

MİMARLIK ÜZERİNE-1

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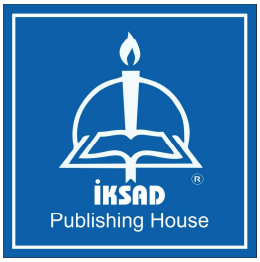
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INNOVATIONS OF ENGINEER-ARCHITECTS ON CONSTRUCTION TECHNOLOGY OF BRIDGES

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INTRODUCTION

The professional role of the architect is defined as *"building art and science"* in its simplest form and is to design a physical environment as a suitable place for certain human behaviors. This physical environment should meet the basic needs of the user and create a space to ensure certain norms such as survival, safety, physical health, mental health. However, an architectural design is not independent, while providing a facility for a limited number of human activities and focusing on its specific goals and functions; it is part of a hierarchical environmental system. Therefore, an architectural design is an intervention and adaptation to a large natural or man-made environment. In this context, architecture is a special action that is simultaneously introverted and specific; it is also a general public action on the environment (Herbert, 1999; p108). The role of the civil engineer is defined as *"the art of managing large power resources in nature for human use and comfort"* and shaping the macro environment according to the needs of the human. This definition is practically refers to the design of large urban and regional projects such as bridges and aqueducts, roads and highways, canals and railways, ports and dams, infrastructure schemes for drainage and sewage. Generally, the scope that defines the field of activity of the engineer is significantly expanded to include the design and construction of large-scale buildings, such as train stations, factories, exhibition halls or sports stadiums, in which innovative structural design or complex mechanical installations dominate (Skempton, 1996).

Architecture, which has turned into a heterogeneous profession, is associated with many disciplines and a wide range of specialized knowledge (İlerisoy ve Aycı, 2019). In this regard, the most advanced interaction takes place with engineering discipline in terms of both theory and practice. Despite the professional differences between architects and engineers; they use their professional knowledge, skills and experience for common interests of society, the protection of universal human achievements or cultural heritage, and for the development of human well-being. Their responsibility for the health, safety and well-being of society is always above their personal interests or the interests of the community of architects and engineers (Kumbasar, 2003; p17).

In the early design period, architects adopted flexible solutions to their designs freely. However they were concerned that if a structural engineer joined the design process at this stage, their design discoveries could be suppressed. In contrast, architect Arthut Erickson said, *"The structure is the strongest element of the form, and even if the structure of the building is not decided at the beginning of the design, then it may disrupt or change all the other determinants of the building."* The success of collaborative designs of architects and engineers in the 20th and 21st centuries structures show that there is a positive attitude on this issue among the professions. However, there are also issues that create conflicts between these professions. Structural engineers criticize the lack of structural understanding of architects, being late to get advice for appropriate structural solutions, and architects' overall standards of cooperation. On the other hand, architects criticize engineers for their lack of innovation and poor participation in architectural design ideas (Charleson ve Pirie, 2009; p102). Despite these criticisms; architecture and engineering has been one of the unquestionable components of life since the beginning of the human need for shelter. The first examples started in the Ancient Egypt and Mesopotamia regions, when people needed to move into settled life and build shelters (Çubukçuoğlu, 2016; p2). During the transition to settled life of the nomadic people, the importance of transportation and transportation vehicles has become an increasing need with the development of wheels and sails. In this context, "bridges", which are one of the most important structures that facilitate transportation in rugged areas gained importance.

Until about 1950, bridges were built by professionals without a clear distinction between engineers and architects. While there was no distinction between engineers and architects at that time; after 1950, engineer-architect distinction was made for the construction of bridges and all other building groups. In this study, it was evaluated how different

perspectives of people who have both architect and engineer ethics are reflected on the design of *bridges*.

1. DESIGNERS WITH ARCHITECTURAL AND ENGINEER ETHICS

In this section, Robert Maillart, Pier Luigi Nervi and Santiago Calatrava, who played an important role with their works in the light of both architecture and engineering ethics, were examined and an evaluation was made on the bridge examples.

1.1. Robert Maillart

Highway bridges are often subject to lighter loads than railway bridges and their paths are sharply curved or steeply inclined. Most bridge designers have begun to work with reinforced concrete in which steel bars installed as a new structure material to meet required needs. The master of this new material was considered to be Swiss structural engineer Robert Maillart, who designed the most original and influential bridges of the modern era. Born in Bern in 1872, Maillart studied engineering at the Federal Polytechnic Institute in Zurich. He developed an innovative method for designing bridges, buildings and other concrete structures. He avoided the complex mathematical analysis of the loads and stresses and the decorative elements used by many engineers. He designed new shapes to solve basic engineering problems by not imitating architectural styles and not using design elements for ornaments (Billington, 2000; p86).

