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EXPERIMENT WITH THE USE OF CABLE-SUPPORTED STRUCTURES AS AN EXPRESSION OF ARCHITECTURAL AVANT-GARDE

EKSPERYMENT Z ZASTOSOWANIEM KONSTRUKCJI CIĘGNOWYCH JAKO WYRAZ AWANGARDY ARCHITEKTONICZNEJ

Abstract

In the field of architecture, experimental projects are usually called innovative projects – implemented as a result of beliefs about the validity of the innovative solutions used, not necessarily checked with laboratory methods. The term experimental is used to categorize objects with ground-breaking, prototype solutions. This architecture is formally and technologically advanced, innovative – avant-garde for its time. In fact, a great experiment has been underway since the mid-nineteenth century, also on a gigantic social scale. The article highlights its specific “variable” – experimental architecture based on tension structures. The research on this issue was based mainly on a literature review, own observations and multiple case studies.

Keywords: architectural form, avant-garde, cable-supported structures, experiment

Streszczenie

W dziedzinie architektury eksperymentalnymi nazywamy zazwyczaj projekty nowatorskie – realizowane w wyniku przekonań o słuszności zastosowanych innowacyjnych rozwiązań, niekoniecznie sprawdzanych laboratoryjnymi metodami. Pod pojęciem eksperymentalnych przyjęło się kategoryzować obiekty o przełomowych, prototypowych rozwiązaniach. Jest to architektura formalnie i technologicznie zaawansowana, nowatorska – awangardowa w swoim czasie. W zasadzie od połowy XIX stulecia trwa wielki eksperyment, także na gigantyczną społeczną skalę. W artykule zwrócono uwagę na jego swoistą „zmienną” – eksperymentalną architekturę stworzoną w oparciu o struktury cięgnowe. Badania owego zagadnienia oparto głównie na przeglądzie literatury, obserwacjach własnych oraz wielokrotnym studium przypadku.

Słowa kluczowe: awangarda, eksperyment, forma architektoniczna, konstrukcje cięgnowe

*We are entering a period in which construction
has become the avant-garde of architectural design*¹

Tony Robbin

1. INTRODUCTION

When analyzing the history of art, the experiment does not seem to be something specifically modern. It appears as a permanent element of culture occurring under conditions of favorable coincidence – when extraordinary creative personalities encounter, in the area of their activity, favorable external conditions.

The modern experiment referring to the disciplinary matrix of the scientific method is closely related to the notion of the avant-garde. It can even be considered that this direction has elevated it to the rank of the Creator's duty. In architecture, there is a common need to search for innovative solutions to problematic issues, which ultimately penetrate into construction practice, taking the form of specific detailed proposals. There are projects that draw mainly from new technologies, but also from ecological and social ideas, and even directly from a philosophical observation focused on aesthetics. Successful design experiments are subject to institutionalization and over time become a common solution used by all participants of the engineering and architectural creation market. This process is one of the basic elements of culture. In relation to architecture as a discipline that organizes and shapes space in real forms, we are rather dealing with a creative experiment; however, for its full implementation to be successful, it is necessary to draw on the resource of successful engineering technical experiments. Due to the systematically growing role of science, an architect should have full knowledge based on strict scientific research procedures to maintain the status of an expert profession.

However, some architects see the experiment as a threat, considering the construction industry too expensive to be treated as a field for the implementation of engineering inventions. In the history of design innovations, we often find examples where the earth's gravity has taught engineers a dramatic lesson in humility. Even in projects with an extremely strong theoretical basis, confrontation with the forces of nature may reveal underestimations and erroneous basic computational assumptions². Ignoring the costs incurred for introducing innovations, as it were, the avant-garde classifies the experiment as a necessary mission of all Creators. It is reflected in the slogan of Alexander Rodchenko, a representative of constructivism: *it is our duty to experiment!*

¹ T. Robbin, *Engineering a New Architecture*, Yale University Press, New Haven, 1st edition April 24, 1996.

