Steel in architecture

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The objective of this article is to define the aesthetic role of steel in architecture, considering the technical characteristics of this material.

The use of steel in architecture dates back to the 19th century, although initially it mainly served as a material for the construction of bridges or industrial buildings, which in the then understanding were just part of infrastructure and, as such, they were unworthy of competing with the works of architecture [1]. On the other hand, the technical advantages of steel were perceived almost immediately. Steel contributed to the construction boom in American cities, first in Chicago and later on in New York. Along with the invention of elevators, the American architecture is rising up. The enthusiasm over the technical possibilities offered by steel was not, however, accompanied with the perception of its aesthetic values. In the 'Home Insurance Company Building' in Chicago (1883-84, by William Jenney), considered to be the first steel-frame high-rise building in the world, the innovative structure is hidden under the 'mask' of the Italian neo-renaissance. Also the slightly later built skyscrapers, especially those designed by F. Adler and L.H. Sullivan, the representatives of the so-called Chicago School, still quite often show the features of the European historicism.

However, it is structure built in Europe, namely the Eiffel Tower, that has become a symbol of the use of steel in architecture. It was built for the occasion of the 1889 Exposition Universelle in Paris, reaching a sky-high, for its era, elevation of 300 m. The structure was a demonstration of the technical capabilities of the world of construction of that time and is still considered to be a masterpiece of engineering. As written by Tadeusz Broniewski, a Polish architect: 'the lines of force (…) of this structure manifest themselves immaculately in its outline' [1]. The open lattice wrought-iron framework weighs just 7,300 tons out of 10,100 tons total weight of the structure. Despite its technological advantages, the Eiffel Tower failed to gain the acceptance of the contemporary artistic circles, including architects' circles. The above outline of the history of steel in architecture prompts us to have a closer look at its modern day usage.

Spatial form

A characteristic feature of steel is its high tensile strength, that concrete does not have. With this high tensile strength, steel is also relatively light. Owing to these advantages, from the construction point of view it is perfectly suited for large-span coverings and is a material of choice for production buildings, warehouses, public buildings, sports venues, etc. From the architectural point of view, these applications have a particularly strong impact, when a steel structure not only forms a structural element of the building but also creates its visual aesthetics. The main concourse of the Lyon Saint-Exupery Airport railway station (1994, by Santiago Calatrava), and more specifically, the 180 m long steel link building between the rail station and the airport, has become one of the most recognizable examples of such use of steel in the contemporary architecture. It is main concourse structure, including a 120 x 100 m in size and 1,300 tons heavy roof with the maximum elevation of 40 m and the span of 53 m. The steel structure of the roofing is largely exposed, forming two upwards oriented roof planes. This is an evocation of an animal skeleton, characteristic of Calatrava's style, in this case resembling the wings of a bird taking off into the sky [2].

Steel as a construction material allows architects to develop bold architectural visions in terms of building shapes. It is a material frequently used in projects aiming at creating dynamic forms, for instance detached from the ground, strongly overhanging or leaning forms – one could say: in creating spatial forms which, in a sense, defy the law of gravity. An interesting example illustrating this design approach is the Dockland Office building in Hamburg (2005, by BRT - Bothe Richter Teherani). The spatial form of the building, which is situated in the sea port area coincidentally brings to mind the hull of a modern ship or yacht due to its strongly tilted shorter facade walls deviating 66 degrees from plumb. The top edge of the building's exterior wall extends 47 m beyond the wall's edge at the ground level. This form could be obtained owing to the use of steel beams forming bracings along the entire elevation of the two longer exterior walls. The steel structure is responsible for the transfer of horizontal loads acting in the lengthwise direction. The fragment of the structure forming the protruding 'bow' of the building, was made as a single-element, prefabricated steel structure and was transported by a river barge directly to the site and then attached to the reinforced concrete structure of the building (with lateral loads sustained by the reinforced concrete cores and floor slabs).

In the Cosmopolitan high-rise building located in Warsaw (2013, by Helmut Jahn) steel was used as part of the cable-stayed (cable-supported) structure (Fig. Photo 1). A unique spatial form of the building was obtained in this way, featuring a massive recess in the lower part of the building volume. In structural terms, this recess is ob-

Fig.1. Schematic diagram, Photo 1a (courtesy of Hochtief Poland) and Photo 1b (courtesy of Donat Brykczyński) of the Cosmopolitan high-rise building located in Warsaw (2013, by Helmut Jahn) where steel was used as part of the cable-stayed (cable-supported) structure.

tained by a cantilever of 11.7 m in length, which supports 30 storeys of prestressed reinforced concrete construction. Loads are sustained by sets of cable stays anchored at three levels, each of them supporting ten storeys (Fig.). The cable stays are inclined at the angle of 76 degrees. Each of them, approximately 35 m in length is composed of 75 or 109 No. high-tensile strength (1,860 MPa) steel cables encased in casing pipes.

