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THE SUN, WIND AND WATER IN DESIGNS OF EXTERIOR WALLS AND FACADES – NATURAL FORCES POTENTIAL IN SHAPING THE ARCHITECTURE OF SUSTAINABLE DEVELOPMENT

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Abstract
Examples of utilizing the potential of the sun, wind and water in design of the exterior walls and facades are shown against the background of the architecture of sustainable development. Use of renewable energy (photo-voltaic cells and wind turbines integrated with the body and facade of the building) and attractive external image of the building and design solutions of facades are discussed together with the need of protecting the building from the impact of the natural forces.

Streszczenie
W artykule na wybranych przykładach zostały omówione zagadnienia korzystania z potencjału: słońca, wiatru i wody w projektach ścian zewnętrznych i elewacji, w celu kształtowania architektury zgodnej z zasadami zrównoważonego rozwoju. Poruszono między innymi problemy pozyskiwania energii ze źródeł odnawialnych (ogniwa fotowoltaiczne oraz turbiny wiatrowe zintegrowane z bryłą i elewacjami budynku), ale także atrakcyjnego kształtowania wizerunku zewnętrznego obiektów. Zwrócono również uwagę, że rozwiązania fasadowe muszą zabezpieczać przed niekorzystnym wpływem wymienionych czynników naturalnych na budynek

Keywords: **Sun; Wind; Water; Facades.**

1. INTRODUCTION

In modern architecture Sustainable Development is a very fashionable issue. However, it should not be narrowed down to ecology, maintenance costs minimization and energy conservation. The issues concerning Sustainable Development are discussed in terms of ecological equilibrium, social and cultural, as well as economic sustainability [1]. According to *E. Niezabitowska*, ecology is superficially conceived in common social awareness as "care over the preservation of the existing eco-systems", whereas; the protection of social and cultural values is not associated with the quality of the built environment, which may hinder the social and cultural growth if users needs and expectations are not fulfilled [1]. Conversely, sustainable solutions in economic terms as related to state-of-the-art technologies are often experimental and not always successful. Nevertheless, "the utilization of the so called free resources (the air) should be always considered in the total economic profit and loss account" [1].

M. Stawicka-Wałkowska enumerates three distinguishing features of Sustainable Development:

1] Sustainability, i.e. maintaining the right proportions between human civilization need and environmental protection requirements;

2] Durability – restoration, protection and rational formation of the environment;

3] Self-sustainable development – including, among other factors, the creation of incentives promoting further development of the environment [2].

W. Mikoś-Rytel distinguishes four principles of modern sustainable architecture [3], classified in a summary form by means of the following Table:

Table 1.
Issues discussed in the paper set against the principles of modern, sustainable architecture (the author's elaboration on the basis of [3])

No	Principle [3]	Reasoning [3]	Issues discussed in the paper
1	**Drawing from sources** – (according to Vitruvius: durability, utility, beauty)	Creative	Cultural and social values associated with the external aesthetics and image of the building
2	**Synergy** – cooperation to achieve better effects	Synergic	Interdisciplinary approach- collaboration at all stages of the life cycle of the building (including research cooperation)
3	**Cohesion of solutions:** man/environment/friendship	Environmental	Users' physical and psychological comfort
4	**Effectiveness of solutions:** ecology/ energy/ economics	Market-based	Renewable energy, water recovery, natural ventilation

The above-mentioned components of sustainable architecture entail the issues concerning the interior and exterior space of buildings. The exterior walls and facades lie at the border line of the two spatial zones. Their design solutions may draw from the potential of the natural sources, such as the sun, wind and water which is discussed in more detail in the next chapters of this publication.

2. SUN

The Sun offers opportunities of natural lighting and creating the daily image of the building depending on its form, articulation of the surface of its facade and construction materials. The solar light potential in the design of facades is used to create helio-plastics. In stylish buildings of historic importance it was achieved by the light and shadow softly distributed on the façade tissue and its architectural details. Modernism focused the attention to the aesthetic values of simple, geometrical bodies exposing clear light and shade divisions. An interesting example of such approach is "Renoma" building in Wroclaw. Its old part, although modernist in form has a lot of historic-bound details, such as inter-storey cornices, glittering ceramic plates and overt brick binds that endow the facades with a delicate light-and-shade mode (designed by H. Dernburg, the building was commissioned in 1930) (Fig. 1). The façade of the new, added part to the building is emphasized by multiplication, explicit cornices, rendering the effect of strong horizontal partitions and clear light and shade division (design: Maćków Design Office, the building was commissioned in 2009) (Fig. 2) [4], [5].

