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IMPACT OF CLIMATE CHANGE BY 2100 ON THE MICROCLIMATE OF PUBLIC PLACES

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Abstract
Climate change has been mankind's main concern over the last century, with its many impacts such as rising temperatures, water stress, increase in natural disasters and reduced thermal comfort in urban spaces due to the Urban Heat Island (UHI) effect, a phenomenon that causes several deaths around the world every year and for which measures must be taken to mitigate its impact. The aim of this paper is to assess the impact of climate change on the urban microclimate and the resulting thermal comfort. The Place de Ettoute in Blida city centre, Algeria, is considered as a case study. This case is considered as a reference on which 3 scenarios, B1, A1B and A2 are applied representing three possible ways of the future of climate change according to the prospective study for 2100 of the IPCC for future periods. Envimet V3.1 is used to model the Ettoute urban square, in a 120x120m square with a 3x3m grid. It is based on a three-dimensional digital model that takes into account fluid dynamics and thermodynamic models to simulate the impact of surfaces, vegetation and the atmosphere at the micro-scale of the square. The comparison between the four scenarios shows an increase in temperature (from 0.5 to 1.24°C), particularly at night (8.8 to 10.03°C), which would reduce thermal comfort in Ettoute square, but scenario B1 has less impact on the urban microclimate and scenario A2 represents the worst case. In addition, a reduction in relative humidity (up to –19%) is expected for the scenarios A1B and A2 while a relative increase would be observed for the B1 scenario up to 2%. This study highlights the urgent need for adequate mitigation measures to reduce the impact of UHI for future periods.

Keywords: urban microclimate; climate change; envimet; public spaces

INTRODUCTION

Climate change is the most important phenomenon facing mankind in the 21st century. Its unpredictable impact and its harmful effects on both man and the earth make it particularly worthy of study, because its impact affects people's quality of life and makes the elderly even more vulnerable, with a growing number of cases of morbidity caused by increases in heat during the summer, with significant morbidity observed in Paris [B. Dousset et al. 2011], while in England UHI was responsible for half of the mortality observed during August 2003 [C. Heaviside et al. 2015]. According to various IPCC reports since its creation in 1988 [I. Tumini, C. Rubio-Bellidol 2016], despite all the actions taken by governments around the world, the earth will experience an increase in temperature of at least 0.1 degrees Celsius per decade until 2100 [IPCC 2014]. Natural disasters will accelerate with greater aggressiveness and impact on humans, infrastructure and the built environment in general [R.S. Tol 2018; T. Emilsson, A. Sang 2017]. The main constraint limiting control of the impact of climate change is the fact that it is unpredictable and intimately dependent on four driving forces: economic development, demographic development, the rapprochement between countries and the mode of development [N. Nakicenovic et al. 2000].

Among the phenomena that are being further accelerated by the impact of climate change is the urban heat island phenomenon, which accentuates the temperature in urban areas by increasing it more than in rural areas [T.R. Oke 2011]. This phenomenon gen-

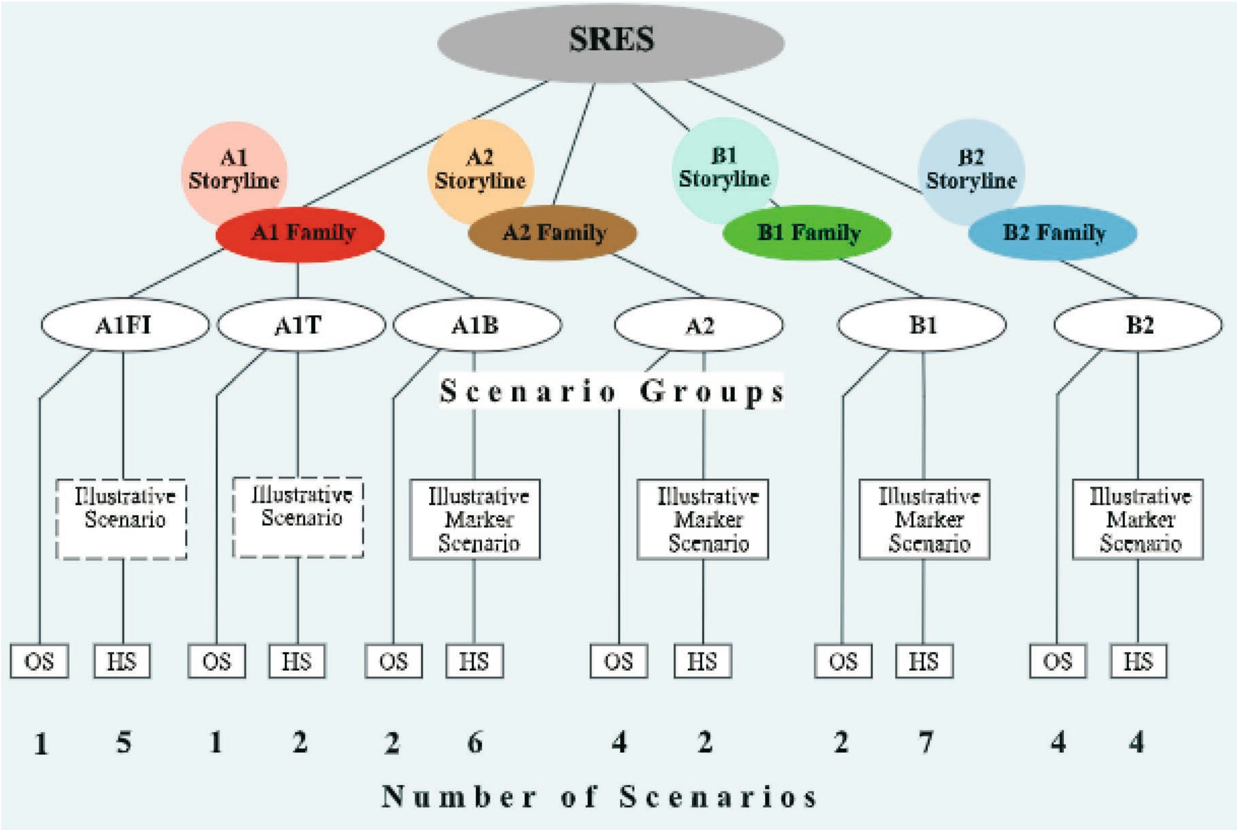


Fig. 1. The 40 scenarios of climate change; source: N. Nakicenovic et al. 2000

erates a particular microclimate that depends on the weather conditions, urban morphology, human activity, Green-blue urban grids and the thermal characteristics of building materials [T.R. Oke 1980; M. Santamouris et al. 2001]. According to the IPCC report, the mode of future development is the key factor in predicting climate change. In order to limit the scope for uncertainty, the IPCC has developed around forty models, organised into 4 main categories of possible climate change development, namely the A1, A2, B1 and B2 families, the development of which is summarised in the figure below. On the basis of these possible scenarios, the IPCC and the world meteorological organisation state that it would be possible to predict emissions and climate change. In this context, several authors have contributed to climate data morphing operations and have made it usable in common formats such as EPW, see M.F. Jentsch et al [2008] or A.L.S. Chan [2011] and A. Mylona [2012]. All these contributions have made it possible to develop databases that can be used to study more precisely the impact of climate change on different aspects of urban space.

The Covid-19 health crisis has highlighted the importance of public spaces in health resilience, that is why we are focusing our attention in this paper on the Ettoute public square in the city centre of the city of Blida (36.46N, 2.82E), Algeria, in order to assess its environmental quality and its microclimatic variation under different climate change scenarios for the summer period and for the hottest day of the year for the current state and according to the climate change scenarios. This study would make it possible to propose potential adaptation scenarios to future climate variations with a view to improving the hygrothermal comfort of the public square, which would improve its habitability.

1. METHOD

This paper aims to explore, on the basis of a simulation campaign, the impact of climate change on the hygrothermal comfort of the *Ettoute* public square in the city of Blida. The elements defining the microclimate are air temperature, relative humidity, wind speed, and mean radiant temperature (MRT). Some studies go so far as to quantify the amount of air exchange between the upper and lower parts of the urban canopy [S. Kitous 2013], or the energy budget expressed in terms of energy balance [T.R. Oke 1989] or air quality by assessing carbon emissions into the air; while other authors directly target the impact of a morphological device on the microclimate by addressing atmospheric pressure and wind speed [L. Khelifi et al. 2019; S. Boukarta, A. Mokhtari 2017]. In this paper, we will focus on the elements that define the microclimate and hygrothermal comfort, i.e. potential air temperature, MRT, air speed and humidity.

Morphing is an important step in the implementation of climate data for simulation. There are now a number of programs available for converting climate data for future periods and making it transferable. A recent study by Tootkaboni et al. [2021] exploring the quality of the predictions made by the 3 simulation models shows that the quality of the above-mentioned programs is almost identical, which makes morphing accessible to different disciplines and also makes it possible to make better use of climate data in terms of its impact on the various elements of the built and natural environment.

1.1. Future scenarios

In this paper we will focus on the current state of the Ettoute public square and three future scenarios, B1, A1B and A2, whose impact is to be considered in ascending order. Scenario B1 represents a future world that will experience population growth until 2050 and then decline until 2100. Economic development will be service-oriented with well-established regional convergence and the use of universal solutions and renewable energy. The A1B scenario is a sub-scenario of the A1 family, characterised mainly by continuous demographic growth until 2050 and then a decline until 2100, with rapid economic growth and the rapid introduction of more efficient technology. Regional convergence will also be strong, characterised by significant cultural and social exchange, with less variation in terms of GDP per country. The particularity of this scenario is that, despite rapid economic growth, it tends towards a world that is fairly balanced in terms of the use of fossil fuels and renewable energy. The A2 scenario describes a very heterogeneous future world whose development principle is based on local identities and weak regional convergence, with an increase in population without any decrease in growth. Technological exchange and use is slow and fragmented, not going beyond the scale of a single region [N. Nakicenovic et al. 2000; S. Boukarta 2019].

1.2. Morphing climate data

The morphing of climate data into Envimet was carried out using Meteonorm for the 2100 projection, based on the guidelines of the IPCC's fourth report [J. Remund 2010]. The climatic data thus obtained was transposed to Envimet version 3.1. The day chosen was the hottest day of the year, i.e. 20 July for the current period and 21 July for the future period, in order to assess the impact of the worst-case scenario and evaluate the role of the development of the public square on hygrothermal comfort. Also, in order to reduce the calculation time for the simulations, we focused on the critical periods of the day, i.e. 3 p.m. and 11 p.m., because the first period is the time of the earth's thermal inertia, which coincides with the temperature peak, and the second period is linked to the urban heat island phenomenon, the peak of which is often felt three to five hours after sunset [T.R. Oke 1975].

The climatic data obtained is presented in the graph below, including the temperature recorded during the chosen hour, the wind speed and the relative humidity.

Tab. 1. Weather data for the different scenarios

Scenario	3pm			11pm		
	Air temp °C	Relative humidity (%)	Wind speed km/h	Air temp °C	Relative humidity (%)	Wind speed km/h
Current	40	40	6,1	30,7	57	0,7
B1	41,6	40	6,6	32,7	74	0,7
A1B	43,1	26	6,5	32,5	56	0,7
A2	43,9	27	6,8	33,1	57	0,7

Source: own preparation

1.3. Presentation of Envimet software

Envimet is a three-dimensional grid-based prediction software designed to model microclimates under different configurations and is widely validated by the scientific community [S. Tsoka et al. 2018]. It is capable of predicting the complex interactions between air-surface-water and vegetation to give in return data characterising the microclimate; such as air temperature, humidity, wind speed, wind direction and radiative exchange etc, with a resolution of up to 0.5m grid in a time span ranging from 1 to 5 seconds [S. Huttner 2012]. In order to reduce the simulation time and given the size of the Ettoute square, we opted for a 3x3m grid model, specifying the simulation periods to include the critical periods in terms of heat.

1.4. Presentation of the case study (morphology)

The square of Ettoute is right in the centre of the city of Blida, at 36.28N and 2.49E. The city of Blida is in the humid climatic zone according to the DTR C3-2 classification, characterised by cold winters and hot, humid summers, with annual rainfall averaging over 600 mm and summer humidity exceeding 70%. The urban density surrounding Ettoute public square is medium, with buildings having an average of 2 storeys above ground level. The layout of the square is characterised by a predominance of mineral features, with two tree lanes surrounding the square on all four sides. The square is almost square in shape, with 67m-long sides. The centre of the square contains a monument surrounded by a fountain (Fig. 2).

Fig. 2. Ettoute public square, Blida city, Algeria (36.46N, 2.82E); source: left – Google Earth, top right, Flickr.com, bottom right: Wikimedia commons. Licensed under the CC BY-SA 3.0

The thermal characteristics of the building materials and those of the surface of the square are characterised by the heat transmission coefficient and the albedo of the walls and roof. See table below.

From the outset, it would appear that the current layout of a predominantly mineral square is not suitable for improving hygrothermal comfort, except at its periphery or even in the centre of the square. The habitability of the square is subject to the layout and it is only really used as a passageway.

Tab. 2. Materials' thermal characteristics

Thermal characteristics	Values
Walls' heat transmission	1.94 W/m^2.K
Roofs' heat transmission	2.00 W/m^2.K
Walls' albedo	0.275
Roofs albedo	0.25

Source: own preparation

1.5. Assessment method and limits of the investigation

Based on the modelling of the Ettoute square and on current and 2100 climate data for the 3 future scenarios presented above, the approach followed in this paper is based on the comparison of a series of simulations between the data characterising the microclimate. In this paper, we have limited the study to comparing 3 future scenarios with the current situation of the square. The other possible scenarios are not considered in this paper.

2. RESULTS AND DISCUSSION

The Ettoute square is modelled in Envimet using an image obtained from Google Earth with a grid of 3x3m (Fig. 3).

The results of the simulations are presented in the two tables below at 3pm and 11pm, comparing the microclimatic data, air temperature at 1.2m, wind speed, mean radiant temperature and relative humidity. A first reading of the maps obtained allows us to distinguish three different zones, a central zone constituting of the most vulnerable part, the vegetation zone of the trees, and the zone close to the buildings.

2.1. Ettoute square at 3pm

The most unfavourable air temperature seems to develop in the least shaded zone of the square and in future scenarios, the air temperature in the same central zone increases by 0.5°C, 0.94°C and 1.24°C respectively. The air temperature decreases relatively towards the vegetated periphery of the square by an average of 1.15°C. See table below.

The average radiant temperature follows the same logic, rising from 58.45 to 58.25 and 59.22 to 59.12°C for the actual, B1, A1B and A2 scenarios respectively. The increase is relatively small and even falls below the current level by almost 0.2°C for the scenario B1.

Relative humidity will increase by +2% in scenario B1 compared with the current situation (from 79% to 81% on average) and will fall by –19% and –16% respectively in scenarios AB1 and A2 at 3 pm on the hottest day of the year.

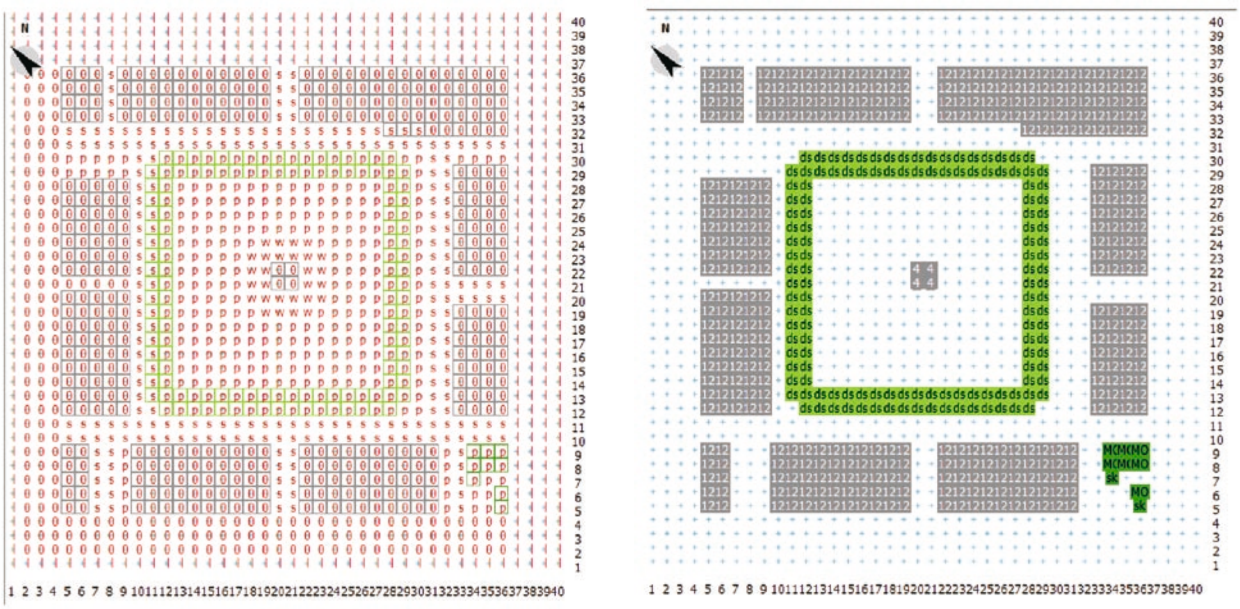
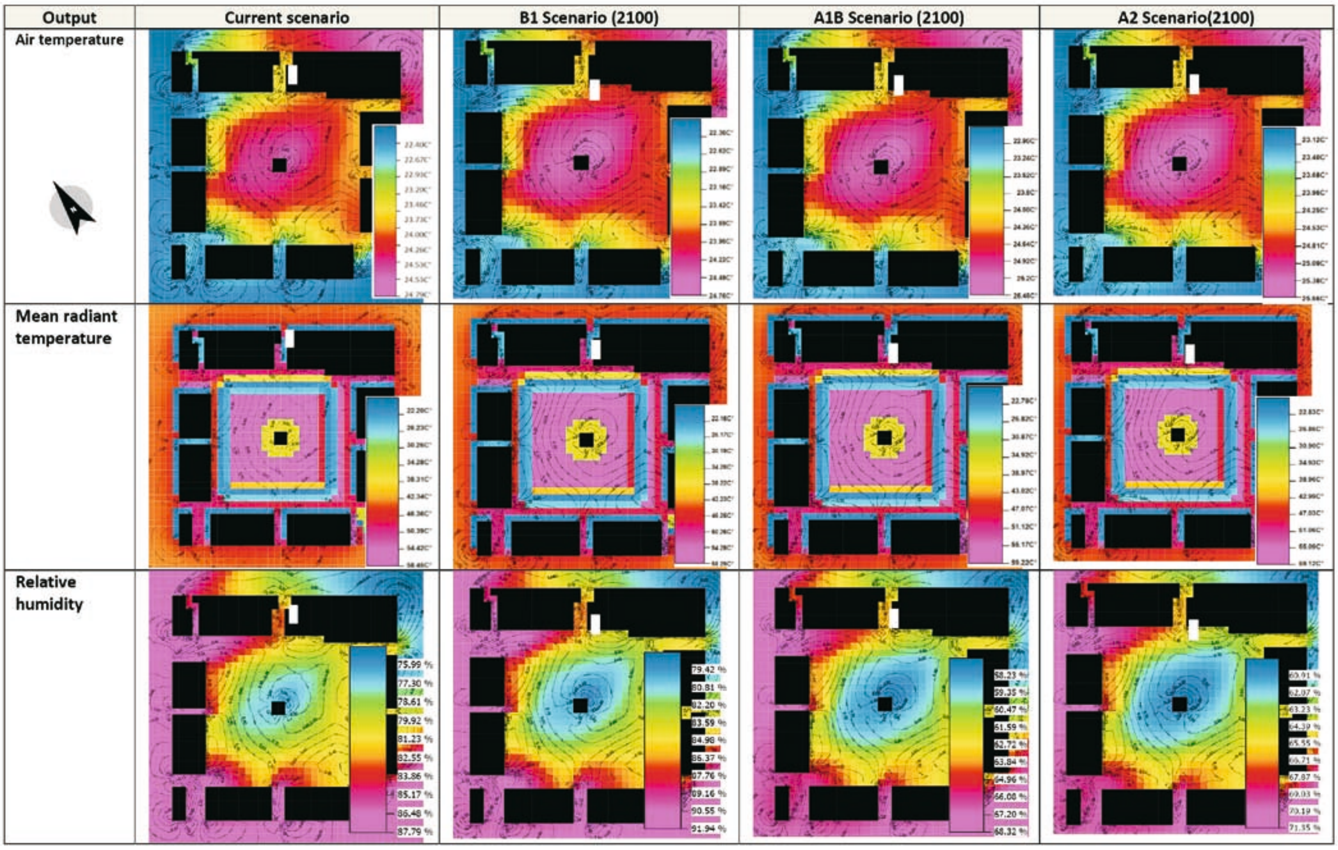


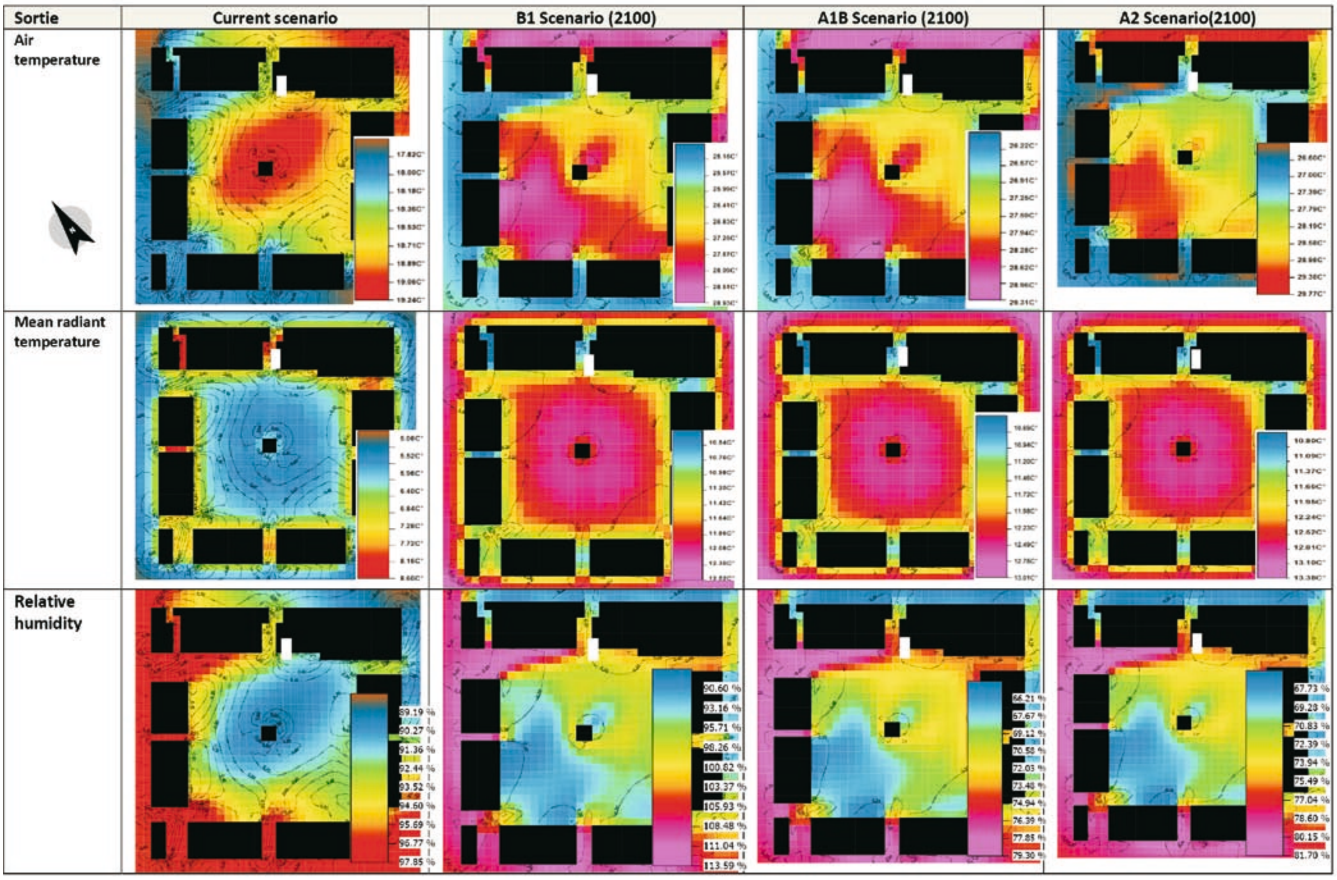
Fig. 3. 3D modelling of the Ettoute square; source: prepared by the author

Tab. 3. The Ettoute square at 3pm



Source: own preparation

Tab. 4. The Ettoute square at 11pm



Source: own preparation

2.2. Ettoute square at 11 pm

The simulations carried out at night (11pm) clearly show a significant rise in temperature between the current baseline scenario and the future scenarios for the 2100 horizon, rising from 18.95°C for the current period to 27.81, 28.37 and 28.98°C for scenarios B1, AB1 and A2, i.e. a rise of over 10°C for the worst case (A2).

The surface of the square is divided into three zones for the three future scenarios when considering air temperature. The central zone will see the greatest increase, as it is completely mineral and will experience a temperature of almost 30°C in the A2 scenario. The vegetation zones, on the other hand, will experience an air temperature of almost minus 2°C compared with the central zone.

The average radiant temperature will also rise by almost 7°C compared with the current situation. Lastly, relative humidity will increase slightly in scenario B1, by almost 2% compared with the current situation (90.84%), while the other two scenarios will see a fall in relative humidity of 69.41% and 70.91% respectively in scenarios AB1 and A2.

