. Reality is built by the subject itself or has been built for itself by others. It embraces the language of dreams because they have no meaning. It glorifies love and passion because it is a non-psychotic state that can be described as psychotic.

At the end of the 19th century, narrative painting and academicism were broken (Manet) due to technological change, i. e. photography appeared.

Impressionism was the first artistic movement to rebel against the aesthetic tastes that prevailed at the time. Monet's work: "*Impression, Rising Sun,*" mockingly quoted by a critic, gave the group its name. Impressionists considered that sooner or later, their art would end up being recognized for its own merits (Milicua, 1994).

Thanks to new printing technologies and especially influential photography with its discovery of four-color printing, achieving infinite colors with the mixture of primary colors, Neo-Impressionism or Pointillism arises, conducted mainly by two authors, Seurat and Signac. They built on impressionism, but the form had already appeared.

Outside of these two movements are Vincent Van Gogh, Gaugain, and the subjective view of Toulouse-Lautrec. They were given the artistic-historical term of Post-Impressionists. All three figures had highly innovative in the world.

Cezanne is also worth mentioning as an icon of the line, of the intellect. His painting represents the form, not impression; it is an analytical, rationalized painting. He said that a man has to be in the world to geometrize it, give it shape, and intellectualize it. In opposition to that, with "Starry Night" (Figure 5), in 1889, Van Gogh spoke of color, of emotion, both being two pillars of the avant-garde.

Neither Munch nor Gaugin would seek the form since they did not believe in rationality. Instead, they followed the symbolism where the artist cannot represent what he or she sees because, according to them, it is not art if this is the case. Therefore, for them, a man has to be in the world interpreting symbols.

Due to this heritage, the artistic vanguards will follow two distinctive tracks: the rational one of Seurat, Signac, or Cezanne and the 'form' way that will lead to Cubism, the other being the emotional track of Van Gogh and Gaugin with color, followed by the Fauves and Expressionism.

From the Avant-Garde on, art is not designed to please, and what is more, paintings are about art, not history. The Artistic Vanguards are more an attitude to art than an aesthetic, and they abandoned the imitation of nature to focus on the language of shapes and colors.

It is the hegemony of the unconscious, of the mental reconstruction of the work.

The viewer must have a new attitude toward the work of art. Artistic styles are no longer international and have become characteristic of a group of artists.

Painting and the Avant-Garde will follow two principles. One is the autonomy of art concerning reality in that art is not linked to the represented object. Representation is left to photography and cinema. The other is the abandonment of academicism of pure technique and the pure formula and the appearance of new techniques: collage, photomontage, and valuation of animal drawing.

The development of art is closely related to the development of science, technology, and technique, but also the development of mindset and approach to the world.

Engineering and Bridges

The role of science, applied in technology, technique, and art, is transcendental. In bridges, calculation and beauty go hand in hand (Arenas, 2002). Likewise, bridges built during Artistic Vanguards define hereby authenticity and innovation.

The typology of a bridge is intimately linked to the technology and characteristics of the materials composing it. Thus, the history of bridges can be divided into the period of stone, wood bridges, iron, and concrete bridges. It is worth highlighting almost 2000 years between the two eras.

Metal Bridges of the 19th Century. Coalbrookdale, built-in 1779, was the first metal bridge made of cast iron. It marked the beginning of a new era, even if it still suggested the figurative composition of stone bridges.

Wrought iron is a soft and malleable alloy with very low carbon content. As a result, it has low compressive strength and high tensile strength. The first large bridges built with wrought iron were Conway and Britannia. They have been one of the most innovative constructions (Fernández-Troyano, 1999).

At the end of the 19th century, one hundred years after the initiation of metal bridges, steel began to be used to build bridges. An alloy of iron with more carbon than wrought iron but less than cast iron, combining the former's tensile strength with the latter's compressive strength, is one of the important achievements of technology.

The first great bridge whose main structure was made of steel was that of St. Louis over the Mississippi River in the United States, built-in 1874.

From the end of the 19th century, steel imposed itself over iron as a building material. The two great bridges of the turn of the century were the first made of steel: the Brooklyn Bridge and the Firth of Forth Bridge.

Concrete Bridges from the 20th Century. Reinforced concrete with steel bars or mesh embedded in it offers increased tensile strength for bridges. It appeared at the end of the 19th and was developed at the beginning of the 20th century. The first reinforced concrete bridge was the Chazelet footbridge, built-in 1875.

The Martín Gil Viaduct will be considered the Spanish engineering masterpiece of the first half of the 20th century. It was a compendium of the most innovative systems of the time. Moreover, it was the largest reinforced concrete arch in the world of its time.

The prestressed concrete was modern, with stretched steel strands embedded to impart additional tensile strength. Nevertheless, it did not make reinforced concrete or metal bridges disappear; each had its field of application. In 1941, Freyssinet started the Luzancy bridge over the Marne river in the middle of the World War.