Another effect is sun blaze on metallic facades. There are many examples in modern architecture of buildings shining in sunlight, thanks to their facades made of steel or titanic plates. The most well-known are: F. Gehry's designs: The Guggenheim Museum in Bilbao (1991-1997), or one of the buildings of Neue Zollhof Complex in Düsseldorf (1997-1999). Yet, it should be noted that such effects may be inconvenient to the surroundings (the neighbors, passers-by and drivers). Such was the case of polished steel plates in a part of the façade of Los Angeles Walt Disney Concert Hall (commissioned in 2003). It was necessary to mat the facade panels, as they reflected the sunlight and directed it towards the windows of the surrounding buildings [6]. Copper plates (before they become covered by green patina) also glazed in sunlight. Such solution was applied in the course of extension works of PWST building in Wroclaw (design: KKM Kozień, Project: 2008-2011, implemented in 2009-2011), by covering the façade of the added part with TECU® Brass (copper with the additive of zinc and other metals) [7]. The outcome was an appealing, contemporary image of the building, changing together with the natural lighting conditions (Figs. 3 and 4) [8].

The effects that can be achieved at the sun/glass contact face are amazing. Jean Nouvel, while designing the façade of Residential Tower 100 11th Avenue in New York (constructed in 2009) showed true mastery in this field. The building, serving as a specific "optical device" takes advantage of the potential hidden in variability of sunlight. Glass panels of different size were mounted vertically and horizontally at various angles, resulting in the reflexes and glass reflections of the surroundings in the façade and shades emerging at places where the plates are embedded in frames. The façade shimmers with light and colors

Figure 1.
Facades details of the old and new part of "Renoma" building in Wrocław (photo J. Tymkiewicz)

Figure 3.
Fragment of the added part of the PWST building covered with copper plate, Wrocław (photo J. Tymkiewicz)

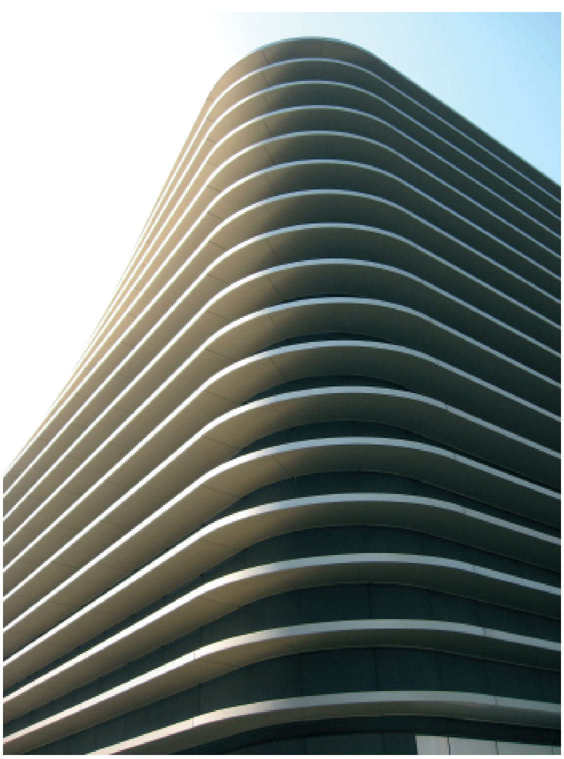

Figure 2.
Facades details of the old and new part of "Renoma" building in Wrocław (photo J. Tymkiewicz)