CONCLUSIONS

This paper highlights the importance of studying the impact of climate change on microclimatic variations and hygrothermal comfort of public spaces, based on a comparison of simulation results between 4 scenarios: a baseline case (current), and 3 IPCC potential scenarios, namely, B1, A1B and A2. The comparison of the future scenarios in relation to the current state of the microclimate in Ettoute square clearly shows an increase in air temperature, particularly visible during the night hours, with an increase of over 10°C for the most unfavourable scenario. Relative humidity increases slightly for scenario B1, and drops to 69 and 70% for scenarios AB1 and A2. Scenario B1 is the most conservative scenario with the lowest increase in daytime air temperature and a slight increase in relative humidity. The vegetation area is 2°C cooler than the mineral central area of the *Ettoute* square. This conclusion highlights the importance of vegetation in mitigating the effect of the urban heat island. Urban vegetation plays an important role that is already well documented in the scientific literature. Through its urban multifunctionality, such as shade generation, plant evapotranspiration, urban greenery helps to soften the urban microclimate, helps with air purification, and it can even play the role of a natural insulator for buildings by reducing the incidence of solar radiation on facades, without losing sight of the aesthetic aspect that vegetation can play in enhancing public spaces. The gradual integration of vegetation in public spaces will enable the microclimate to be more resilient and better adapted to future climate change. Potential areas of research include combining vegetation with the introduction of innovative construction materials such as TiO_2, which can reflect solar radiation and even reduce urban pollution through its photocatalytic properties.

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ANALOGUE AND COMPUTATIONAL FORM-FINDING TECHNIQUES IN SHELL STRUCTURES DESIGN

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Abstract
The article is dedicated to the problem of design of shell structures in terms of architectural form-finding methods from a historical and contemporary perspective. The form-finding theory and techniques formulated by Robert Hooke were put into practice by Antonio Gaudi with his designs of the churches of Colònia Güelland and Sagrada Familia. Moreover thin concrete shell structures were used in the middle of XX century and their structural forms were derived from experiments with physical models. Innovative form-finding techniques were developed by Frei Otto for the design of membrane structures. The article presents some historic, physical models based methods used for experimental determination of form and verification of the structural systems. Nowadays, computational methods are used in static analysis with dynamic environmental load simulation, which allow predicting the behavior of designed forms and structural systems. Architects can use 3D modelling twinned with visual programming to perform conceptual analyses enabling structural optimization of the architectural form. The Exhibition Pavilion of the University of Zielona Góra concept project was presented as an example of the use of computer numerical form-finding tools in supporting architectural design in the analysis of the effectiveness of structural solutions.

Keywords: parametric design; form-finding; wooden architecture; finite element analysis

INTRODUCTION

The efficient load carrying capabilities of shell structures are reflected in their widespread use in both architectural and structural design. Innovative engineering applications and the continuous development of new structural materials lead to ever increasingly complex structural design of shells that require careful analysis. Models representing calculations, design processes and their physical implementations have been evolving for centuries. Various disciplines have developed numerical, geometric, and material aspects, but at the core is the externalization of ideas into material construction in various forms of abstraction, from representations of numerical systems to dimensionally scaled architectural artifacts.

Physical models are an effective tool for problem-solving, experimentation, and representation equally adept at realizing abstract, construction aids such as scale models and full-scale architecture.

As pointed out by B. Kolarevic: "*In a radical departure from centuries old traditions and norms of architectural design, digitally-generated forms are not designed or drawn as the conventional understanding of these terms would have it, but they are calculated by the chosen generative computational method. Instead of working on a parti, the designer constructs a generative system of formal production, controls its behavior over time, and selects forms that emerge from its operation. The emphasis shifts from the "making of form" to the "finding of form", which various digitally-based generative techniques seem to bring about intentionally*" [B. Kolarevic 2003].

1. FORM-FINDING OF SHELL STRUCTURES

The term form-finding, or 'finding form', means the process of designing, researching and finding optimal structural shapes based on the behavior of materials under the influence of gravity. The method of finding form was first used by Robert Hooke in 1675. The English scientist used a suspended model in which the components of the structure were subjected to stretching as a result of gravity. This allowed us to determine a form in which only compression occurs in the inverted form. This method is therefore the oldest and most widespread form-finding technique.

B. Kolarevic and K. Shea state: "*the form-finding techniques used in the design of tensile membrane structures (pioneered by Frei Otto) as the nearest example of performance-driven architectural form generation, in which the form of the membrane is dynamically affected by changing the forces that act on the model. (…) the form-finding techniques in structural engineering are generally limited to either pure tensile or pure compression structures*".

In the chapter entitled "What is shell?" Chris Williams describes the shell as a structure defined by a large surface, curved in three directions. Additionally, we can distinguish between shell structures and tensioned structures, such as membranes or cable meshes [C. Williams 2014]. As noted by P. Debney: "*Incredibly thin arches and shells are achievable when they are geometrically optimised, such as Robert Maillart's 1939 Cement Hall from the Zurich National Exhibition. The door openings on the bridge indicate both the scale and the thinness of this reinforced concrete shell. When the shell is constructed from a grillage or lattice, often of timber, then it is referred to as a gridshell. The nature of these structures enables very organic forms to be produced; a well-known example being the Mannheim World Garden Exhibition building*" (Fig. 1a–b).

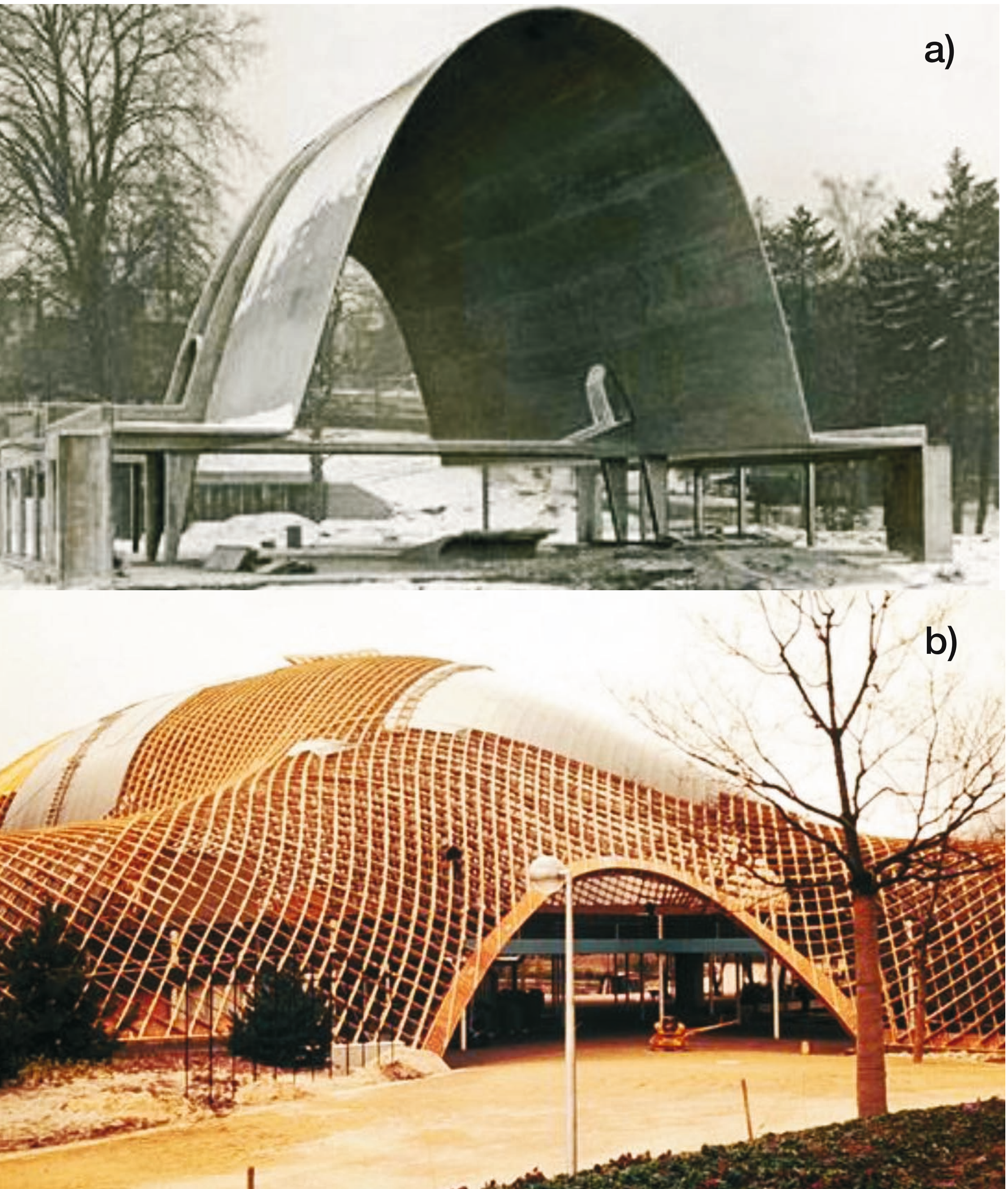


Fig. 1a–b. Shell structures, a) Robert Maillart, Cement Hall, Zurich National Exhibition, 1939, b) Frei Otto, Carlfried Mutschler, Joachim Langner, Multihalle, Mannheim, 1975; source: Debney P. (2015).

2. FORM-FINDING IN ARCHITECTURAL AND STRUCTURAL DESIGN

Until the beginning of the 20th century, form-finding was based on analog research processes. Antoni Gaudí (1852–1926) worked with physical models of the churches of Sagrada Familia and Colonia Güellin Barcelona. Gaudí was obsessed with finding the structural and material given limits, which is why he investigated every detail in scale models [M. Burry 2011].

Antoni Gaudi used suspended chain models to prefigure profiles of vaults and arches (Fig. 2a–b). The Catalan architect constructed suspended models made from chains, changing their form with weights to obtain the shape of the supports. The beauty of a form shaped in this way lies not in aesthetics, but in the way in which this form was created, referring to both the material and the structure of the form [C. Chuang, J. Clinton 2016]. Frei Otto in his experiments with soap bubbles explored the properties of matter to generate minimal surfaces. Otto was fascinated with the experimentation to understand the physical, biological and technical processes behind material organization of structures. Goldsmith writes that Frei Otto, an architect and structural engineer well known for his tensile structures, described the role of the architect in the form-finding process – "*the architect is more acting as a midwife than God the creator*" [N. Goldsmith 2016]. M. Liżewska in her article describes the design solutions developed by Antoni Gaudi on the basis of physical spatial models built by the architect, in which he focuses on the search of the optimum form in the form of the principle of "honesty of architecture". The author also presents test results concerning the catenary that prove the validity of using traditional methods of construction of physical models at the stage of preliminary design of a form consistent with the construction's action [M. Liżewska 2019].

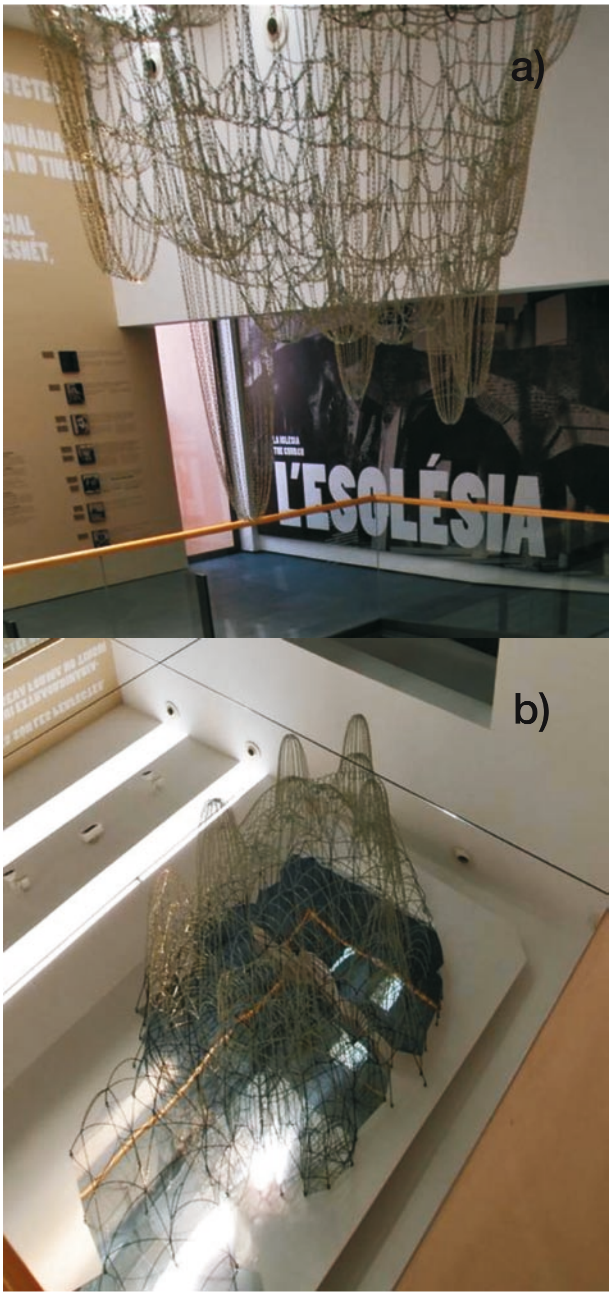


Fig. 2a–b. Antoni Gaudí, funicular model of Colònia Güell church exhibited at Colònia Güell Interpretive Centre; source: Debney P. (2015).

3. ANALOGUE FORM-FINDING TECHNIQUES IN DESIGN SHELL STRUCTURES

In the 1950s Heinz Isler (1926–2009), famous for his intuitive engineering creativity, broadly divided form-finding methods into three categories: analytical, experimental and free form modeling. Moreover, for him, double curvature shell structures were the most efficient shapes in terms of load-bearing capacity, material use and spatial values. Shell structures, he said, constitute both the structural element and the envelope of a building; these are shell structures that create static and functional units.

Heinz Isler used physical models to obtain structurally and materially effective shapes of coating surfaces formed by gravity forces. The chosen method did not answer the question: how the surface would be shaped and, along with it, how the lines of force would run. In his works, Gaudí used suspended models made of chains to determine pressure lines. He also investigated how and whether it is possible to influence their shape using the weights of a scale. Gaudí's explorations focused more on the shape of the ribs and columns than on the geometry of the surfaces. Heinz Isler's experiments were focused on searching

Fig. 3a–c. Heinz Isler, Sicli SA Factory in Geneva, 1968–1969, a) elastic rubber model small-scale epoxy resin model, b) the model used for the evaluation of structural behavior of the Sicli SA Factory in Geneva, c) Sicli SA Factory in Geneva; source: J. Chilton (2011); C.C. Chuang, J. Chilton (2016)

for the shape of the surface formed by the law of universal gravity, which would be characterized by the best efficiency of the structural design. Form-finding techniques used today include a variety of experimental strategies and tools, both analog and virtual [M.W. Weller 2010].

The shapes Isler created in the form finding process were based on physical models structurally optimized according to the principles of physics. Isler found the basic principles of his shell structures in three observations he made by accident in 1955: an inflated membrane, a hanging membrane, and frozen elastic structures. Based on these principles, he designed most of his forms using physical models. He obtained the final geometry for implementation using independently developed methods of collecting data on curvatures through scaled measurements from physical models. In other words, the logic of construction and form are in harmony, as postulated by Eduardo Torroja y Miret, describing the purpose of designing load-bearing structures as the interaction of material, structure and form [J. Chilton, C. Chuang 2017].

The concrete shell for Sicli SA Factory was a project carried out in Geneva (1968-1969) in cooperation between Isler and the architect Constantin Hilberer (Fig. 3a–c). The shell of the factory has seven supports, its formation is characterized by freedom of shape and departure from symmetry. The basic dimensions of the object are 35 × 9 × 30 m, with a height of approximately 8.75 m. The thickness of the SAF shell coating is only 90 mm and 50 mm of insulation. Originally, the facility consisted of a production hall with an area of 1,100 m^2, a spacious hall and an administration center [J. Chilton 2012].The geometry of the form was determined without the help of analytical functions, but rather as a result of using an analytical and experimental method based on finding the form under the influence of the law of gravity. The model made of plexiglass was made on the basis of a wooden form in accordance with the designer's concept. The test results were used to design the distribution of reinforcement in the thin concrete shell.

The diligent search for integral structural forms also characterized the work of the Italian engineer Sergio Musmeci (1927–1981). Examples include form-finding experiments with saddle supports in the Palazzo del Lavoro in Turin (1959), as well as with a curvilinear funnel-shaped roof for the church in Villaggio del Sole in Vicenza (1960) and the Basento Bridge project (1967–1976) [S. Musmeci 1971].The shapes of the engineering structures designed by Musmeci's team far exceeded the design and construction possibilities of the time. Musmeci envisaged the use of digital tools allowing the control of a greater number of parameters in order to research design solutions and use the full possibilities offered by new materials. Already in the 1970s, the Italian engineer supported himself in the static analysis of structures with the first digital engineering program ANSYS. The results of numerical methods of analyzing the deformation and strength of structures largely coincided with the results of calculations performed using analog methods. Unfortunately, his premature death in 1981 did not allow him to take full advantage of the possibilities of new technologies.

Analogue research methods used by architects allow for a greater understanding of both material and structural aspects. Working with physical scaled models requires intuition, helping to overcome the inability to perform accurate calculations. The analogue approach has clear limitations resulting from physical model scaling of complex geometries and requires a number of tests and variations.

4. COMPUTATIONAL FORM-FINDING TECHNIQUES IN DESIGN SHELL STRUCTURES

As noted by Bucalem and Bathe: *"Although analytical techniques are very important, the use of numerical methods to solve shell mathematical models of complex structures has become an essential ingredient in the design process. The finite element method has been the fundamental numerical procedure for the analysis of shells."* [M.L. Bucalem, K.J. Bathe 1997].

The development of computer science initiated the development of computer-aided design (CAD) systems, and now the adaptation of sensor-enabled robotic systems is revolutionizing design processes and geometric representations to establish a closer link between the computational model and the material domain. Since the end of the 1960s, the rise of computer science has made it possible to develop form-finding methods in the theoretically unlimited design space offered by computers. Block and Veenendaal categorize algorithmic form-finding methods in three fundamental families [S. Adriaenssens et al. 2014]:

- Stiffness Matrix Methods, e.g. Natural Shape Finding (1974) which are based on standard elastic and geometric stiffness matrices;
- Geometric Stiffness Method, e.g. Force Density Method (1971), Thrust Network Analysis (2007);
- Dynamic Equilibrium Methods, e.g. Dynamic Relaxation (1984), Particule Spring System (2005).

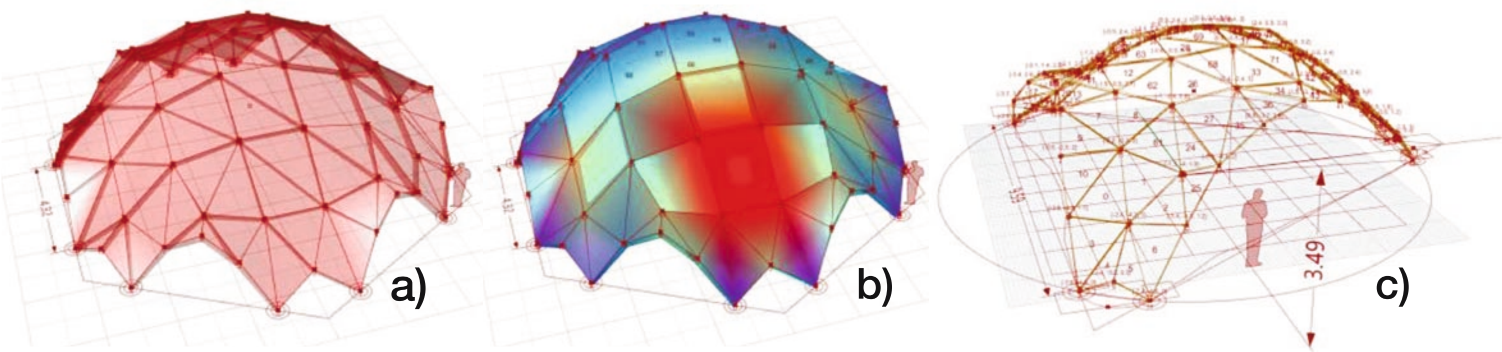


Fig. 4a–c. Computational design of the Exhibition Pavilion of the University of Zielona Góra; source: J. Juchimiuk and Author

Computational design is the convergence of computational power and design techniques through a sequence of logical processes. For centuries, architects have designed relying on their experience and intuition to come up with new design solutions. The advanced technology available at our disposal has entirely changed that process. Using 3D numerical modeling as a tool in architectural design can facilitate structural form-finding and general decision making. The use of numerical models ensures access methods required to obtain a computational simulation of the structural behavior of the designed building (Fig. 4a–c).

These methods can then be classified into two categories: static problem methods (stiffness matrix methods) and dynamic problem methods (dynamic equilibrium method). F. Chéraud claims that: "*The first category includes methods that require a rigorous description of boundary conditions (geometry, topology, material, loads), the simulation is dependent on the material and on solid geometry, which is difficult to reconcile with any prospective approach. Methods such as the FEM consume a lot of computing power and are intended to evaluate a given solution. In short, it is a knowledge-based process, while the objective of the form-finding process is precisely the opposite; to produce variety.*" According to the same author: "*The second category includes methods making it much easier to perform interactive deformations and manipulate complex interactions with only a few equations and parameters. In fact, these methods are well suited to generate visually correct simulations. For example, the Dynamic Relaxation Method is based on the resolution of the balance of forces to reach the static state of a structure.*" [F. Chéraud 2020].

K. Januszkiewicz writes about natural form-creating processes as an inspiration for form-finding methods and the connections between mathematics and architecture: "*Mathematics provides operational tools for science to create mathematical models that are descriptions of simple and complex real phenomena. Such modeling is used to learn about a given process by replacing it with a simplified system that reflects only selected features of the process. The mathematical description of the model is presented here in the form of a system of algebraic or differential equations. The studied processes describe models with complex parameters, and the variables included in them are subject to changes both in time and space.*" [K. Januszkiewicz 2013b].

5. CASE STUDY – CONCEPT DESIGN OF UZ EXHIBITION PAVILION, 2022

An example of the use of parametric modeling methods in the design of wooden structures is the Exhibition Pavilion of the University of Zielona Góra (Fig. 5). The pavilion, with a span of 9.6 m and a height of 3.5 m, was designed as a shell structure. The idea behind the project and its intended implementation is a presentation of the possibilities of contemporary architecture, digital design and new technologies. The concept project of the pavilion was created in 2022 by Justyna Juchimiuk and Michał Golański from the Institute of Architecture and Urban Planning WBAIŚ UZ. Students from the Architecture in Sustainable Space Scientific Club were invited to cooperate. Design work on the pavilion project continued in 2023. The project is going to be realized at the university Campus A in Zielona Góra. The pavilion will host small exhibitions, lectures, concerts and meetings.

Structural and material solutions are being considered and analyzed with plywood as a structural material. FE analysis was carried out to assume occurrence of permissible deflection in accordance with PN-EN 1995-1-1:2010 and NA 3. The form-finding modeling of the pavilion and FE analysis were carried out according to a Grasshopper script (Fig. 6.). Design methodology:

- Definition of input parameters: size of projection, determination of the number and location of support points and types of loads,
- Form-finding (KangarooPhysics),
- FE Analysis of the structural model (Karamba3D) in terms of the use of material properties (wood) and structural and material efficiency,
- Visualization of FE analysis results (node displacements, stresses).

Form-finding techniques were used in the design of the pavilion. The doubly curved architectural form was created by using the inverted hanging model form-finding method using Kangaroo Physics. The resulting structural form primarily transfers compressive loads and limited bending loads (Fig. 7a–d).

Kangaroo Physics, which belongs to this category, is an add-on for Grasshopper/Rhino and Generative Components which embeds physical behavior directly in the 3D modeling environment and allows one to interact with it 'live' as the simulation is running. It can be used for various sorts of optimization, structural analysis and animation. Kangaroo is a Live Physics engine for interactive simulation, form-finding, optimization and constraint solving. It consists of a solver library and a set of Grasshopper components D. Piker 2013].