Composite Bridges for the 21st Century. The composite structure's innovation incorporates the platform's concrete slab into the resistant structure. It comprises a metallic lower head, webs of the same material, and an upper concrete head connected; steel must resist traction and concrete compression. In this sense, the raceway establishment supposed additional possibilities for metal bridges arising before or simultaneously with the appearance of concrete before the generalization of composite decks (Godard, 1924).

The tests of composite structures began shortly before World War I. After World War II, this system spread throughout the world, with time becoming almost as known as metal or concrete bridges. The German bridge over the Steinbach valley is a pioneering realization ahead of its time. In Spain, after the civil war, important constructions were built by Torroja (Torroja, 2010).

METHODOLOGY

The methodology of this study is based on a comparison of historical developments of art and bridge engineering, looking for a parallel between the milestones and periods of one and the other from the end of the 19th century towards the middle of the 20th century.

The scientific paradigm of Constructivism/Interpretativism is applied from the theoretical perspective and methodology of critical analysis (Crotty, 2012), breaking down the period of Historical Avant-Garde, comparing the different milestones of bridge engineering with artistic movements from the point of view of painting chronologically, always with the special focus and link of progress or technological innovation which principally emerged thanks to the development of science. As an approximation to understand the choice of the historical period, it should be noted that industrial revolutions are understood through the long Kondratieff cycles perspective (Kondratieff, 1935), widely described by Pérez (Freeman & Perez, 1988) or technological paradigm shifts, closely related to Kuhn's scientific revolutions (Kuhn, 2017). The studied period of Artistic Vanguards began after the first and second industrial revolutions. Their vision can be seen in Figure 1 as follows.

A schedule historically reflects the advancement of thought and mindset in terms of the sociotechnical landscape advancements has been drawn up, pointing out the most important milestones of the studied period. It is based on

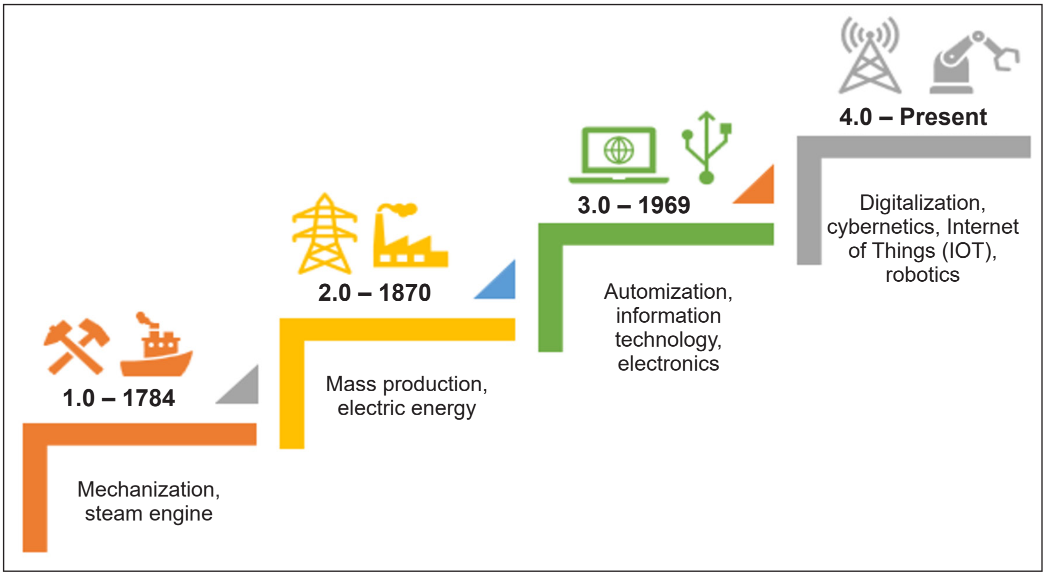

Figure 1. Industrial revolutions

identifying milestones, which are ordered chronologically. Accompanying artistic and technical movements, and new materials, the historical figures that made a difference are named for being the forerunners of this period of rupture and advancement of thought and praxis.

This analysis also follows the conception of different innovation ecosystem actors (Fernández et al., 2019). It is a more structural and collective intelligence-oriented approach to innovation than the romantic vision of an innovative entrepreneur or enterprise, which stems from the more reduced vision of relation dynamics (Schumpeter, 1911). According to this conceptual framework, three principal actors articulate the flow of relations in the innovation ecosystem. 'Government' is understood as a provider of physical and legislative infrastructure for the activity of other actors. 'Academia' is centered on the generation and diffusion of knowledge through its research and education functions. 'Industry,' in turn, is focused on productive exercise.

It corresponds with the underlying process of innovation developed under the multilevel perspective (Geels, 2010), with the phases of innovation being emergence in diverse niches, incubation, and diffusion towards the sociotechnical regime of socioeconomic reality functioning, and transposition towards the societal mindset at the sociotechnical landscape level. It is a never-ending spinning process, pushed forward by different challenges acknowledged at different levels, but mainly by the mindset of an evolving society.

RESULTS AND DISCUSSION

This study proves that in a century, in the aftermaths of the first and second industrial revolutions, and specifically in the interwar period, there is an accumulation of great innovations and changes in ways of understanding art and engineering.