Robert Maillart (1872-1940) is considered the pioneer of concrete construction. He made experimental studies to achieve the highest stress that reinforced concrete can resist (Billington, 1979). After his first experience as a bridge designer, in 1902 Maillart founded his own construction company in Zurich, Switzerland (Laffranchi ve Marti, 1997; p1280). He has accomplished many firsts with his designs by implementing different functions to the bridges. The Giesshubel Store in Zürich is known as the first building where mushroom slap flooring was applied. The column system with its mushroom-shaped head and slab with no beams, was soon adopted by other architects and started to be implemented. After his death, in 1991, the Salginatobel Bridge of the Maillart (1930) was declared an international historical civil engineering icon by the American Association of Civil Engineers.

1.1.1. Zuoz Bridge

Zouz Bridge (1901), with a span of 40 meters, was the first concrete hollow box structure ever built. Maillart reflected his evolving innovative

concrete structure view to his designs (Fig. 1.1). Engineer-Architect Maillart improved the bridge he built in Stauffacher (1899) and used following definition for the Zuoz bridge; *"It will not have big weight but it will have a great virtue as it was made with stone*." With this bridge, Maillart started a new era in concrete bridge construction, proving that the new arch form can be stronger, lighter and cheaper than a wall structure (Bruun, 2014; p364-2).
The bridge is about 4m wide. The central hinge is approximately 3m higher than the hinges at the ends. The bridge slab is 20 cm thick and the thickness of the arch varies from center to end points from 18 cm to 50 cm (Billington, 1979).



Figure 1.1. Zuoz bridge view (Billington, 1979)

1.1.2. Tavanasa Bridge

Tavanasa Bridge, designed by Robert Maillart, was the first application of articulated crate beams. The bridge was 61 meters in total and was completed in less than a year (Fig. 1.2). Since innovative designs, which were common in Switzerland at that time, required full-scale load testing to verify their durability. The bridge was opened to traffic after testing with overload in 1905.

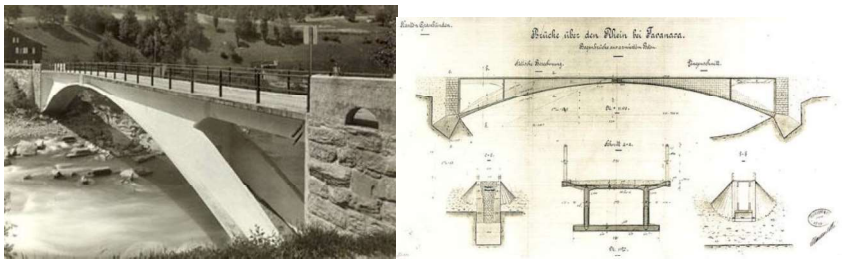


Figure 1.2. Tavanasa Bridge view and drawing of Maillart design (Caprez, 2018)

Unfortunately, the bridge was completely destroyed as a result of the landslide in September 1927. Professor Mirko Ros analyzed some concrete remains after a short time and determined that the strength of the material did not deteriorate. It has been proven that the collapse of the bridge is merely a misfortune of nature (Caprez, 2018).

1.1.3. Salginatobel Bridge

Salginatobel bridge, built in 1930, has an important place in the 20th century bridge design and attracted almost all experts and artists since it is considered as combination of engineering and modern art. The British traditional newspaper chose it as the best bridge of the century as a result of the worldwide survey conducted in the field of *"bridge design and engineering"*. Engineer-architect Maillart considered several different design options, but returned to the form he used in the old Tavanasa bridge, due to possible minor foundation movements in the soft rock that formed the Salginatobel.



Figure 1.3. Salginatobel bridge view (Billington, 1974; p62)

Maillart's previous experience in both design and construction of such arches encouraged him to use the three-hinged solution in Salginatobel (Fig. 1.3, Billington, 1974; p69). Salginatobel Bridge is 135 meters long and the arch is 90 meters wide. (Fig. 1.4) (Tapping, 2007).