Fig. 5. Exhibition Pavilion of the University of Zielona Góra, 2022–2023; source: J. Juchimiuk and Author

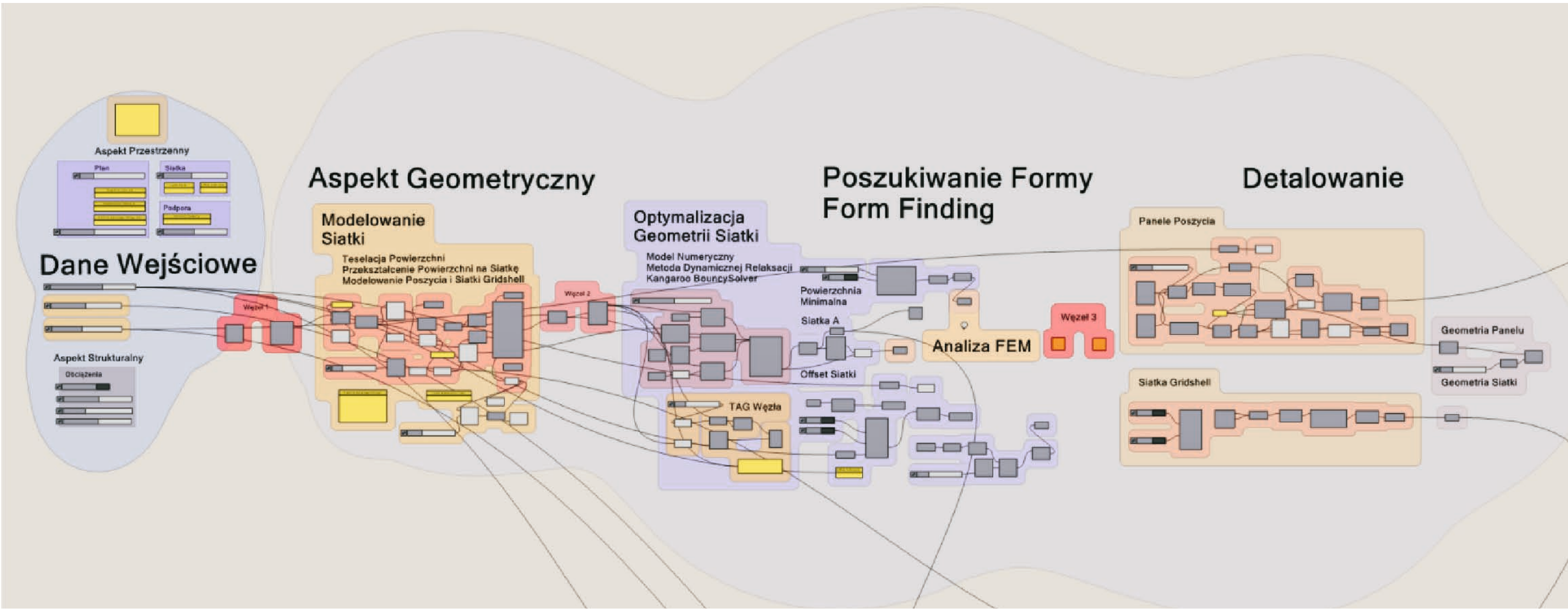
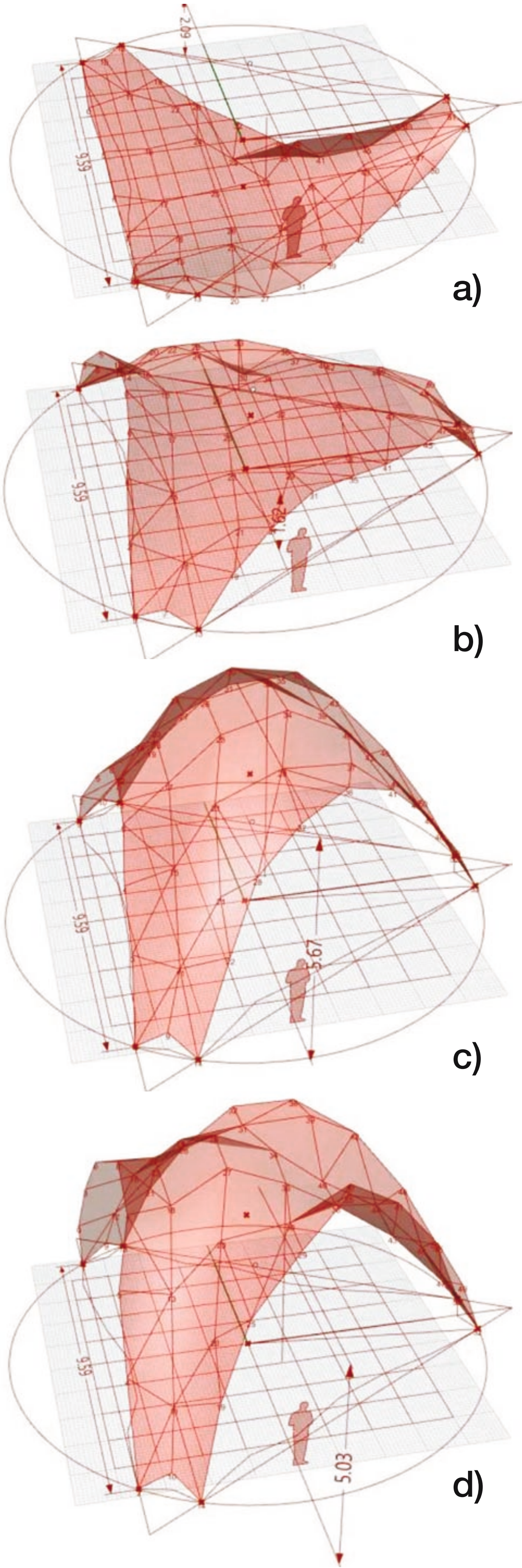


Fig. 6. Exhibition Pavilion of the University of Zielona Góra, 2022–2023 – Grasshopper script for form-finding; source: Author

Kangaroo Physics developed by Daniel Pikeris the most popular tool within the large community of designers using Rhinoceros for integrating physical behaviors through fast simulations within the modeling process. Piker described Kangaroo as a physics engine directly embedded in the parametric modeling environment of Rhinoceros-Grasshopper allowing interactive exploration of geometrical shapes through simulated behaviors based on material properties and applied forces. Kangaroo Physics, a physical simulation engine, is dedicated for users with moderate computation skills. It provides a simplified interface for an advanced simulation tool. Thanks to the visual scripting interface provided by Grasshopper, the user has access to a fixed set of physical ‘goals’ and unitless variables, without having to work with more complex aspects of the Kangaroo physical model. This setup induces a disconnection between the user and the physical model with its variables. It is a Particle Spring System (PSS) relying on the Dynamic Relaxation method and offering a wide design space. A physics engine is a collection of algorithms that enable a computer to simulate some aspects of the behavior of real-world objects [D. Piker 2013].



FE Analysis of the structural model was carried out in Karamba3D in terms of the use of material properties (wood) and structural and material efficiency (Fig. 8a–e). Karamba3D is an interactive, parametric add-in for Rhino/Grasshopper that expands its capabilities in Finite Element analysis. According to C. Preisinger: "*Karamba3D is embedded in the parametric environment of Grasshopper which is a plug-in for the 3d modeling tool Rhinoceros. The initial computational core of Karamba3D has been developed by Clemens Preisinger during the research project 'Algorithmic Generation of complex Spaceframes' at the University of Applied Arts Vienna. Upon completion of the research project, the initial code basis was further developed in continued cooperation with Bollinger+Grohmann. The first release came in 2010 as an interactive structural design plug-in for the visual scripting environment of Grasshopper for Rhinoceros. Since then, Karamba3D has spread around the world through practice, research and academia*" [C. Preisinger 2013].

Karamba3D provides accurate analysis of shell structures, spatial trusses and frames. It calculates and visualizes displacements based on loads, materials (primarily Young modulus and shear modulus), cross sections and supports, which must be considered in both ULS and SLS analysis. In structural design, ULS (ultimate limit state) refers to the maximum loads or forces that a structure can withstand without collapsing or experiencing any irreversible damage. To calculate the ULS, engineers designing the construction system use a combination of analytical and numerical methods. The ULS is an important concept in structural engineering as it ensures that design structures are safe and can withstand extreme loads and environmental conditions. The SLS (serviceability limit state) is defined as the state of design beyond which a structural system loses operationally its serviceability for the actual service load that the structure is subjected to.

Architects can use Karamba3D in the early concept phase to perform quick, interactive analyses of different design options for shell structures. However, advanced FEA tools such as Robot, SAP2000, GSA would be required to perform the final code checks during the later design phases. Despite limitations, Karamba3D is a convenient Finite Element Analysis (FEA) tool, which allows for accurate prediction of the behavior of the structure under various loads. The designers can also consider the effects of various environmental factors, such as solar radiation, wind, humidity, earthquakes, and temperature changes, which can affect the behavior of the building and its structure.

Fig. 7a–d. Exhibition Pavilion of the University of Zielona Góra, 2022–2023 – Kangaroo Physics form-finding; source: J. Juchimiuk, Author

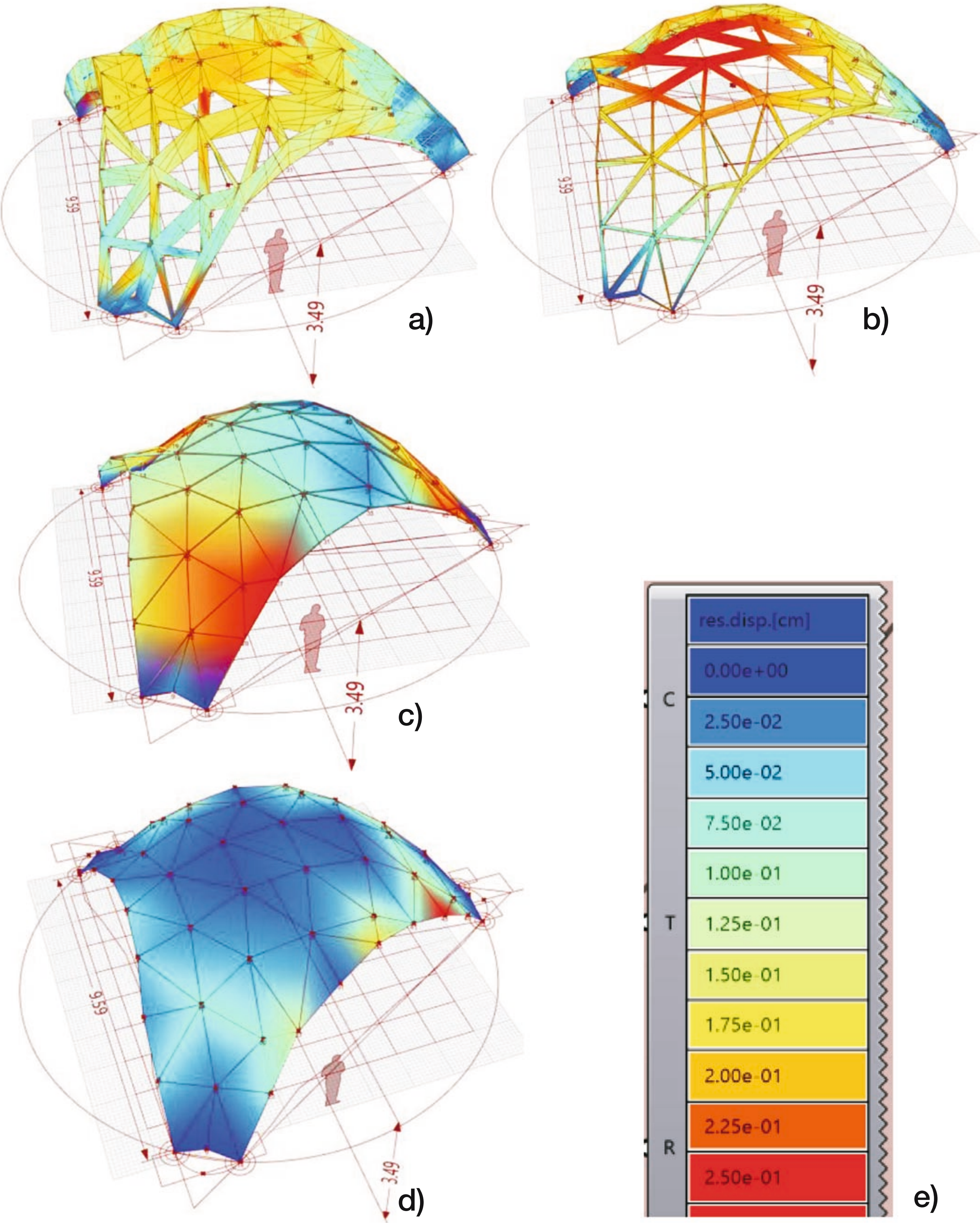


Fig. 8a–e. Exhibition Pavilion of the University of Zielona Góra, 2022–2023 – Karamba3D FE analysis (max. nodal displacement), a–b) gridshell structures, c) Segmented shell (structural panels), d) Segmented shell (flat panels), e) color scale (0–2.5 mm); source: Author

CONCLUSIONS

In architecture, defining form is an important stage of the design process in which the material obtains its spatial configuration consistent with the structural, functional and aesthetic intention. This process is iterative, in which constant changes allow obtaining the appropriate form for a specific design problem. Architectural and construction aspects are inextricably linked in design. In particular, this applies to shell structures carrying mainly compressive loads, as well as purely tension structures such as architectural membranes. Because their shape is subject to physical laws, the physical model plays a significant role in design because it represents the most comprehensive method of acquiring knowledge. It is a medium through which, at a first approximation, allows the initial idea to be materialized and translated into a feasible structure. The physical model helps both in the process of searching for a form and in the procedure of validating a conceptual idea [J. Chilton 2010].

The digitization of computational processes has meant that many complex, often non-linear phenomena of reality can now be described by mathematical models. Computer graphics have become helpful in illustrating the course of modeled processes. Currently, there is some exchange of ideas and techniques between architecture and disciplines such as biology, physics, chemistry and mathematics to imitate recognized processes occurring dynamically in nature. Architects' attention is increasingly focused mainly on natural form-finding processes for structural optimization and adaptation and on their instrumentalization through mathematical models and computational techniques, as well as their simulations and digital visualizations.

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REINTERPRETATION OF TRADITIONAL CARPENTRY JOINTS IN CONTEMPORARY WOODEN ARCHITECTURE

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Abstract
The article is devoted to the problem of design and fabrication of joints in contemporary wooden architecture. The CAD/CAM design methodology results in new production and assembly methods used in the creation of novel structural systems. Connections used in structures are often derived from traditional carpentry connections used in a new way. They are reinterpreted and adapted to their new role in new structural systems.

The article presents the results of an analysis of three experimental pavilions conducted in the context of the types of element connections used in their construction. Carpentry joints in traditional architecture were used and fabricated with technologies available at the time and were developed and used in post-beam constructions that utilize large, widely-spaced wood to provide structural support to the building. Timber frame technologies were dependent on mechanical connectors (nails, screws, shear plates, nailed plates). Digital era technologies provide new ways of joining elements according to new structural systems.

Keywords: architecture; wind analysis; CFD; wind tunnel; research based design

INTRODUCTION

Wood has long been used as a construction material, but the properties of solid wood in terms of strength, maximum length and natural wood defects have always been a limiting factor in the implementation of ambitious projects with complex and unconventional geometry. The first civilizations that developed advanced woodworking were the Egyptians and the Chinese. Woodworking is depicted in many ancient Egyptian drawings, and a considerable amount of furniture (such as stools, chairs, tables, beds, chests) has been preserved in tombs. Commonly used woodworking tools included axes, adzes, chisels, pull saws, and bow drills. Mortise and tenon joints are attested from the earliest Predynastic period. These joints were strengthened using pegs, dowels and leather or cord lashings. Animal glue came to be used only in the New Kingdom period. Ancient Egyptians invented the art of veneering and used varnishes for finishing, though the composition of these varnishes is unknown [K. Zwerger 2011].

The fundamental skill of the woodworker throughout the ages has been measured by his ability to join securely—and with elegance—two pieces of wood (hence the English *joiner* and joinery, derived from the Latin *iunctura*). Carpentry wooden joints do not require metal fasteners, but the use of nails and metal plates, such as gussets, makes the task easier. The woodworker needs greater skill and expends more time in making strong joints of wood alone. In the ancient world, wood-to-wood joints were often made without the use of glue, nails, or clamps, although all these aids were known. Vitruvius Polio discusses the origins of wooden architecture and suggests that basic principles resulted from a consideration of Nature herself (Fig. 1) [K. Zwerger. 2011].

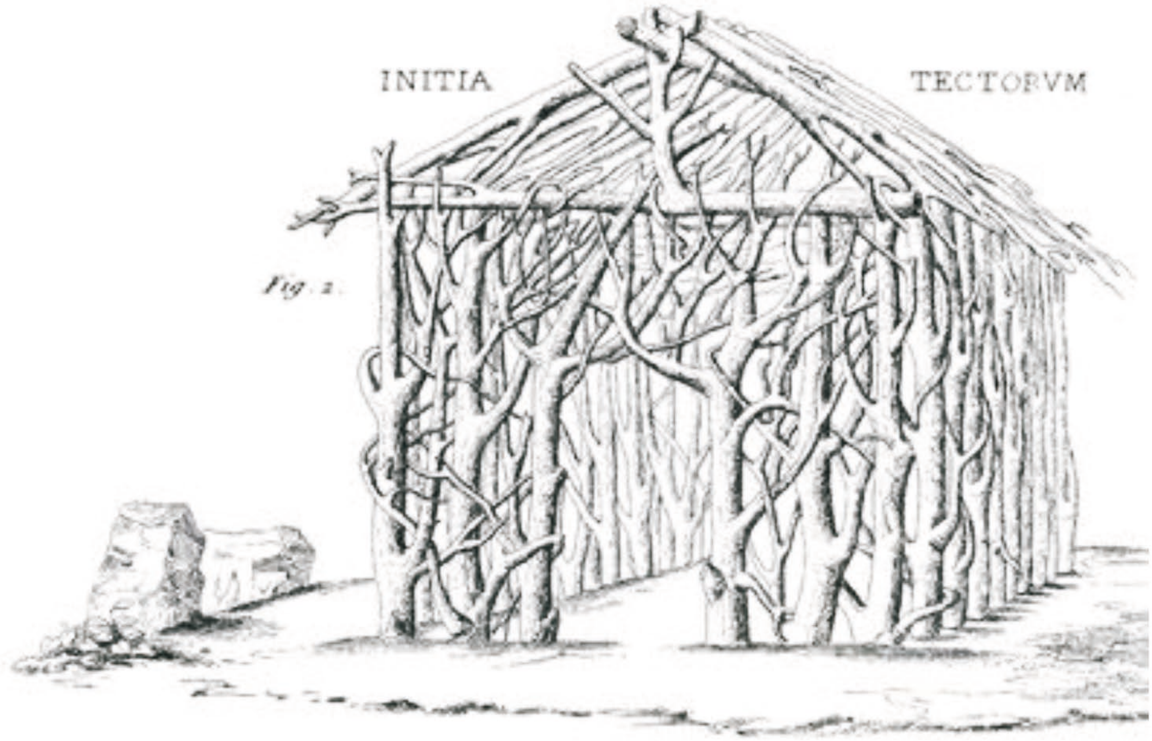


Fig. 1. Johann Rondelet's interpretation of Vitruvius's description of the beginnings of timber construction, J. Rondelet, *Theoretisch-praktische Anleitungzur Kunst zu bauen*; Leipzig; 1833–1835,; source: K. Zwerger 2011.

1. CURRENT RESEARCH CONCERNING CONTEMPORARY WOODEN ARCHITECTURE

The development of CNC technologies allows fabrication of complex architectural forms and structures. Application of wood in structural elements requires discerning particular, anisotropic material properties. Structural timber joints in contemporary wooden architecture often incorporate mechanical connections techniques and reinterpreted traditional joinery. According to S. E. van Nimwegen and P. Latteur: *"Interlocking timber connections that are steel-free and adhesive-free are uncommon in modern construction, but the necessity to maintain cultural heritage alongside the rise in demand for sustainable buildings has revived interest in traditional carpentry techniques, as well as contemporary wood-wood and all-wood connections"* [van Nimwegen, S. E., Latteur, P., 2023]In the article *Historical carpentry joints* the authors say that: *"Historical structures include several hundred different types of carpenter's joints, which were developed through the experience gained by carpenters in a specific area or time-period. Joints are classified in different ways, depending on their form: dowel, glued and notched or their function: extending, increasing dimensions, integrating elements etc."* [J. Jasieńko, T. Nowak, A. Karolak 2014]. This paper summarizes the current state of knowledge related to historical carpentry joints and presents a typology of joints found in timber walls and roof structures.

J.L. Arlet presents the specific examples of the latest solutions presented above which demonstrate that traditional wooden structures and the carpentry joints employed therein remain a model for outstanding contemporary architects and constructors. Conducted research mainly focused on the joints used in construction, as well as their perception. From among many examples, some original and innovative solutions were selected and analyzed [J.L. Arlet 2021].

J. Szewczyk has provided a valuable and multi-disciplinary overview of the development of wooden architecture in a series of articles published in "Builder" [2019a-c]. Three articles comprise its systematization from the perspective of architectural criticism, from a somewhat historical perspective, although focused on the latest phenomena, emphasizing the most interesting current trends. The first part is introductory and generally summarizes the entire phenomenon, first placing it in three categories: material, structure and – briefly – also the aesthetics (form), and indicating those products that determine the current state and the expected (future) horizon of development of modern wooden architecture. The second part is devoted to high-speed wooden construction systems described in a chronological description, starting from their beginnings (11th century AD) to the latest phenomena strictly related to computational technologies and CNC fabrication. The argument also systematizes the approaches to high-speed wooden construction over the last millennium. The third part of the article describes the history of the use of wood in the tallest buildings and systematizes the relevant ancient and contemporary achievements, relating them to four conventional categories of building heights and to analogous records of nature. The significance of the phenomenon was established as a cultural phenomenon in recent years, which for almost a decade has been referred to in the media as "plyscrapers" and increasingly involved in the multilateral relationships between the worlds of business, culture, art and academic science [J. Szewczyk 2019c]. As J. Szewczyk declares: *"The last two decades have brought a revival and development of the idea of wooden architecture at the aesthetic, structural and critical levels… In terms of structural elements, wooden buildings began to be built from volume elements (plates, slabs) instead of columns and beams, but the flexibility of the building material and the stiffness of the connections encouraged engineers to look for new ways to assess the strength of such structures that do not fit into the framework of statically determinate structures. Currently, two groups of methods are being tested: new analytical and computational methods and non-analytical experimental methods based on real measurements. The latter group also includes laboratory seismic tests of wooden buildings, including on 1:1 scale models."* [J. Szewczyk 2019b].

Advanced Timber Structures: architectural designs and digital dimensioning publication from 2016 by prof. Yves Weinand is devoted to research on the use of wood to implement structures characterized by free forms and complex geometry conducted at the Wooden Structures Laboratory (at the Federal University of Technology in Lausanne (EPFL). This unit was founded in 1978 by Prof. Julius Natterer (1938–2021), a leading figure in the field of wooden construction, a pioneer in the use of mass timber, glued timber and nailed timber techniques in the construction of domes and shell structures [Y. Weinand 2016].

The monograph *Advancing Wood Architecture – A Computational Approach* published in 2017, edited by scientists associated with the University of Stuttgart – Achim Menges, Tobias Schwinn, Oliver David Krieg, focuses on the issue of using the inherent properties of wood in the contemporary context of digital design, simulations of behavior in environmental conditions and CAD/CAM digital fabrication technologies. The publication offers a comprehensive overview of new architectural possibilities that are opened up by cutting-edge computing technologies in wooden structures [A. Menges, T. Schwinn, O.D. Krieg 2016].

Digital Wood Design monograph edited by Fabio Bianconi and Marc Filippucci and published in 2018 presents strategies for the digital representation of wooden architecture as a combination of tradition and innovation in design. The articles in the monograph concern advanced digital modeling, with particular emphasis on solutions related to dynamic and generative models [F. Bianconi, M., Filippucci 2019].

2. EXPERIMENTAL PAVILLIONS MADE OF WOOD

The aforementioned academic centers investigate both theoretical and a practical aspects of designing and engineering novel and non-standard wood architecture integrating computational engineering and advanced analysis methods together with fabrication and development of full scale prototypes. An experiment (Latin *experimentum*) is a trial or research performed to confirm or reject a specific hypothesis. In architecture and structural design, these are physical objects of various sizes made at a specific scale. These are material formations that are intended to be a test for the adopted design solutions. Today, parametric modeling tools based on NURBS allow you to efficiently create virtual models at all stages of architectural design, as well as physical models and prototypes in the CAD/CAM system. Experiments with many parameters and the simultaneous action of many different formative forces are almost a new challenge - especially when it comes to assessing various criteria, especially material ones. World architectural universities integrate the processes of: parametric modeling of free-form objects with the numerical production of its components, in search of innovative ways of combining them and to explore the behavior of prototype surfaces in environmental conditions. Below are selected examples of designs that introduced new solutions in building free-form curvilinear structures from wood.

The University of Stuttgart is one of the leading centers dealing with wooden architecture in the era of the digital revolution. The research projects carried out by ITKE and Institute for Computational Design and Construction (ICD) at the University of Stuttgart demonstrate the latest developments in material-oriented computational design, simulation, and production processes in architecture. The Institute for Computational Design and Construction (ICD) is dedicated to the teaching and research of computational design and computer-aided manufacturing processes in architecture. The ICD's goal is to prepare students for the continuing advancement of computational processes in architecture, as they merge the fields of design, engineering, planning and construction.

Zurich's ETH Institute of Structural Engineering (IBK) and Robotic Fabrication Laboratory (RFL) carry out research on designing nonstandard timber frame structures, which are enabled by cooperative multi-robotic fabrication at building scale. In comparison to the current use of automated systems in the timber industry for the fabrication of plate-like timber frame components, the research relies on the ability of robotic arms to spatially assemble timber beams into bespoke timber frame modules.

The University of British Columbia School of Architecture and Landscape Architecture in Vancouver organizes design and construction workshops providing a unique insight into the new opportunities and challenges of advanced design to fabrication processes for timber structures. Numerous experimental pavilions were built: Wander Wood Pavilion (2018), Dragon Skin Pavilion (2019), Zippered Pavilion (2019), C-Shore Pavilion (2020), Mille-feuille Pavilion (2022). These experimental structures are usually assembled without any metal fasteners, drawing inspiration from Japanese and Chinese building traditions.

The subject of this analysis is the study of three pavilions from the years 2014–2022. They were designed and built as full-scale models in leading research projects on wooden architecture and advanced wooden construction. The comparative analysis method was used in order to select characteristic features and types of connections of elements used in the pavilions presented as case studies.

2.1. Case study 1 – ForestPavilion, Schwäbisch Gmünd, Germany 2014

The Forest Pavilion was designed and developed under the supervision of Achim Menges, Jan Knippers and Volker Schwieger at the ICD, ITKE and IIGS Institutes at the University of Stuttgart. The facility was implemented in cooperation with KUKA Roboter, Müllerblaustein Holzbau GmbH, Landesgartenschau Schwäbisch Gmünd 2014 and the forest administration of Baden-Württemberg (Forst BW). The building was built in 2014 as part of the Regional Horticultural Exhibition in Schwäbisch Gmünd in Germany, where it served as an exhibition space [J. Li, J. Knippers 2015].