In bridge engineering, progress was made notably due to the appearance of new materials, firstly steel and principally reinforced concrete. Likewise, in art, there is a break from what is commonly understood as art due to the introduction of new materials and new forms of expression and interpretation of the creative process.

The history of art has been marked by science and technique, in the sense that many artists have been involved in creating new techniques that finally enabled different ways of expression for them. For example, creating new pigments, types of paper, or new materials, led to their expressive use. Many times, the discovery and development of these techniques undoubtedly allowed the introduction of new forms of expression.

In engineering, the creative impetus is also linked to discovering new materials that allow expressive advancements.

Following the schedule (Figure 2), the appearance of determining materials in the construction of bridges, such as steel first and reinforced concrete later, coincides with the birth of Impressionism, the first artistic movement to break with tradition or rather with what is established to be seen as art.

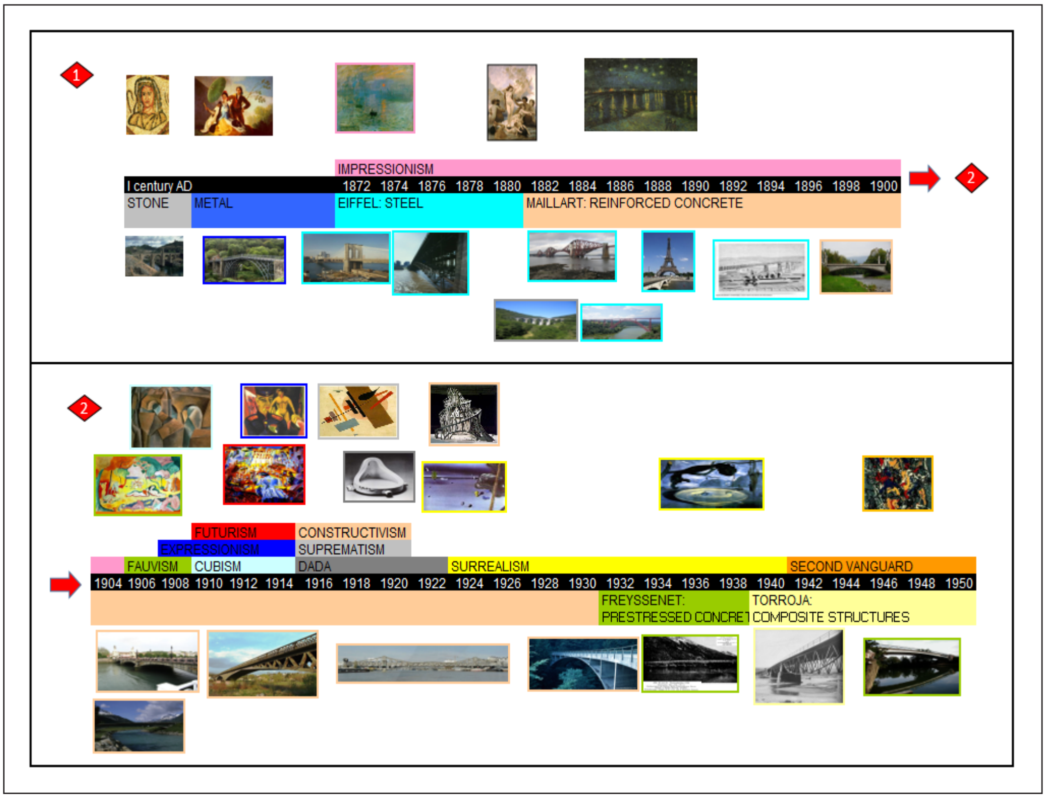

Figure 2. General schedule of artistic vanguards and bridges
Note. Image descriptions and sources are detailed in the partial view figures below

Monet's "*Impression, Sunrise*" focused on capturing reality, the moment, and the impression. Meanwhile, the Brooklyn Bridge by the Roeblings was built (Figure 3, section 2–2). At the time of its inauguration, it was the largest suspension bridge in the world. Like many other engineering works of this period, it has become one of the city's most recognizable symbols, in this case, New York. It was a record for a span until the Firth of Forth was built in 1889. It is an emblem of 19th-century engineering because of the innovative use of steel as a construction material on a large scale. It was also the first bridge suspended on steel cables.

