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RENEWABLE ENERGY SOURCES IN ARCHITECTURE OF THE WORLD EXPO

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ODNAWIALNE ŹRÓDŁA ENERGII W ARCHITEKTURZE WYSTAW ŚWIATOWYCH EXPO

Abstract
The article deals with the topic of implementation of renewable energy sources (RES) in architecture. The method of comparative analysis was adopted in order to identify certain directions, emerging trends regarding the use of solutions based on RES in architecture at various scales. Conclusions were formulated on the basis of study visits and analysis of selected national pavilions at Expo 2015 in Milan and the main assumptions related to the implementation of the adopted solutions and strategies for sustainable development. The article also analyses policies related to the application of advanced technologies in the Digital Smart City Milano 2015 strategy as a part of the Italian Smartainability project, initiatives and projects related to the use of RES presented at the exhibitions inside the national pavilions, as well as overviews of Expo 2017 Astana and Expo 2020 Dubai in the field of renewable energy.

Streszczenie
W artykule podjęto tematykę zastosowania w architekturze rozwiązań czerpiących energię z odnawialnych źródeł. W celu wyłonienia pewnych kierunków oraz zarysowujących się w architekturze w różnych skalach tendencji zastosowania rozwiązań bazujących na OZE przyjęto metodę analizy porównawczej. Wnioski sformułowano na podstawie wizyt studialnych i przeprowadzonych analiz wybranych pawilonów narodowych na Expo, a także głównych założeń związanych z realizacją przyjętych rozwiązań i strategii dotyczących rozwoju zrównoważonego. Przeanalizowano również zagadnienia odnoszące się do wprowadzania zaawansowanych technologii w ramach koncepcji *Digital Smart City Milano 2015*, stanowiącej część włoskiego projektu *Smartainability*. Zaprezentowano też inicjatywy i projekty związane z wykorzystaniem alternatywnych energii w ramach ekspozycji we wnętrzach pawilonów narodowych. Dokonano przeglądu rozwiązań dotyczących OZE na Expo 2017 Astana w Kazachstanie i Expo 2020 Dubaj w Zjednoczonych Emiratach Arabskich.

Keywords: architecture; EXPO; renewable energy; sustainable development; sustainable development goals – SDG

Słowa kluczowe: architektura; Expo; energia odnawialna; certyfikacja wielokryterialna; rozwój zrównoważony

INTRODUCTION

World Expositions are an international phenomenon that took place from the mid-19th century until late 1930s, and since 1958 (Brussels World Exposition) has continued in a slightly different form until the present day. These exhibitions were the successors of the national exhibitions of industrial products that appeared at the end of the 18th century in France and Great Britain. The first international exhibition was held in London in 1851, while the next one in Paris in 1855, and at that time it received an expanded and more universal programme, where, in addition to the products of agriculture, commerce and industry, presentations of intellectual achievements and, in particular, fine arts were prepared. Accommodating thousands of exhibitors and millions of visitors coming from all countries required the design and construction of large-scale

buildings: palaces, pavilions and galleries. Many times the organization of a world exhibition involved the need to modernize the host city, for example to provide new means of transport, such as the construction of a metro line in Paris on the occasion of the 1900 World Exhibition.

Today, EXPO world exhibitions are universal, international and specialized. The exhibitions are organized with a clear theme, cover universal themes or respond to current issues. They open in a spectacular manner and last between three and six months. It has been observed that the investments made for the realization of these global events are not fully utilized, and the main investment effort is directed towards the primary objective – the organization and realization of such a global event – and its subsequent effects are significantly nullified, negating the realisation of the idea of sustainable development, although this is not the rule since Expo exhibitions also carry out successful revitalization activities [B. Czarnecki 2016, pp. 5-13].

Environmental themes run through the slogans of the exhibitions, e.g.: Expo'67 in Montreal (Canada) – 'Man and His World,' Expo'70 in Osaka (Japan) 'Progress and Harmony for Mankind,' Expo'85 in Tsukuba (Japan) – 'Dwellings and Surroundings - Science and Technology for Man at Home,' Expo'88 in Vancouver (Canada) under the slogans 'World in Motion,' 'World in Interconnectedness,' Expo 2005 Aichi (Japan) – 'Wisdom of Nature,' Expo 2010 Shanghai – 'Better, City – Better Life'. Important from the point of view of developing the idea of sustainable development and energy was Expo 2000 in Hannover (Germany), which was held under the theme 'Humanity, Nature and Technology'. The 'Hannover Principles – Designing for Sustainability' by arch. William McDonough in 1992, which were prepared for this Expo [A. Bać 2016, p. 10], formed a basis for the design of the Netherlands pavilion by MVRDV, among others. The last three Expo exhibitions have continued the theme of sustainability and the use of green energy, which is also reflected in the mottos of individual exhibitions and in guidance documents for designers and pavilion builders. Unlike traditional trade fairs, Expo organisers require participating countries to design and build exhibition buildings from scratch, most of which are temporary in nature. In the design of its pavilion, each country is free to interpret a particular theme of the exhibition by adapting to the guidelines related to the implementation of selected sustainable development goals. The Expo becomes an arena for participating countries to compete in creating the most unusual and interesting architectural constructions, but also innovative ones, both in terms of ecological solutions, energy efficiency, use of RES on the scale of buildings and sites, use of building materials and their reuse.

The article's conclusions were formulated on the basis of study visits[1] and conducted analyses of selected national pavilions at Expo 2015 in Milan, i.e. Azerbaijan, Belgium, Japan, Germany, Italy and the United Arab Emirates, as well as the main assumptions related to the implementation of the adopted solutions and strategies for sustainable development, and, finally, an analysis of Expo 2020 venues.

1. EXPO 2015 AND THE IDEA OF SUSTAINABLE DEVELOPMENT

In an era of year-on-year unfavourable climate change and growing environmental awareness among the public, the issue of energy efficiency in the built environment is gaining importance. Construction is one of the most energy-, material- and pollution-intensive categories of human activity. The architecture of buildings largely shapes the social space, both visually and functionally, and thus determines the quality of life of members of society. Although the theme of the Milan Expo 2015 was food, the themes of sustainability, construction and energy efficiency of buildings were clearly present. The organisers of the Milan Expo paid much attention to the efficient use of energy and raw materials during the preparation of the site and the realization of the newly constructed buildings, as part of the implementation of the adopted environmental strategies and programmes, among others: *Digital Smart City Milano, Smartainability* and *Towards a Sustainable Expo* based on sustainable development rules.