The architectural form of the pavilion is created by two synclastic dome-shaped surfaces, connected by an anticlastic saddle-shaped area (Fig. 2a–b). The free form of the pavilion surrounds spaces related to its basic functional zones: the reception area, accessible from the south-facing entrance zone, and the main exhibition hall, 6 m high, which can be reached after passing through the narrowing of the building's body. Glass facades on both sides of the building provide views of the surrounding landscape [T. Schwinn 2016]. The shell structure with an area of approx. 245 m^2 is composed of flat polygonal wooden panels with various geometries connected with finger joints and screws. The wooden panels are arranged according to a changing pattern generated parametrically, which allowed the curvature of the shell surface to be reproduced using flat elements. The Forest Pavilion is a segmented shell structure. The building uses an innovative system of light segment construction made of 50 mm thick beech plywood boards [T. Schwinn, O.D. Krieg, A. Menges 2014].

Fig. 2a–b. Forest Pavilion, Schwäbisch Gmünd, Germany 2014; source: J. Li, J. Knippers 2015.

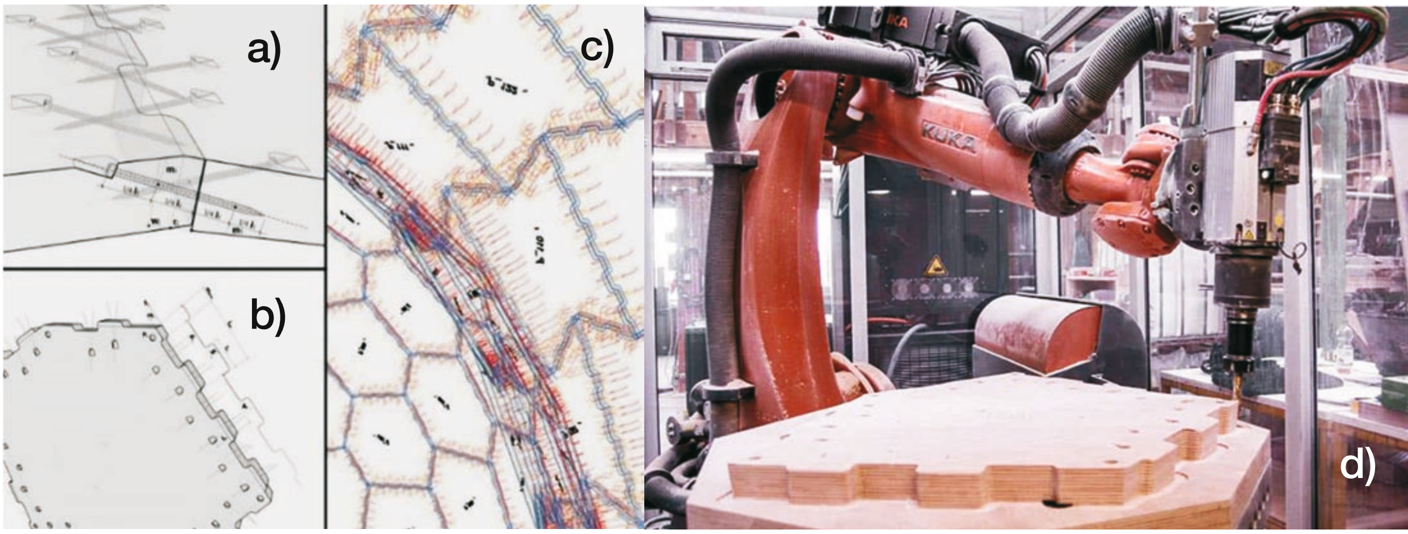


Fig. 3a–d. Forest Pavilion, Schwäbisch Gmünd, Germany, 2014, a–c) finger joint connections strengthened by screws, d) CNC fabrication of structural panels; source: J. Li, J. Knippers 2015.

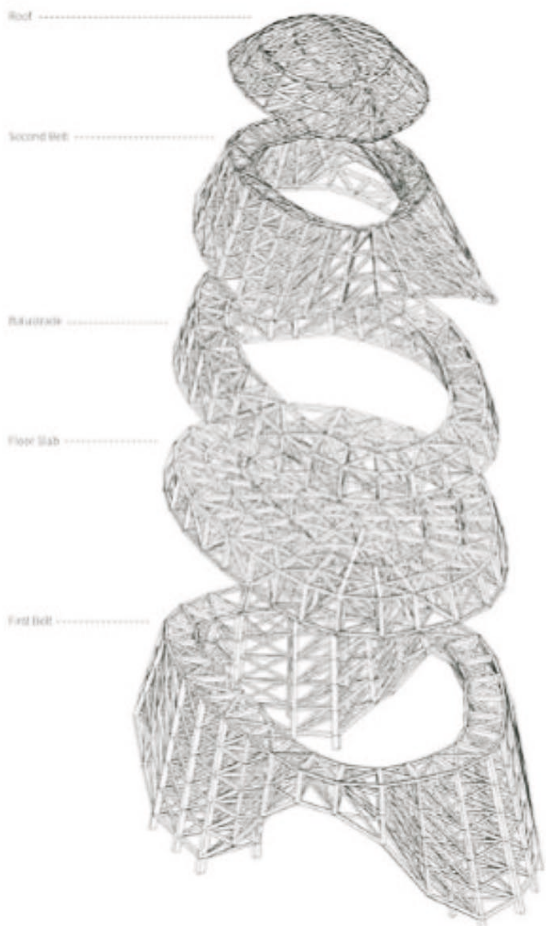
As in the case of other projects implemented at the ICD, ITKE Institutes at the University of Stuttgart, the inspiration for the construction of the pavilion came from biological systems. Compared to man-made structures, structural systems created by Nature show a much higher degree of morphological diversity. This variation in form and structure is a key aspect for their structural performance and efficient use of material resources. For this reason, the principles of structural morphology and material organization observed in the world of Nature can be successfully transferred to technical applications, including architectural and construction design [T. Schwinn, A. Menges 2015].

The development of the complex plate structure of the pavilion was possible thanks to advanced CAD/CAM computer-aided design methods. The geometry of each component of the segmented shell structure was the result of automated processes of analysis, simulation and optimization of structural work, taking into account material properties and the limitations of CNC robotic production. During the design process, the main emphasis was placed on developing a new collaborative practice based on the digital process loop - from the geometric model to structural analysis and digital CNC production. Robotic production covered all 243 geometrically diverse beech plywood boards for the main structure, as well as prefabricated elements of thermal insulation, waterproofing and cladding (Fig. 3a–d). One of the most important challenges in the project was to make approximately 7,600 unique finger joints using a 7-axis CNC robot [A. Menges, T. Schwinn, O.D. Krieg 2015].

2.2. Case study 2– Robotic Shingled Pavilion, Zurich, Switzerland 2018

The experimental Robotic Shingled Timber pavilion designed under the supervision of scientists from the Gramazio Kohler Research studio was implemented in 2016 at the Federal University of Technology in Zurich (ETH/EPF) as part of a one-year master's degree program in the use of advanced digital support methods in architectural design and manufacturing. Students participating in the course built a full-scale prototype object using an extensive fleet of robotic machines in the ETH laboratories in Zurich. The pavilion is approximately 8 m wide, 10 m long and 6 m high [P. Eversmann 2017]. It is a free-form two-story wooden structure covered with cedar shingles. The supporting structure consists of prefabricated elements in the form of three-dimensional spatial trusses (Fig. 4a–b).

The structure was based on space-trusses of various form but same geometry principle. The structural system based on platform (balloon) frame was adapted to create architectural form of non-standard geometry. Substructure elements built according to this system can perform the functions of a wall, ceiling, slab, roof and staircase. Many prototypes were designed, manufactured and analyzed, which, when improved, led to the final design solution. The structure uses four profiles of solid spruce wood strips, which are connected together with steel bolts and screws. The maximum distance of the truss rods on the external side is limited to 450 mm for surfaces with an angle of inclination in the range of 40–90° to enable the attachment of shingle roof tiles in a way that guarantees the required waterproofness (Fig. 5a–b). Portions of the



b)

Fig. 4a–b. Robotic Shingled Pavilion, Zurich, Switzerland 2018, a) view of the pavilion; b) the structure of the pavilion; source: P. Eversmann, F. Gramazio, M. Kohler 2017.

surface with less slope, such as the roof, have denser diagonal bracing that allows for double or triple layers of cedar shingles. As Eversmann reports: *"Structural connections since each joint acts in a combination between shear and axial forces, we used full threaded carbon steel screws. Considering the beam's thickness and the angle between the screw axis and the directions of the beams' fibres, we calculated the length and orientation of the screw for each joint. We optimized for four different sizes with similar diameter"* (Fig. 5a–b) [P. Eversmann 2017].

The Shingled Timber Pavilion is the world's first two-story wooden facility built using robots (Fig. 6). The scientific and research intention related to its implementation was to search for new ways of using robotic machines in working with wood. A method of designing a structure consisting of prefabricated modules was examined. The designed geometry of the building's form is composed of expandable surfaces in the form of wavy ribbons creating irregular openings [J. Mairs 2017].

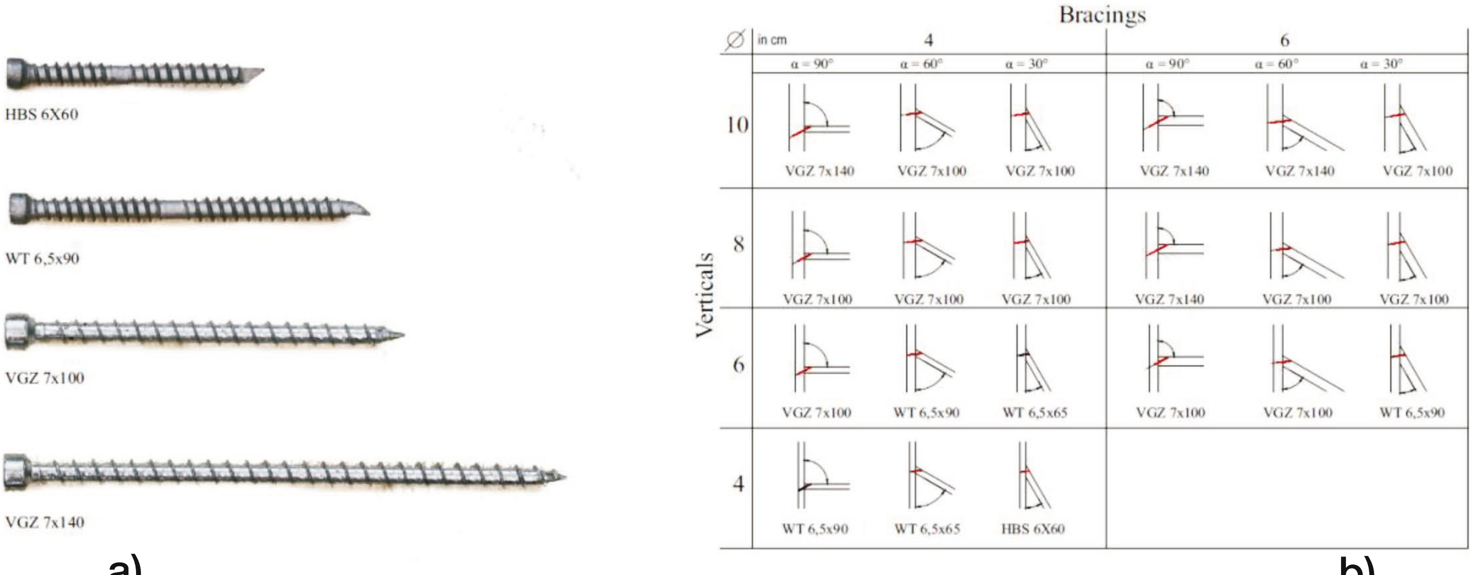


Fig. 5a–b. Robotic Shingled Pavilion, Zurich, Switzerland 2018, a) different types of full-threaded screws used for the joints, b) calculation of screw type, length, and angle depending on corresponding geometry and material thickness; source: P. Eversmann, F. Gramazio, M. Kohler 2017.

Fig. 6. Robotic Shingled Pavilion, Zurich, Switzerland 2018, Human-Machine Interaction; source: P. Eversmann, F. Gramazio, M. Kohler 2017.

2.3. Case Study 3 - Mille-Feuille Pavilion, Vancouver, Canada 2022

The temporary Mille-Feuille Pavilion is an experimental facility that shows the potential of parametric design and robotic production to change the way wood is perceived and used in architecture. The object, approximately 3 m wide, 8 m long and 2 m high, is a free-standing partition in the form of a ribbon with a two-curvature unfolding surface (Fig. 7a–b). In the process of designing and fabrication of the pavilion, intensive use was made of digital computational design tools and robotic woodworking tools. The layered structure of the pavilion is composed of 43 overlapping plywood strips, consisting of a total of 150 elements of cut plywood with various geometries.

The name of the pavilion *Mille-Feuille* meaning a traditional French dessert (cake of a thousand petals), refers to the multi-layer construction of the wall-

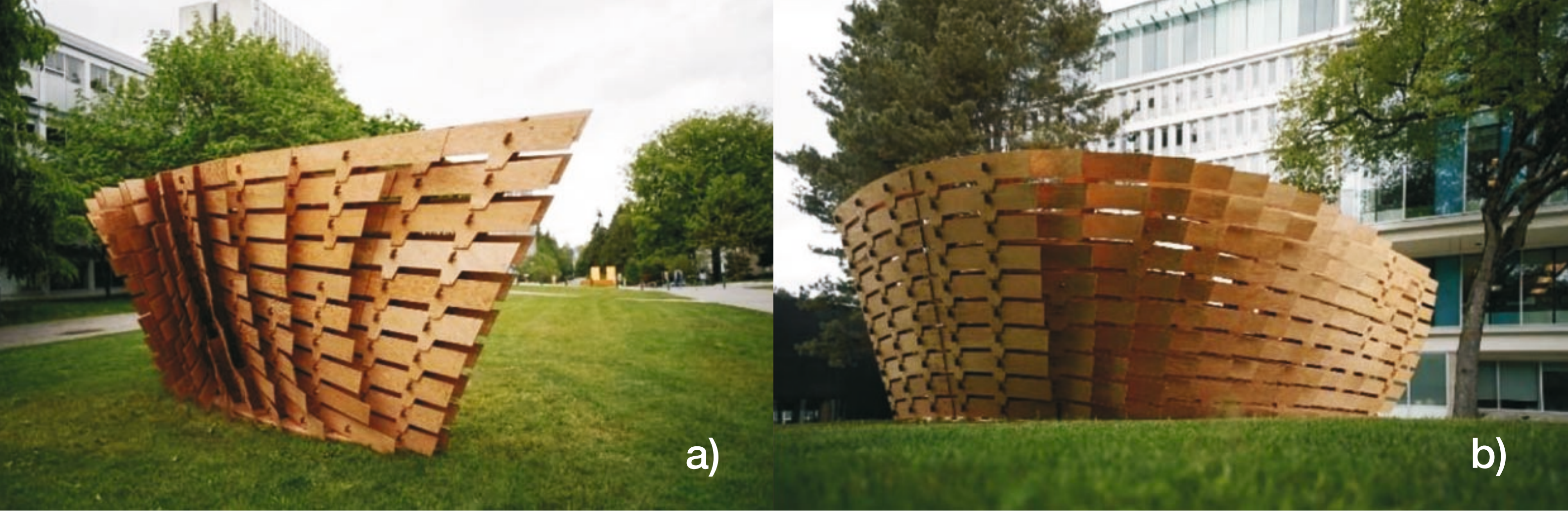


Fig. 7a–b. Mille-Feuille Pavilion, UBC, Vancouver, Canada 2022; source: O. Herwig 2023.

Fig. 8a–c. Mille-Feuille Pavilion, UBC, Vancouver, Canada, 2022, a) robotic CNC fabrication of plywood strips, b) wedging of joints, c) wedged mortise and tenon joint; source: O. Herwig 2023.

shaped structure with variable thickness. The pavilion was created as part of a five-day workshop conducted by scientists: Anna Lisa Meyboom from the University of British Columbia (UBC), David Correa from the University of Waterloo and Oliver David Krieg from the Intelligent City studio. The workshop was held at the Center for Advanced Wood Processing (CAWP) at UBC in 2022 [A.L. Meyboom 2022].

The structure of the Mille-Feuille pavilion was designed as an adaptable system that can be updated to the local availability of materials and production tools. The multi-layer structure is made of strips cut out of waterproof plywood boards. A digital parametric model of the pavilion was used to design the geometry of the elements and their corresponding connections. An important idea was to use the material properties of wood, in this case the flexibility of three-layer birch-alder plywood. In the geometry modeling, the bending limits of each element were taken into account, and if they were exceeded, overlapping of the board strips was used. This principle is a reference to the tradition of building wood, in which the elements remain in a tectonic hierarchy. The use of bent wood is a historically known method of making double curved surfaces (e.g., ship hulls). Plywood, as an anisotropic material, bends effectively in only one direction, one direction of curvature is used as the primary direction of curvature, and the second direction of curvature is provided by connecting elements (spacers and pins) that allow localized bending in the secondary direction [A.L. Meyboom 2022].

In the designed modular system of tensioned elements, each section maintains structural autonomy, which allowed for the prefabrication of parts of the structure. This assembly principle is widely used in the shipbuilding and aerospace industries, where the scale of ship and aircraft hulls poses a challenge similar to that of building structures. The pavilion was made on an 8-axis KUKA industrial robot at the Center for Advanced Wood Processing (CAWP) at UBC. The digital fabrication and assembly of the structural elements took just three days (Fig. 8a-c). The parametrically designed geometry of each individual element ensured precise cutting, machining and identification during assembly. All boards and spacers produced in the robotic production process were assembled in a specific order without the need to use steel connectors, only using wooden connectors and dowels. Pre-drilled holes ensured accuracy when assembling the structural elements. The location of the connecting elements was determined by the form-finding method during the computational design process.

The connections used were wedged mortise and tenon joints which do not require any additional steel connectors. The self-supporting structure needed neither nails nor screws by combining parametric design with robotic fabrication [O. Herwig 2023]. The Mille-Feuille pavilion demonstrates the formal potential of wood's flexibility in the implementation of structures with two-curvature geometry. The combination of traditional materials and digital technologies allows architects to use the material properties of wood while maintaining high design flexibility.

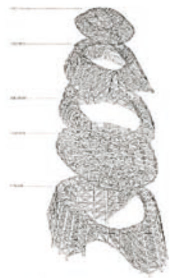
3. ANALYSIS RESULTS

The analysis of three experimental pavilions designed between 2014 and 2022 showed a deep integration of geometry of form, material properties and manufacturing technologies (Tab. 1).

The analysis revealed that all pavilions are characterized by architectural free-form based on doubly curved surface. The free-form surface is modeled parametrically using NURBS techniques. The dynamic development of digital technologies observed since the end of the 20th century is changing the way we think about architecture. The development of modeling software based on NURBS and scripting languages has made programming an integral part of an architect's work. The potential of parametric design and digitally aided manufacturing technology has also changed designers' perception of the material and reintroduced it as one of the main parameters of the design process.

The analysis of the experimental pavilions has shown that the material most often used to construct the presented objects are building materials based on engineered wood products, such as plywood. Wood-based panel boards are a composite material, produced industrially by gluing an odd number of thin layers of wood. Depending on its thickness, thin-layer or thick-layer plywood is produced. Native wood species are used for production, such as alder, birch, beech pine and wood from exotic trees. The strength and elasticity of plywood depends on the number of layers of wood used during its production. Moreover, the strength parameters also depend on the direction of the fibers in the outer layers and on the direction of the load in relation to the board surface. Wood-based materials in the form of boards: plywood, chipboard and MDF fiberboard, laminated veneer wood (LVL), cross-laminated wood (CLT) are quasi-orthotropic materials. Their strength properties change in thickness - along the Z axis, while in the plane of the plate (in the XY plane) they are approximately constant.

Tab. 1. Analysis of experimental pavilions

Pavilion name	FOREST PAVILION	SHINGLED TIMBER ETH	MILLE-FEUILLE PAVILON
Location	Schwäbisch Gmünd, Germany	Zurich, Switzerland	Vancouver, Canada
Year	2014	2016	2022
Design	University of Stuttgart ICD, ITKE IIGS	Swiss Federal Institute of Technology in Zürich (ETHZ)	UBC SALA (School of Architecture & Landscape Architecture)
Architectural form	Free-form surface	Free-form surface	Free-form surface
Structure type	 Double curvature segmented wooden shell	 Double curvature hybrid structure	 Wall-shaped double curvature layered shell
Substructure type	 Hollow building segments	 Matching space-frame substructures	 Plywood strips
Structural material	Engineered wood product – birch plywood	Construction timber (spruce)	Engineered wood product – birch-adler plywood
Robotic fabrication	5-axis KUKA KR QUANTEC industrial robot	robotic setup of two large-scale ABB industrial robots on a linear track	8-axis industrial robot at the Centre of Advanced Wood Processing at UBC
Human Machine Interaction	-	+	-
Construction time	2 months	5 weeks	3 days
CONNECTION TYPES	 **INTERLOCKING EDGE JOINTS STANDARDMECHANICAL CONNECTORS (SCREWS)**	 **STANDARD MECHANICAL CONNECTORS (SCREWS)**	 **WEDGED MORTISE AND TENON JOINT**
Relation to tradition of wood architecture	Reinterpretation of woodworking joint	Reinterpretation of steel connectors technology	Reinterpretation of carpentry joint

Source: prepared by the author based on: J. Li, J. Knippers 2015; P. Eversmann 2017; O. Herwig 2023.

New material and manufacturing options open new ways to innovative structural solutions. The experimental pavilions utilize new structural solutions. In 21st century architecture the surface of the architectural form is activated and serves as the covering skin of the building but acts structurally [K. Januszkiewicz 2013]. Each of the analyzed pavilions represents a different structural system:

- Segmented wooden shell,
- Hybrid structure,
- Wall-shaped layered shell.

Each analyzed structural system also has a different subsystem in the form of:

- Hollow building segments,
- Matching space-frame substructures ,
- Plywood strips.

The analysis in terms of structural connection revealed following connection types:

- Interlocking Edge joints,
- Standard mechanical connectors (screws),
- Wedged mortise and tenon joint.

4. REINTERPRETATION OF CONNECTIONS OF CONSTRUCTION ELEMENTS

Free-form wooden structures require a much higher number of joints, much greater than in conventional post-and-beam structures. This is due to the presence of a much larger number of elements that are connected to neighboring elements on the edges or side surfaces. New structural solutions are commonly based on engineered wood materials which are becoming more and more common and require new types of connections. These joints have not been previously used in the tradition of building with wood (interlocking edge joints), have been used in a modified form (pegged mortise and tenon joint) or have used existing technology (mechanical connectors) for structural joining.

4.1. Interlocking edge joints

A box (finger) joint is a basic woodworking corner joint made by cutting offset profiles in two pieces of wood and interlocking the resulting rectangles or "pins" together. These types of joints have been widely used in woodworking, carpentry and furniture manufacturing (Fig. 9a–c). Instead of using one connection as it was logical in connection of two elongated elements like post and beam in traditional construction, a new way of use is to arrange finger, box or dovetail notches rhythmically on the edges. The pieces are cut at an angle, creating finger-like projections that interlock with each other. Since these profiles are cut straight, they can be assembled directly into one another. The joints are then

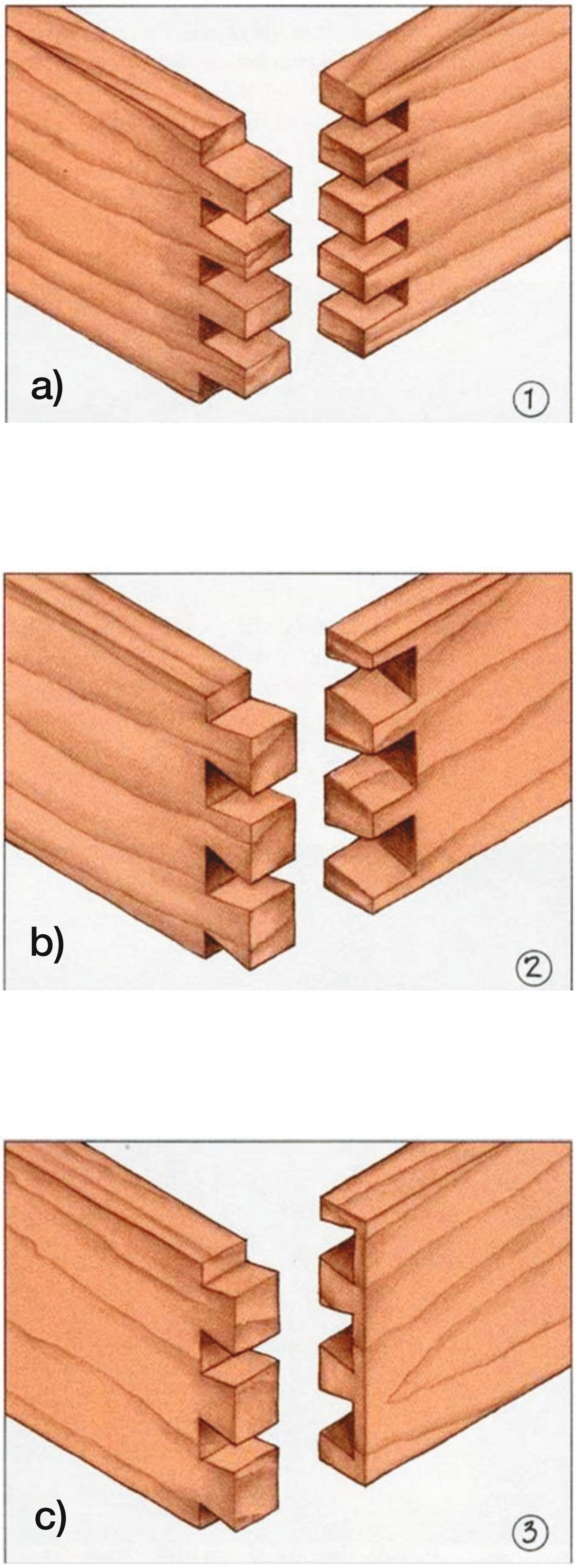


Fig. 9a–c. Interlocking edge joints of board elements in woodworking, a) box joint, b) dovetail joint, c) half-blind dovetail joint; source: Woodworking Archive 2023.

glued to create solid, seamless pieces of wood. Interlocking wooden joints are a material driven traditional structural method that is used in complex wooden structures. Nowadays they are frequently used in computationally designed and digitally fabricated wooden structures.