Figure 1.4. Salginatobel bridge contruction (Tapping, 2007)

1.2. Pier Luigi Nervi

Nervi, who won the Royal British Architects Institute (RIBA) and the American Architects Institute (AIA) Gold Medals in 1960 and 1964, is

regarded as one of the most influential structural designers of its era (Cresciani ve Forth, 2014; p51). He contributed to the creation of an innovative era for structural architecture. Art historian Nikolaus Pevsner described him *"as the most brilliant reinforced concrete artist of our time"*. Pier Luigi Nervi graduated from Bologna University Civil Engineering Department in 1913 when the new reinforced concrete techniques were started to use by several pioneers, builders and designers such as Wayss, Hennebique and Maillart. Pier Luigi Nervi's professional career began in a period involves the innovative use of reinforced concrete. After working in the technical department of a construction company, he founded his own construction company in 1920 (Chiorino, 2010; p107).

Nervi is defined as a designer and structural engineer with the audacity of an engineer, the imagination of an architect and the practical realism of a businessman. He has always realized using advanced technical solutions and not only by seeking formal elegance, but by equally handling the technical and economic aspects of the building process (Chiorino, 2010; p107).

Nervi explained a general manifestation of *"structural architecture",* which summarizes the main features of his works, as follows (Nervi, 1963; p43):

> *"As the basic conditions of structural architecture:*
> *1. It must give a convincing answer to a real and demanding static imperative.*
> *2. Static in design, visible inside and outside; must be understandable.*
> *3. The material used in the building should be clearly stated and the technological features of the material should be used in architectural detail solutions."*

The structures of Nervi are more than successes in engineering, they are also considered as an architectural masterpiece with their formations, creative spaces, functional solutions and impressiveness. Nervi designed the buildings on his own, but also he was in close cooperation with other architects for the structural design of their buildings. All these features have made it one of the most important contemporary designers, which are equally adopted by both structural engineers and architects (Oggero, 2019).

1.2.1. Opera Bridge

The project of the four-span bridge in the center of Ankara was completed in 1969. After several changes, construction began in the early 1970s and

was opened to traffic in 1972. The Municipality took special care to realize the project with its original details and created a special budget for the project. The bridge was located on an intersection which connects city's main arterial roads (Örmecioğlu ve Er Akan, 2012; p257). Bridge; tight curved roads look quite different in shape with the main arcs. The bridge was created by a series of supports, combining the features of a cone and a cross shaped section structural quality and minimize concrete use (Fig. 1.5). Nervi also used cross-shaped columns in some of his other structures, including the Corso di Francia viaduct (URL-1).



Figure 1.5. Ankara Opera bridge view (URL-1)

1.2.2. George Washington Bridge – Bus Station

The 10.000 m^2 complex designed by the Italian engineer-architect Nervi; it was built as the only terminal building between New Jersey and New York. The building consists of steel and reinforced concrete beams. Fourteen of them were supported from the middle of the Trans-Manhattan Expressway. Special shape of the main beams supporting the roof was created to meet the natural light and ventilation needs. Nervi made it easier for natural air and light to reach the interior spaces by using triangular trusses. Although the main function of the building is a 'service building' that speeds up the transit of passengers, the Italian engineer designed similar details with his more iconic functions (Fig. 1.6, Cresciani ve Forth, 2014; p52).



Figure 1.6. George Washington Bus Station view (Cresciani ve Forth, 2014; p52)

George Washington Bridge and Bus Terminal, known with the award of the Concrete Industry Board, attracted attention not only for its expressive forms, but also with its design. The exposed concrete forms that make up the high view of the Bus Terminal are shown as a major engineering example (Taylar, 2012; p60).

1.3. Santiago Calatrava

Spanish architect, engineer, sculptor and painter Calatrava having international reputation and success, argues that the structure should be considered as the fundamental of the design. He has combined engineering and architecture in projects where aesthetic and structural harmony is aimed. Bridge designs, airport buildings, museum and concert hall projects of Calatrava make him a pioneer in recent architectural developments in Europe (Sharp, 2003; p13). Calatrava, which is among the distinguished architects of twentieth century engineering, goes beyond an approach that solves only technical problems. For Calatrava, a structure is at the balance between the scientific criterion and the novelty of the forms. He sees engineering as *"the art of the possible"* and designs in search of a new form based on technical knowledge (McQuaid, 1993; p9). He often uses sculptural forms that resemble living organisms in his projects. Although his projects are subjected to both admiration and a wave of criticism, it is seen that he contributed innovation to the architecture of the 20th century. In his original and innovative works as an engineer and architect; he has designed many buildings that change the immediate environment and refer to nature/living things (Mazur, 2019; p8). The biomorphic attitude is due to the similarity of Calatrava structures to animal skeletons or skeletal components. Their structures show the forms found in nature. This biomorphic approach of Calatrava seems to be in harmony with the intellectual atmosphere of the age. This is the usual result of the conscious search process of an engineer-designer who is not satisfied with the statics of the prime geometric forms (Ekincioğlu, 2000).