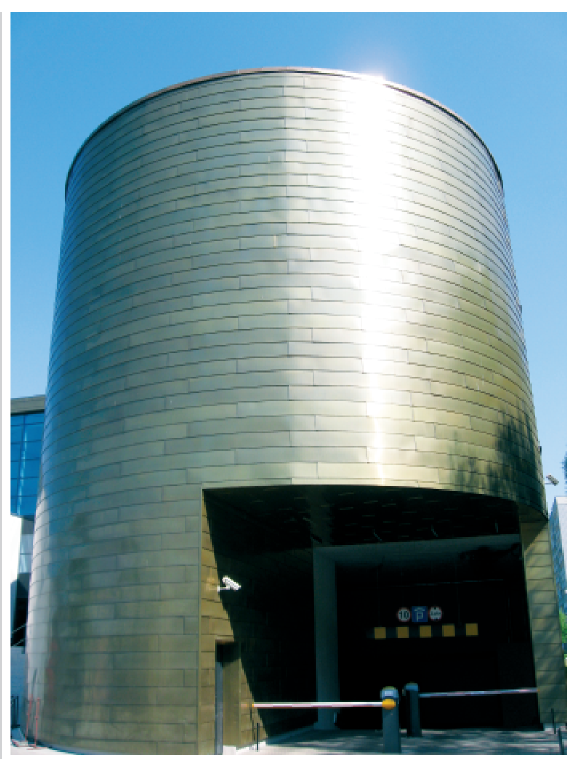

Figure 4.
Fragment of the added part of the PWST building covered with copper plate, Wrocław (photo J. Tymkiewicz)

depending on the season, daytime and weather [9].

However, the Sun also couses a problem of protection of glazed surfaces (and the ensuing overheating of the interiors), and regulation of sunlight penetration. A good solution is the use of movable sun blinds, the selection of which may substantially influence the aesthetics of the building, and, in some cases, may even constitute the main architectural work. An interesting example of this is Thespian building in Wroclaw, with white drapes placed in the inter-façade space (Maćków Design Office, Benoy, Ove Arup & Partners International Limited, constructed in 2009) (Figs. 5 and 6). Each movable drapes module does not only function as sun protection but also plays an important part in shaping the image of the façade that varies every day, every hour, thanks to the participation of the users who can control the drapes position depending on their individual needs. As far as intelligent facades are concerned, they enable the integration of sun blinds systems with BMS (Building Management System) and optimization of the blinds position depending on the weather conditions, while saving energy and maintaining users' comfort [10], [6], [11].

Through facades, solar energy can also be acquired. The most recent are systems integrated with the architecture of buildings, so called: BIPV (Building-integrated Photovoltaics), offering novel solutions and opportunities for experimenting with new technologies [12]. It can be only the replacement of façade materials with PV cells or architectural creation subordinated to the concept of photovoltaics, where the main emphasis is put on efficiency, and, in consequence, on creating forms with specific orientation and optimal angle of the external walls surfaces with exposed PV panels, giving evidence of the ecological awareness of investors [12], [6].

BIPV may also be integrated with the concept of media façade, for example GreenPix Zero Energy Media Wall in Beijing (2008), designed by S. Giostra. Combined with glass, the photovoltaic cells accumulate energy at daytime, and, at night, by means of LED diodes, enable media spectacle occurring on the surface of the façade [13], [6].

Figure 5.
White drapes in the inter-facade space, the Thespian building, Wrocław (photo J. Tymkiewicz)

Figure 6.
White drapes in the inter-facade space, the Thespian building, Wrocław (photo J. Tymkiewicz)

3. WIND

The wind is a renewable energy source. The first skyscraper that integrated the shell design, the façade and the construction with the concept of energy acquisition from wind turbines is Bahrain World Trade Center in Manama (designed by Atkis, commissioned into operation in 2008). Two 240 m towers in the shape of sails are connected by three platforms, on which wind turbines are mounted. The cylindrical form of the towers, tested in the air tunnel, directs the wind towards the gap containing turbines in the shape of the letter "S". According to the tests results, the wind blowing at the angle of 45° at both sides of the central axis generates the flux perpendicular to the turbines, which increases their potential. Vertical carves in the shell of the building have an impact on gradual pressure reduction, to level the wind velocity in the vicinity of each turbine [14]. Despite the high cost of the turbines that had to be incurred in the past, Bahrain World Trade Center created a precedent proving that it was possible to integrate wind turbines with architecture. Since that time more and more daring projects have emerged. One of the examples is "Wind Tower" (Envision Green Hotel), a luxurious hotel. With its egg-like form, it is almost entirely self-sufficient and self-sustaining as a building, independent from external energy sources and functioning like a living organism (designed by Richard Moreta Architecture) [15].

The wind is also a certain threat. Strong blows may damage facade elements, such as exterior sun blinds therefore, automatically controlled systems are popular, operating depending on wind pressure gauge readings. In very tall buildings it is necessary to use systems protecting facades against wind thrust and suction. Therefore, building scale models are tested in air tunnels. What is more, advanced design software makes it possible to optimize the architectural form in view of the concept of air circulation around and inside the building and introduce natural ventilation also in very tall objects, for example in Swiss Re Tower in London (designed by Norman Foster, constructed in 2004), where the form of the building was devised to prevent drafts at the street level. This building is the first sustainable tower block in London, with the natural ventilation supporting mechanical (Figs. 7 and 8).