1.1. Towards a sustainable Expo – the beginning of changes

World exhibitions have always set technological trends and have also played an important role in promoting and disseminating technical innovation as well as knowledge transfer in many fields. Expo 2015 clearly highlighted the energy-saving potential offered by reducing energy intensity through the use of RES-based installations. With this in mind, the Italian Ministry

[1] National Scientific Conference and Study Tour „Wyżywić planetę, energia dla życia" /'Feeding The Planet, Energy For Life' – Milan 05.2015, under the auspices of the Committee on Architecture and Urban Planning, Polish Academy of Sciences, organizers : WBiA ZUT in Szczecin, WBAiIŚ UZ Zielona Góra.

of the Environment, Ministero dell'Ambiente e della Tutela del Territorio e del Mare, in collaboration with Expo 2015 S.p.A., developed a programme entitled 'Towards a Sustainable Expo,' with the overarching objective of stimulating and strengthening the adopted solutions and initiatives in the spirit of implementing sustainable development principles relating to a wide range of activities. The 'Towards a Sustainable Expo' was based on several categories including: architecture and urban planning, design and building materials, energy, catering services, equipment, responsible trade, as well as product promotion and the organization of accompanying events and initiatives. Particularly noteworthy was the first category addressing design and material solutions in buildings, 'Design and Materials of the Buildings' [MTTM 2015]. This category addressed the design, implementation, use and subsequent disposal of national and corporate pavilions, as well as larger-scale solutions within the entire area of the Milan Expo 2015 exhibition grounds. The national pavilions of many countries and organisations were equipped with active and passive systems, solar and wind energy installations as well as resource-saving systems, particularly water and energy. As part of the adopted design process and its later implementation, the criteria of the US LEED certification system were also applied.

1.2. Intelligent technologies – Smartainability and Digital Smart City

EXPO 2015 World Exhibition presented a wide range of innovative smart technology solutions implemented under the Digital Smart City (DSC) model, which was part of Smartainability® – a Milanese project developed by the Ricercaper il Sistema Electrico (RSE)[2]. Its aim was to measure quantitative and qualitative indicators, and attempt to answer the question: 'is a smart sustainable city changing due to the applied smart technologies and services, and if so – how?' a methodology based on a dynamic comparison of applied smart technologies with their traditional counterparts on the scale of the adopted area was applied.[3]

The model *Digital Smart City* (DSC) was based on the use of dedicated intelligent solutions related to both conventional and RES energy management, innovative IT services for infrastructure, a broad support platform for IT services, ensuring security and an adequate level of service for visitors to the Expo 2015 site. The DSC system consisted of three pillars: *SMART CITY, ECOSYSTEM EXPO* and *DIGITAL EXPO*.

The first pillar of the DSC model was the SMART CITY platform, divided into five thematic areas referred to as levels. The first of these, Smart Buildings &Smart Energy, was directly related to the first one, Smart Buildings &Smart Energy, and addressed the issue of integrated energy management both in the buildings and in the whole area of the World Expo 2015, as well as its metering based on smart metering and the use of smart grids.[4]

The Digital Smart City – DSC model used at EXPO 2015 was also co-created by means of two other platforms: Ecosystem EXPO (EO15) based on high-tech services, and Digital Expo. Unlike Smart City Milano, these two platforms did not directly address renewable energy issues at EXPO 2015 but complemented the DSC model adopted for this emerging new part of the 'smart city' as part of the wider Milan project underway *Smartainability.*

2. EXPO PAVILIONS AND RES

The World Expo is, on the one hand, a kind of testing ground for innovation, in the field of architecture and advanced accompanying technologies. On the other hand, it offers an opportunity to promote countries and their achievements, as well as strengthen their image on a global scale, sometimes taking the form of propaganda for their resilience and power [B. Czarnecki, 2016, pp. 5-13] expressed in terms of the scale of the building, the amount of materials used to erect it, and what this translates into in terms of the financial outlay for its construction and the area of land. 'We look to architecture as a reflection of the progress our period has made in becoming aware of its characteristics – its special limitations and possibilities, its needs and goals. Architecture provides an insight into this process, being so connected to the life of the period as a whole.' [S. Giedion, 1968, p. 43].

2.1. EXPO 2015

The venues of Milan Expo 2015, both in the design and construction phases, were by definition subject to special regulations in the thought of the adopted principles of sustainable development. To this end, a series of guidelines, programmes and dedi-

[2] See: Ricerca Sistema Energetico (RSE) (Energy Research System) Report 2015 p. 49
[3] See: https://www.telecomitalia.com/tit/it/notiziariotecnico/numeri/2014-21/capitolo-3/approfondimenti-3.html
[4] See: Ricerca Sistema Energetico- RSE (2015), *Energy Research System*, Report 2015,
Caterina Grimaldi (ed.) *EXPO MILANO 2015*, the Bureau International des Expositions (BIE) 2015, www.expo2015.it

Tab. 1. Model of Digital Smart City and 5 levels of Smart City Expo Milano 2015

• ECOSYSTEM EXPO;	
• DIGITAL EXPO;	
• SMART CITY MILANO 2015 (5 levels):	
Level 1 Smart buildings and Smart Energy	integrated energy management; advanced energy distribution and metering systems smart metering and smart grid; charging points for electrical appliances and vehicles; intelligent lighting management systems
Level 2 Telecommunications & IT Systems	extensive telecommunications network; 'cloud' IT solutions, high-tech solutions; online support services; fibre optic, Wi-Fi and satellite networks and satellite networks
Level 3 Safe City	main operations centre; video security system; access control system; secure service communication
Level 4 Edutainment	electronic signature; dedicated solutions for pavilions; dedicated mobile systems; smart ticketing electronic system (SMET); logistics systems for visitor management (Visitor)
Level 5 Services	cashless electronic payment systems; integrated transport, e-health system – medical and online services; dedicated solutions for people with disabilities; electric car fleet and use of RES

source: own elaboration based on C. Grimaldi (ed.) *Feeding the planet, energy for life*, EXPO MILANO 2015, the The Bureau International des Expositions (BIE) 2015, and *Sustainability Report Expo Milano 2014*, Expo Milano 2015, BIE, Milan 2015, www.expo2015.it

cated guides related to environmental management have been developed for designers and contractors. Prominent among these are the rather precise UNI EN ISO 19011:2003 – Guidelines for auditing management systems for quality and/or systems of environmental management; as well as UNI EN ISO 14001:2004 – Environmental management systems – Requirements and guidelines for use; BS OHSAS 18001:2007 – Occupational health and safety management systems – requirements. Some venues at Expo 2015 were also subject to multi-criteria LEED certification [C. Grimaldi 2015, BIE 2013a, 2015, MTTEM 2015].