² In 1940, the famous disaster of the Tacoma Suspension Bridge took place. The bridge located in Washington state in the United States had a span of 853 m. The wind blowing at a speed of up to 67 km/h set the structure of the pier into a twisting motion with a deflection of 8.5 m; after 30 minutes the first elements of the pier began to detach, and after an hour the entire deck collapsed. Even in the 21st century, we are not able to avoid some mistakes. A spectacular failure was caused by the designers of the Millennium Bridge – a pedestrian crossing over the Thames. The predominantly steel suspension bridge was opened on June 10, 2000, but only for two days. Insufficient research on the phenomenon – vibrations caused by the synchronized movement of a huge number of users forced the authorities to close and costly rebuild.

2. INSPIRATIONS – MOTIVATIONS – INNOVATIONS

Reaching far into the past, examining the history of human activity, and especially analyzing the biographies of extraordinary personalities, we notice that from time to time there is a phenomenon of breaking the existing patterns that provokes changes and progress. The intensification of this phenomenon took place in modern times, especially during the industrial revolution – the heyday of science and technology. During this period, we are dealing with a consciously planned and methodically implemented experiment³.

In 1889, during the world exhibition in Paris, the Gustave Eiffel tower revealed an innovative engineering concept with its over 300-meter height, unprecedented in construction, and a new statics formula based on an openwork system of steel trusses. The construction of this building was not to fulfill any functional tasks. The aim itself was to demonstrate the possibilities of the new construction, to show that building by trial and error is a thing of the past. Today, the tower seems to symbolize the era of technical culture.

The awareness of the existence of gravity and the need to counteract it have always been the motivation behind the experimental search for solutions in which the static idea and appropriately selected building material determined the durability of the object under construction. Regardless of beliefs, preferred style or direction in architecture, the structure and form of a building are inextricably linked. Sigfried Giedion draws attention to the special nature of this relationship in the history of construction⁴.

These desires were the earliest that came true during the construction of suspension bridges. Improved steel technology was used in the production of ropes and made these basic elements of the load-bearing structure unexpectedly strong. America overtook Europe in these experiments. In 1798, a suspension bridge on steel cables was built in Pennsylvania, and in 1824 near Tournon, France⁵. The principle of transferring the entire load to uniform, flexible steel cables running along the structure, adopted at that time, is still the basis for the construction of the boldest bridges in the world.

In the nineteenth century, buildings with cable-stayed roof were not completed, but then there appeared objects that can be considered ideological, prototype models of this architecture. They revealed the possibility of realizing the desires to take over the spaces of huge volumes for new utility functions. In 1851, Joseph Paxton placed an orangery on the surprising scale of the Cristal Palace space. In 1889, the constructor Victor Contamin and the architect Ferdinand Dutert built the Palais des Machines – a hall for displaying machines with unusual dimensions at that time: span of 117 m, height 46 m and length 420 m⁶.

The system of steel trusses used at that time in both buildings allowed for an innovative shape of the architecture, which was not expressed in the mass of matter, on the contrary, it gave the impression of lightness intensified by glazing. The static idea allowed to create single-space interiors not disturbed by partitions or pillars. All this meant that an architecture appeared where movement seemed to penetrate the space, movement perhaps as innovative as

³ In terms of methodology, an experiment is always planned and means an ordered set of activities aimed at verifying a hypothesis. By experimenting, we expect results, the analysis of which will provide a certain amount of knowledge.

⁴ S. Giedion, *Przestrzeń, czas i architektura. Narodziny nowej tradycji*, PWN, Warszawa 1968, p. 10.

⁵ *Ibidem*, p. 206.

⁶ N. Pevsner, *Pionierzy współczesności. Od Williama Morrisa do Waltera Gropiusa*, Wydawnictwa Artystyczne i Filmowe, Warszawa 1978, p. 136.

the one that Francesco Borromini captured in his architecture. From around the mid-twentieth century, such effects appear in structures with a tension structure. The work of this structure is indispensable wherever the static idea has to cope with huge spans and volumes, i.e. in all those facilities where the functional program requires single-space interiors⁷.