Hallgren (2014) starts an article about Calatrava by using the words *"movement, dynamism, inspiration from nature"*. The buildings of Santiago Calatrava reflect the natural form and movement with a mixture of art, architecture and engineering. The choice of white as the only color in their structure strengthens the emphasis on the form and movement. The sketchbooks he draws himself show the direct connection between his designs and human form. Despite being inspired by human form and nature, his works are unique and differ from repetitive constructed forms (Hallgren, 2014; p9).

1.3.1. Bac De Roda Felipe II Bridge

The bridge, which has a span of 140 m, is designed to connect two main streets (Sant Marti and Sant Andreu), and constitutes a reference point for the city. The difference in the elevation of the land in the design of the bridge was used to create a basin in the railway area. Two steel arches 8 m above the railway; one of which extends towards the rails and the other allows pedestrian traffic through the structure (Fig. 1.7). Four staircases that follow these steel arches and provide connection to the lower level are designed to direct pedestrians to the station and the park at the same time (Winstanley, 2011).



Figure 1.7. Views form Bac De Roda Felipe II Bridge (Kutlu, 2016)

In the design of Bac De Roda Felipe II Bridge, which is designed for 1992 Olympics in Barcelona, Calatrava aimed to integrate the bridge with its surroundings, to create a steep axis (park and main road), and to create an urban space by turning its sidewalk into a closed area with its structural design. Thanks to the innovative line of the profile, which is designed with the opportunities provided by the engineering technique; it looks light and thin, but also elegant and bold. On the bridge, Calatrava's presentation of different perspectives (cultural, artistic) reflects the goal of recreating, decorating and developing the urban space. In addition, one of the most important points in design is to create an integrity between the new structure and the urban space (Cadafalch, 1994; p360).

When the scale of the bridge is examined in terms of its surroundings, the peaks of its arches are designed lower than the surrounding buildings. It appears that the arch form and the side arches are derived from a simple fish shape after Barcelona's relationship with the sea, and the tails of two fishes are used to the shape of each curve (Figure 1.8) (Thoume, 2009; p4).

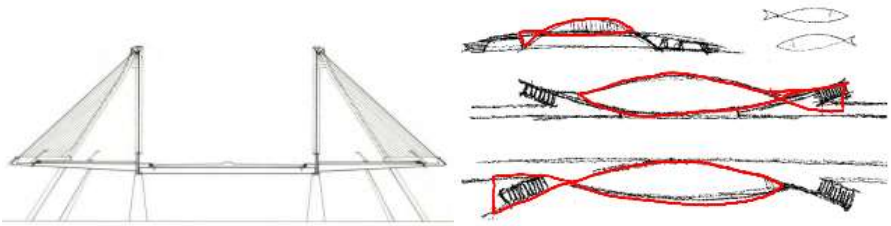


Figure 1.8. Section of the bridge and fish drawings of Calatrava (Thoume, 2009; p4)

Spatial symmetrical double arch bridge sample was applied for the first time in this bridge (Sarmiento-Comesías vd., 2013). Spatial arch bridges are bridges that are not located in the arch plane due to their geometric and structural configuration and contain vertical floor loads that produce bending moment and shear force (Sarmiento-Comesı´as, 2009).

1.3.2. Alamillo Bridge

Alamillo is a long span bridge that crosses the Guadalquivir river, built for Expo '92 at Sevilla in 1992. The bridge is a cable supported structure covering 200 m without intermediate supports and its stability is provided by the backward slope of a large pylon (Fig. 1.9) (Aparicio ve Casas 1997; p432).