The following section of the article presents and analyses design solutions for selected national pavilions: Azerbaijan, Belgium, Japan, Germany, Italy and the United Arab Emirates, as well as energy efficiency and RES initiatives.

2.2. The Azerbaijan Pavilion

Simple architectural forms, traditional materials combined with advanced technologies characterised the Azerbaijan pavilion designed by Simmetrico Network in collaboration with Arassociati Architectural Studio, IDEAS and AG&P Landscape Architectural Studio (Fig. 1a). The facility was characterized by low energy consumption and the use of recyclable materials. The exhibition inside it was dedicated to the themes of organic food production, the preservation of biodiversity for future generations and the extensive protection of the environment as well as the use of renewable sources. The three levels of the pavilion and the three glass spheres called biospheres highlighted the various aspects of the country starting with the landscape and the specific characteristics of the regions, the nine climatic zones and tradition in connection with culture and innovation. The canopy of the terrace restaurant was formed by a glass structure with a substantial installation of PV modules, generating electricity for the facility. After EXPO 2015, the Azerbaijan pavilion was dismantled and rebuilt again in the capital Baku as a local cultural centre[5].

2.3. The Belgium Pavilion

The Belgium pavilion was designed by Patrick Genard & Asociados in collaboration with M. Belderbos and Besix-Vanhout, based on the principles of su-

[5] See: www.azerpavilion2015.com and www.simmetrico.it/en/project/expo2015

stainable construction using innovative technologies, while preserving the Belgian identity (Fig. 2b).

Three important aspects of the Belgian pavilion's sustainable building concept are at the heart of its implementation. These include: reducing energy and water demand, rational demand management using natural, recycled materials, recycling and water, rational demand management using natural, recyclable materials and recycling. The authors' aim was to create a symbolic Belgian farm. The architecture of the pavilion consists of three components. The first resembles a house with an elongated gabled roof covered with laminated glass that filters the amount of light to protect the building from overheating.[6] Further elements of the pavilion include a glass geodesic dome, to which four elements resembling chimneys with a polygonal base were adjoined. The glass dome is covered on the south side with nearly 315m^2 of photovoltaic cells. The used SunEwat XL – AGE and Heliateck system consists of two glass panes, between which the photovoltaic cells are embedded. The system utilises solar radiation to generate electricity required for the operation of the entire pavilion. The average energy production is 130 kWh per day, which is comparable to the energy requirements of nearly 15 single-family houses. The Belgian pavilion's official partner was AGC Glass Europe, which supplies innovative high-performance energy-generating glass products that also guarantee good thermal insulation and solar protection, also seen in the Japanese pavilion.[7] In addition to solar energy, the Belgian pavilion also uses wind power. An F100-10 turbine from the Belgian company Fairwind was installed in front of the facility on a 9-metre mast. It features an output of 10 kW and a vertical axis of rotation of three straight blades. Aerodynamic calculations of the Fairwind turbine design are based on the use of special software developed in collaboration with scientific centres.[8] Both the wind turbine and the BIPV system ensured the energy autonomy of the Belgian pavilion (Fig. 2b) and the carefully selected natural building materials allowed them to be recycled. The pavilion's modular wooden structure allowed it to be easily dismantled after the Expo and rebuilt elsewhere. The use of wood as a renewable material at the Expo is also noteworthy in other wooden pavilions, e.g. in the French one or in a more technologically advanced form – Chilean [M. Golański, 2017, pp. 23-37], and the issues related to their prefabrication [E. Goczyńska, 2016, pp. 32-39].

2.4. The Japan Pavilion

The architecture of the Japanese pavilion combines renewable, traditional materials with advanced technology in juxtaposition with modernity, environmental protection and aesthetic excellence of forms. In the symbolic sphere, the Japan pavilion presents the country's wealth and cultural greatness. According to the building's author, arch. Atsushi Kitagawara, the shape of the pavilion alludes to Japan's 'diversity bowl', and the three-dimensional wooden grate embodies sustainability, symbolizing the source of Japan's heterogeneity – the four seasons, nature, ecosystem and food [C. Grimaldi 2015, p. 97]. Natural materials, such as wood and bamboo, were used to realize the design. The three-dimensional wooden grate is an innovative earthquake-proof construction and at the same time the first ever to combine traditional knowledge with research into modern wooden frames and analytical issues on their compression. The elements of the wooden grate were connected to each other thanks to the 'wooden compressive strain method' without the use of metal connectors.

The Japanese pavilion used both passive and active technologies and energy-saving systems. The roof over one of the entrances consisted of two composite glass panels, with BIPV photovoltaic cells embedded between them, which generated additional green energy for the facility. A similar solution was also used on the roof and dome of the Belgian pavilion, but on a larger scale. The facade of the 1.100m^2 Japanese pavilion was built using Stopray Lami Smart 24 ACG magnetron-coated glass,[9] which protects against excessive solar radiation and guarantees a good temperature inside the pavilion. Glass was also used as a medium for projecting information and images by means of overlaying LCD screens. This resulted in large-area multimedia display boards, which were also quite represented in other Expo venues, supported by various new technologies (Fig. 2c) [J. Fidor, 2016].

Both the Belgian and Japanese pavilions are examples of how high-tech glass solutions, integrated with photovoltaic cells, are part of the trend towards sustainable and innovative energy-efficient architectu-

[6] See: *AGC, Official Partner of the Belgian pavilion* and *Expo Milano 2015: AGC glass in the Belgian and Japanese pavilions showcases durability, innovation and diversity* , http://www.agc-glass.eu/
[7] Ibid.
[8] See: *Fairwind, Pour Un Pavillon Dans Le Vent* p.77, http://www.wawmagazine.be/
[9] *Expo Milano 2015: AGC glass in the Belgian and Japanese pavilions showcases durability, innovation and diversity* , http://www.agc-glass.eu/

re, setting a certain course for the integration of solutions also seen in other projects in Milan [A. Gumińska, 2016, pp. 19-32].

2.5. The Germany Pavilion

Organic photovoltaics opens up new possibilities for the application of RES in architecture as evidenced by the German pavilion and its Solar Trees with OPV modules. Five twelve-metre-high 'Solar Trees' were a distinctive feature of the pavilion, where other issues related to innovative technologies, ecological and economic use of resources and space were also noticeable. The innovative Solar Trees were the centrepiece of the German pavilion and, symbolically, they represented the germination of 'innovation seedlings' in the German 'Fields of Ideas' designed by Schmidhuber, Lennart Wiechell, Milla & Partner and Nüssli [C. Grimaldi 2015, p. 95].