4.2. Mechanical connectors

Connecting wooden elements without using steel connectors requires extensive knowledge and experience. The use of metal connectors in wooden structures ensures faster assembly, saves construction material and guarantees the stiffness of connections and stability of the structure (Fig. 10). A wide range of available system solutions (nails, mounting screws, profiles, clamps, nail plates, etc.) allows to make connections for various applications. The system of connecting wooden and wood-based structural elements using nail plates was introduced in the United States in the 1960s and is increasingly used in modern construction [M. Major, J. Różycka 2013]. All connecting systems are made of hot-dip galvanized steel sheet or stainless steel, which protects them against corrosion.

4.3. Mortiseand tenon joints

Mortise and tenon joints connect structural elements, usually in an L- or T-shaped arrangement, with an angle between the connected elements from 45° to 90°. A socket is made in one joined element, in which a tenon made in the other element is placed. It is important to match the contact planes between the elements. Such connections are often pinned. Mortise and tenon joints are strong and stable joints additionally connected by either pegging, gluing or locking into place. There are many variations of this type of joint, and the basic mortise and tenon has two components: the tenon, formed on the end of a member generally referred to as a rail, fits into a square or rectangular hole cut into the other, corresponding member (Fig. 11a–c). The tenon is cut to fit the mortise hole exactly. It usu-

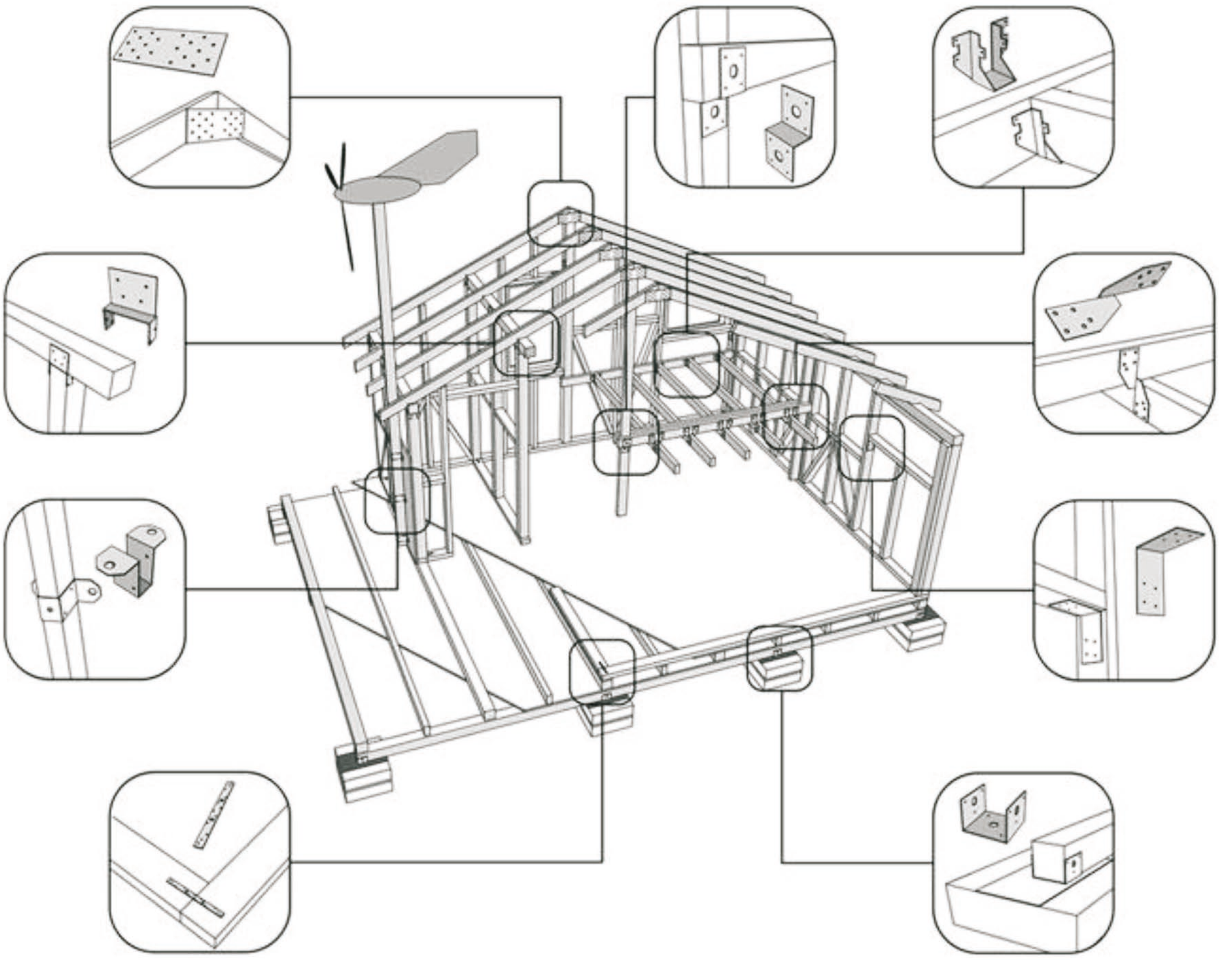


Fig. 10. Mechanical connectors used in wooden construction; source: J. Woodsman 2022

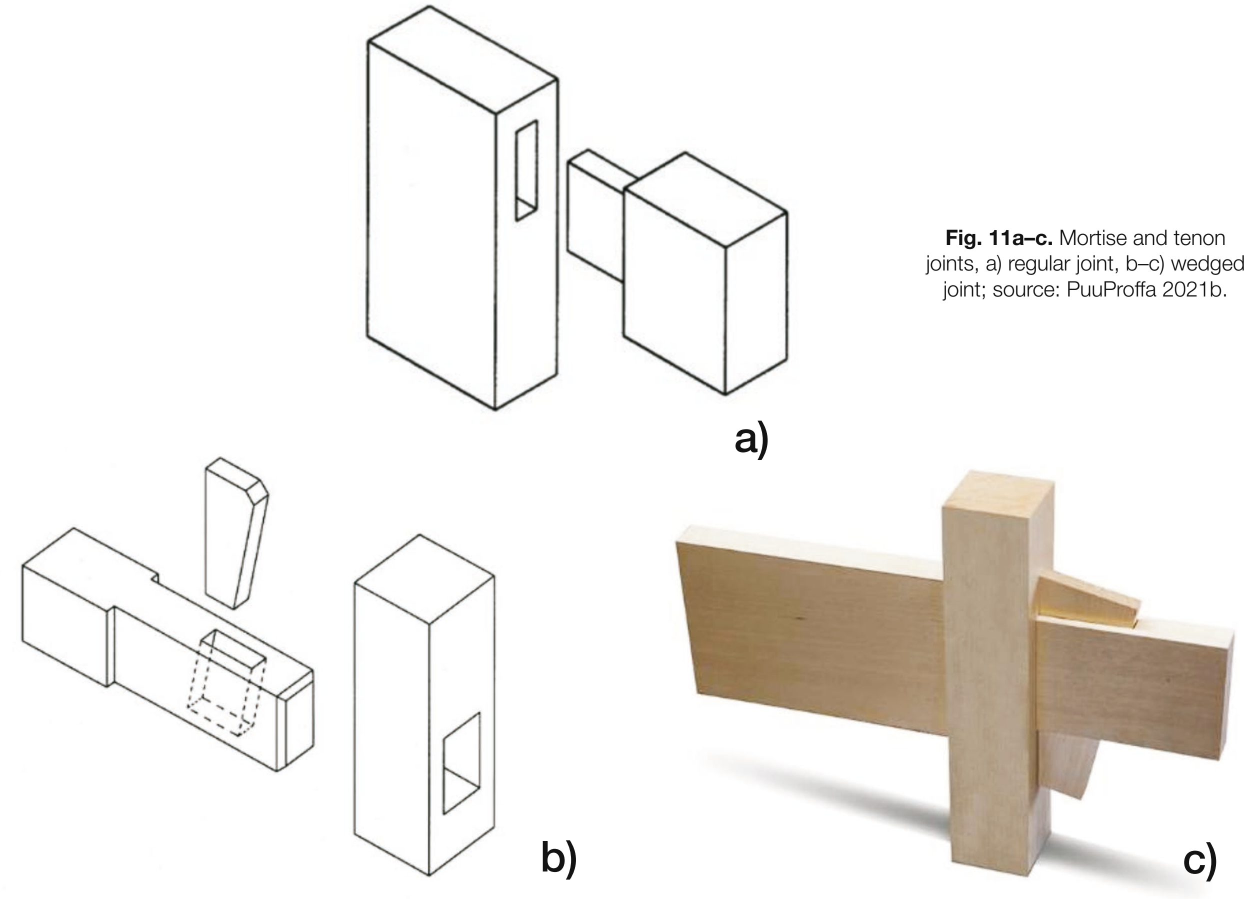


Fig. 11a–c. Mortise and tenon joints, a) regular joint, b–c) wedged joint; source: PuuProffa 2021b.

ally has shoulders that seat when the joint fully enters the mortise hole. The joint may be glued, pinned, or wedged to lock it in place. One drawback to this joint is the difficulty in making it because of the precise measuring and cutting required. In its most basic form, a mortise and tenon joint is both simple and strong [J. Woodsman 2022; Woodworking Archive 2023].

The wedged joint is a traditional connection with a wedge pushed into the hole of the mortise piece (Fig. 10b–c). The hole must have the same inclination as the wedge. The wedge angle must be under 20° so that the wedge will stay tight.

CONCLUSIONS

The development of computer technologies has opened new paths for design based on parametric modeling and digital manufacturing. This potential is making a decisive contribution to renewing the interest of designers in the use of wood. Although wood is one of the oldest building materials, in recent years many innovations have influenced production techniques and design tools that have paved the way for new formal, aesthetic and structural solutions that can fill the fields of application of this material.

New material characteristics of wood-engineered materials in conjunction with the design and manufacturing aspects in the digital CAD/CAM process chain opened up new possibilities for formal expression. However, due to the high cost of implementation of free-forms in architecture the curvature of the surface is most often approximated by linear or flat elements. The architectural form of the buildings is therefore divided into smaller elements, which facilitates the manufacturing and assembly process. The conventional carpentry joints developed in the past most often do not meet strength requirements and are not applicable to forms of geometric complexity. These joints were developed for connections in post and beam and frame structures used in wooden structures.

New structural solutions for complex geometry based on engineered wood materials are becoming more and more common and require new types of connections. In modern wooden structures new kinds of connections referring to historical solutions are successfully used in a reinterpreted and modified way.

These joints have either not been previously used in the tradition of building with wood (interlocking edge joints), are used in a modified form (pegged mortise and tenon joint) or are using existing technology (steel connectors) for structural joining.

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APPLICATION OF CFD ANALYTICAL TOOLS IN ARCHITECTURAL DESIGN IN THE CONTEXT OF WIND LOADS – PART 1

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Abstract
The article discusses the impact of air flow on architectural form. Climate change related extreme weather events expected in the near future pose a significant challenge and require the integration of building aerodynamics in the architectural design process. Windage analyses carried out at an early design stage are an essential tool in the process of searching for the architectural form of buildings designed to resist extreme wind events.
Due to the breadth of the topic and the limitations of the article's length, the text has been divided into two parts. The first part of the article presents early concepts of building aerodynamics, historical methods of wind flow analysis based on observations and physical models, as well as the use of CFD (Computational Fluid Dynamics) analytical tools. The article reviews and compares three wind analysis tools based on the CFD methodology: Autodesk CFD, Autodesk Flow Design and Butterfly (Ladybug plug-in). The results of an original study of the aerodynamics of the building of the high-mountain meteorological observatory on Śnieżka using the Autodesk Flow Design software were also presented as a case study of a facility located in extreme weather conditions and designed with a clear reference to aerodynamics. The second part of the article discusses the methodology of research on the aerodynamics of high-rise buildings and the impact of wind load on the architectural form of buildings. Case studies of two high-rise buildings located in Warsaw, made using the Autodesk Flow Design program, were also presented.

Keywords: architecture; climate change; wind analysis; CFD; wind tunnel; research based design

INTRODUCTION

Computational Fluid Dynamics (CFD) is a tool for analyzing fluid-flow problems with various numerical methods that convert the partial different equations that govern a physical phenomenon into a system of algebraic equations. CFD analysis can be performed on either physical models or simulations. When this is done on physical models, CFD software analyzes the airflow around the model and predicts what will happen when the air interacts with the object under study. When CFD analysis is performed on simulations, the CFD software analyzes the airflow over an object that has been created in a computer simulation program. The next step in the CFD analysis and simulation process is to generate a mesh. CFD software creates a mesh of the test object. It can then be used to calculate some of the airflow properties around the test object. On this basis, the software in which the CFD simulation is performed analyzes the particle data and generates 3D visualizations. The final step in CFD analysis is to analyze the particle data and generate 3D visualization data. This data allows you to see how air flows over and into the object. The purpose of conducting this type of analysis is to help choose the best facility design.

Globally, the building sector is the source of approximately 40% of total energy consumption. According to United Nations Framework Convention on Climate Change long-term shifts in temperatures and weather patterns are attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. It is an established fact that human-induced greenhouse gas emissions have led to an increased frequency and/or intensity of some weather and climate extremes since pre-industrial time, in particular for temperature extremes.

Climate change has a significant impact on the built environment and architects and designers must consider these consequences. The frequency and intensity of extreme weather (including storms, cyclones, heatwaves) have increased. As members of the Committee on Extreme Weather Events and Climate Change state: "*The observed frequency, intensity, and duration of some extreme weather events have been changing as the climate system has warmed. Such changes in extreme weather events also have been simulated in climate models, and some of the reasons for them are well understood. For example, warming is expected to increase the likelihood of extremely hot days and warming also is expected to lead to more evaporation that may exacerbate droughts and increased atmospheric moisture that can increase the frequency of heavy rainfall and snowfall events.*" [National Academies of Sciences, Engineering, and Medicine 2016].

1. IMPACT OF AIRFLOW ON ARCHITECTURAL AND URBAN DESIGN

Designing comfortable buildings has been a goal of architects since the writings of Marcus Vitruvius Pollio and Leon Batista Alberti. Vitruvius, a Roman architect and engineer during the 1st century BC, known for his multi-volume work titled *De architectura* had a simplistic view of winds, regarding all as undesirable (Fig. 1a–b). Vitruvius regarded all winds as deleterious to health: *"if the winds are cold they damage the health, if hot, they are infectious, and if humid, they are noxious"* [A. Nova 2006]. He argued for their complete exclusion: "*Excluding the winds will not only make a place healthy for people who are well, but also…* [diseases] *will be cured more rapidly in these areas because of the moderate climate created by the exclusion of winds*" [A. Nova 2006]. Vitruvius concern with winds makes sense given that window glass wasn't widespread at the time. The ancient Romans were the first known to use glass for windows, but the technology was first produced in Roman Egypt, in Alexandria around c. 100 AD.

Vitruvius described wind distribution in a diagram of eight-sided wind rose. The diagram was not used to map the directions of the predominant winds, because Vitruvius did not recognize that different locations for cities might have different prevailing winds. Rather, he thought that the winds could come only from these eight directions and, for a given location, from any and all of them at various times (Fig. 1a). This eight-wind logic suggested to Vitruvius that orienting the street grid in a city 'between' these eight directions, no matter where the city was located, could ensure that the inhabitants were not unduly exposed to the winds: "*For these reasons, the rows of houses should be aligned away from the directions in which the winds blow, so that when they arrive, they buffet the corners of the blocks of houses and so are repelled and dissipate themselves*" (Fig. 1b) [A. Nova 2006].

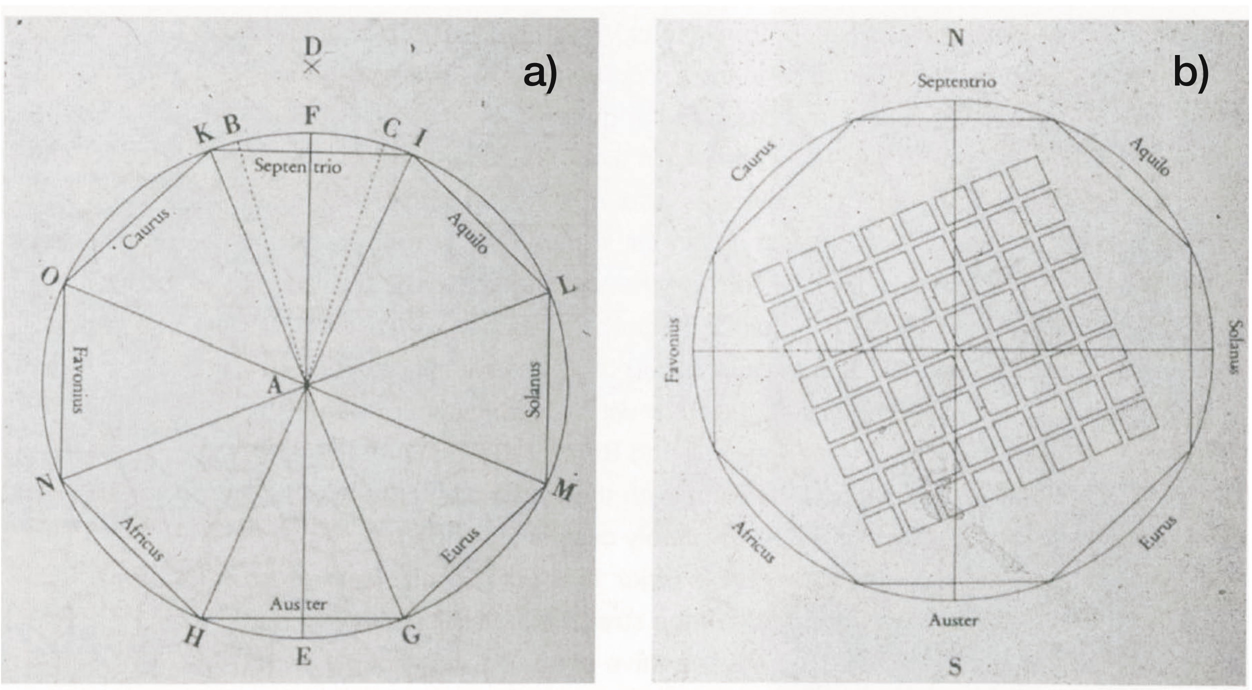


Fig. 1a–b. Wind engineering according to Vitruvius, a) reconstruction of the "scheme" of the major wind, b) reconstruction of the orientation of the city's urban plan in relation to the blowing winds; source: A. Nova 2006

In book 1 of *De Re Aedificatoria* (*On the Art of Building*) the Italian renaissance architect Leon Battista Alberti defines buildings as consisting of *lineaments* and *matter* – design and matter. Alberti viewed the idea of *lineaments* not only with regard to architecture but also as a property of a living body. Alberti writes, of the comparison between the body of a fish and a ship's form: "*If these 'lineaments' were laid out correctly, with the proper flaring and tapering from bow to stern, the ship would indeed be fish-like, moving through the waters as if of its own accord*". They can also be seen as an essential vivifying characteristics of that body, qualities of motion and experience particular to that body. Due to this the idea *lineaments* is performative, not just an aesthetic one. In Alberti's view that *lineaments* are an essential characteristic of living bodies, there is the implication that if the *lineaments* of the artificially constructed objects is done correctly, they could possess the qualities of life itself. *Lineaments* seem to describe the essence of life as it relates to matter itself rather than any aesthetically-oriented codification of proportions. Buildings should therefore be constructed with regards to the site, sun, and wind. Elements such as walls and roofs as well as openings have an imperative to protect against weather while also allowing for light and ventilation. Alberti recognizes the limitations that the forces of nature impose on builders. Among the elements, he considers air to be the most powerful: "*If the Earth or Water had any defect in them, Art and Industry might correct it; but neither contrivance nor multitude of hands was able sufficiently to correct and amend the Air*" [A. Nova 2006]. For Alberti as he stated in his treaty the wind is incredibly important in decision making: from the temperatures it brings, the strength it carries, the direction it has etc.

Alberti's interests in atmospheric phenomena included scientific aspects. It's worth noting that the Italian architect invented the first mechanical anemometer in 1450. This instrument consisted of a disk placed perpendicular to the wind. It would rotate by the force of the wind, and by the angle of inclination of the disk the wind force momentary showed itself. The same type of anemometer was later re-invented by Englishman Robert Hooke [A. Nova 2006].

2. AERODYNAMIC MODELING IN ARCHITECTURAL DESIGN

Building aerodynamics accurately accounts for various project specific factors that include: aerodynamic influences associated with building shape, directionality of wind associated with regional wind climate and influence of neighboring buildings and land topography The research of building aerodynamics deals with the investigation of flow processes in the atmospheric layer, with emphasis on the analysis of wind flow within the influence area of buildings and to the resulting wind loads on buildings and structures. The study of the wind comfort and pollutant dispersion in urban areas is also taken under considerations of building aerodynamics including urban landscape, static and dynamic wind loads, pedestrian comfort, and ventilation. The word aerodynamics combines 'aero' meaning air, atmosphere or gases, from the Greek *aero* or lower atmosphere and 'dynamic', relating to mechanical forces not in equilibrium from the Greek *dynamikos* meaning powerful. Aerodynamics have been a consideration in the construction of sailing boats and windmills for many years, whilst aerodynamic concepts date back to Aristotle and Archimedes in the 2nd and 3rd centuries BC. Sir Isaac Newton was the first to develop a theory of air resistance in the early 1700's, expanded some years later in *Hydrodynamica* which describes the relationships between pressure, density, and flow velocity, known as Bernoulli's principle after its author, it also provides a method to calculate aerodynamic lift [Designing Buildings 2022].

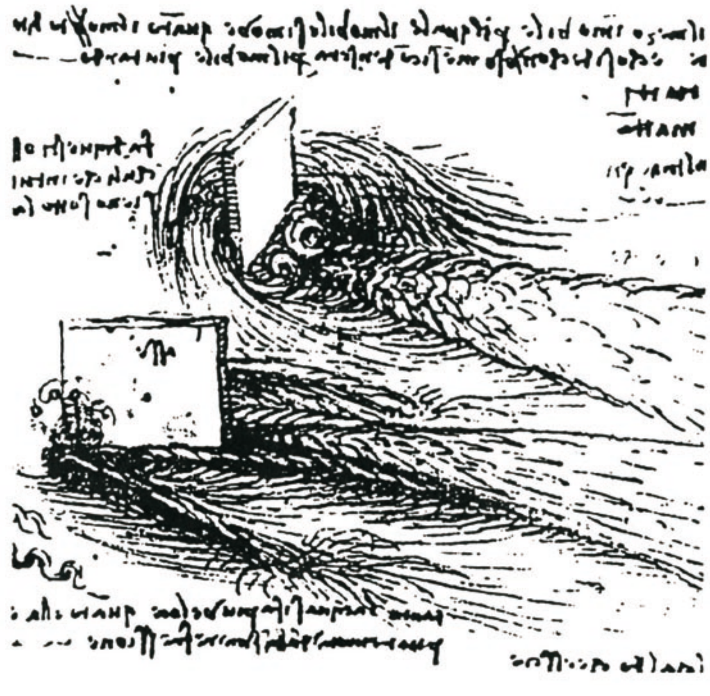


Fig. 2. Leonardo Da Vinci, Flowlines and flowplanes found in the Codex Atlanticus; source: J.D. Anderson Jr. 2008

In addition to this quantitative contribution to an amazingly broad variety of subjects Leonardo Da Vinci was a consummate observer of nature. His sketches of various flowlines and flowfields are significant examples of Leonardo's awareness of complex aerodynamics.

The drawings demonstrate an experiment either physical or conceptual of a flat plate washed by streams of gas or liquid (Fig. 2). His assumptions of vortex structure of the flow around blocking objects are amazingly accurate in the light of modern scientific research. As J.D. Anderson notices: "*At the top, the plate is perpendicular to the flow, and Leonardo accurately sketches the recirculating, separated flow at the back of the plate, along with the extensive wake that trails downstream. At the bottom, the plate is aligned with the flow, and we see the vortex that is created at the junction of the plate surface and the water surface, as well as the bow wave that propagates at an angle away from the plate surface. These sketches by Leonardo are virtually identical to photographs of such flows that can be taken in any modern fluid dynamic laboratory, and they demonstrate the detail to which Leonardo observed various flow patterns.*" [J.D. Anderson Jr. 2008].