Figure 1.9. Alamillo Bridge views (Orr, 2008; p2)

Although the bridge has a steel structure, it is a composite material formed with an external steel formwork that is structurally attached to the pylon concrete (Aparicio ve Casas 1997; p432). In the design of the bridge, which has a special character at the end of the exhibition area in Seville, Calatrava realized two different functions for both vehicles and pedestrians. The 4.5 m wide pedestrian road in the project shows that special attention is given to pedestrian traffic (Casas ve Aparicio, 1998; p24). Calatrava used a new cable-supported bridge type with support ropes balanced the weights of the 58 degree bent pylon. 13 pairs of ropes

with 200m long supports articulated crate beams with hexagonal shapes that extends on river Meandro San Jeronimo. The Alamillo bridge eliminates the belief that static elements should be symmetrical and rigid (Figure 1.10) (URL-1). In this design, it is seen that Calatrava created his design with the inspiration of nature and living things (Figure 1.11).

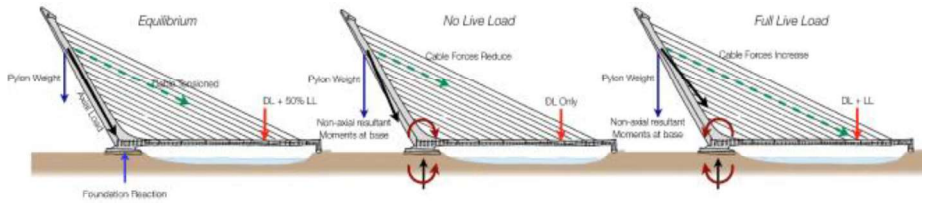


Figure 1.10. Alamillo Bridge loads to the ground (Orr, 2008; p2)



Figure 1.11. Alamillo bridge inspired by nature in design (Orr, 2008; p2)

1.3.3. Puente de La Mujer Bridge

Puente de la Mujer (Women's Bridge) is a movable and rotating bridge made of reinforced concrete and steel in Buenos Aires (Fig. 1.12). It is the only project of Calatrava in Latin America to date. The bridge was created by abstracting a couple's tango dance. The 39 degree slope pylon standing to hold the cables represents the man holding the woman leaning over. The bridge is similar to the Alamillo Bridge in Seville (Groysman, 2011; p105).



Figure 1.12. Puente de La Mujer Bridge view (Wrana, 2016; p172)

The bridge, which is made only for pedestrian use, has suspension (wired) structure. It consists of three parts; two immovable and one movable sections (Wrana, 2016; p172). The platform, 170 m long and 6.2 m wide, is supported by 19 ropes. The construction of the pylon with ropes is asymmetrical to the bridge axis. However, the section mounted on a movable support allows the watercourse to be opened in the port channel. In the open position, the pylon axis is perpendicular to the main axis of the bridge. The characteristic color of Calatrava designs contrasts with other buildings/structures in the port and emphasizes structural lightness (Fig. 1.13, Dąbrowiecki, 2009; p42).



Figure 1.13. Puente de La Mujer views (Dąbrowiecki, 2009; p42)

Calatrava fulfilled an important requirement both in terms of structure and design in this bridge. The institution that applied for the project, La Corporación Antiguo, has demanded a pedestrian bridge that would connect the plazas on both sides of the embankment and a space for a loading port used for sea traffic (Madero, 2007). As well as providing all these requirements, Calatrava has given the region an important focus in terms of aesthetics.

2. EVALUATION

The features and chronological evaluation of the bridges of three designers with engineering and architectural ethics, which are important in terms of the innovative features brought to the 20th century architecture and structure design, are evaluated in Table 2.1. First of all, with the development of the steel industry in building materials, it was observed that the steel was started to be used more frequently and bridge spans increased due to the properties of the steel. In addition, it was observed that the three designers produced different alternatives and designs in different countries. **It is seen that bridge could create a focus point in the city as a design element apart from the function of providing only transportation due to increasing aesthetic anxiety.**

Table 2.1. Evaluation of the bridges scope in the study

Bridge Prop. / Bridge Name	Y.– L.	H.	S.	M.	Innovation	Arch.
Zuoz Bridge	1901-Switzerland	51 m.	40m.	C	"The first three-hinge arch bridge"	Robert Maillart
Tavanasa Bridge	1905-Switzerland	-	61m.	C	"Articulated crate beam"	Robert Maillart
Salginatobel Bridge	1929-Switzerland	90 m.	135 m.	C	"The most economical bridge"	Robert Maillart
G.Washington Bridge-Bus Station	1963-USA	-	-	C	"Concrete Industry Board Award"	Pier Luigi Nervi
Opera Bridge	1968-Turkey	-	-	C	"Cross-sectional columns"	Pier Luigi Nervi
Bac De Roda Bridge	1987-Spain	8 m.	140 m.	C+St	"Symmetrical double arch bridge"	Santiago C.
Alamillo Bridge	1992-Spain	140 m.	250 m.	C+St	"Cable supported bridge type"	Santiago C.
Puente De La Mujer Bridge	1998-Argentina	35 m.	170 m.	C+St	"Architectural solution originality"	Santiago C.