Figure 7.
Swiss Re Tower in London (photo A. Tymkiewicz)

Figure 8.
Swiss Re Tower in London (photo A. Tymkiewicz)

An interesting solution providing the users with an option of opening the windows at the concurrent maintaining high level of energy efficiency is KFW Westerkade in Frankfurt (Sauerbruch Hutton Architekten, 2006-2010). This office building has a ferro-concrete structure and an oval form of a 14-storey tower reaching out of the 4-storey main base, and two-layer wind-pressurized façade [16], [17], the external one is equipped with vertical, independently regulated panels (ventilation flaps). Such solution makes it possible to achieve positive pressure ring an intelligent system of pressure co around the building. An advanced control system processes sent data from the meteorological centre and sensors located inside the buildings and measure temperature, pressure and light exposure. Thanks to LED diodes installed by the windows, the users obtain the information which ones should be open at a certain time [16]. As far as aesthetics is concerned, the facade of the building reflects the colours of other urban objects and of the park surrounding it [18].

The potential of the wind may also be utilized in facades for purely aesthetic reasons, for example in the designs of Ned Kahn Studios: Dutch Water Departments in Utrecht, Technorama Science Center in Winterthur which have facades shielded by means the lattice structure with plates that spin and swoosh in the wind. Such facades ripple, and even "lead" their own life in accordance with the strength and direction of the wind blows [19]. Another solution is the transposition of variable in time wind conditions in the vicinity of buildings to software-aided luminous presentations, for example: Tower of Winds in Yokohama, (designed by Toyo Ito, 1986), or the façade of Galleria Department Store in Seoul (2004) [6].

4. WATER

Water has been a threat to building facades for centuries. Different structural, material and architectural solutions have been applied to protect the exterior walls and facades against dampness [6].

Figure 9.
Patio with the caryatids – edifice of the Supreme Court in Warsaw (photo J. Tymkiewicz)

The use of water for aesthetic reasons in buildings involved the provision of a surface reflecting attractive façade solutions. One of the modern examples is the edifice of the Supreme Court in Warsaw (designed by *M. Budzyński*, *Z. Badowski*, commissioned in 1999). The rear glazed facade has a patio endowed with the sculptures of three caryatid. An amazing aesthetic effect is created by the bulk of accumulated glass facades, reflecting one another on glazed surfaces as well as in the water levels filling up the shallow stone pool in which the caryatids are mounted (Fig. 9).

Nowadays, the potential of water is used in designs of exterior walls and facades of buildings in diverse manners. In the literal sense, the facade in the form of a water curtain may be admired in a multi-level garage of Texas Medical Center in Houston [20] http://houston.culturemap.com/newsdetail/06-02-10-a-water-wall-parking-garage-only-in-houston/. Even more novel solution may be observed in Digital Water Pavilion – tourist office building and enquiries centre for EXPO 2008 in Saragossa (designed by Carlo Ratti Associatti in cooperation with scientists from the Massachusetts Institute of Technology). The exterior walls were created from the surfaces of water flowing from computer-controlled nozzles and rendering the effect of a curtain that changes in time and interacts with the users [21].

Conversely, in Zollverein School of Management and Design building in Essen (designed by SANAA, 2003-2006) water was utilized in a way that is invisible but that has a significant ecological and energy efficiency effect. The heating system is run on geothermal water supplied from the nearby shut-down mine (the mean temperature of the water is 29°C). The water is distributed by means of the system of pipes embedded in the structure of concrete walls and the floor. Such "active" insulation enabled the application of thin monolithic exterior walls with the thickness of 30 cm. Although the drawback of the system is the 80% heat loss through the walls, this is insignificant in view of the fact that the energy source supplying the building is free of charge [22]. It should be added that the warm walls are attractive to insects.

A diverse solution – not water consumption but water recovery by means of a façade – was applied in Melbourne Rectangular Stadium, designed by Cox Architects, Arup Sport, commissioned in 2010, which has a cupola structure consisting of triangular glass or aluminum panels, holding gutters that collect and remove rainwater to the underground tank. After treatment, the water is used for potable purposes [6].