Solar Trees is a bent steel structure with a stretched milky-white membrane textile structure into which double-sided OPV cells are integrated using a steel cable system that forms a grid of modules with a hexagonal shape. The OPV modules covered the upper part of the solar tree's membrane cup cover, passing smoothly along a conical mandrel to the lower level of the pavilion.[10] OPVs are flexibilized photovoltaic cells that use organic materials for radiation absorption and charge transport. The OPV cells that form the modules, due to their flexibility, offer the possibility of a wide application of such solar systems in architecture. The used polymer OPV photovoltaic cell manufacturing technologies are not among the most complex, which may result in future large-scale use and guarantee affordability. This photovoltaic technology is referred to as third-generation technology after silicon cells (generation I) and thin-film cells (generation II) [E. Klugmann-Radziemska , 2014].

Solar Trees, as a whole, was a futuristic element dominating the space of the German pavilion, providing shade for visitors on the one hand, and a system generating green energy at the same time on the other. The OPV modules of the German pavilion's five solar trees were embedded in the aforementioned flexible foil, totalling 300 m^2 of organic hexagonal double-sided photovoltaic panels with diameters ranging from 35 cm to 1 metre. This was the first such extensive use of OPV modules in architecture. The total output of all the artificial solar plants is close to 5 kW at maximum sunlight (Fig. 2d).[11]

The cells used in the German 'solar trees' are the result of a collaboration between companies Belectric and Merck (The Organic Photovoltaic Technology Consortium – ARGE OPV).[12] This flexibilized polymer OPV cell technology shows many advantages over traditional first-generation silicon cells. The innovative photoactive materials are printed on extremely thin layers of film, using a patented technique for applying so-called 'ink' by spin coating, inkjet printing, gravure printing or flexographic printing. The materials used are a chemically selected mixture of substances which, when applied, exhibit the ability to generate electricity when exposed to sunlight. The organic double-sided modules can come in a variety of shapes and colours depending on the composition of the medium used to produce them, giving wider possibilities for their use in architectural design. By using non-halogenated solvents to coat the OPV modules, the manufacturing process has minimal environmental impact. These semi-transparent modules also exhibit high flexibility and have a low dead weight. As a result, they can be used on large and curved surfaces – both on roofs and on the facade of buildings, acting as their second skin. OPV modules generate constant power even under unfavourable sunlight conditions. Thanks to the absorption of scattered light, organic photovoltaic panels are able to generate electricity regardless of the angle of incidence of light on their surface, whether from horizontal, vertical or curved surfaces.[13]

2.6. The United Arab Emirates Pavilion

Architects from Foster + Partners in the design of the United Arab Emirates pavilion for Expo 2015 in Milan used the traditional planning principles of an Arab city – a desert city. The interior of the pavilion resembled a narrow Middle Eastern street that provides plenty of shade, evoking the experience of ancient communities living in the territory of the current Arab Emirates while demonstrating the natural energy efficiency of this compact urban form.

The pavilion, located in the central part of the EXPO 2015 World Exhibition, was accessible from the main pedestrian walkway – the Decumanus. The exhibition area showcased strategies and reports related to sustainable green economy, smart solutions, clean

[10] See: *Generating power and creating shade*- M-The Explorer Magazine, http://www.magazine.emerck
[11] See: www.schmidhuber.de
[12] See: *Merck Presents Organic Photovoltaic Materials at EXPO 2015 in Milan,* http://www.merckgroup.com.
[13] See: *Fields of Idea,* https://expo2015-germany.de/en/pavilion/about, www.schmidhuber.de

energy, among others: *Dubai Integrated Energy Strategy 2030; State of Energy Report Dubai '14; UEA Vision 2021; Dubai Plan 2021*.

The design of the pavilion was developed to meet the requirements for LEED 'Platinum' certification by combining the principles of passive and active techniques, from the capture of rainwater in a garden located on the roof, to the more efficient integration of photovoltaic cells. The architects' task was to design a building for two different climate zones. They had to create a natural and comfortable place for tourists in Milan and, given the plan to move the pavilion after the Milan World Exhibition to the United Arab Emirates, at the same time provide as much protection as possible from the intense sun. A priority in the selection of building materials was their localness and recycled content. Materials were chosen for their durability and reusability. The mechanical ventilation system provides an air exchange 30% more efficient than the required standard. The pavilion has an installation to collect rainwater from the surfaces of the paved floors and roof for the vegetable and herbal garden located on the roof. Adaptive species requiring minimal irrigation were planted on the green roof. Hygienic and sanitary installations as well as fittings were selected with a view to minimizing water consumption. As a result, a saving of 40% was expected. The UAE building and its solutions are an example of the integration of passive and energy-efficient solutions based also on RES [Fig. 2e].[14]

2.7. The Italy Pavilion

The Italian national pavilion, known as Palazzo Italia, was located in the central part of Expo 2015, designed by Studio Nemesi & Partners Srl, Proger SpA and BMS Progetti Srl. The pavilion was intended by the designers to be the symbolic heart of the entire Expo 2015 exhibition area, located adjacent to the surrounding lake and arena with the Tree of Life, an interactive installation planted in the centre of the Expo symbol. Unlike the buildings erected by the participating countries, the Italian pavilion was not temporary and is now the dominant feature organizing the surrounding space. The pavilion is inspired by the life-giving tree. This motif is present in many traditions and religions of the world. The closest to European culture is the apple tree of paradise, also known as the tree of the knowledge of good and evil [C. Grimaldi 2015, pp. 46-49]. The organization of the energy system in the Palazzo Italia building refers to the symbolic motif of a tree. It consists of three interacting main elements, i.e.: leaves, bark and roots. The leaves are represented by a photovoltaic installation located on the roof and facades of the building and in its function of capturing solar energy. The bark is represented by the sunscreens and the walls of the external enclosure, made of cement biodynamic panels. The final element is the roots, which are represented by heat pumps that capture geothermal energy.[15]

The Palazzo Italia consists of six floors, representing nearly 13,000 m^2 of space and a large part of the inner atrium. This inner courtyard plays an important role in illuminating the building with natural light as well as allowing a continuous exchange of air. This space, both in winter and summer, is characterized by favourable bioclimatic conditions. The design of the Italian pavilion was geared towards meeting high quality standards in terms of energy efficiency and environmental protection. The designers paid particular attention to reducing the building's energy consumption by:

- the use of renewable energy sources: geothermal energy and photovoltaic systems to produce electricity;
- the use of passive systems in the building envelope;
- the use of highly efficient sanitary installations.