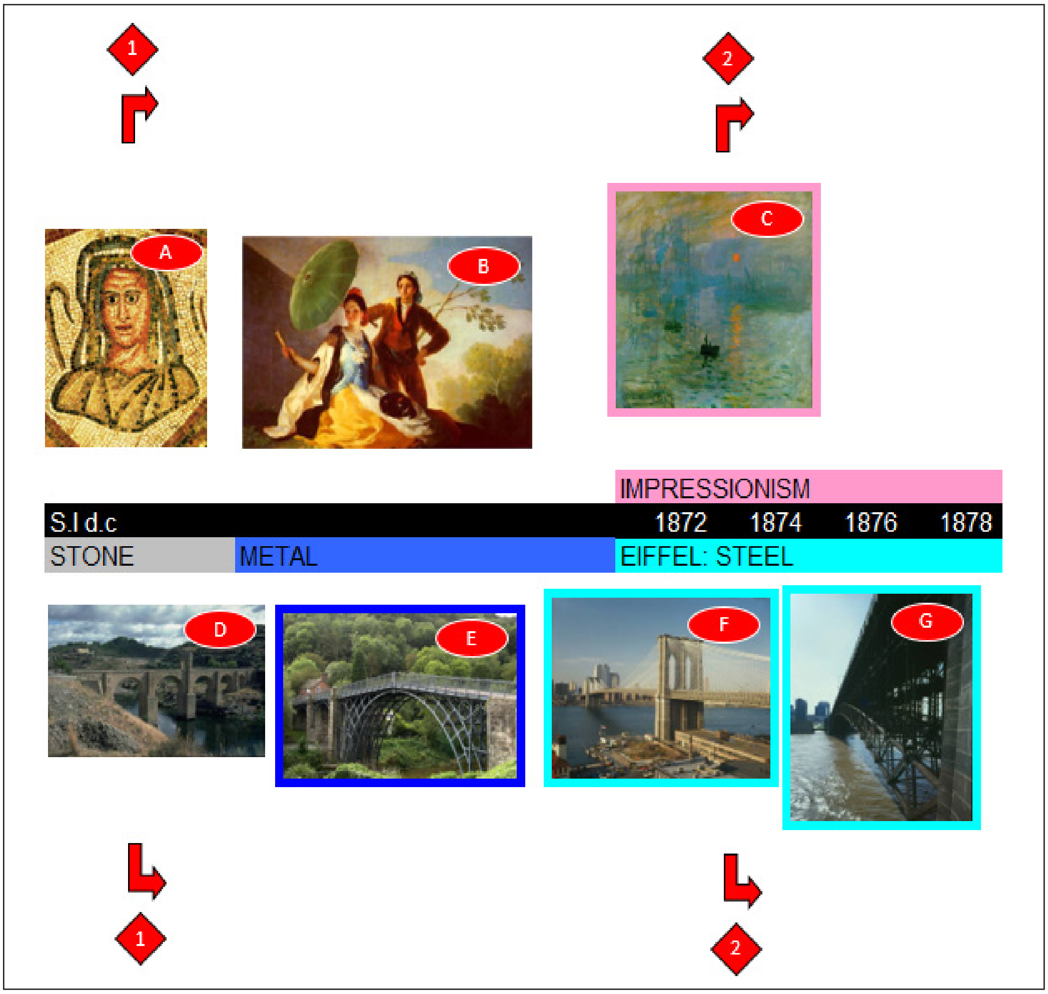

Figure 3. Impressionism and steel
Note. A: Mosaic ``Villa Romana La Tejada´´, Spain. Source: A - *www.terranostrum.es/turismo/villa-romana-de-tejada*. B: Goya (1777). The Parasol. Source: *www.museodelprado.es*. C: Monet (1872). Impression, Sunrise. Source: *www.artehistoria.com*. D: Bridge at Alcántara (Spain, 104-106), E: Ironbridge at Coalbrookdale (England, 1777-1779), F: Suspension Brooklyn Bridge (NY, 1869-1883), G: Eads Bridge (St. Louis, 1874). Source: www.structurae.com

They are even perceived as works of art, an example of that being the Golden Gate. It was inaugurated in 1937 as a display of 20th-century engineering. It was a milestone in the history of San Francisco and has become its most universal image.

Eiffel quickly became famous for his metal structures and is undoubtedly an example of an engineer of his time. He was a creator of symbols. Eiffel Tower is an emblem of France and its capital city. According to Eiffel (Coupérie-Eiffel, 2012), the construction should be strong, durable, elegant, and harmonious. This opinion becomes a catalyst for artistic movements and influences the progress in materials and bridge construction in the case of engineering.

Coalbrookdale led to the spectacular development of bridges in the 19th century. In those years, Goya painted "The Parasol." Goya's art also represented the beginning of contemporary painting (Milicua, 1994), and he is considered a precursor of the pictorial avant-garde of the 20th century.

It can be noted how an eagerness to break with the styles of the past is revealed. The parallelism and the audacity and eagerness to incorporate innovation in art and bridges seem clear; both result from the same need for expression and transcendence.

At the end of the 19th century, tradition, and its representatives, at the time considered true artists, such as Bouguereau (Figure 4, section 3-3), coexisted with transcendental and groundbreaking characters in history, such as Van Gogh or Eiffel.

One hundred eleven years elapsed between the construction of the Coalbrookdale Bridge and the construction of the Firth of Forth Bridge. It is the same period between "The Parasol" and "Starry Night over the Rhone" that Van Gogh painted in 1888 (Figure 4, section 4-4).