As regards the discussed aspect the advantages of steel over reinforced concrete are also related to its lower weight. This can matter when new, bolder spatial forms are given to the existing buildings under refurbishment. Under the modernization project of the office building at Modlińska Street in Warsaw (2018, by Studio Budowlane Unity, Janusz Marchwiński – architecture and Bronisław Karcz structural design) a change of the roof part was proposed. The proposed roof pla-

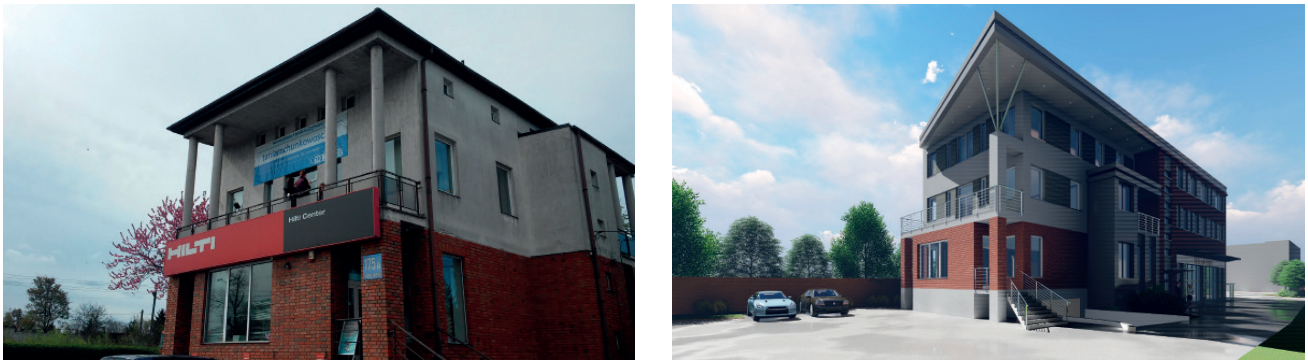

Photo 2. An office building located in Warsaw (by Studio Budowlane Unity Janusz Marchwiński, Gerard Jeleń): (a) before modernisation (b) after planned modernisation (b) (author's materials)

ced atop the vertical extension of the existing building was to be provided with a 2 m long cantilever on the north side and another cantilever jutting out ca. 3 m and supported at the external corner by three steel pipes, see Photos 2a and 2b. Considering the masonry structure of the existing building and the fact that it had been in operation for a few dozens of years it was decided to choose a lightweight roof structure. Although a reinforced concrete floor slab would be appropriate for the architectural concept this option was rejected due to excessive weight. Assuming 20 cm thickness and 500 kg/m2 areal weight the whole floor with the surface area of 168.4 m2 would weigh 84,200 kg. This would be a considerable load imposed on the existing walls and foundations calling for strengthening them and this would involve a considerable extra cost. For this reason the option with the steel structure roof over the existing building was chosen. In this case the roof weight was three times lower and the extra load imposed on the foundations did not exceed 20%.

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Aesthetics of exterior wall finishes of buildings

Modern architecture is often referred to as steel and glass architecture. A seemingly gross oversimplification as it may seem, one cannot deny that both these materials are among the most commonly used ones. This is particularly evident when we take into account the expensive commercial construction projects, especially those involving urban office buildings, hotels and public buildings. Steel is a material that complements glass very well, both in terms of technology and aesthetics, as demonstrated by glazed curtain walling systems, although actually in this case steel it is often replaced by aluminium. However, this does not apply to glass facades which constitute a structural element of the building. The hotel building in Macau (2018, by Zaha Hadid) is an excellent example illustrating the use of steel in the construction of glass facade walls. For the existing abandoned building with predefined regular blueprint Zaha Hadid proposed an external steel and glass facade structure called exoskeleton, as it is an exposed, external steel skeleton clad with aluminium panels. In this way the building obtained a one of a kind, amorphous shape. The shell comprises a grid of bent steel members filled with glass elements, arranged into triangular and rhomboidal panels. This type of facade structure, apart from giving the building unique aesthetic appeal, made it possible to do without columns at the façade on the interior side, this improving the building flexibility.