The aim was to make the building as autonomous as possible and to make it independent of external energy sources. In accordance with the provisions of the European Directive EPBD 2010/31/UE,[16] the Italian pavilion is a building with almost zero energy consumption nZEB (Nearly Zero Energy Building) [P. Hernandez and P. Kenny 2010, pp. 815-882] and is rated A+ under the Lombardy certification scheme [L. Santoli et al. 2014, pp. 534-539] .

The Italian pavilion is also characterized by the use of an innovative biodynamic material on the facades. Almost 9,000 m^2 of external facade area and part of the interior were clad with 'i.active BIODYNAMIC' cement panels. This innovative material was developed in the laboratories of Italcementi, Italy's and the world's leading cement producer, in cooperation with Styl-Comp, which cleans the air of pollutants in the building.[17] When exposed to direct UV light in the sunlight, the active substance contained in the material captures and inactivates pollutants present in the

[14] See: *Fields of Idea,* https://expo2015-germany.de/en/pavilion/about, www.schmidhuber.de
[15] See: *Sustainability Report Expo Milano 2014,* Expo Milano 2015, the Bureau International des Expositions (BIE), Milan 2015, p.42-47.
[16] *Towards nearly zero-energy buildings, definition of common principles under the EPBD, Final report*, (2012), Ecofys, www.ec.europa.eu/energy/sites/ener/files/documents/nzeb_full_report.pdf
[17] See: *Media and Communication2015 EXPO: Palazzo Italia "wears" i.active BIODYNAMIC*, www.italcementigroup.com/

air (nitrogen oxides, sulphur oxides, carbon monoxide, ammonia and volatile organic compounds, e.g. toluene and benzene) and transforms them into inert salts, thus cleaning the air of smog including toluene and benzene (and converting them into inert salts), thus cleaning the air of smog. Another environmental advantage of the mortar used is its 80 per cent recycled aggregate content, some of which is recycled waste from cutting the Carrara marble. As a result, the material used in the Italian pavilion is characterized by a noble colour and brilliance unattainable with traditional cements. The adjective 'dynamic' describes the material's particular ductility, allowing the creation of complex shapes, as exemplified by the panels used on the facades of the Palazzo Italia pavilion. Thanks to their high workability, the Italian 'i.active BIODYNAMIC' panels can be cast individually, which ensures their uniqueness and exceptional surface quality, evident in the Italian pavilion towering over the central part of Expo 2015 (Fig. 2c).

Tab. 3. Selected projects and initiatives related to renewable energy at EXPO 2015 in Milan

Country	Pavilion/object's name	Architect/design team	Area/budget	RES technology type/ Installations based on RES				Energy efficiency/ environment friendly installations/ LEED certificate
				Solar system	Wind system	Geothermal system	Biomass facilities	
EXPO 2015 – Milan (Italy) – 'Feeding the Planet, Energy for Life' (2015, May 1 – October 31) / area: 1.2 km2								
NATIONAL PAVILIONS								
Azerbaijan	Treasure of Biodiversity	Simmetrico network	887 m2	•				PV/BIPV, energy and water saving systems
Belgium	Our Food, Our World Sustainable Future	P. Genard&Asociados, coop.: Marc Belderbos	2,717 m2	•	•			PV/BIPV Wind turbine with a vertical axis of rotation
Japan	Harmonious Diversity	Atsushi Kitagawara	4,170 m2	•				PV/BIPV system
Germany	Fields of Ideas	SCHMIDHUBER Lennart Wiechell, Shmidhuber, Milla & Partne, Nüssli	4,913 m2/ EUR 40 m	•				Organic Photo Voltaic (OPV) modules
Italy	The Nursery Garden of Italy/ Pallazzo Italia	Nemesi&Partners, Proger SpA, BmsProgetti Srl	26,900 m2/ EUR 40 m	•		•		nZEB, energy class building: 'A', PV/BIPV, geothermal
United Arab Emirates	Food for Thought-Shaping and Sharing the Future	Foster & Partners	4,386 m2	•				solar and PV system, energy and water management systems, compatible with LEED Platinum
CORPORATE PAVILIONS								
ENEL	Cultivating Smart Energy	Piuarch	890 m2	•	•	•	•	intelligent energy distribution networks, energy flow optimization and integration with RES systems

McDonald's	Fattore Futuro	McDonald's	-	•				solar and PV installation and energy and water management systems
ASSOCIATED FACILITIES AND THEMATIC AREAS								
CasinaTriulza Expo2015	CasinaTriulza Civil Society Pavilion Energies to changes the world	-		•				PV installation, LEED certification for retrofitting
EXPO 2015	Service Area	Onsite studio I Liverani - Molteniarchitetti	64,000 m2: large buildings: 13, medium: 17, small: 16					solar and PV installation, energy and water management systems
EXPO 2015	Open Air Theatre San Carlo	-	-					PV installation on the entire surface of the amphitheatre stage canopy
EXPO 2015	Rocchetti Children Park Ring around the Planet-Ring around the Future Ring Around Energy-	Reggio Children - ZPZ Partners: Michele Zini	-	•	•	•	•	Ring Around Energy - educational pavilion - dedicated to renewable energy and its production
EXPO 2017 – Astana (Kazakhstan)* 'Future Energy' (2017 June, 10 – September, 10)/ area: 25 ha)								
n.d.	-	-	-					-
EXPO 2020 – Dubai/Abu Zabi (UAE)* 'Connecting Minds, Creating the Future' (2021 October, 1 – 2022 March, 31) / area: 438 ha – 200 pavilions								
UAE	Expo Dubai 2020 Terra Sustainability Pavilion Energy Tree - E-Tree	design. Grimshaw	6,000 m2	•				1000 PV panels - pavilion and separate PV in 18 structures of energy trees 2,160 / 4GWh/year
UAE	United Arab Emirates (UAE)	design. Santiago Calatrava	20,900 m2	•				28 kinetic winds with PV panels - LEED Platinum
UAE	Alif – The Mobility Pavilion	Foster + Partners	29,695 m2	•				PV roof - LEED Gold
Italy	Pavilion of Italy	design. Carlo Ratti, Italo Rota, MatteoGatto, F&M Ingegneri					•	Microalgae /Spirulina
Poland	Pavilion of Poland	design. WXCA, Bellprat Partnere	2,030.5 m2	•				PV installation 20 vertical perovskite panels by Saule/ fragment of facade
Holland	Pavilion of Holland	V8 Architects	3,727 m2	•			•	roof with coloured and transparent fanlights OPVASCA (organic photovoltaic), design. Marjan van Aubel