5. CONCLUSIONS

Nowadays advanced technologies that utilize the potential of the light, water and air provide opportunities for achieving high quality of architecture. The full effect of sunlight may be obtained by means of modern materials combined with advanced design methods. These days, the impressive effect of the light and shade play has been replaced by sunlight reflexes on glazing facades. The elements associated with the external image of the buildings are: solar protection shields and photovoltaic cells. Dynamic facades take advantage of the time sequences for the creation of striking architectural forms: movable elements of the external sun protection system mark a breakthrough in the traditional division into full walls and transparent glazed surfaces, turning simple buildings into "machines" equipped with proper "furnishings" such as sun blinds or photovoltaic cells.

The impact of the wind and air on buildings results in aerodynamic problems with their shell, safety of facade elements and issues concerning ventilation and comfort of the internal environment so important to users. Thus, solutions focused on supporting the air circulation in the building are of great significance, as well as the provision of natural ventilation. Other options that are available nowadays involve energy acquisition from wind turbines integrated with the shell and facade of the building.

The potential of water is utilized for heating by unconventional techniques (geothermal water). Thanks to novel facade solutions rainwater may be recovered. For pure aesthetics, water – facades integration is rarely used, although, as in the case of Digital Water Pavilion in Saragossa or Houston garage, such solutions are also to be found.

The discussed manners of utilizing the potential of the sun, wind and water in modern architecture should be confronted with the principles of Sustainable Development. An attempt at such synthesis, outlining an interdisciplinary nature of the problem and the need of cooperation of specialists from multiple disciplines of science and engineering (architects, branch engineers, sociologists, environmental psychologists and economists) is presented in the Table 2.

Table 2.
Natural resources utilized in shaping the Sustainable Development architecture (the author's elaboration)

Sun	Wind	Water	Sustainable Development
• Facade details and materials with specific surface quality create helio-plastics • Buildings with metallic facades – effect of "glimmering" in sunrays, but also threat of being cumbersome to the surroundings • Glass facades – reflecting the surrounding space: the sky, green, architecture; the buildings acts as an "optical device" • Movable systems of sunshields generate the effect of changeability at different time of the day	• Attractive, tall, aerodynamic buildings • Wind concentrations as important elements of glass facades composition • Ventilation elements devised as aesthetically attractive details • Transposing the wind power and direction to: – Luminary presentations on facades – Movable panels fixed to special lattice structures	• Effect of facade reflection in the water level • "Water wall" • Advanced technologies create the water curtain, electronically controlled and interacting with passers by	**Aesthetics in the aspects of cultural and social growth** • Creation of attractive urban zones in districts and cities stimulating their further growth • Education by means of architecture and day-to-day experience of beauty • Objects intensely glittering in the sun – danger of disrupting harmonious continuity of the urban and architectural tissue • Façade materials should be ecological
• Photovoltaic cells mounted on facades or replacement of facade materials with BIPV systems integrated with the facades • Optimization of the position of sun blinds in view of energy efficiency • External sun blinds as architectural details enriching facades	• Wind turbines integrated with the shell and facade design • Protection of facade elements (external louvers, awnings) against destruction or damage caused by the wind • The shell of the building, the facade details as support of air circulation inside and around the building • Natural ventilation – minimization of costs allotted for air-conditioning • Double facades used for reducing the load from the wind and enabling the opening of the windows in the internal layer; it is not always possible to reduce the operation of mechanical systems	• Heating systems utilizing water from geothermal sources, creating active thermal insulation • Rainwater recovery thanks to special gutters laid in space between facade panels	**Energy efficiency** • Possibility of acquiring energy from renewable sources • Alternative heating systems • Rainwater recovery • Visible technological elements (pv cells, wind turbines) – generation of pro-ecological image of the organization occupying the building This is a complex issue, as the designed activities do not always bring about the planned energy savings;
• Sun blinds centrally controlled and equipped with an option of regulation at the level of uses of the building – protection against: – Overheating of the interiors – Visual discomfort – shine and dazzle	• Application of solutions enabling the opening of the windows in the rooms (double facades, wind-pressurised facades); thanks to natural ventilation it is possible to eliminate the sick building syndrome (SBS) • Undesirable acoustic effects evoked by the wind (for example, in the case of external sun protection shutters)	• Favourable microclimate, positive psychological impact • Solutions protecting against water splash	**Physical and psychological comfort of the users** • Sense of thermal and visual comfort • Users' satisfaction – one of the advantages is increased work efficiency

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