Abbreviations
Y. Year **– L.** Location **– H.** Height **– S.** Span **– M.** Material **– Arch.** Architect **– C.** Concrete **– St.** Steel

It is observed that all three engineer-architect pushed the boundaries in terms of bridge heights and openings with innovative experiments. However, with the development of technology towards the end of the 20th century, it has reached the top point with the designs of Calatrava. Calatrava's understanding of aesthetics in the bridges has changed over

time with the world view that *"function does not dictate form"*, which contradicts Louis Sullivan's definition. Calatrava reflected this understanding on the sculptural forms he tried to design on his bridges. However, Maillart and Nervi did not focus on the relationship between form and function as Calatrava did.

In addition, it is seen that bridges affect today's technology in different areas and contribute to innovation. Maillart, who achieved successful results with his experimental studies at the hinge points of the bridges, succeeded the most economical bridge of its period. Pier Luigi Nervi produced aesthetic and innovative systems in its structural experimental studies. These constitute examples for many bridge constructions made today. **Calatrava, on the other hand, proved that bridges can transform into a social life space with sculptural forms and different space designs.** Therefore, he aimed at creating center of attraction in the urban areas, by expanding the conceptual meaning of bridges. In this process, different types of structural materials such as cable-supported bridge types, pre-stressed concrete, and innovative uses were also included.

Robert Maillart designs with different beam types in the early 1900s have reached today. **It provided the concept of cost, which is one of the most important elements that a building should have,** in the Salginatobel Bridge, built on the Salgina River, and it broke new ground in the world of architecture. Nervi's domination on the material was registered with the "Concrete Industry Board Award", he received for the design of the G. Washington Bridge-Bus Terminal. The effects of engineering education and the presence of strong static and dynamic knowledge leaded his designs. **Calatrava, one of the pioneers of today's most interested biomimetic design, also uses dynamic effects in its bridges with this approach.**

3. CONCLUSION

The works of Robert Maillart, Santiago Calatrava and Pier Luigi Nervi in the light of architectural and engineering ethics are investigated on *"bridges"*. When the selected examples are analyzed, it is seen that all three engineer-architects brought different architectural perspectives to the bridge, apart from being part of the transportation system. This architectural perspective is blended with engineering ethics and each architect has brought a different originality to the bridge in each design. While this originality is sometimes provided with the material used, sometimes it is provided with the additional functions brings to the bridge, sometimes with the span length. These architects who try to

overcome the limitations of the structure technology of their time with their own solutions; will be **an important role model for architects and engineers who will design the built environment in the future.** Designers who catch the relationship of form with structure and material as well as the innovative fiction of architectural design with the city at the bridge scale, will make their signatures to the city in the future as in the past.

Structural configurations of evolving bridges with time offer much more than just crossing from one place to another. New types of bridges suitable for different functions and use by different vehicles have come out. Bridges are also expected to respond to aesthetic concerns and make a name for themselves. It is seen that positive effects achieved through bridges such as innovations in architecture and engineering ethics, contributions in user comfort and social life have reached a desired point with time.

In the engineering and architecture relationship discussed from the bridge examples, even though the bridge structures are perceived as engineer structures, it is seen that aesthetic, innovative, cost-effective bridges can be designed by people who have mastered both disciplines. Designers with these two ethics have the ability to create a break between art and technique, pushing the boundaries. They also ensure that the inspiration is transformed into a design and the design into a structure with original and innovative contributions. Three architects-engineers, studied with within the scope of the study, started their designs by trying forms expressing their views of structural art. Then, they used analytical techniques to develop the plans of the forms they designed. **Their works offer valuable lessons for engineering and architecture, which are two different professional ethics.** Since they have artistic sensitivity, broad construction experience and deep technical competence, they create surprising original bridges and industrial structures, giving today's designers the opportunity to examine. **In this context, from bridges to all architectural structures; it is an undeniable fact that the contribution of architectural ethics to engineering ethics is positive in terms of many features. In today's building design art, these two ethics should be handled together.**

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