2.1. Wind tunnel testing

Since its beginnings in the XIX century wind loading effects were determined by wind tunnel tests. Wind tunnels are vitally important tools for aerodynamics research in many areas of technology. They are used to test the aerodynamic effects of aircraft, rockets, cars, and buildings. Wind tunnels are usually technical test devices where an object is held stationary inside a tube, and air is blown around it to study the interaction between the object and the moving air. The first wind tunnel of this kind in the world was built and tested in 1871 by Frank Wenham. The Wright Brothers used a tunnel as an aid in the design of the Wright Flyer (Fig. 3).

In the 1930's, pioneer wind tunnel tests were performed by Danish wind engineers J.O.V. Irminger and C. Nokkentved, who investigated the nature of air movement over buildings, in particular the accuracy of wind-tunnel methods for reproducing the correct air-flow separation and reattachment positions of the vortices formed by winds passing over buildings (Fig. 4a–b.). The experiment shed light on the importance of suction on the overall wind loading [G.L. Larosea, N. Franck 1997].

Fig. 3. Replica of the Wright Brothers' wind tunnel at the Virginia Air & Space Museum in Hampton, VA; source: photo by Erik Axdahl, licensed under the Creative Commons Attribution-Share Alike 2.5 Generic license 2006

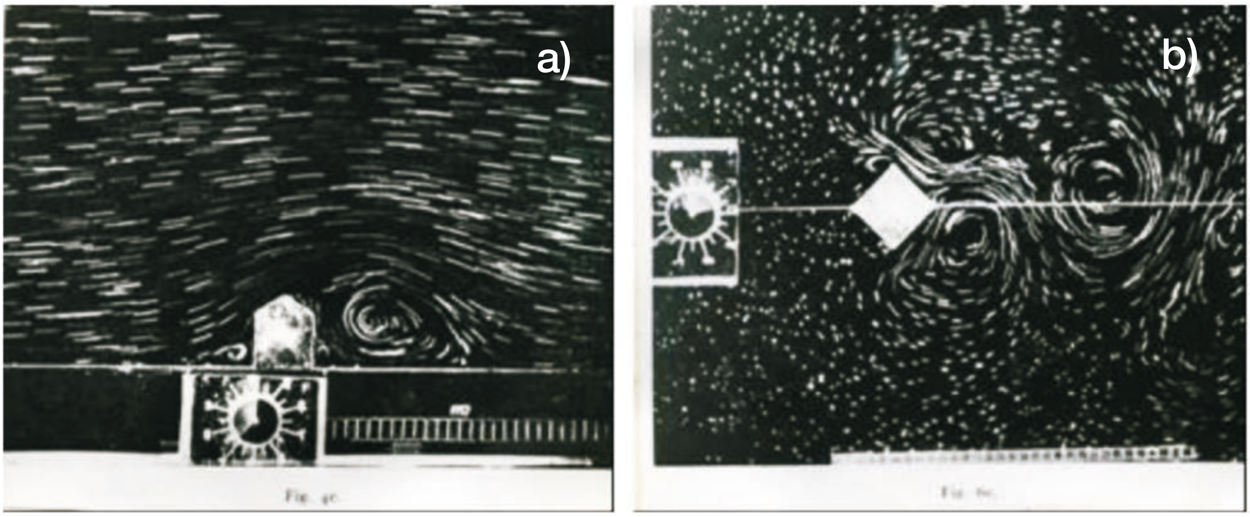


Fig. 4a–b. Early wind tunnel experiments on wind loads on structures by J.O.V. Irminger and C. Nokkentved; source: C.P.W. Geurts 2005

Wind tunnels are used in many engineering and environmental applications as a key tool in understanding the problem associated with the aerodynamics and transport phenomenon. The dispersion of pollutants over industrial and residential areas, the impact of lift and drag on various structures and wind load on civil installation are examples where wind tunnel simulation can be used to understand and control the related problem.

The typical issues for which a wind tunnel test might be commissioned for a building include life safety issues of accurate determination of local pressures and wind-induced structural loads and responses. Also, typical serviceability issues of pedestrian wind conditions, building exhaust dispersion that contribute to the public and occupant perception of the quality of the built environment and fire safety issues are of concern. As wind tunnel testing relies on physical testing incorporating the particular site conditions, unnecessary over design is avoided. Wind tunnel testing accurately accounts for various project specific factors which affect the results and can be modelled in detail. Typical factors may include but are not limited to the following:

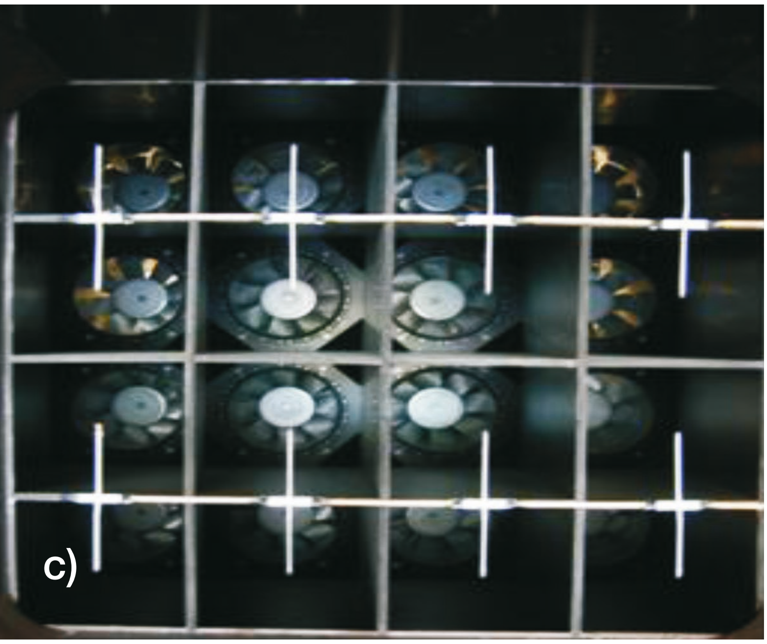
- Aerodynamic influences associated with building shape.
- Directionality of wind associated with regional wind climate.
- Influence of neighboring buildings and land topography.
- Interaction between building motion and wind flow.

KEZO PAN - Wind Energy Laboratory, Jabłonna, Poland

KEZO Research Center of the Polish Academy of Sciences Energy Conversion and Renewable Sources is a branch of the Institute of Fluid-Flow Machinery located in Jabłonna near Warsaw. The center is the most modern complex of research laboratories in Poland dealing with the use of renewable energy. The main scientific tasks, which also constitute the research basis of the Institute of Fluid-Flow Machinery, focus on the conversion of energy from renewable sources in research fields closely related to the country's energy security. The basic task of the Center is to conduct research on energy from renewable sources and its conversion.

The wind energy laboratory has an open low-speed wind tunnel equipped with two independent measurement chambers, one of which is adapted for model testing. The tunnel operates in suction mode and reaches a flow speed in the measuring chamber of up to 30 m/s. The measuring chamber is 4 meters long and has a square cross-section of 2 meters by 2 meters (Fig. 5a–g). The tunnel measuring chamber is equipped with the following measuring systems:

- velocity field measurement – sliding row of thermo-anemometric sensors,
- forces and moments – Stewart platform with optical strain gauge,
- deformations – a system of optical measurement of deformation of elements under the influence of aerodynamic forces,
- noise – portable acoustic camera to measure the intensity and location of the noise source.



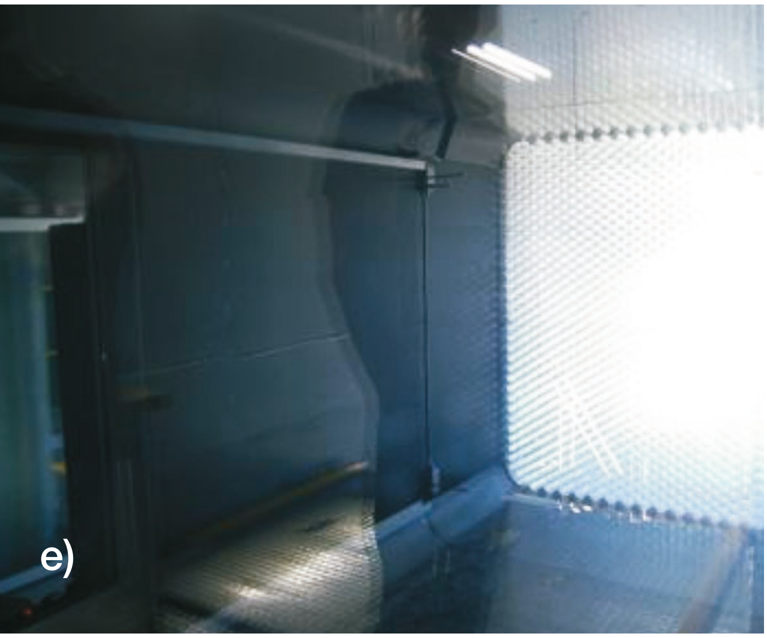
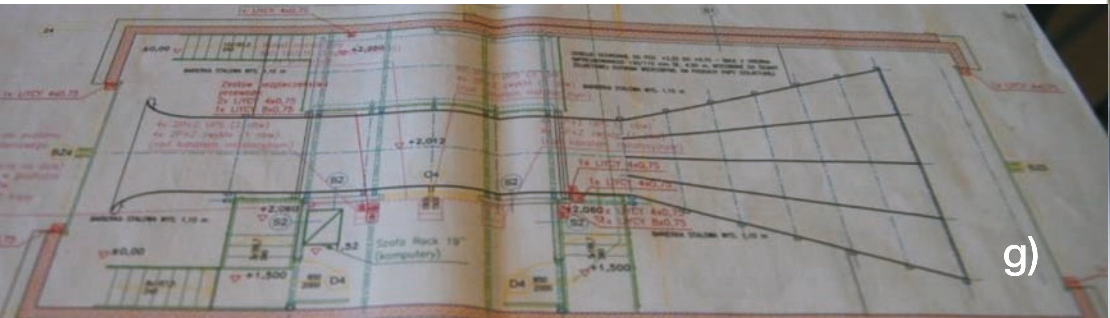


Fig. 5a–g. PAS Research Centre, Energy Conversionand Renewable Resources KEZO, Jabłonna near Warsaw, Poland a) buildings B2,B2/1 and Laboratory of Wind Energy L3, b–g) is provided an open flow low speed wind tunnel designed to testing small scaled wind turbine (equipped with an open low-speed wind tunnel that is equipped with two independent measurement chambers; required for testing small wind turbines or models). KEZO can also realize numerical simulations supporting analysis and design of wind turbine and investigations of other wind energy related issues; source: photo by the author 2019



Wind Engineering Laboratory, Krakow University of Technology, Poland

Wind Engineering Laboratory of the Krakow University of Technology, headed by prof. Andrzej Flaga is the only scientific and research center in Poland that carries out tests of buildings. Simulation tests of snow load on the roofs of the main and training halls are carried out in the laboratory's wind tunnel (Fig. 6a–b). They are used to determine the data necessary for static and strength calculations of the structures of both halls. This is necessary for the safety of the structure. The research also serves to verify the assumptions made in the construction design and to indicate possible savings in terms of reducing the weight of the main supporting steel structure of the roofs of both halls.

2.2. Computational fluid dynamics modeling

The pioneering application of CFD analysis in architectural design in the 1990s were presented by Branko Kolarevic: ***"****Future Systems, a design firm from London, used the computational fluid dynamics (CFD) analysis in a particularly interesting fashion in its Project ZED, the design of a multiple-use building in London (1995). The building was meant to be self-sufficient in terms of its energy needs by incorporating photovoltaic cells in the louvers and a giant wind turbine placed in a huge hole in its center. The curved form of the façade was thus designed to minimize the impact of the wind at the building's perimeter and to channel it towards the turbine at the center. The CFD analysis was essential in determining the optimal performance of the building envelope.*" [B. Kolarevic 2003].

CFD has many advantages. It can be used in conjunction with other engineering disciplines. Besides, engineering calculations using CFD calculation software are more accurate than manual engineering calculations. This is due to the use of a computer-generated, virtual numerical model and computational fluid dynamics software, which uses these models to calculate many variables, as well as the forces acting on each part of the object. The most popular type of CFD analysis is the calculation of pressure and velocity potentials on the surface of an object. This allows for accurate prediction of the forces acting on an object by applying Newton's laws of motion. The equations used for this analysis are described as a boundary condition to obtain accurate predictions. Boundary conditions can be set to calculate the forces and moments acting on individual points on an object.

Over the past 40 years, a wide variety of computational software programs and models have constantly worked on maximizing the accuracy of their tools to simulate and measure the impact of climate on the effectiveness of urban environments. Popular CFD software tools in architectural design are Autodesk CFD, Autodesk Flow Design, Butterfly (Ladybug Tools).

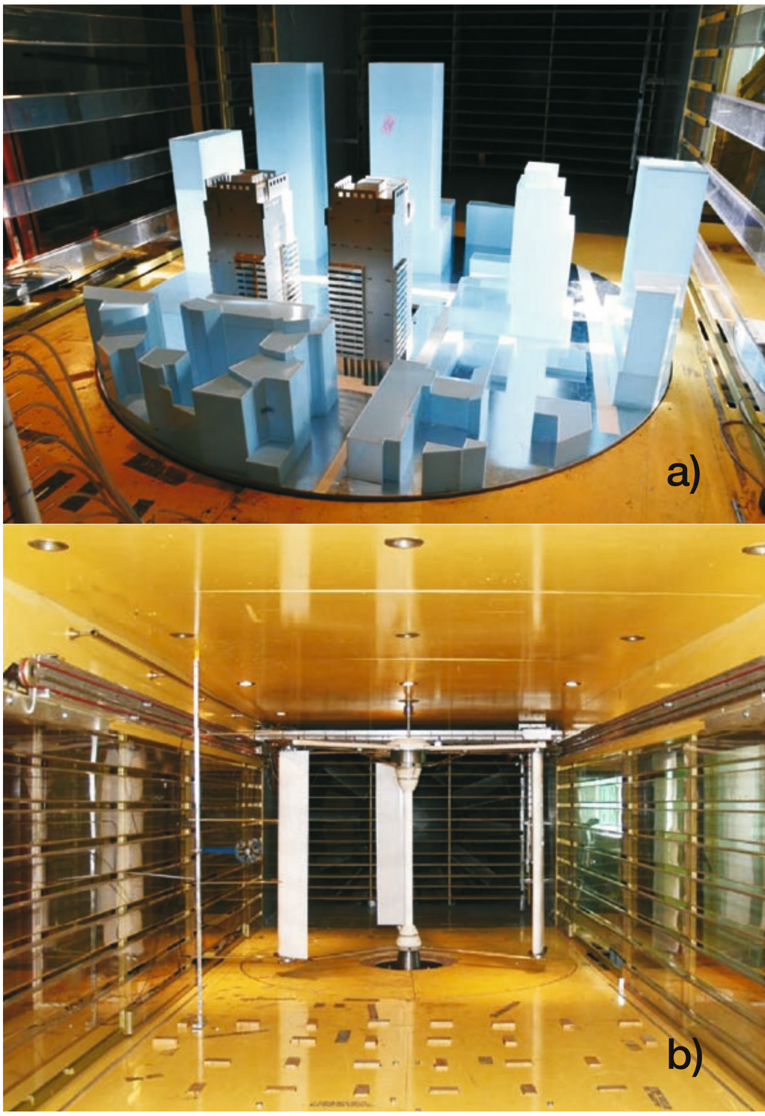


Fig. 6a–b. Wind Engineering Laboratory of the Krakow University of Technology; source: A. Flaga 2015

- **Autodesk CFD** is professional stand-alone software for Design Studies. This fluid flow and thermal simulation tool helps to predict product performance, optimize designs, and validate product behavior including thermal prototyping, architectural and MEP tools, and flexible cloud solving options. It also minimizes reliance on costly physical prototypes. Besides, it enables users to easily explore and compare design alternatives to better understand the implications of design choices using an innovative Design Study Environment and automation tools. A design Study conducted in Autodesk CFD contains a single analysis called a Scenario, where the materials (fluids, solids, devices), boundary conditions (velocity, flow rates, temperatures), and the mesh element size are defined [Autodesk Support 2023]. Using multiple design variants in a study reveals the effects of geometry modifications on airflow inside and outside the building. Comparative analysis method of the results is incredibly valuable while developing new design strategies. Autodesk CFD supports direct data exchange with most CAD software tools, including Autodesk Inventor, Autodesk Revit, Graphisoft Archicad, Rhino and Sketchup software.

- **Autodesk Flow Design** is a discontinued standalone application that simulates wind interactions with a building volume developed by Autodesk Labs in 2014-2018. Its successor Autodesk CFD (2019–2024) is the high-end, multipurpose Computational Fluid Dynamics software package dedicated to professional design engineers and analysts [Autodesk Support 2023]. Flow Design is a CFD standalone application limited in its functionality, control, and accuracy. This purpose built wind tunnel simulator models wind behavior around an exterior and provides an understanding of where there may be risks of elevated wind speeds or where there may be stagnant areas that affect air quality or comfort. The product itself shares many similarities with other Computational Fluid Dynamics (CFD) applications. Instead of solver based on the conditions that gives a solution that matches with seasoned fluid mechanics and meteorological data Autodesk Flow Design uses its native Fluid Dynamics solver based on earlier Project Falcon developed by Autodesk Labs in 2013.
- **Butterfly plugin** is a Ladybug tool and a python library to create and run advanced computational fluid dynamic (CFD) simulations using OpenFOAM, which is one the most rigorously-validated open source CFD engines in existence and is capable of running several advanced simulations and turbulence models (from simple RAS to intensive LES). Butterfly is built to quickly export geometry to OpenFOAM and run several common types of airflow simulations that are useful to building design. This includes outdoor simulations to model urban wind patterns, indoor buoyancy-driven simulations to model thermal comfort and ventilation effectiveness, and much more [Ladybug Tools LLC 2023]. The Butterfly can also simulate CFD-based models in noticeably less time compared to the other models. These capabilities qualify the Ladybug tools to be one of the most efficient CFD tools for architects when it comes to optimization studies and time and resource efficiency.

Ladybug tools are embedded in the Grasshopper interface for Rhino3D and have the parametric abilities of the Grasshopper which is a script-based modeling algorithm. Visual programming language interface allows designers to create geometries and environments manipulating various design parameters and recreating different geometry configurations through geometrical iteration. The Ladybug tools comprise Ladybug, Honeybee, Butterfly, and Dragonfly plugins. Each has its own capabilities that specialize in a particular field and analyze certain factors, and they could also integrate to fulfill further analysis requirements. This potential allows Ladybug tools to simulate numerous geometry configurations as well as measure, evaluate, and optimize their performance throughout the year, as opposed to other models, which can handle a limited number of urban canyon geometries to be able to optimize them. Each of the Ladybug tools basic functionalities have been presented on Tab. 1.

Tab.1. Ladybug tools and their basic functionalities

Ladybug tools A collection of open source computer applications that support environmental design and education		**Honeybee** Daylight and radiation analysis using Radiance software and energy models using EnergyPlus or Open Studio software
Butterfly Advanced Computational Fluid Dynamics (CFD) using OpenFOAM software		**Dragonfly** Analysis of large-scale factors such as district-scale energy models for energy simulation with the URBANopt analytics platform and renewables optimization with the REopt energy planning platform

Source: prepared by the author

Tab. 2. Presents a comprehensive review of CFD analytical tools used in architectural and urban design

SOFTWARE NAME	SOFTWARE TYPE	LICENCE TYPE	CFD ANALYSIS DETAIL LEVEL	FLEXI-BILTY OF USE	USER-FRIENDLY INTERFACE	APPLICABILITY IN ARCHITECTURAL EDUCATION
Autodesk CFD	Stand-alone application	Trial Commercial	Mesh based comprehensive CFD Analysis	+	+/-	+/-
Autodesk Flow Design	Stand-alone application discontinued in 2019	Educational available in 2023	Voxel based simplified CFD Analysis	+/-	++	++
Butterfly (Ladybug Tools)	Plug-in application for Rhino-Grasshopper	Open-source	Mesh based comprehensive CFD Analysis	++	+/-	+

Source: prepared by the author

CFD analysis enables engineers to visualize, test, and analyze their product designs for problems concerning fluid flow, heat transfer, turbulence, etc. Alternative CFD tools comprise Ansys, SimScale, COMSOL, RayMan, CityComfort+, CitySim Pro. The main reasons behind using CFD tools in architectural design is:

- To validate design,
- To optimize design,
- Reduce reliance on physical testing,
- Accelerate project design and development.

Table 2 presents comparison of computer tools (programs, plug-ins and applications) available in architectural education. Three software tools: Autodesk CFD, Autodesk Flow Design, Butterfly (Ladybug Tools) were compared in terms of license type, CFD analysis detail level, flexibility of use, user-friendly interface, all resulting in their applicability in architectural education. All three tools can be used in the field of architectural design in research on environmental impacts of buildings on its surroundings as well as fields of civil and mechanical engineering, urban planning analysis & simulation in other scientific disciplines.

CFD meshing applies a numerical grid to a fluid body and boundary, similar to meshing in finite element simulations. Meshes are the input for computational fluid dynamics (CFD) analysis, whose size and quality have important impact on the simulation results. Voxel-based volume modeling and simplified meshing strategies enable interoperability between the domains of architectural design and building aerodynamics, as well as enable simple and rapid iteration of a particular conceptual design while maintaining a reduced level of mesh cells. With meshless CFD methods like Autodesk Flow Design and FFD (Fast Flow Dynamics) that improve the effectiveness of data computing, the analysis gains efficiency at the cost of simplifying the detail of the simulation. This increases efficiency without increasing the computing requirements, which is very important in education. The educational status of the discontinued Autodesk product combined with a user-friendly interface and fast voxel-based CFD solver makes Autodesk Flow Design a very valuable tool in architectural education.

3. APPLICATION OF CFD TOOLS IN ARCHITECTURAL DESIGN

J. Yao clearly stated that: "*Computational Fluid Dynamics (CFD) and physical wind tunnels have been applied in the field of flow simulation and analysis in many research papers. However, more accurate simulation results require higher-precision parameter settings and mesh grids that require more computation time from CFD software. If there is a series of buildings that need to be simulated, the experiment might be deemed impractically lengthy. Furthermore, the relationship between the wind and the building form through digital tools is highly complicated. On one hand, accurate simulation of fluids is a very com-plex process: modeling accuracy, fluid initial velocity, axial static pressure gradient settings, meshing, iteration steps and so on, will obviously influence the simulation results to a certain extent. On the other hand, the problem of interconnecting the CFD software to common architectural modeling software still needs to be resolved.*" [J. Yao et al. 2018].

Computer simulations such as CFD have opened up new possibilities for design and research by introducing environments in which we can manipulate and observe. However, using such simulation tools in a meaningful manner is not a straightforward or easy task. While visualization helped both parties – the architects and the engineers – in communicating and documenting the process, the meshing remained fairly time-consuming even for initial analysis of concept designs at the early stages of project development. As was noticed by S. Kaijima, R. Bouffanai and K. Willcox: "*Historically, most computational methods were developed based on structured meshes, which, in general, are generated effortlessly. This is particularly true when boundaries have a simply geometry. However, with the advent of more powerful computers, CFD practitioners started simulating more complex flows and geometries for which structured meshes are commonly computationally prohibitive. Unstructured meshes have gained popularity in recent years as an alternative approach for analyzing flow dynamics involving complex geometries*" (Fig. 10a–b) [S. Kaijima et al. 2013].

Case study - High Mountain Meteorological Observatory on Śnieżka

The High Mountain Meteorological Observatory on Śnieżka in Poland, designed by prof. Witold Lipiński in cooperation with prof. Waldemar Wawrzyniak (interiors) from Wrocław University of Science and Technology was chosen as a case study for wind analysis. This meteorological facility is undoubtedly the clearest example of Polish architecture with a clearly aerodynamic form. The observatory in the form of disks covered with aluminum sheet have become one of the symbols of the Karkonosze mountains. Autodesk Flow Design was chosen to perform a 2D computational fluid dynamics (CFD) numerical simulation considering different velocities and turbulences of air flows.

The method for simulating wind loads can be split into three discrete parts:

1. Site modeling using Cadmapper model of Śnieżka mountain and Autodesk Revit.
2. Case study building modeling using Autodesk Revit.
3. Simulating wind loads using Autodesk Flow.

Results obtained allowed to find a qualitative assessment of the contribution of architectural form on the wind flows in the area surrounding the building.

