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Summary of the doctoral dissertation
"The impact of renewable energy sources on architecture in Poland since 2004"

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The work covers topics related to the use, typology and development of renewable energy sources (RES) in architecture, selected issues in the field of: architecture, civil engineering, design methodology, environmental impact assessment of buildings as well as aesthetics, law and economics. The dissertation presents the results of research on architectural design focused on the use of renewable energy (RES) in Poland after 2004, i.e. after accession to the European Union.

The work systematizes the state of Polish research on renewable energy sources as well as specifies and characterizes renewable energy technologies together with the methods of their use in architecture. Polish buildings equipped with renewable energy systems were reviewed and presented against the background of European and global model examples located in a temperate climate zone. Selected aspects of buildings using renewable energy technologies were discussed, including integrated design process, current legislation and financing programmes. The implementation of the e-learning platform in the form of the Atlas of Polish Renewable Energy Architecture (www.ozearch.pl) accomplishes the educational and implementation goal of the work. The text of the dissertation consists of four parts, each of which has an introduction and summary.

The first part titled "Presentation of the research intent, methods and purpose of the work" contains eight chapters and nine subchapters, in which the field of consideration, scope of research, research subject, research method and objectives, research thesis as well as the current state of research and dissertation structure are presented. The current state of research on subjects related directly and indirectly to the undertaken scientific problem is presented in thematic groups covering research results in Poland and outside of Poland. Research attention focuses on issues in the field of the theory and practice of the latest architecture oriented on the use of energy from renewable sources, sustainable development in architectural and urban design and the resulting aesthetic properties that are relevant to the building as a work of architecture. The scope of research also included issues related to the architectural form modelling in accordance with the idea of sustainable development, the role of renewable energy installations in architectural design and the relationship between human and built environment.

The subject of research encompasses architectural objects built in 2004-2019 in Poland that use renewable energy sources. A comparative analysis based on model buildings using renewable energy built outside Poland was carried out. The considered objects were analyzed due to: the type of renewable energy installation, its importance in architectural composition, functional and spatial solutions, aesthetics, architectural form modelling, role in the urban structure, as well as social impact. The research was aimed at:

- determination of objective factors interpreted as aspects related to the theory of architecture, knowledge of human sciences as well as architecture design strategies using renewable energy sources technologies, which have a decisive impact on the architectural form, structure and functional features.
- systematization and defining the role of these factors in the formation of creative trends in the design of energy-efficient buildings using renewable energy sources with particular emphasis on their external form and its environmental impact. Assessment of the impact features in architectural design enables it to reflect the aesthetic characteristics of the analyzed buildings’ creation period, here architectural objects using RES,
- defining the development trends of Polish architecture using renewable energy in the 2030 perspective expressing the tendencies in world architecture and urban development shaped under the influence of the environmental protection imperative, the principles of sustainable development and technological development.

Attention is focused on determining the characteristic features of the external appearance of the studied objects often originating from creative trends in contemporary architecture occurring in the world. Knowledge of these features is necessary to illustrate the direction of changes in the architectural modelling form of buildings occurring in the studied period. Mass Customization regarding the design of single-family houses using renewable energy technologies has also been described.

The second part is entitled "Determining the elements of analysis of architectural objects taking into account the use of renewable energy sources" and has ten chapters and eleven subchapters.

The first chapter presents the definitions of renewable energy with their division into individual types of renewable energy (hydropower, sea currents, waves and tides, wind energy, solar energy, biomass, geothermal energy), historical outline of the use of renewable energy with emphasis on contemporary technology development stages developed in the 20th and 21st centuries and comparative analyzes concerning Poland against the background of the presented research materials.

The second chapter demonstrates selected examples from Italy, Germany, Denmark and the Netherlands considered as groundbreaking, model or innovative.

The third chapter presents energy-efficient architecture and the use of renewable energy in the urban areas of Europe, North America and China. Selected examples of the buildings and urban complexes in the above-mentioned locations have been discussed in the context of the assumptions of sustainable development as well as its implementation in architecture.

The fourth chapter presents the role of World EXPO Exhibitions (EXPO 2015 Milan, EXPO 2017 Astana, EXPO 2020 Dubai) constituting a platform for the exchange of the latest technologies and dissemination of scientific, technical and civilization progress. Selected national pavilions were described, highlighting their design links with the principles of sustainable development and promotion of renewable energy solutions.