Although steel is generally perceived as a structural material it is also increasingly used for façade cladding purposes. Mainly stainless steel is used in such applications which, apart from corrosion resistance, has also aesthetic qualities imparting facades with characteristic metallic shine, connoting luxury, modernity, technological advancement and industrial aura. That was exactly the idea of the first use of stainless steel cladding in architecture in the famous art deco ornament adorning the Chryler Building tower in New York (1931, by W. van Alen, Reinhard, Hofmeister & Walguist). The material was favoured by architects identified with the postmodern high-tech style, such as Norman Foster, Nicolas Grimshaw or Richard Rogers. The latter is the author of the design of the Lloyds office building (1986) situated in the heart of London, being one of the iconic works of high-tech architecture and one of the most recognizable "glass and steel" facades. .At this point it is necessa-

Photo 3. Building of the European Centre of Solidarity in Gdańsk (photo courtesy of K. Zielonko-Jung).

ry to remark on potential urban planning and functional problems related to uncontrolled solar reflections from stainless steel cladding applied on large surfaces. These result from a relatively high degree of reflectance of this material (the albedo values for stainless steel are min. 65% [4] and, obviously, refer to buildings situated in a dense urban fabric. These aspects are becoming an area of knowledge increasingly developing within the framework of research on sustainable urban development1.

In newer projects, next to conventional, solid stainless steel cladding systems one can encounter also openwork cladding systems. An original facade finish was applied in the modernisation project of two different in terms of style buildings of the Ministry of Culture in Paris (2005, by Francis Soler, Frederic Druot). The facades of the buildings were clad with openwork stainless steel panels which, by projecting from the façade face, form a sort of a mesh entwining it, which in line with the designers' intention brings both buildings together into a compositional unity. Owing to perforated cladding the appearance of building facades changes during the day and night as light and shade play upon them.

A different aesthetic result is achieved with an increasingly popular (though still relatively little known) cladding option based on corten steel sheet metal. Corten steel is a material which looks like copper or corroded steel, and this look is actually given by a coat of patina developed on the surface due to weathering, reducing the rate of corrosion of the steel underneath. This material needs to be isolated from other materials susceptible to corrosion. That is why the cladding needs to be attached to stainless steel back-up frame using stainless steel fasteners. Due to the dripping rusty deposit the facades need to be protected from staining and installation in vertical position is recommended. Corten steel is a material requiring carefully considered use in terms of aesthetic results of its application. This distinctive material is associated mainly with the world of industry and there are certain limitations as to its use as such. That being said, when used aptly it can enhance the power of non-verbal expression. Such an aesthetic and metaphoric role is fulfilled by this material in the European Centre of Solidarity building in Gdańsk (2014, by FORT Architekci). Ample use of corten steel sheet metal on the building's facade was, in line with the designers intention, to symbolically and visually evoke the shipyard environment with its raw, industrial landscape. Resemblance to a ship hull was also intended, see Photo 3.

In the Centre for the Documentation of the Art of Tadeusz Kantor building in Kraków called CRICOTEKA that was opened two weeks later (2014, by Wizja and nsMoon Studio) the facades were clad with perforated corten steel sheet metal cladding. As a result, the building, acquires visual lightness, especially when the interiors are lit. The building, which came to existence as a result of restoration of the existing buildings of the former Kraków Podgórze power plant, is a clear symbol of the dialogue between the world of industry and the world of art.

A similar idea was pursued by the author of this article along with the design team when working on the competition project of the Ruczaj Centre – a branch of

Photo 4. Design of the Ruczaj Centre building, branch of the Podgórze Culture Centre in Kraków (by Studio Budowlane Unity: Janusz Marchwiński, Gerard Jeleń, in collaboration with Michał Dołbniak) - a) front view, b) the authors' motif idea made of corten steel sheet metal (illustration is the author's property; visualisation by M. Dołbiniak)

the Centre of Podgórze Culture in Kraków (2017, \ by Studio Budowlane Unity: Janusz Marchwiński, Gerard Jeleń, in collaboration with Michał Dołbniak – 2nd prize). The project's hallmark is the authors' concept of the facade made of perforated corten steel sheet metal inspired by folk motifs characteristic for the Kraków region outfits, which in this case is to constitute a symbolic dialogue between the Kraków region culture and the industrial character of the city district, see Photos 4a and 4b

Summing up

The use of steel in architecture has undergone a thorough evolution since the time of its first applications. The aesthetic qualities of steels have become appreciated by architects and, as a consequence, it is a fully established part of the architectural work. Undoubtedly, owing to its erection and structural characteristics, steel has become one of the most commonly used materials for construction of buildings.h.

1) This issue has been covered by, for example: Givoni, B. (1998). Climate Considerations in Building and Urban Design. New York: Willey@Sons, Zielonko-Jung, K. (2013), Kształtowanie przestrzenne architektury ekologicznej w strukturze miast [Spatial design of sustainable architecture in the structures of cities], Warsaw, Poland: OWPW.

Abstract: The objective of the article is to define the aesthetic role of steel in architecture while taking into account its unique characteristics. The article gives selected examples of contemporary buildings (already completed or planned), referring also to some historic design examples. In summation it is concluded that steel plays both a direct and indirect role in shaping the spatial forms of buildings and may bring new aesthetic qualities to the contemporary architecture.

Key words: contemporary architecture, steel in architecture, architectural style, aesthetic qualities

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