Sweden	Pavilion of Sweden	Alessandro Ripellino Architects, Studio Adrien Gardère and Luigi Pardo Architetti	2,600 m2	•			•	heat pumps and, for energy generation, photovoltaic panels and special roof tiles Soltech
EXPO 2020 -Dubai - Al Wasl Plaza	Dome and 5 buildings	Adrian Smith + Gordon Gill Architecture	100,000 - 300,000 m2	•				roof and facades with PV/BIPV CEEQUAL EXCELLENT

Source: own preparation based on analysis and data of C. Grimaldi (ed.) *Feeding the planet, energy for life*, EXPO Milano 2015, the Bureau International des Expositions (BIE) 2015, www.expo2015.it

After Expo 2015, almost all national, corporate and accompanying pavilions were demolished, relocated to other countries or recycled. The exceptions are the modernized, historic Casina Triulza – Civil Society Pavilion (Fig. 1c) serving as a civil society centre and the Italian pavilion Palazzo Italia, described above, which was transformed into a technological innovation centre for the city of Milan. The Expo 2015 post-exhibition site, after much perturbation, is currently undergoing a revitalization transformation into a zero-carbon MIND innovation district – the MilanoInnovation District – described as 'a city of the future' – a great ecosystem for socio-economic development, open to human exchange, mobility and a fusion of sustainable architecture, greenery with the technology of tomorrow.[18]

2.8. EXPO 2017 – Astana, Kazakhstan and EXPO 2020 Dubai, UAE

The role of renewable energies, as at Expo 2015, has also become an important theme and even a leading trend at subsequent world exhibitions in Kazakhstan and the UAE. Expo 2017 Astana entitled 'Future Energy' developed the theme of energy and its economic, social and environmental aspects, with a special focus on sustainability issues from a global point of view. And in relation to the socio-economic sphere, it addressed issues related to the promotion of RES and other alternative energies together with energy efficiency and responsible consumption, but also those related to energy security or addressing the issue of universal access to clean energy.[19] In turn, Expo 2020 Dubai 'Connecting Minds, Creating the Future. Opportunity. Mobility. Sustainability' presented innovative approaches to mobility, energy and water through the use of new technologies and intelligent systems in cities and under-urbanized areas. Expo 2020 set a target for energy production from RES to cover close to 50% of the exhibition's energy needs from locally generated RES (Fig. 3-4). The first such large-scale application for buildings was also presented – *Building-Integrated Photo Voltaic & Solar Technology.*[20] The UAE event was monitored and reported similarly to the Milan and Kazakhstan events in terms of carbon emissions to achieve a water-neutral balance, while managing recycling and reuse of materials.

Table 2 summarizes in general terms of selected facilities and solutions used in Dubai and Milan relating to RES.

2.9. Selected initiatives at EXPO 2015 related to RES

In addition to buildings with architecture showcasing RES solutions, it is also worth highlighting those initiatives realized inside the national pavilions at Expo 2015 using renewable energy. Noteworthy is the exhibition of the 1 GW Solar Park – *Mohammed Bin Rashid Al Maktoum Solar Park* (MBRAM Solar Park) in the pavilion of the United Arab Emirates and the initiative of the Association *WAME & Expo 2015 (World Access to Modern Energy)* presented in *Casina Triulza – Civil Society Pavilion* within *WAME Energy Corner.*

The WAME, which took as its goal raising public awareness of universal energy access, also promoted small and large, local and global project solutions to counter the effects of exclusion from access to electricity. Through the involvement of international NGOs, the global scope of the problem has been highlighted, and there is also an exchange of information and good practices, including in the use of renewable energy sources and innovation in the provision and dissemination of such solutions. According to WAME data, nearly 1.3 billion people, about 20% of the world's popula-

[18] https://www.mindmilano.it/mind/, https://www.arexpo.it/en/mind/
[19] See: *Expo 2017 Astana*, https://expo2017astana.com
[20] Cf.: *Sustainability*, https://expo2020dubai.ae

Fig. 1 a-c) EXPO 2015 pavilions and RES: a) Azerbaijan, b) NGO Italy pavilion, c) service pavilions; source: photo by the author