Chapter Five presents the European Union's climate policy focused on reducing greenhouse gas emissions and increasing the share of renewable energy sources in energy production by 2030, as well as national policy issues in this area.

Chapter Six describes the financial programs (NFOŚiGW, WFOŚiGW, UE) implemented in the field of energy efficiency in building sector as well as the production of energy from renewable sources.

Chapter Seven describes the IDP (Integrated Design Process) in which energy efficiency and renewable energy installations of the building are already considered at the concept design stage. The main features and benefits of the integrated process as opposed to the conventional one are presented. In the field of renewable energy, IDP is of key importance for increasing the aesthetic, technical and functional quality of the building. The necessity of cooperation of all participants of the investment process (architect, civil and environmental engineers, energy consultants and future users of the facility) in integrated design teams was emphasized. Integrated design issues have been supplemented with BIM (Building Information Modeling), BEM (Building Energy Model), IED (Integrated Energy Design) and the assumptions of the MaTRID (Market Transformation Towards Nearly Zero Energy Buildings Through Widespread Use of Integrated Energy Design) project. Methods of multi-criteria assessment and certification (BREEAM, LEED, DGNB, HQE and WELL) promoting integrated design process and digital energy efficiency simulations of the designed building were also discussed.
The most popular computer software for the simulation of energy efficiency of buildings (Design Builder, DIVA for the Rhino, Ladybug environment, Honeybee for the Rhino-Grasshopper environment, Insight 360 for the Revit environment, integrated tool are presented ArachCAD energy efficiency analysis) was presented later in this chapter.

The selection of buildings using renewable energy constructed in Europe, Japan, the United States, China and Canada in 1996-2012 presented in Chapter Eight facilitated the determination of the chronological development of renewable energy technologies in architectural design.

Chapter Nine discusses the prosumer model of energy production, energy poverty and the possibilities of converting the Polish, centralized model of the energy system into a dispersed energy system (e.g., local networks from renewable energy micro-sources, cogeneration power plants, energy cooperatives) modeled on the German energy transformation "Energiewende".

Chapter Ten summarizes the second part of the dissertation.

Part three of the dissertation “The analysis of the selected buildings using renewable energy in Poland”, preceded by the introduction, consists of three chapters and six subchapters, in which the results of research on 45 Polish architectural works using RES realised in 2004-2019 were included in four functional groups. The examples were selected from the initial review (80 facilities with various functions and volumes) in order to present the variants of the use of renewable energy sources at various scales and with a different degree of their integration with the architectural form.

In the dissertation, six analysis considerations and five groups of visual and structural characteristics were adopted, described and tabulated. The analysis considerations include following categories: usability, functionality, durability, beauty and energy efficiency; tectonics and spatial articulation; architectural form, its structure and aesthetics, style; technique and technology, stylistics and cultural symbolism; reactivity, environmental performance of building; RES integration with the building envelope.

Case studies were compiled according to the adopted model containing a descriptive and illustrative part, pictograms representing renewable energy and the degree of their integration with the form of the building. The descriptive part of the cards contains the following information: date of construction, name of the facility/complex, names of architects, design collaborators, consultants, investors; location, type of building/complex, area, volume, investment costs/financing obtained; awards/distinctions, type of project, start dates of the design and construction stages, certification systems, energy certificates, energy efficiency, degree of integration with renewable energy sources, degree of project/implementation complexity, characteristics of the design process (traditional, conventional, integrated). The illustrative part includes: original photographs or materials obtained from other sources (available literature, netography, architects, administration), i.e. general views, illustrations related to renewable energy systems and in some cases detailed drawings: projections, schemes, diagrams of renewable energy systems in facilities and spatial plans.

The results of research and analysis obtained in the dissertation are presented in tabular form, including auxiliary and compilation tables showing all objects in chronological order, ending with a synthetic table on visual and structural features characteristic of the analysed architectural objects in the four functional groups that were adopted.

In the conducted research of 45 architectural buildings using renewable energy sources particular attention was paid to:

- tectonics of architectural form (layout and logic of its parts),
- spatial articulation (i.e. highlighting or hiding its spatial components),
- articulation of flat/curved surfaces,
- structure and material articulation,
- visual articulation of renewable energy devices,

which enabled the emergence of two groups of impact factors: direct and indirect, which were discussed in the last part of the dissertation.
In addition, the third part presents the concept of the e-learning platform OZE[Arch] (www.ozearch.pl) in the form of an interactive Atlas of Polish Architecture with RES, which accomplishes the educational goal of the dissertation and is focused on promoting, implementing and dissemination of solutions in the field of renewable energy use in architectural facilities realized in Poland since 2004.