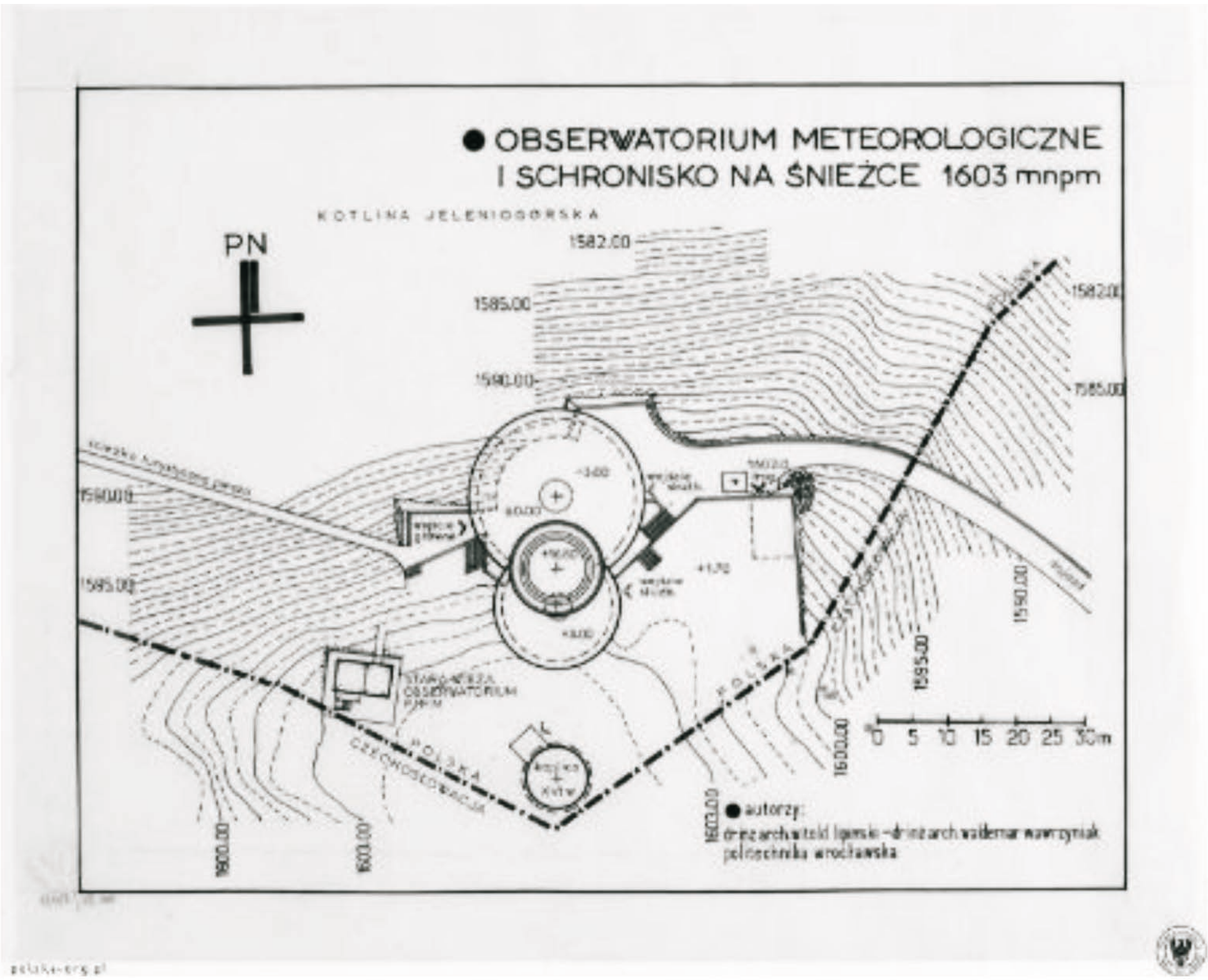


Fig. 7. High Mountain Meteorological Observatory on Śnieżka, site plan;
source: prepared by the author based on Ł. Wojciechowski 2014

Fig. 8 a–i. High Mountain Meteorological Observatory on Śnieżka – in the past and present: a), f) original drawings of Witold Lipiński and archival materials presented at the exhibition *Shape of Dreams – The Architecture of Witold Lipiński*; source: Museum of Architecture in Wrocław 2023, b-e) and g–i) Śnieżka 2022; source: J. Zych 2022

The observatory on Śnieżka, due to the uninterrupted meteorological measurement chain since 1880, is an ideal place to analyze climate change. These data are unique because the Śnieżka peak is devoid of local influences related to human activity. WOM Śnieżka is one of two Polish IMWM observatories included in the global system of high-mountain stations of the International Meteorological Organization (WMO), obliged to continuously conduct research and measurements. Architect Witold Lipiński who experimentally researched new technical solutions was in charge of design and project planning of the observatory. Before starting the design Lipiński performed a number of study flights above the peak of Śnieżka. His experience in gliding aviation gave him an intuitive approach to problems of building aerodynamics. This attitude is clear and evident in the design of the streamlined forms of the meteorological facility located in a difficult mountain climate. Lipiński also attached great importance to combining his works with the surrounding landscape.

The highest peak of the Karkonosze Mountains, Śnieżka, has been a popular hiking destination since the mid-19th century. In 1945, when the Polish administration took over the former German recreation infrastructure, the top of the mountain was relatively densely built-up – there were two shelters (one of them on the Czechoslovak side), a 17th-century chapel of St. Wawrzyniec and the meteorological observatory built in 1899. Due to the very poor technical condition of the wooden buildings, in the first half of the 1950s, preparatory work for the construction of a new facility was started, combining the functions of a shelter and a meteorological observatory. The first concept designs (Borys Lange and Czesław Sosnowski) assumed the construction of solid, cuboid forms with stone cladding.

The new observatory was supposed to be more than just an ordinary building replacing the over a hundred-year-old log structure in which meteorologists had previously worked. Therefore, the first concepts of a traditional rectangular shape were rejected by the investor and the project was commissioned to Witold Lipiński - then an assistant professor at the Faculty of Architecture, who was just starting to build his own house

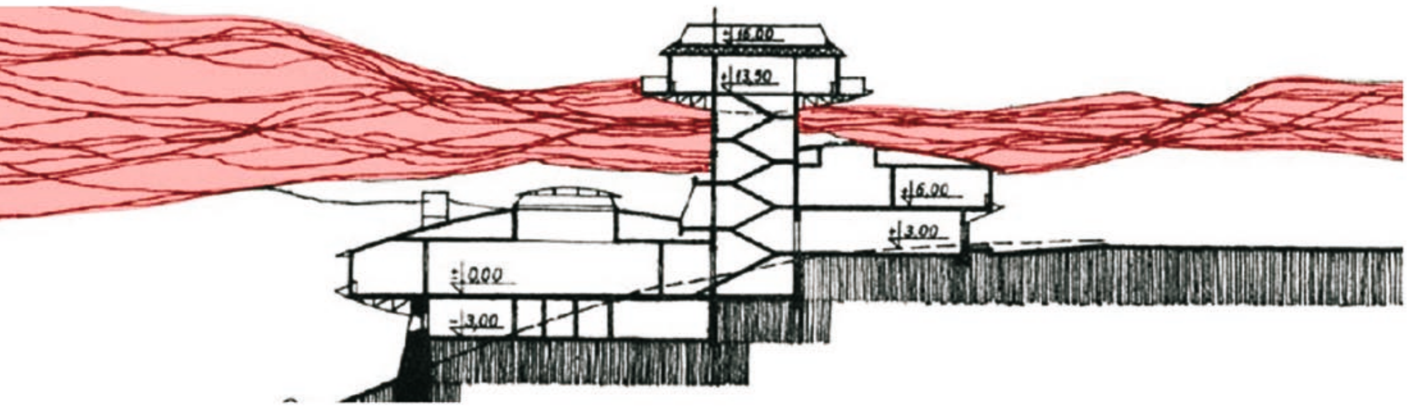


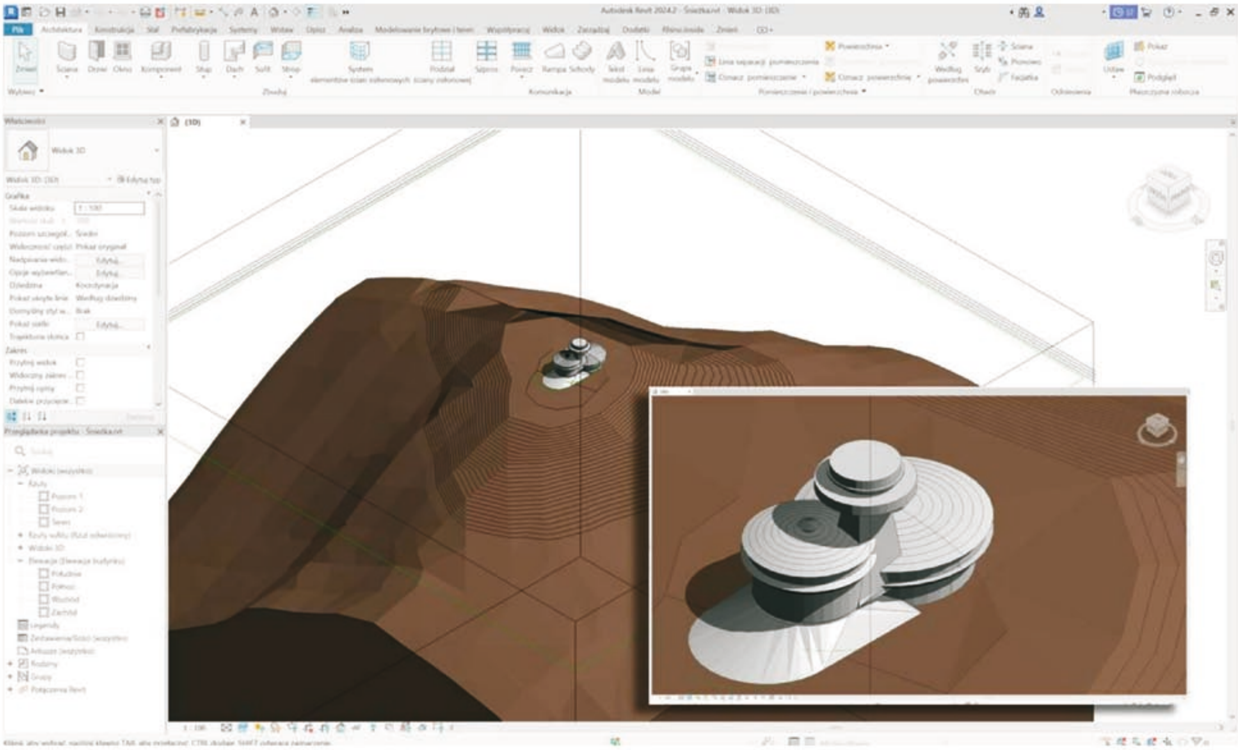
Fig. 9. Intuitive understanding of building aerodynamics, windflow marked on longitudinal section with highlighted airflow between discs of the High Mountain Meteorological Observatory on Śnieżka. Source: original drawing of Witold Lipiński presented at the exhibition *Shape of Dreams – The Architecture of Witold Lipiński* Museum of Architecture in Wrocław, source: author (2023)

in the shape of an igloo in Zalesie in Wrocław. Discussions about the final shape of the investment lasted until 1963, when Lipiński's design was finally chosen as more attractive and, due to the prefabricated steel structure, potentially cheaper. The architectural form comprised of three disks bound by the structural core element. The facility was located at the very top of the mountain arranged on three levels. The lowest disc was occupied by technical rooms, a restaurant and accommodation rooms, while the middle one was intended primarily for station staff. The highest disk – was to be the heart of the observatory. It had a terrace on the roof and a gallery around it. This is where the measuring equipment and the position of the meteorologist-observer were to be located.

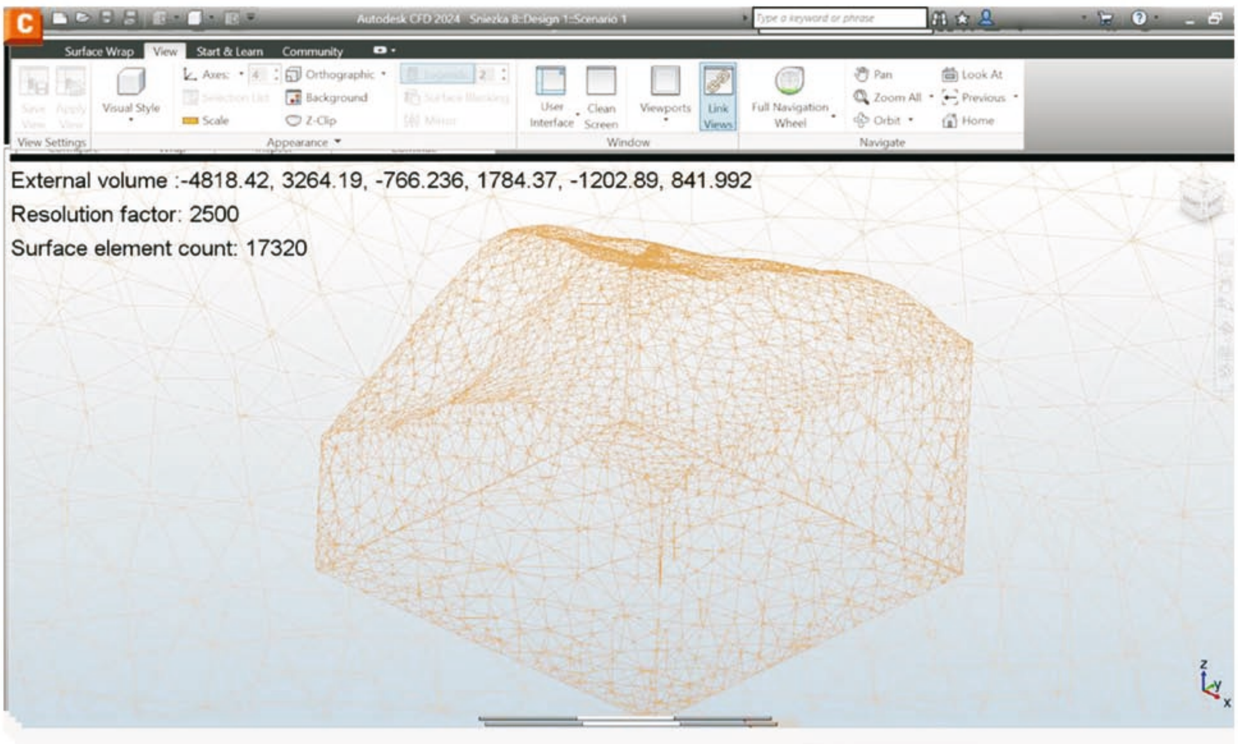
Recalling his inspirations Witold Lipiński mentioned three sources. The first was climate characterized by harsh weather conditions – the only sensible response to the hurricane winds at the top of Śnieżka was the use of aerodynamic building forms. As an amateur pilot Lipiński knew this perfectly well. As the second source, he indicated nature with rock formations shaped by erosion, so characteristic of the Karkonosze Mountains. As Witold Lipiński explained: "*I was suggested by the rock groups formed by erosion, characteristic of the Karkonosze Mountains. I borrowed the future shape of the object from the piles of elliptical boulders. There was also an aerodynamic aspect at play, dominant in the design of airplanes, which I read a lot about as a passionate glider pilot*" [Ł. Wojciechowski 2014]. Several glider study flights that Lipiński made over the peaks, helped him to come to the conclusion that the most resistant form to the prevailing conditions would be the circular form. It is impossible to predict the dominant wind direction on Śnieżka – it blows almost always and from every direction. The structure of the disks is a steel truss, centrally supported on a concrete foundation [Ł. Wojciechowski 2014]. Jerzy Ramotowski gives the opinion of prof. W. Wawrzyniak "*Śnieżka with its three disks is primarily a variation on the Karkonosze boulders polished by mountain winds over millions of years*" [J. Ramotowski 2012]. Only in third place did pop culture fascination with unidentified flying objects appear.

Construction at an altitude of 1,602 m above sea level required an individual design that would respond to difficult weather conditions, fit into the silhouette of the mountain, and at the same time fulfill a propaganda role. Lipiński managed to reconcile these apparent contradictions in his concept of three disks connected by a vertical core resting on a foundation embedded in the terrain. Wojciechowski quotes Jerzy Hryniewiecki's opinion from 1965: "*[the disks] are a form of a set of central elements influenced by the mood of the climate, strong winds and the need to create an interior that is as connected and closed as possible, and at the same time providing the widest possible panoramic possibilities. Cutting the bowl off from the terrain allowed for minimal interference in the shape of the mountain peak*" [Ł. Wojciechowski 2014].

One of the concept drawings of a longitudinal section of the building shows airflow as originally designed and drawn by Lipiński. The architectural form of the building is clearly aerodynamic, ensuring free and continuous wind flow through its parts (Fig. 9.). Both primary inspiration for architectural form (eroded rock-pile) and secondary (aerodynamic forms of glider plane) show intuitive understanding of building aerodynamics. In both aspects wind flow is an important factor. Its energy, velocity, the pressure it creates, humidity, and



a)



b)

Fig. 10 a–b. High Mountain Meteorological Observatory on Śnieżka, a) 3D model, b) complex mesh model generated in Autodesk CFD. Source: author (2023)

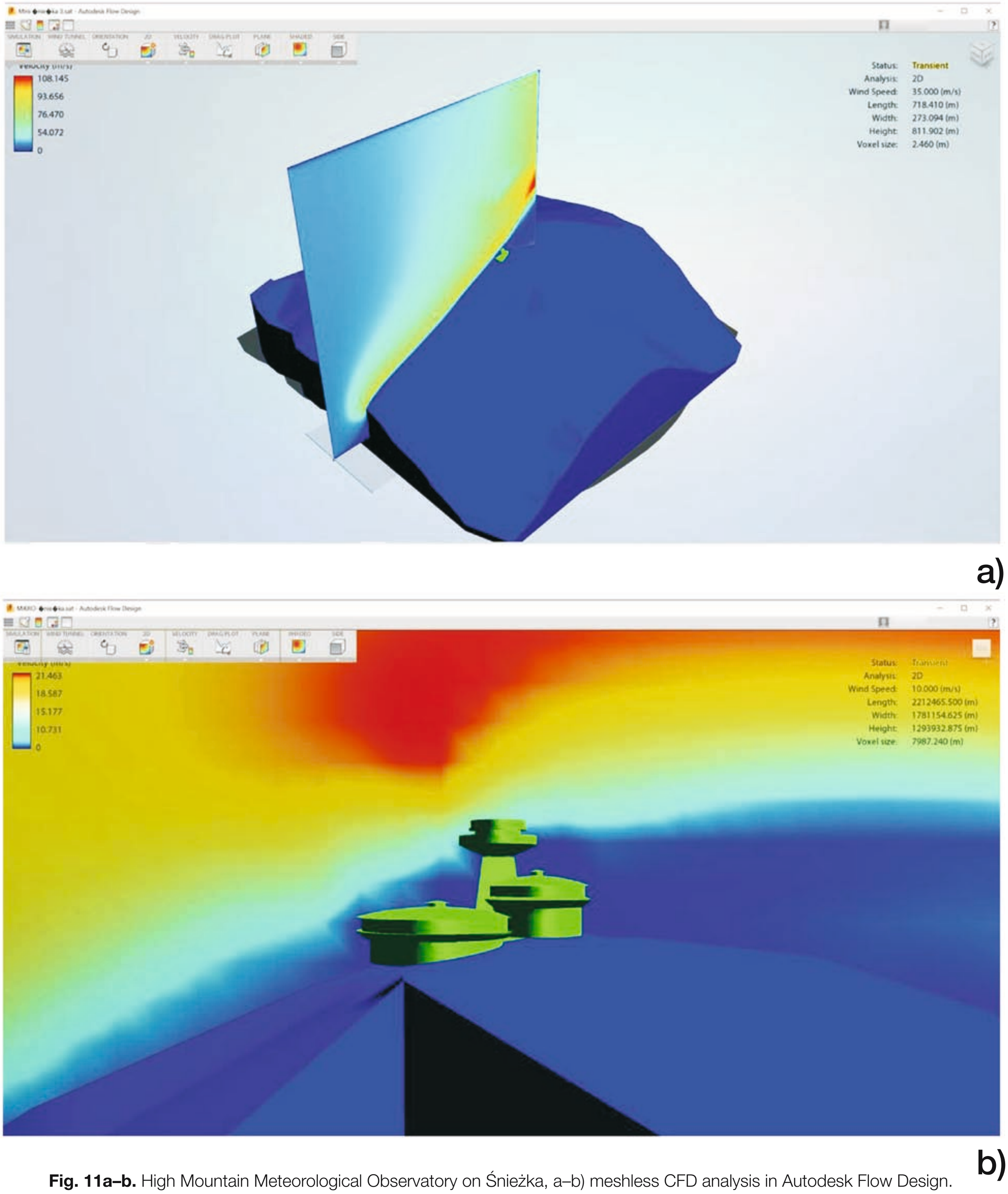


Fig. 11a–b. High Mountain Meteorological Observatory on Śnieżka, a–b) meshless CFD analysis in Autodesk Flow Design. Source: author (2023)

the particles it carries create continuous environmental impact on the building and in longstanding terms causes erosion of rocks. Śnieżka observatory is located on the top of the mountain and exposed to extreme weather conditions.

The observatory building is located at the height where climatic loads reach high values that determine the safety of the structure. The location of the building is considered one of the windiest places in Europe, with recorded wind speeds reaching 240 km/h. The wind was highlighted to clarify the aerodynamic idea of continuous and undisrupted flow of wind that is extreme at the peak of the mountain at an altitude of 1,602 m above sea level. According to measurements, wind speeds lower than 10 m/s are recorded only 60 days a year.

The construction of the observatory was done in the years 1966–1974. It has the form of three interconnected disc – or saucer-shaped shapes. According to Łukasz Wojciechowski, "*The Observatory of the National Hydrological and Meteorological Institute is Witold Lipiński's greatest achievement. It resembles some of the designs of Frank Lloyd Wright, John Lautner or the visions of the American set designer Norman Bel Geddes. It is the first such futuristic building in Poland incorporated into the landscape. The project was in line with the stylistic trends of the time, inspired by the conquest of space and the development of science fiction*" [Ł. Wojciechowski 2014]. In 2020, by the decision of the Provincial Conservator of Monuments of Lower Silesia, the facility was included into the register of monuments.

As Wojciechowski says: "*The middle plate contains the employees' living rooms and a kitchen with a dining room. At the top there is an observation post with a terrace, where you can conduct research in the harsh climate of Śnieżka [...] The foundations for the observatory are made of reinforced concrete - the benches rest on the rock, the core and brick walls are reinforced with reinforced concrete pins and rings, while the disks are made entirely of steel – the lattice elements were prefabricated*" [Ł. Wojciechowski 2014].

In 2009, under severe weather conditions, the lower part of the highest disk collapsed, threatening the lower structure. Fortunately, two years after the disaster, this fragment was rebuilt and the saucer's original shape was restored. The facility still functions in accordance with its original assumptions and is one of two Polish observatories of the Institute of Meteorology and Water Management operating in the global system of high-mountain stations [P. Gadomska 2020].

High Mountain Meteorological Observatory on Śnieżka wind analysis run in Autodesk CFD is based on advanced meshing of initial model (Fig. 10a–b). Since it is a professional CFD tool, solving each design study takes time providing rather obvious and not requiring high detail resolution.

The meshless CFD analysis in Autodesk Flow Design provides good interoperability between the domains of architectural design and building aerodynamics (Fig. 11a-b). Students and architecture practitioners can use this tool for rapid simulations of architectural forms created during the conceptual design process. This together with quantitative analysis of solar radiation and natural lighting fully demonstrates the link between the architecture and surrounding environment.

A key issue in architectural education is to find the right proportion between simulation accuracy and computational requirements. Simplified modelling strategies like voxel based systems, as well as dynamic visualization of flows of wind lines and wind planes significantly increase the speed of calculations needed for simulation generation.

CONCLUSIONS

Wind engineering is a combination of art and science, and it is important for structural engineers to understand just enough to check that the right studies are being conducted and, if not the reasons for unusual results, the appropriate questions to ask to elicit explanations. This model is also easier to modify if a range of building shapes are being investigated. Form-finding studies are sometimes used during concept design of particularly slender and wind sensitive towers to optimize building shape and minimize building responses. Previously, most building-related issues such as ventilation analysis, wind loading, wind environment etc. were examined using wind tunnel tests. Nowadays all these tests can be done effectively with CFD which can resolve all of the above-mentioned issues in a relatively short time period. CFD stands for Computational Fluid Dynamics and is a type of analysis that uses a numerical method to solve and analyze problems related to particle flows. Computer simulations can be used to predict the behavior of air and other fluids as they interact with objects, such as wind shear, thermals, or temperature inversions.

Architects do not require high-end CFD applications in school or in practice. Available CFD software applications are eligible to easily run air flow studies, such as the effect of wind around designed buildings. Simulation based analysis results, particularly of airflow parameters in the vicinity of buildings, can form a common general framework methodology for architectural, structural and mechanical engineering as well as for the renewable energy sources industry. Presented software tools are valuable instruments in architectural education to enrich students' profile as professional architects ready to design in close cooperation with other disciplines in integrated design processes. Research-based Design is commonly the most used work methodology in the architecture discipline. The connection between research and design gradually becomes established, the question of how to construct knowledge and understanding out of a design or a design process increases in significance. Accessible software tools and applications are valuable instruments in in-depth studies required in the conceptual phase of the architectural design process.

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APPLICATION OF CFD ANALYTICAL TOOLS IN ARCHITECTURAL DESIGN IN THE CONTEXT OF WIND LOADS – PART 2

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Abstract
The second part of the article discusses the assessment of extreme weather conditions on architecture in the era of climate change with the aid of CFD analysis tools. Computer simulations such as CFD have opened up new possibilities for design and research by introducing environments we can manipulate and observe. The article presents two case studies of high-rise buildings: Plac Unii (2013) and Q22 (2017) located in Warsaw, showcasing the increasing role of new technologies, particularly CFD simulation tools, in studying the aerodynamics of urban environments. The paper includes CFD wind studies of the buildings and their urban surroundings performed in Autodesk Flow Design.

Keywords: architecture; wind analysis; CFD; wind tunnel; research based design

INTRODUCTION

The idea of streamlines is an important concept in the study of aerodynamics. A streamline is a path traced out by a massless particle as it moves with the flow. For most buildings, aerodynamic damping has positive effects. This is beneficial in reducing the resonant dynamic response of the building. Wind flow over buildings leads to separation and hence a complex spatial and temporal mechanism that governs the nature and intensity of aerodynamic forces. This complexity mainly comes from the transient nature of incident turbulent winds and the fluctuating flow pattern in the separation bubble. The study of building aerodynamics is vital for the evaluation of cladding pressures, drag, shear, and uplift forces that are essential for safe and economic design. Flow separation makes it challenging to estimate loads without referring to direct physical and/or computational simulation. For several decades, aerodynamic testing has been employed for the estimation of wind pressures and forces on buildings.