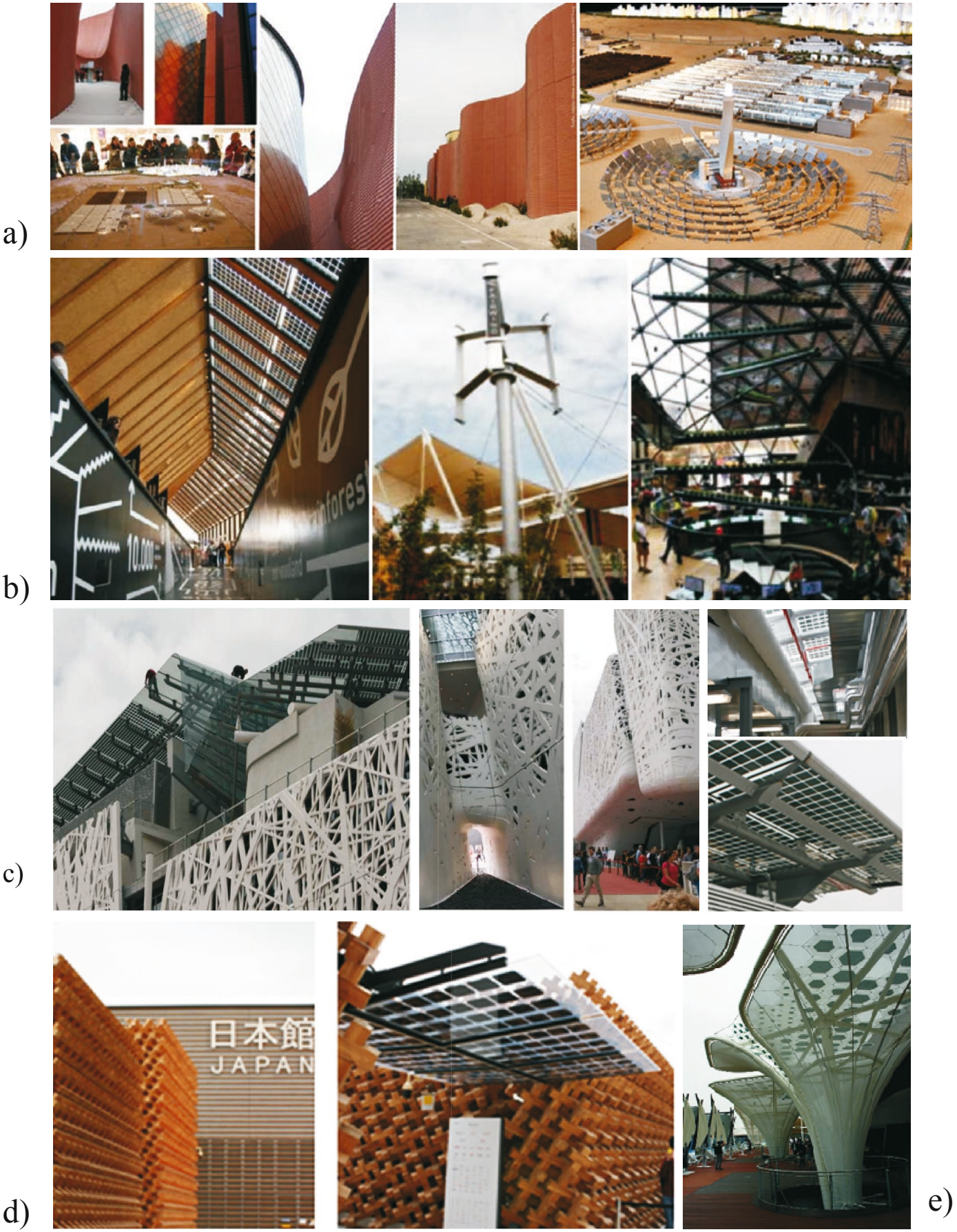

Fig. 2a-e) EXPO 2015 national pavilions and RES, a) UAE Pavilion, b) Belgium Pavilion c) Palazzo Italia - PV roof, d) Japan Pavilion - wood and PV e) Germany Pavilion and OPV -Solar Trees; source: photo by the author

Fig. 3. Expo 2020-Dubai - Al Wasl Plaza- central square of the Expo site with a dome surrounded by three multifunctional buildings with PV/BIPV energy-active facades and roofs; source: photo by Joanna Legierska-Dutczak, 2022

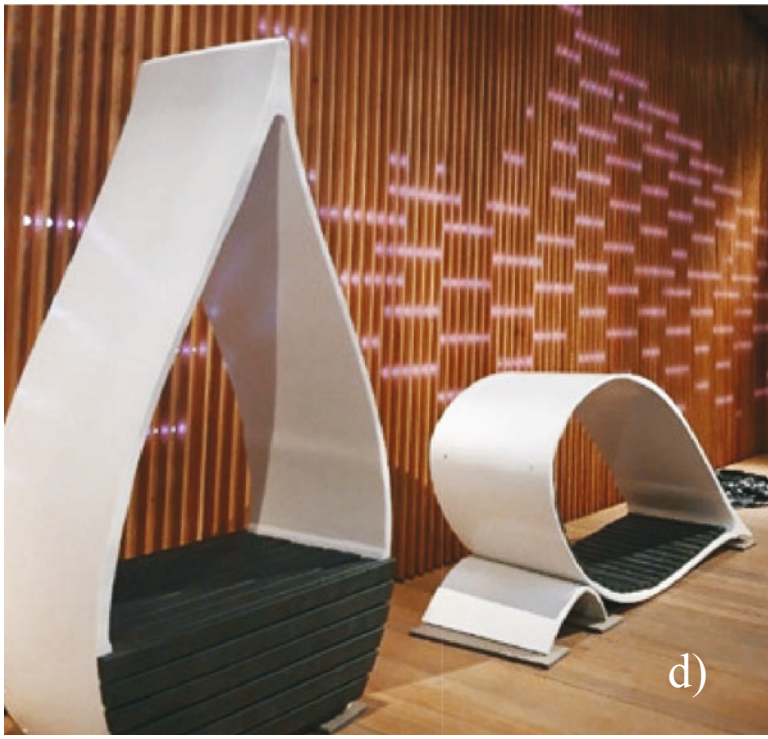

Fig. 4 a-d. Expo Dubai 2020 - Polish Pavilion “Creativity inspired by nature” proj.WXCA - Pracownia Architektoniczna, Bellprat Partnere. (a) Polish Pavilion,Temporary exhibition (b,c,d) concerning the exhibition of Lubuskie Voivodeship - installation based on materials from PET felts forming wavy acoustic walls, seats made with the use of recycled redesign method, garden furniture using fragments of wind turbines (author of the concept of exhibition / felts - J.Legierska-Dutczak, Institute of Contemporary Art UZ, research cooperation with Anmet company. The designs of the acoustic walls were realised thanks to the cooperation and research work of “PETarda Design”, HEI UZ; source: photo by Joanna Legierska-Dutczak, 2022

tion, do not have access to electricity.[21] Providing increased access to modern energy sources, including those derived from RES, increases access to drinking water and food resources, thus reducing the level of extreme poverty in relative terms and resulting in an improved quality of life for the population. The WAME & EXPO 2015 Association, which brings together leading European companies involved in the energy sector at Expo 2015, organizes regular meetings and debates, awards prizes and displays its initiatives and projects in the aforementioned Casina Triulza – Civil Society Pavilion as the WAME Energy Corner. It is worth mentioning that the building itself, which dates back to the end of the 19th century, is also interesting in terms of its high energy efficiency and RES-based power supply. As part of the refurbishment, the building was adapted to meet the requirements and regulations, which are higher than those in force in the EU, related to energy efficiency, while also obtaining LEED Italia 2009 Nuove Costruzioni e Ristrutturazioni certification, an example of the use of solar energy by means of the installation of PV panels on a large part of the roof (100% of electricity comes from RES, 64% of the demand is provided by roof-mounted PV panels).[22] *Casina Triulza – Civil Society Pavilion* is also referred to as a showcase for social responsibility in architecture, energy and the implementation of sustainable development.

The UAE's flagship Solar Park project (MBRAM Solar Park), on display in the UAE National Pavilion, will eventually produce 1GW of electric power for the national grid, using both solar and PV technologies.[23] The park is located approximately 50km south of Dubai, in Seih Al Dahali, covering an area of nearly 40.45 square kilometres. The construction of this multi-phase development began in 2013 with the assistance of the Dubai Electricity and Water Authority (DEWA). The MBRAM Solar Park development was based on the Independent Power Producer (IPP) model of renewable energy production, placing Dubai and the UAE at the forefront of the region's clean and renewable energy production.[24] In doing so, it meets the objectives of the existing UEA Vision 2021, Dubai Integrated Energy Strategy 2030 for diversification of energy sources in the country's energy mix to 15% solar, 7% clean coal, 7% nuclear and 71% natural gas.[25]