Artistic Vanguards was also the time of those who are understood today as great, global engineers. Due to their comprehensive work ethics, engineers understood projects from multiple perspectives. To translate this approach, they introduced new materials. In a sense, contemporary painters' aspiration was the same. With their transversal work ethics, they captured their thoughts and conception of reality on canvas, going far beyond what was believed and understood then by good technique. The Impressionist Monet and Eiffel, or the Cubist Picasso and Ribera, were all great connoisseurs. Nevertheless, starting from an absolute understanding of the technique and the past paths, they did know how to take another step. They dared not to copy but to transcend the past, to advance, and at the same time, consolidate almost two thousand years of history of art and engineering.

The Avant-garde itself was inaugurated with Fauvism, which questioned art as a representation of reality. It can be seen in Figure 5, sections 5–5, that the trees Matisse painted in "The Joy of Life" can be identified even when there are no pink trees or their shape is different. The painting does not capture reality, but the composition arouses emotions; simultaneously, excitement is captured through spots of color. Isn't art an emotion but science too? (Einstein, 1979). In parallel, Maillart, a truly innovative engineer with a clear aesthetic perception,

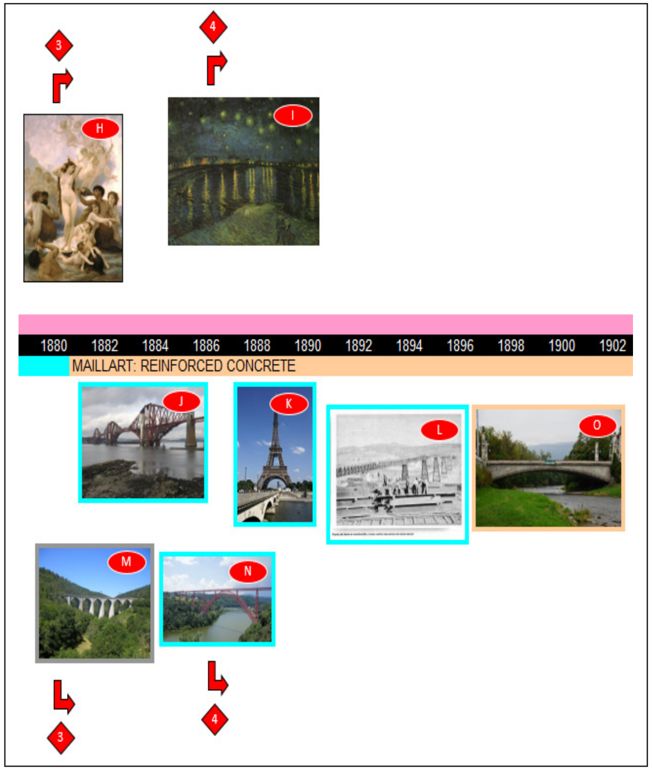

Figure 4. The rupture
Note. H: Bouguereau (1879). The Birth of Venus, I: Van Gogh (1888). Starry Night over the Rhone. Source: www.historia-arte.com. J: Forth Rail Bridge (Edinburgh, 1882-1890), K: The Eiffel Tower (Paris, 1887-1889), N: Garabit Viaduct (France, 1884), O: Stauffacher Bridge (Zurich, 1899). Source: www.structurae.com. L: Hacho Bridge (Spain, 1898). Source: www.puentedelhacho.blogspot.com/2007/09/el-ferrocarrl-digital.html. M: Crueize River Viaduct (France 1880). Source:www.wikipedia.org.