In the light of the past, it is confirmed that the buildings constructed in the 19th century laid the foundations for the modern art of building. Today, construction knowledge, including that of cable-supported structures, is based on new calculation methods that check and confirm intuitive static ideas. Structural elements are treated in calculations as linear elements, and the assigned work of forces is to act in precisely defined directions. Technological innovations facilitate the modification of methods and methods of implementation. They enable standardization and prefabrication of structural elements, which in practice leads to their precise integration at the construction site. Economic considerations and the time of implementation are also important here. All these undertakings are supported by work with a computer. It allows you to quickly perform all complex calculation and design operations. This enables the choice of variants of static assumptions: reduction of mass, increase of stiffness and stability of the structure. Computer images represent the characteristics of a thing before it is realized⁸.

Without bold, pioneering production experiences dating back to the 19th century, appropriate corrections would not be possible. They would also not be possible without continuous improvements in technology⁹ and building materials. Achievements in this area meant that

⁷ The first facility to use high breaking strength ropes was the Raleigh Arena. This facility gave rise to the development of modern – pre-tensioned – hanging cover structures. The pioneering structure of the “Cow Palace” arena, designed in 1950 by Maciej Nowicki, was erected in 1953. The supporting structure of the roof is a pre-tensioned tension mesh in the shape of a hyperbolic paraboloid. Thanks to this saddle surface of the roof, an extremely important problem of rainwater drainage has been solved – water flows down to the lowest points of the arches crossing. The aforementioned wire mesh of various diameters was attached to two mutually intersecting parabolic reinforced concrete arches. The hall is covered with a glass wall, which enhances the impression of lightness and dynamism of the architectural form of the building resulting from the covering solution used. This object, considered to be a prototype of a “hanging roof”, won the AIA Honorary Award in 1953, was included in the list of 10 most significant buildings in the history of architecture by the Architectural Record in 1957, provoked numerous imitations and inspired many artists.

In America, the pioneers in the development of hanging covers were also: Buckminster Fuller, who was stubbornly looking for new solutions, designing tension covers on the wheel projection, and Walter Bird. The latter and his team formed Birdair Structures Incorporated in 1956 to promote, design and manufacture pneumatic structures.

Another American designer, David Geiger, who is considered to be the creator of the system for erecting suspended domes of the largest spans, also has an important contribution to the development of tension structures. In 1968, as a constructor, together with Davis Brody Associates from New York, he designed the United States pavilion at Expo’70 in Osaka. 100,000 m².

⁸ P. Jodidio, *Nowe formy. Architektura lat dziewięćdziesiątych XX wieku*, Musa SA, Warszawa 1998, p. 44.

⁹ In this field, the achievement of the outstanding American engineer Johan August Roebling was particularly important. This talented constructor developed in 1841 an innovative method of making suspension bridge ropes. Until then, they had been prepared in advance – outside of the construction site, it was only Roebling who identified and patented a method of forming large, strong cables from thin single rods continuously wound on site. This fast, effective and much cheaper method opened new, great opportunities for bridging – since then it was possible to build bridges with much larger spans and overcome more difficult obstacles.

steel and reinforced concrete found their permanent place in everyday construction practice, and the implementation of bridges and hanging covers could not do without them¹⁰. Steel is used in suspension bridge elements: in the main load-bearing ropes, suspension hangers, lattice pylons and platforms, and in suspended bridges also in guy ropes. In the case of concrete, its strength and plastic qualities are used to model the sculptural shapes of the pylons. It was concrete that made the pylons of the Alamillo Bridge in Seville or the Marian Bridge in Usti seem more like sculptures set in the urban landscape than elements of a load-bearing structure. Reinforcement and steel also appear in static elements of cable-stayed roofs: in supports – columns, masts, arches and the entire rigging system. Glass completes the programmed whole.