With the use of RES on this scale, the MBRAM Solar Park project ranks as one of the largest in the region. Its impact is expected to be significant, with a reduction in carbon emissions compared to current methods using fossil fuels. It is also estimated that emissions will be reduced to 1 million tonnes of carbon per year with the production of 1,000 MW of solar energy, in the number of 2,000 operating hours of MBRAM Solar Park infrastructure. The main goals and objectives pursued for the MBRAM Solar Park include supporting the UAE's energy diversification strategy, reducing carbon emissions nationally, promoting sustainable development and conservation of the earth's natural resources using renewable resources in electricity generation. It is assumed that the set objectives will also influence the accelerated development of technologies related to the generation of electricity from renewable energy sources, particularly solar energy. Research and development and the involvement of local communities and universities in the field of renewable energy are also supported, thereby raising awareness of climate change, sustainable energy and energy efficiency. It is planned to develop an interdisciplinary expertise of the UAE in the field of RES utilisation with a particular focus on the country's potential in solar energy and its role in construction. Two centres have also been realised within the MBRAM Solar Park: Renewable Academy and Research & Development Centre. It is estimated that the implementation of all these tasks within the MBRAM Solar Park is a significant contribution to strengthening both the UAE's position on the international stage, as well as Dubai's position as a smart city with state-of-the-art infrastructure, host of EXPO 2020 in 2022, while at the same time developing socially and economically (Fig. 2a).[26]

Energy production and its efficient use should take into account social, environmental and health effects, and the impact on future generations. The initiatives and projects implemented or presented at Expo 2015 and summarized in Table 3, selected initiatives and projects related to RES, are examples of harnessing the potential of renewable energy and replacing fossil sources with alternative ones.

[21] See: *Cascina Triulza – Civil Society Pavilion,* http://www.expo2015.org/en/the-triulza-farmhouse
[22] See: *Cascina Triulza: certificazione LEED in vista dell' Expo 2015*, http://www.greenews.info, http://nova.ilsole24ore.com
[23] See: *Mohammad Bin Rashid Al Maktoum Solar Park on right track,* www.gulfnews.com
[24] See: *DEWA announces 800MW third Phase of the Mohammed bin Rashid Al Maktoum Solar Park* http://www.dubaisce.gov.ae
[25] See: *UEA Vision 2021; Dubai Integrated Energy Strategy 2030* and *Mohammad Bin Rashid Al Maktoum Solar Park on right track.* Tender for the third phase of the project to open in third quarter, www.gulfnews.com
[26] See: *DEWA announces 800MW third phase of the Mohammed bin Rashid Al Maktoum Solar Park*, http://www.dubaisce.gov.ae

Tab. 3. Selected projects and initiatives related to renewable energy at EXPO 2015 in Milan

Name of the project/initiative (presented projects of countries/organizations/ corporations inside pavilions related to energy and renewable energy sources) at the indicated EXPO	EXPO/ Country/ affiliated organizations/ Corporations	RES			
		Solar energy	Wind energy	Hydroenergy	Biomass/Biofuels
EXPO 2015 – MILAN					
WAME&EXPO2015 WAME *Energy Corner-* *Sustainable Energy for All*	EXPO 2015, ONZ EDISON, ENEL, ENI, E.ON, GDF SUEZ, GAS NATURAL & TENARIS,	•	•	•	•
Smartainability Ricerca Sistema Energetico (RSE) (Energy Research System)	EXPO 2015, ENEL	•	•		
Digital Smart City Ecosystem EXPO Digital expo/Smart Grid		•	•		
Energy in innovations: Ecocapsule-Independent House	EXPO 2015, SLOVAKIA	•	•		
Energy in innovations: Solar Hug-Charging Bracelet		•			
Ecoboat-floating greenhouse in the city/ arch. B. Bueren	EXPO 2015, HOLLAND and EXPO 2015, New Holland	•	•	•	•
AQGRI& station New Holland		•			•
EXPO 15 - Exhibition – Astana 2017 Future Energy	EXPO 2015, KAZAKHSTAN	•	•	•	•
EXPO Dubai 2020 and Smart Initiatives Dubai Integrated Energy Strategy 2030 Mohammed Bin Rashid Al Maktoum Solar Park State of Energy Report Dubai ‘14 The World Energy Day UEA Vision 20121 Dubai Plan 20121	EXPO 2015, UNITED ARAB EMIRATES (UAE)	•	•	•	•
Solar Trees	EXPO 2015, GERMANY	•			
Be (e) active					•
RES, Hydropower Maluku, Papua	EXPO 2015, INDONESIA	•	•	•	•

Source: own preparation based on analysis and data of C. Grimaldi (ed.) *Feeding the planet energy for life*, EXPO Milano 2015, the Bureau International des Expositions (BIE) 2015, www.expo2015.it

CONCLUSIONS

Globally, buildings account for a significant share of energy consumption. Particularly in the use phase, energy is consumed to provide a comfortable indoor environment for the building. The use of RES reduces the consumption of fossil fuel-based energy and provides many environmental and economic benefits. Maximizing the reduction of fossil fuel-based energy and replacing it with renewable energy is one of the effective methods to ensure energy efficiency in buildings. Renewable sources using the energy of the sun in buildings by active and passive methods provide opportunities for heating, cooling, ventilation, natural lighting and hot water extraction. Wind energy can also be used in active and passive systems for ventilation and cooling. Geothermal energy can be used for heating and cooling purposes. It can be used for heating and hot water supply from hydrogen energy, heating and electricity. All of the aforementioned systems can be used in parallel, if necessary.

In the use of renewable energy, passive systems should be preferred, as they are simpler and more cost -effective. In cases where passive systems are insufficient, they should be supported by active systems. The analysed Expo exhibitions are concerned with achieving the set goals related to energy, pro-environmental management and respect for natural resources, taking numerous actions aimed at stimulating and strengthening the adopted dedicated sustainability solutions and initiatives, also largely related to sustainable architecture in an intelligently managed urban body. Examples of such multidisciplinary design solutions, visible both in urban planning and in the architecture of national, organizational or commercial pavilions, were synthesized. They were analysed in terms of the use of both active and passive technologies, innovative construction and building solutions, integration of technological elements with architecture, environmental optimization, use of renewable materials and applied solutions affecting their aesthetics. In the pavilions of the world exhibitions in Milan and Dubai, there was a noticeable tendency to integrate technological elements with architecture, which gave the objects a modern character and, by co-creating coherent compositions, influenced the final plastic effect of the design concept. The scale of solutions based on RES in relation to the Hannover exhibition also changed, which is best seen in Dubai.

The solutions presented in the article exploit the potential of combining low- and high-end RES-based technologies. This observed trend allows to hope that in the near future realizations of such pro-environmental character will constitute the vast majority of the national pavilions at the next world exhibitions. Similar solutions should also be reflected in the architecture of buildings not only at the Expo, which is, so to speak, a testing ground, but also in the popularized version guaranteeing their application without restrictions on design freedom.

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