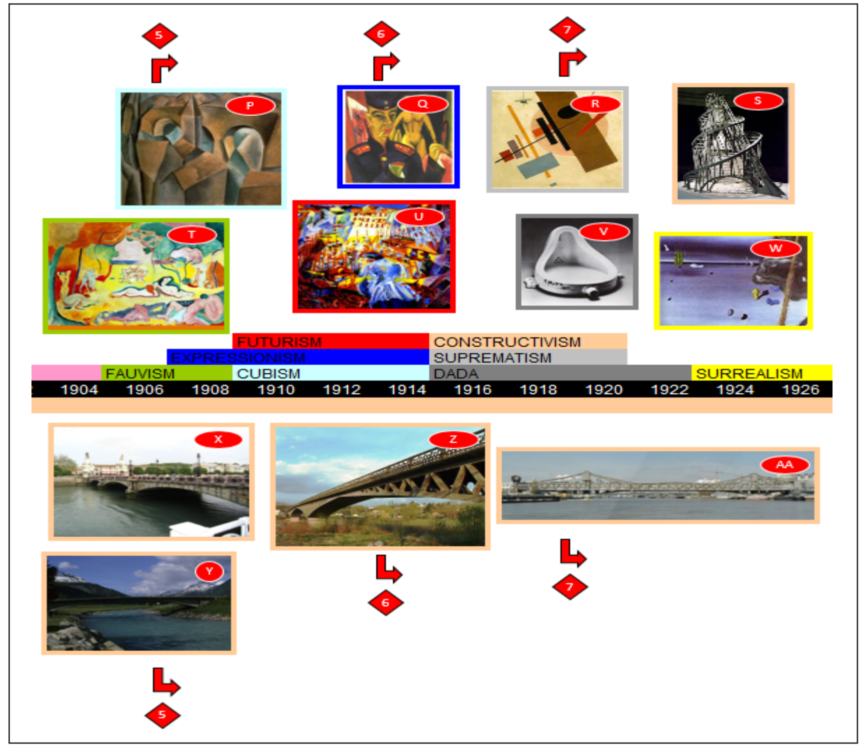

Figure 5. The artistic vanguards and reinforced concrete
Note. P: Picasso (1909). Landscape with a Bridge. Source: *www.paintingpalace.com*. Q: Kirchner (1915). Self Portrait as a Soldier. Source: *www.wikipaintings.org*. R: Malevich (1916). Suprematist composition. Source: www.widewalls.ch. S: Tatlin (1919). Model of the monument III International. Source: www.fahrenheitmagazine.com. T: Matisse (1905-1906). The Joy of Life. Source: www.henrimatisse.org. U: Umberto Boccioni (1911), The Street enters the House, V: Marcel Duchamp (1917). Fountain, W: Tanguy (1927). Mama, Papa is Wounded! Source: www.artehistoria.com. X: María Cristina Bridge (Spain, 1904), Y: Zuoz Bridge (Switzerland, 1901), Z: Boutiron Bridge (Vichy, 1912), AA: Ivry-Charenton Industrial and Pedestrian Bridge (France, 1926-1929). Source: www.structurae.com

collected the constructive and formal analytical heritage of the 19th century and created the tradition of reinforced concrete.

Kirchner, with Nolde and the first German expressionists, chose Die Brücke, meaning bridges, for the artistic movement. They intended to encourage overcoming individual artistic isolation from the beginning of the century, to enhance the spirit of collective creation (Figure 5, sections 6–6).

The First World War brought the Fordian model of division of labor into the production line. The car, which was the Ford product, greatly impacted the dimensions of mobility and, thus, the need for bridge construction. The conditions of immediacy and augmented technical requirements accompanied the demand explosion. Also, the beginnings of historical Bauhaus were strongly influenced by the trauma of the First World War and the need to absorb the shocks of the first two Industrial Revolutions. In the aftermath of the First World War, there was a pressing need for housing. It is, therefore, no coincidence that 'form follows function' was the main principle of the Bauhaus philosophy. However, it did not mean any form but rather a 'true form' that responded to functional requirements (Forgács, 1997). Moreover, industrialized products and houses were to be made culturally (i.e., socially, economically, symbolically, and practically) acceptable. This assumption holds in the present day when environmental sustainability is considered. From an artistic perspective, other recognized contemporary movements focused on sociocultural transcendence and the transversality of science, arts, and technology. These movements were the roots of recent efforts to unite artists and engineers. De Stijl's movement, in particular, manifested a strong sensitivity toward the social function of art and exerted a decisive. From De Stijl's perspective, art was for everyone, and architecture, as the mother of all arts, had a sacred, almost religious mission to shape life.

The very quality of mass production leads to standardization. Currently, decades after reinforced concrete discovery, the ease of its manufacturing and construction implies that, instead of applying all the knowledge and imagination to bring greater variety to the design of bridges, repetition is the prevailing trend.

The 1930s brought the development of European nationalism, generators of narcissistic withdrawals, and isolation on a collective level. Nevertheless, it is worth noting how, at the same time, it is a period defined by mobility, instability, and the dissolution of mental and physical borders that gave rise to the collective projects' advancement via exile or the educational or creative journey (Borja-Villel, n.d.).

At the artistic level, and in particular, in painting, a group of nonconformist artists appeared. It was a mixture of ingenuities that dynamited conventions and explored art history with the so-called avant-gardes.

Dada (Figure 5, section 7–7) was the most radical of the Avant-Garde movements, art for the sake of exhibiting it in a museum (Dewey, 1980). It can be reasoned that the new inputs were considered because of their 'exposition'. With the Artistic Vanguards first and all the art of the end of the century, the question of what art is reveals itself as very different from what it was until then. It does not seem by chance that one of the artists who most contributed to eliminating intrinsic characteristics from the concept of art, such as Duchamp, dispensing with beauty for beauty's sake, of retinal art that only satisfies the eye, also spoke of bridges; on his way to delve into the art that he makes you think. Reinforced concrete quickly spread throughout Europe thanks to the arch built for the 1880 Düsseldorf Universal Exhibition. It undoubtedly served to publicize this new material. African art from centuries of history was a recurring element in Picasso's work versus the 'Roman stone' of reinforced concrete.

At the end of the 20th century, the theory of conceptual art strengthened the idea that a work of art cannot be understood as something isolated, encapsulated between what divides what is or is not art. From then on, the work of art has to be placed concerning the historical, social, and economic conditions (Graw, 2014). After World War II, Freyssinet's dream was the development of a new technique, the prestressed concrete.