With time, more and more interest was aroused by polymer composites reinforced with carbon, glass and aramid fibers. This also applied to glass or polyester fabrics coated with Teflon or silicone. The surprising strength and lightness of this material allows to reduce the own weight of the structure, and in hanging structures it is an important feature. In facilities where the utility requires natural lighting, the transparency of these materials is an advantage that speaks for their increasing popularity. The interior is not only well-lit, but the mood in the play of lights is constantly changing.

Meeting the new functional needs provoked the exceeding of the existing ones: the height of buildings, the span of roofs and bridges. It turned out that the boundaries that until recently seemed to be insurmountable in the construction of bridges and roofs were easily overcome thanks to cable-supported structures¹¹. This type of construction, being both a means and an end in itself, becomes a starting point for a different organization of space.

In pioneering buildings such as the already mentioned Cristal Palace or Palais des Machines, spaces of interiors free from the forest of supports, which were surprising in the recent past, are now widely used. What is more, without such spaces, it would not be possible to realize today facilities that would correspond to the new habits of living, working and relaxing. These new requirements provoked the expansion of the functional program. Not only the structure and matter, but also the function became the motivation for the search for a new shape of the building¹². There were huge cable-stayed roofs covering the stands of stadiums, roofs hanging over sports facilities, railway and airport stations, exhibition and multifunctional buildings as well as industrial halls with previously unseen spans. That is, wherever a large number of people are present at the same time. This is evidenced by the audience of the Olympic stadium in Munich (1972), which can accommodate 80,000 spectators¹³ (Ill. 1).

¹⁰ At the time, steel was at the forefront of new processes. It not only provided exceptional technical possibilities, but its numerous properties made it the material preferred by architects. Its greatest advantage is the unlimited freedom of creation, and the combination of various materials with it allows for rich expressive forms. In combination with glass, it allows for the perfect use of light and space.

¹¹ M. Salvadori, *Sila architektury. Dłaczego budynki stoją*, Wydawnictwo Murator, Warszawa 2001, p. 289.

¹² M. Misiągiewicz, *Kolejne granice współczesności – refleksja o architekturze pod koniec wieku*, [in:] *Czasopismo Techniczne Architektura*, Kraków 1998, p. 48.

¹³ The surprising buildings that make up the functional program of the entire Olympic complex were created thanks to precisely prepared experimental tests carried out by the Freia Otto team. Computational techniques did not allow to capture the influence of wind on large-scale suspended structures at that time. Therefore, an innovative method of tests performed in a wind tunnel was developed. Descriptions of the procedures for successive flow-loading tests, measuring responses, and verifying data are admirable to this day.



III. 1. Olympic Stadium in Munich, 1972, photo by: Kulmalukko, source: <https://www.budowle.pl/budowla/olympiapark> (access: 28.06.2022).



III. 2. The Golden Gate Bridge, situated at the entrance to San Francisco Bay, 1937 – its span of 1,280 m was the largest in the world until 1964, photo by: Patryk Brylka.

To cope with such a task meant the necessity to erect buildings of previously unimaginable dimensions. In engineering practice, span is the starting point and it was the basic criterion in finding solutions. Static rules of tension structures turn out to be extremely useful for such purposes. Due to functional motivations, an architecture that is surprising in its scale appeared in the world transformed by man (Ill. 2). It became possible thanks to the tension structure, which expanded the repertoire of forms used in the architectural composition.

Perhaps it will be true what the English constructor Felix Samuely said in the 70s of the twentieth century “in the centuries to come, historians will consider our epoch as one whose structure has developed from a plan into a spatial system, thus giving rise to a new architecture”¹⁴.