The platform enables users to publish and explore architectural works in the form of illustrative and detailed drawings, energy diagrams, photographic and audio-visual materials, animations, 3D models, as well as lists of cooperating design units, energy system designers and companies providing RES technologies. The platform also gives users the opportunity to exchange experience and valuable comments related to the design, implementation and use of buildings with RES. The theoretical section (knowledge base) contains a glossary of terms and enables to publish and view thematic articles related to renewable energy in architecture, as well as research and analytical studies.

The renewable energy platform OZE[Arch].pl can be a support system for architects, design offices, students of architecture faculties, investors and in the implementation of comprehensive solutions to increase the use of renewable energy in architecture, towards its more effective integration with new active systems based on renewable energy and promote the integrated design process.

Part four “The implementation of the research intent” consists of five chapters, which contain the results of research on the effects of introducing renewable energy into Polish architecture after joining the EU. The work refers to the impact of renewable energy on the conceptual side of architecture, describes the influence factors, both direct and indirect. This part of the work draws attention to the educational dimension of renewable energy architecture. An attempt was made to systematize modern building envelope as three models: static, hybrid (static-dynamic) and dynamic (responsive, reactive, adaptive, additive and active), referring to directions of further research in the field of renewable energy in architecture. The fourth part was completed with motions.

The results of research on examples of the use of renewable energy sources in architecture confirm the accepted thesis: "The use of renewable energy sources in Poland leads to the construction of buildings whose appearance and aesthetic and functional properties are determined by the methods of obtaining renewable energy. The use of renewable energy sources leads to changes in the design process, expanding its integrated character. This is due to the need to simultaneously take into account both the energy aspect as well as utility, functional and material guidelines. In addition, in field of architectural design, this means a need to revise current thinking about the aesthetic properties of buildings."

The final conclusions highlight the role of innovative solutions in the aspects of renewable energy production and energy efficiency as the basis for creating the architecture of the future. The development of technology is moving towards the greatest possible energy self-sufficiency of individual buildings. The goal of sustainable architecture is zero-energy facilities (whose technical systems generate sufficient energy from renewable sources to cover operational demand at least) and aim at plus-energy. Technologies that enable energy storage and interaction with energy systems help to achieve a balance between energy supply and demand. Zero and plus energy buildings in global energy policy are defined as one of the most beneficial design solutions in terms of environmental performance.

Nowadays, the building envelope, often compared to a skin of a living organism, has a complex structure and performs many functions: isolation of the internal environment from the external (physical, chemical and biological factors), gas exchange, thermoregulation and perception. Modern building envelope is designed as a system of multi-layer components that regulate environmental conditions inside a building in response to changes in external environment conditions, affects energy consumption, and can be used for its production and storage. An analysis of the evolution of modern building envelope shows that their character has changed due to a new task, energy acquisition.

Sustainable architecture becomes an example of a new way of thinking: building generates energy instead of consuming it. Depending on the location of the building, its envelope can be used to produce energy from renewable sources. The degree of integration of installations acquiring renewable energy with the building envelope has an impact on its form. Creating a design of an energy-efficient building, equipped with renewable energy installations and having at the same time architectural value
requires close cooperation of an architect, civil engineers, environmental engineers and manufacturers of RES technologies. The integration of active renewable energy systems stands for designing them in a way that these elements take over the functional, technical or aesthetic tasks of the building envelope. This opens up new possibilities for architectural design. Elements of renewable energy installations used in the building should become an integral part of its external casing, replacing typical materials or building components, fulfilling their functional and structural tasks. The integration of renewable energy systems with architecture must guarantee that the installation will not interfere with the requirements and properties of building envelope but will give assistance in architectural and structural terms. Decisions regarding technical parameters and dimensions of installation elements, connection geometry and profile cross-sections influence the aesthetics of the building envelope.

The whole dissertation consists of four main parts, which are internally divided into chapters and subchapters, the main text is found on pages 6-441. The work is supplemented by a list of literature (279 items), netography (114 items), list of legal acts (31 items), list of tables (77 tables, including 266 illustrations in the tables), list of illustrations with authors and/or their online sources (242 illustrations) multi-element case studies, 701 illustrations in total), glossary and abstracts in Polish and English.

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