Surrealism developed in that same period, an unstable interwar time in which intellectuals tried to understand the psychic depth of man through dreams. Among dreams were those of Torroja Miret. He was one of the great engineers of his time, a great innovator, creating revolutionary forms never used before. Engineering makes up the border space between concepts and brings together the territories that do not have clear demarcations, according to one's attempt to understand the world. It champions the four dimensions of intelligence (logic), techné (practice), phronesis (wisdom), and metis (improvisation) (Scott, 1998), as it relies on the engineer's intuition in the different readings of reality; it enables direct work with sensitivity and commonality with art. An example of this in engineering practice was the work of Eduardo Torroja, for whom calculations only served to confirm his intuition. He was a master of reinforced concrete and contributed to composite bridges through what he defined as 'functional reason'. An example is the Tordera bridge (Figure 6, sections 8–8).

There are many examples of arts fascination with science, and new art forms emerge thanks to technology and materials developments. A good example was Salvador Dalí. This artist felt an unprecedented fascination for science: Einstein's theory of time, the uncertainty principle, nuclear physics, and as a surrealist, psychoanalysis. Furthermore, he managed to capture it in his works, merging creation with the main discoveries of the 20th century. The artist regretted that knowledge was too compartmentalized (Ruiz, 2010).

What is understood by functionality when designing can be considered another discussion. However, if anything, the orientation of the profession towards serving society, bearing in mind exclusively economic parameters, forgets that a functional bridge must have an acceptable aesthetic quality.

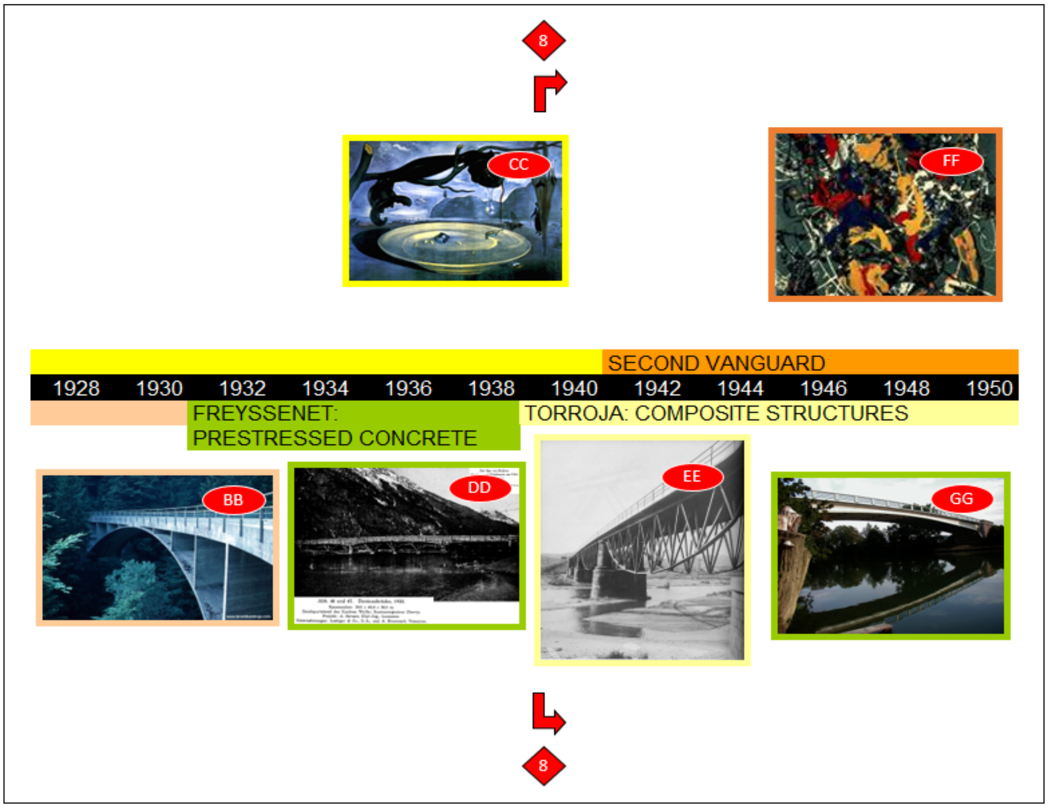

Figure 6. World War II: Prestressed concrete and composite bridges
Note. BB: Schwandbach Bridge (Berna, 1933), DD: Dorénaz Bridge (Switzerland, 1933), EE: Tordera Bridge (Spain, 1939), GG: Bridge over the River Marne (France, 1947-1950). Source: www.structurae.com. CC: Dalí (1939). The Enigma of Hitler. Source: www.obraporobra.com. FF: Pollock (1948). Number 3. Source: *www.wikipaintings.org*.

In this line of thought, and although it has been discussed repeatedly, it can be considered that there is still room for the analysis of art-engineering dimensions. Throughout history, they have gone hand in hand or diverged. This unequal road traveled together can be seen in the fourth-century Encyclopedia of Liberal Arts by Martianus Capella from the 5th century, which later led to a distinction between the arts of the mind and the hands.

Throughout the avant-garde movements, art tries to locate itself in a separate position, alienating itself from the other fields of human endeavor. In parallel, Constructivism, with a high political and ideological charge characteristic of the Russian Revolution, sought the union between the arts, painting, sculpture, and architecture. It, therefore, shared a goal with one of the most famous schools in the history of art, the Bauhaus. When understanding art as an expression of beauty, it is striking that the bridge is the construction most represented in the painting of the 20th century (Lanza, 2007).