3. EXPERIENCING

As a result of the experiment, we receive some feedback – a theory, hypothesis or assumption is confirmed or disproved. In the field of art, that is also architectural creativity, this response is experienced not only by the authors, but also by the recipients of the work. As the Danish architect and town planner Steen Eiler Rasmussen argued in the mid-1900s in his famous book *Feeling Architecture*: “it’s not enough to see architecture; it still has to be experienced” – the direct, physical experience of architecture is shared by the recipient with its creators¹⁵. “Architecture is created by ordinary people for ordinary people, and therefore should be easily understandable for everyone. It is based on a certain set of human instincts, on discoveries and experiences [...] – primarily on our attitude towards inanimate things”¹⁶. The sense of sight remained privileged in the modernist theories of perceiving architecture. The aim of architecture was to create a system that was a form of visibility. Rasmussen’s reflections on the feeling of architecture sensitized him to the ways of perceiving the composition and architectural form: as a set of vertical-horizontal directions, as a form seen from the perspective of a pedestrian or moving vehicle, outside and inside, in natural and artificial light, as a textural form or smooth, colored or neutral in color... and all other possible ways to create an affective form.

The architectural form of bridges and roofs with a cable-supported structure is expressed, above all, in the apparent negation of the force of gravity. Thanks to these structures, it is possible to eliminate the impression of massiveness, inter alia, by apparently detaching the building object from the ground. Sometimes it is the astonishing lightness of the slender elements creating an equivalent composition based on the rhythm or sequence of forms. Another time, the unusual shape is built through contrast, accent, apparent imbalance of elements not inscribed in the Cartesian grid of verticals and levels.

The architectural form of bridge structures and roofs with cable-supported structure is also included in the multitude of directions of visual reception. A special feature of these

¹⁴ As cited in: P. Trzeciak, *Przygody architektury XX wieku*, Wydawnictwo Nasza Księgarnia, Warszawa 1974, p. 278.

¹⁵ S.E. Rasmussen, *Odczuwanie architektury* (wyd. 1, Kopenhaga 1957), transl. B. Gadomska, Wydawnictwo Murator, Warszawa 1999, p. 33.

¹⁶ *Ibidem*, pp. 14–15.

buildings is the multiplicity of diametrically opposed images perceived in perspective. Lines – main cables, tie rods, hangers as well as planes and solids, and above all convex or concave surfaces of a suspended covering involved in multidirectional movement – are perceived in perspective by frames of interpenetrating plans. All this multiplies the enormity of the seemingly endless space where the boundary between the outside and inside is ambiguous.

Boldness and dynamics, slenderness and delicacy are the features that characterize this architecture and determine its grace and artistic value.

4. AFTERMATH

Advanced technology ensures progress in many areas of the economy. Currently, innovation and sustainable development are extremely fashionable concepts. Observing the postulates, it seems that the leading element is the issue of energy – savings in consumption and obtaining its resources from renewable sources. All experiments towards low technology present a lot of development potential. Steel, as the main building block of tension structures, offers excellent mechanical properties, which allows for the construction of spacious structures, optimizes the construction process at the construction site and enables quick implementation of projects.

But there is also another aspect. In cable-supported structures, we observe the principle of optimal work efficiency, i.e. the maximum effect with the minimum expenditure of resources, which has a general aesthetic and moral character. This aspect concerns neither the financial resources nor the amount of human energy used in building, but relates to the sum of elastic energy accumulated in the structures. The “economy” implemented in this way has a decisive impact on the appearance of the object, making it surprisingly light and often original in form, so one can look for aesthetic values in it.

The famous view of Antonio Gadi, expressed in the words “the simplest forms have the greatest dignity”¹⁷ presents one of the most important features of the discussed tension structures – their synthetic character.

5. SUMMARY

The instinct to create keeps restless minds constantly searching for new things. Experiment is the purpose and means of satisfying curiosity. More and more different motivations and inspirations expand the territories of exploring architecture with shapes that have not been seen before. The architect’s and constructor’s intuition and talent make irrational visions take the form of real buildings. There are projects in many places around the world that are the triumph of their thoughts. All this creates an extremely interesting and still open road in the field of construction. The cable-supported structures have inspired and still inspire creative experiments in contemporary architecture.

¹⁷ As cited in: B. Szulczewska, R. Giedych, *Przestrzeń przyrodnicza i społeczna osiedli mieszkaniowych w XX i XXI wieku*, Warszawa, Wydawnictwo SGGW, 2011.

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