This study is intended to be a bridge between two worlds: first, that of science and technology, and the other of art and culture, and in this way, bring the artistic vanguards period ideal of innovation into the current era. This historical tendency has been and is supported by many individuals, from Goethe (Goethe, 2002) to Einstein (Allimant, 2009).

CONCLUSION

This article critically reviews the art and engineering of bridges in the first half of the 20th century. As demonstrated, it is a historical moment where the expression of thought was directed with special intensity towards innovation. The choice of this historical period can be traced back to its wealth of breakthroughs in painting and bridge construction. Moreover, it served as a kernel for identification when these leaps brought a virtuous cycle of innovations.

The theoretical approach is articulated through a multilevel perspective, including the social malleability of technology. Likewise, the chosen period is located within the industrial and scientific revolutions. Therefore, they were relevant because of the direct change due to concrete technological innovation and the generation of indirect changes related to art transcending different societal levels.

Different milestones were chronologically compared following the common thread of the Artistic Vanguards. Specifically, in this interwar period, radical, disruptive innovation occurred in art and engineering. New tools for the development of creative impetus were sought. New figurative or material means were found, such as concrete in bridges.

Both the art and engineering of bridges have taken a parallel course, though, mainly but not only technological innovations. The Impressionist Monet and Eiffel, or the Cubist Picasso and Ribera, were great connoisseurs of the past. However, they dared to go one step further, to advance and simultaneously consolidate almost two thousand years of transversal history of art and engineering.

Analyzing the artistic vanguards, we can think that engineering innovation will also do so based on the relational character, the principles of transversality, and environmental and social sustainability. It is to absorb the impact and overwhelming cultural consequences of the subsequent two or three industrial revolutions, the last being sustainability. It should keep its position away from the dividing lines between disciplines and its idea of closeness between the functional and the aesthetic.

The sociotechnical regime, the main structure of economic and social functioning, tends to 'harden' to resist change, recoiling from radical or disruptive innovation to an incremental one. In the case of bridge engineering, knowledge of the regulations, their functioning, and construction methods retract towards repetition, incremental instead of radical innovation, as was the case of concrete discovery. There is a tendency to settle due to knowledge value chains, with suboptimal lock-ins and at least transitory rejection of new technology.

The sociotechnical landscape, hereby the art level, constitutes an exogenous environment beyond the direct influence of the regime actors. Nevertheless, it influences mindsets and allows the creation of a niche, thus fostering innovation.

It would be interesting to delve into new studies on why different artists have defined art as the engine of knowledge. From Paul Klee to Nacho Criado (National Prize for Plastic Arts, Spain 2009), the representation of anti-art, ante-exhibition, and a continuation of Dadaism can be found buzzing.

Art and engineering are, therefore, engines that can explain the world itself. They document society and its way of living, each of them expressing it in its unique way. They convey the evolution of human thought and endeavor, leveraging collective intelligence. From this transversal perspective, it is possible to spearhead the concept of STEAM (Science, Technology, Art, Mathematics) in education practice and research. A new educational system is required. It is a fact that people are overcoming the test of a new world with the education they received, far from what is required in today's world. In this new education, there must be a deeper interrelation between disciplines and art. On the other hand, the indefinite progress ideology is overcome through sustainable development. The cybernetic revolution has fragmented the previous world of objects in which the artistic vanguards developed. It is the society in which all the approaches are expected for the new revolution. Technology at the service of human happiness, freeing ourselves from repetitive tasks, which are now assumed by machines, is the result of this successive automation. The objective must be to reconcile the benefits and progress with sustainability, care for the environment, and respect for human rights.

This study pretends to broaden the vision of engineers and artists, encouraging them to take advantage of the potential of transversality. The fourth and, to some, even fifth (sustainability) industrial revolutions are already operating at different levels, disrupting almost all sectors of society. With concepts such as sustainable mobility, the new and inspiring field of bridge engineering, including aerial ones, can be envisioned. Art opens the ways of the imagination, valid also for engineers. It would be stimulating to apply this approach to different epochs.

In this study, art and engineering are placed at two levels in the innovation multilevel perspective. It would be inspiring to continue working on the concepts of artistic expression and how engineering can be considered a work of art.

It is necessary to study the history of civil engineering, public works, and their heritage as foundations to conduct the evolution of professional ethics. Humanities are not contrary to the techniques. On the contrary, their transversal, historical analysis, is compatible and complementary. Likewise, it is worth reflecting on the social ethos of the engineer. Hopefully, engineering ethics can be recomposed, choosing its heritage as a starting point the in the evolution toward new cultural dimensions.

There is little or no presence of women in the development of trends, both artistic in painting and technical in bridge engineering. As a line of future research, it could be highly recommended to revisit the role of women in innovation, thus expanding the evolution of the social mindset.

It is also necessary to review the concept of environmental sustainability and its applicability in the construction of bridges and, why not, in art.

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