Wind is the horizontal or almost horizontal movement of air relative to the Earth's surface caused by a pressure difference. In open, undeveloped areas, its operation is modified by the topography and material diversity of the substrate, which heats up differently. In highly urbanized areas, aerodynamic phenomena at the level of building heights are very complex. The air does not fall on a flat surface, but on a strongly deformed surface, most of which is hardened, and therefore heats up much more intensely than the surrounding area [K. Zielonko-Jung 2018]. Additional loads appear due to aerodynamic interference and various constrictions that accelerate the flow. In many cases, mainly high-rise buildings, the impact of wind often determines the shape of the structure itself, for example it forces the use of rounded corners or additional elements in the façade placed in the corners of the buildings, making structural openings or installing vibration dampers [T. Lipecki 2015].

In contemporary architectural design it is necessary to accurately and precisely assume the wind load. Detailed study of local geographical and environmental conditions can be the basis for long-term strategies in the architectural design process. The impact of extreme wind is in many cases a factor determining architectural and structural design. Various forms of wind impact and the loads they cause may constitute values that influent dimension the cross-sections of structural elements.

1. CLIMATE CHANGE RESPONSIVE ARCHITECTURE

Climate change is a recent topic that needs to be addressed much more in architectural design education to prepare students for unforeseen challenges. Buildings are designed for a specific climate yet they often have a lifetime of 50–100 years and climate change may require a building to operate over a range of climatic conditions as a result of the impact of global warming. Winds are commonly classified by their spatial scale, their speed and direction, the forces that cause them, the regions in which they occur, and their effect. Undoubtedly, weather phenomena in the era of climate change in many areas of the Earth will be characterized by extreme winds (hurricanes, typhoons, etc.) and where there are tall or long-spanning structures, flow loads are the most important at the design stage.

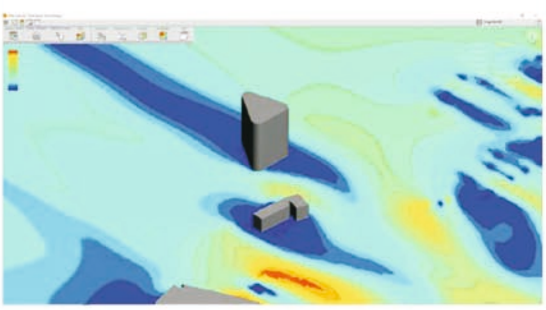
Climate Change is impacting global wind patterns in many ways. In the era of climate change, there is an urgent need for climate responsive architecture adapting to changing environmental conditions. This means resistance to extreme weather that includes heat waves, cold waves and heavy precipitation or storm events, such as hurricanes and cyclones. Weather anomalies that are forecast in this dynamic process will mark the development of new ways of building, especially with regard to architectural design. Air circulation within and around buildings and its surroundings can be examined in both physical and virtual ways. Airflow can impact all aspects of a building design. Wind and airflow affect urban and building design strategies such as natural ventilation. Airflow has a direct impact on the comfort levels of using a building, and the following factors should be considered:

- Air circulation can impact passive cooling and overall energy efficiency of the building;
- External airflow can impact internal ventilation;
- Wind airflow loads on the main structural elements (overall wind loads);
- Wind airflow loads on the facade, openings or roof details and ancillary building items;
- Localized wind anomalies effects on air quality, particulates and pollution around buildings on external or public spaces in the built environment.

2. CFD IN ARCHITECTURAL DESIGN

Using CFD analysis, it is possible to find the suitable information (local wind velocity, convective coefficients, and solar radiation intensity) for optimal orientation, site and location selection of buildings. It is becoming increasingly important to provide occupants comfort in pleasant building environments. Architects and wind engineers are often asked to look over the design (orientation, site, location and gaps between the surrounding buildings) in the formative planning stage of construction. Computational fluid dynamics modeling, or CFD, is based on the principles of fluid mechanics, utilizing numerical methods and algorithms to solve problems that involve fluid flows. The equations governing fluid motion are the three fundamental principles of mass, momentum, and energy conservation. CFD has many applications in the field of architectural design. It can be used to optimize the design of both internal and external spaces of a building by predicting how it will behave under specific conditions.

Tab. 1. Application of CFD in architectural design

CFD ANALYSIS	ARCHITECTURAL DESIGN
	– optimal orientation, site and location selection of buildings – ventilation study in buildings – heat balance calculation – thermal analysis – renewable energy generation – wind assessment for urban planning and architecture

Source: prepared by the author

The role of the parametric model in modeling construction information in BIM technology was described by K. Januszkiewicz and K.G. Kowalski [2020]. The process of parametric modeling of an object's surface can be linked directly to CFD analyses included in the Digital Project GT software. The results of these analyses allow the optimization of the shape of the form due to wind loads [K. Januszkiewicz 2012].

In the selection of building site and location, among other local geographical and environmental conditions, wind loading plays an important role. For example, in the case in which two buildings at a location exist side by side with a gap, when a volume of wind blows around the ends of the buildings and through the gap, the sum of flow around each building and then its velocity increases as it travels through the gap, at the expense of pressure loss. As a result, there is a build up of pressure entering the gap, which leads to higher wind loads on the sides of buildings. When wind blows over the face of a high rise building, a vortex is created by the downward flow on the front face. The wind speed in the reverse direction near the ground level may have 140% of the reference wind speed, which can cause severe damage (especially to the roof of building). Such damage to buildings can be prevented if the effects of wind loading are considered in the early stage of construction of a building [K. Klemm 2022].

Recently ventilation and its related fields has become a great part of wind engineering. The ventilation study in buildings is done to find the thermally comfortable environment with acceptable indoor air quality by regulating indoor air parameters (air temperature, relative humidity, air speed, and chemical concentrations in the air). CFD finds an important role in regulating the indoor air parameters to predict the ventilation performance in buildings. The ventilation performance prediction provides the information regarding indoor air parameters in a room or a building even before the construction of buildings. These air parameters are crucial for designing a comfortable indoor environment, as well as good integration of the building in the outdoor environment. This is because the design of appropriate ventilation systems and the development of control strategies need detailed information regarding the parameters of airflow, pollutant and contaminant dispersion and temperature distribution. A ventilation study can be done using wind tunnel investigation (experimentally) or by CFD modeling (theoretically). Natural ventilation systems may be preferred over forced ventilation systems in some applications, as it eliminates or reduces the need for a mechanical ventilation system, which may provide both fan energy and first-cost savings. In the present era, due to development of a lot of CFD software and other building performance simulation software, it has become easier to assess the viability of natural/forced ventilation systems in a building. In order to reduce heat losses from buildings, CFD thermal analysis can be done for the optimum configuration of composite walls, roof and floor. In buildings, heat transfer takes place in all modes i.e. conduction, convection and radiation through walls, roof and floor of buildings.

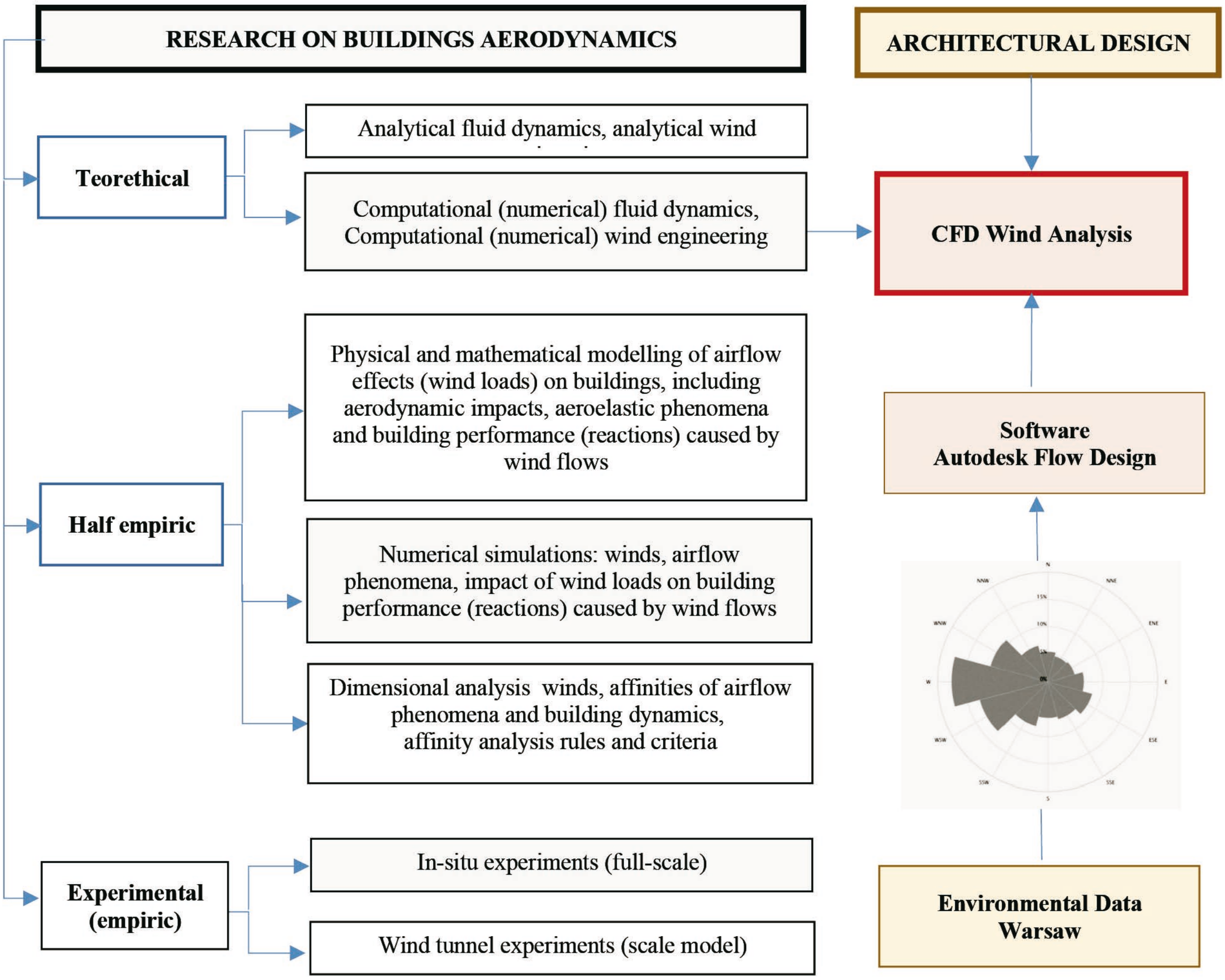
CFD simulation may be used to assess windflow over small wind turbines and solar panels, which help to define overall efficiency of the building. The impact of renewable energy sources on the architecture of selected buildings in Poland after 2004 was described by J. Juchimiuk. [J. Juchimiuk 2018].

3. WIND ANALYSIS OF Q22 AND PLAC UNII HIGH-RISE BUILDINGS IN WARSAW

Tall buildings are particularly prone to wind loads and aerodynamic phenomena. One way to minimize wind-induced vibrations in tall buildings is to focus more on their shapes in the design stage. High-rise buildings in cities adversely affect wind regimes by changing the air currents in their surrounding areas. In particular, extreme climate phenomena caused by climate change are stronger and more frequent, causing damage in cities. To better understand wind behaviors around high-rise buildings, actual measurements are necessary to determine the environmental assessment of the wind effect. Two high-rise buildings: Q22 (2017) and Plac Unii (2013) located in Warsaw were analyzed by the author.

Wind engineering by A. Flaga is the first monograph in Poland on wind engineering. It presents issues related to, among others, the impact of wind on the natural environment and people, as well as on buildings and engineering structures. The use of wind as an energy source was discussed, and the topic of natural disasters caused by extreme winds was raised. Particular attention was paid to current research on building aerodynamics (Tab. 2) and the issues of safety and reliability of structures exposed to wind loads [A. Flaga 2005].

Tab. 2. Research on building aerodynamics, CFD Wind Analysis using Autodesk Flow Design.



Source: prepared by the author based on A. Flaga 2008

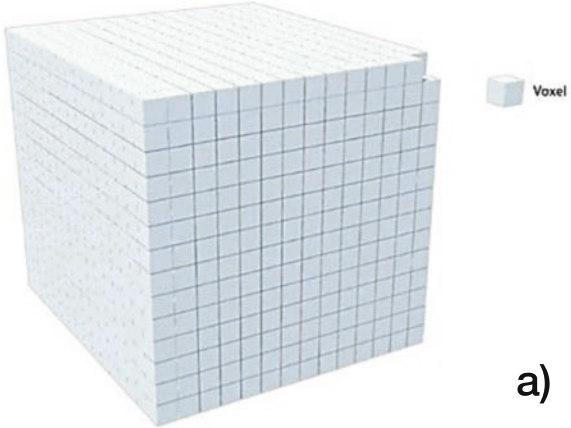
3.1. Methodology

Air flow is highly determined by the layout of surrounding buildings. The CFD analysis of case study buildings was carried out by the author using Autodesk Flow Design software according to the following methodology:

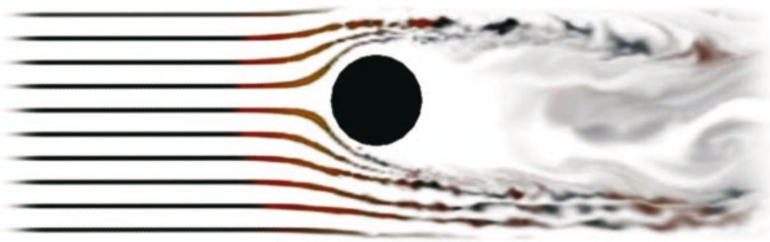
1. Flow problem formulation.
2. Geometry modelling.
3. Establishing the Boundary and initial parameteres of analysis.
4. Voxel grid generation.
5. Establishing Simulation strategy and wind speed parameters.
6. Simulation.
7. Monitoring.

The Autodesk Flow Design analysis mechanism is presented in the article at the TOI-Pedia (digital repository of the University of Delft): "*The Fluid Dynamics simulation uses a special type of geometry to make the fluid calculations possible, called voxels (volume pixels). These are 3 dimensional pixels, basically a set of cubes nicely stacked into a container. Every cube will contain the mathematically defined properties of a fluid and therefore behave like a particle of fluid. A cube (voxel) will behave like one mathematically defined object, calculating the forces, pressure and temperature placed on the cube and then emitting the result to its neighboring cubes. Transmitting effects of heat, pressure and movement throughout the container holding all the cubes*" (Fig. 1a–b) [TOI: Design Informatics, 2020].

The aim of the wind study of two high-rise buildings performed by the author was to determine the impact of the architectural form of the high-rise buildings on their surroundings. The heights of buildings and the widths of individual street canyons and the heights of the buildings in 3D models used in wind analysis were determined by on-site visits and by analyzing Cadmapper, Geoportal 2 and Google Earth 3D models. Due to the lack of access to accurate data, accuracy of up to 5m was assumed.



a)



b)

Fig. 1a–b. The Fluid Dynamic simulation; source: TOI: Design Informatics 2020

A similar study of urban areas of central Warsaw was performed using ANSYS Fluent software by A. Chudzińska, M. Poćwierz and M. Pisula in 2021. Analysis of aerodynamic phenomena in a selected quarter of building developments in downtown Warsaw with reference to air pollution covered about 43 ha and included densely developed tenement houses, high-rise buildings and more extensive volumes, such as the Złote Tarasy Shopping Center (ZT) and the Palace of Culture and Science. [A. Chudzińska, M. Poćwierz, M. Pisula 2021].

3.2. Case study: plac unii high-rise building, Warsaw (2013)

Plac Unii – an office and commercial complex at ul. Puławska 2 near The Union of Lublin Square, designed by APA Kuryłowicz & Associates Studio, was realized in Warsaw in 2010-2013. The skyscraper was properly used as a spatial dominant located at the end of ul. Puławska. However, there are reasonable concerns about the unfavorable impact on the viewing openings in the area of Łazienki Park, and in particular the disruption of the view of the Belweder Palace by the silhouette of the skyscraper [H. Markowski, K. Owczarczyk, K. Szulborski 2014].

Fig. 2a–d. Plac Unii building, Warsaw, APA Kuryłowicz; source: photo by the author (2023).

Fig. 2e–g. Plac Unii building, Warsaw, APA Kuryłowicz; source: photo by the author (2023).

The Plac Unii complex consists of three buildings, the tallest of which is a 90-meter tower with a form inspired by the New York Flatiron building constructed in New York in 1902 (Fig. 2a–g). The form of the building is compact. Rounded corners of the tower reduce the impact of wind on the structure of the object. The use of an extended skyscraper base in the form of two lower buildings connected by glass roofs also reduces the impact of the wind. This type of solution for shaping the body of a tall building significantly improves the windy climate in its surroundings.

Model tests and study analyses of the impact of wind on a tall building were carried out by the team of prof. A. Flaga at the Wind Engineering Laboratory of the Cracow University of Technology in 2008 [A. Flaga 2015]. Dynamic pressure measurements on the walls of a building model used wind flowing from 33 different directions. Determination of basic patterns of equivalent wind impact on this building for static and strength calculations are shown above (Fig. 3a–b.).

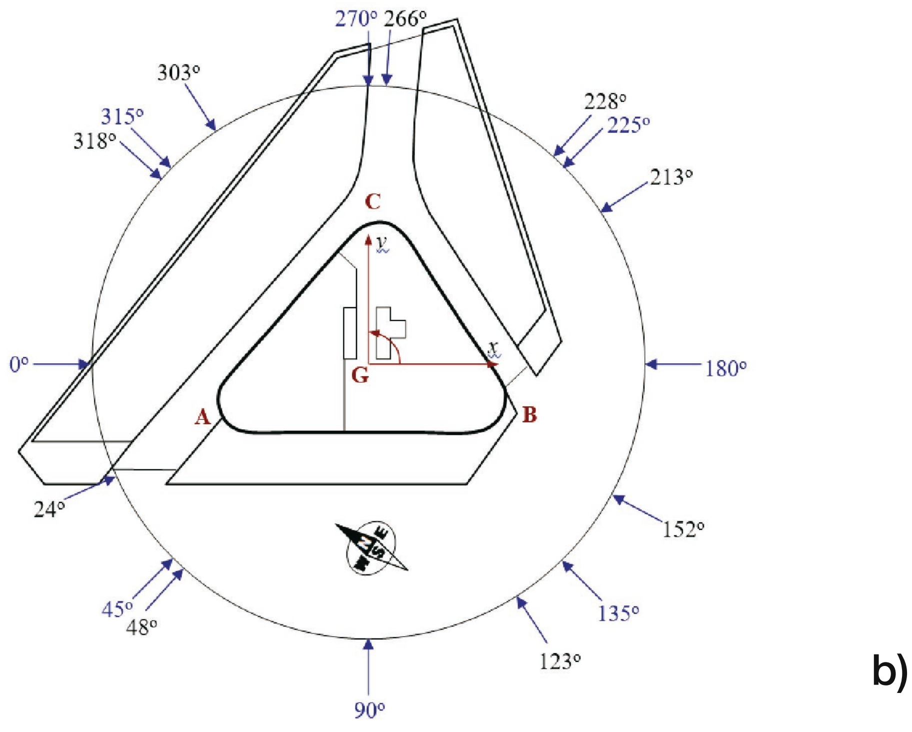


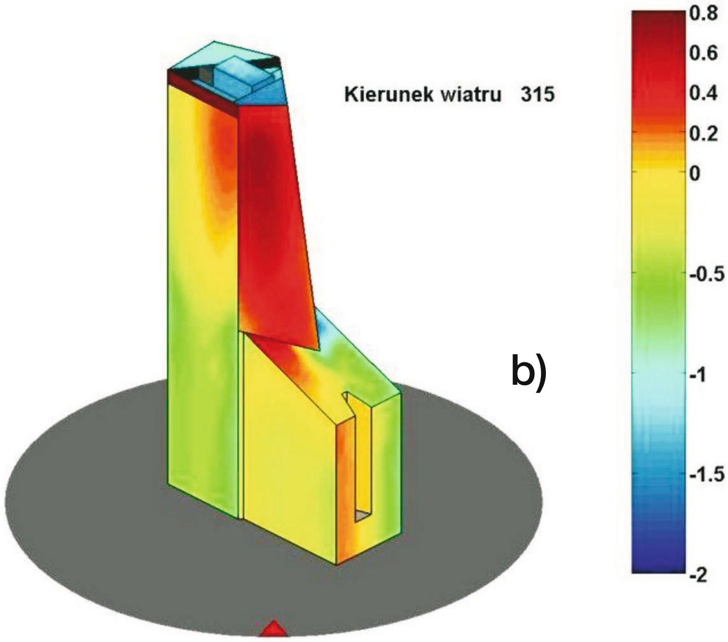
Fig. 3a–b. Wind analysis Plac Unii high-rise building, a) view of the model in the measurement space of the wind tunnel, b) analyzed directions of wind inflow during research;; source: A. Flaga 2015, Laboratory of Wind Engineering, Cracow Univ. of Tech.

Fig. 4.a–f. Q22 Office Building, Warsaw, APA Kuryłowicz. Source: photo by the author (2023)

3.3. Case study: q22 high-rise building, Warsaw (2017)

Fig. 5a–b. Building model and the surrounding environment in the measurement space of the wind tunnel. Visualization of the distribution of the average wind pressure coefficient on the external surface; source: A. Flaga 2015, Laboratory of Wind Engineering, Cracow Univ. of Tech. 2013

Q22 skyscraper in Warsaw was designed by the leading Polish architectural office Kuryłowicz and Associates. This 155 m tall high rise office building was built in 2017 (Fig. 4a–f). Buro Happold was appointed to provide building services engineering as well as BREEAM assessment and consulting for this project. Model tests and study analyses of the impact of wind on the tall building were carried out by the team of prof. A. Flaga at the Wind Engineering Laboratory of the Cracow University of Technology in 2013 (Fig. 5a–b.) [A. Flaga 2015].



The building has a unique asymmetric shape designed to resemble a quartz crystal. The irregular shape coupled with the fact that the structural core had to be shifted away from the center, demanded rigorous design supported by wind tunnel and CFD simulation. Sustainable objectives also informed the building's solutions incorporating a number of innovative techniques including tri-glass facade, which give better thermal and acoustic isolation, minimizing the building's heat loss during the winter and solar gains during the summer. Thermal and lighting zoning further reduce power consumption. To capture solar energy, a photovoltaic system was incorporated into the design of the sloping glass roof. This generates renewable energy which can be used to power the charging points for electric vehicles. Sustainable objectives also informed the building's heating, ventilation and air conditioning design. Using air-water heat pumps, energy is recovered from the server and technical rooms and redistributed around the building, providing significant energy savings.

According to Mycielski: "*The designers of Q22 did not have an easy task also because the skyscraper, built among blocks of flats from the 1960s, was subject to numerous restrictions related to the need to ensure access of light to single-sided apartments located in neighboring buildings. The architects treated these difficulties as an excuse to shape the structure and turned it into an advantage. Analyzing the impact on the neighborhood and controlling the effect on the urban model, the skyscraper was bent, tilted and carved with cuts, while simultaneously improving its slenderness on all sides. At the same time, the transparent and minimalist character of the architecture has not been lost*" [K. Mycielski 2017].

3.4. Wind analysis results

Windflow analysis performed in Autodesk Flow Design make it possible to reverse engineer two different form optimization strategies used by the architects who designed the buildings. The results are presented in Tab. 3.

The analysis of case studies was carried out using Autodesk Flow Design software according to the methodology mentioned earlier. Both analyzed buildings are located in a dense urban environment. Neither of the analyzed buildings was the first obstacle to the incoming air from the west. As a result of simulation tests, the distribution of wind speed and pressure around the building was obtained. The air flow determined by the building arrangement also plays an important role in the convection and evaporation processes occurring both on the outer surface of the partitions and in their near-surface zones.

The analysis revealed a relatively high influence of designed forms and their aerodynamic interference with neighboring buildings, including the occurrence of:

- local changes to average wind speed for each wind direction,
- aerodynamic couplings: airflows, vertices,
- differences in pressure pattern distribution,
- vertical airflows,
- near-façade wind flow pattern and surface pressures patterns.

Direct outcomes include horizontal and vertical pressure variations resulting in dynamic movement of air masses sideways, upwards and downwards with increased speed. The aim of the analysis was to monitor and limit unfavorable phenomena such as excessive local accelerations of air masses and wind impacts resulting from turbulence. As a result of simulation tests, the wind speed distribution around the building was obtained.

Tab. 3. Form optimization strategies

BUILDING NAME	BUILDING HEIGHT	WIND ANALYSIS METHOD USED BY ARCHITECTS	FORM OPTIMIZATION STRATEGY
PLAC UNII HIGH-RISE BUILDING	90 m	Scale model	Triangular plan Edge filleting
Q22 HIGH-RISE BUILDING	155 m	Scale model CFD	Form-finding of aerodynamic shape

Source: prepared by the author

The architectural forms of the two high-rise buildings were assessed in terms of features determining the occurrence of aerodynamic phenomena for prevailing western winds with a speed of 25 m/s at an altitude of 40 m. In order to illustrate the effect of wind on heat loss, a numerical CFD analysis was performed around the high-rise buildings. The study shows airflow effects on the two high-rise buildings located in a dense urban area of Warsaw: Plac Unii complex (Fig. 6a–c) and Q22 building (Fig. 7a–c).

The ease of use makes Autodesk Flow Design available not just to traditional users (mainly in aerospace and automotive industry) but also for architects. Flow Design provides easy input of 3D data into their software from many sources. Simplified CFD solver that simulates airflow with rather low detection of weather anomalies and seasonal patterns is an obvious disadvantage, however Flow Design has demonstrated its ability to give information about:

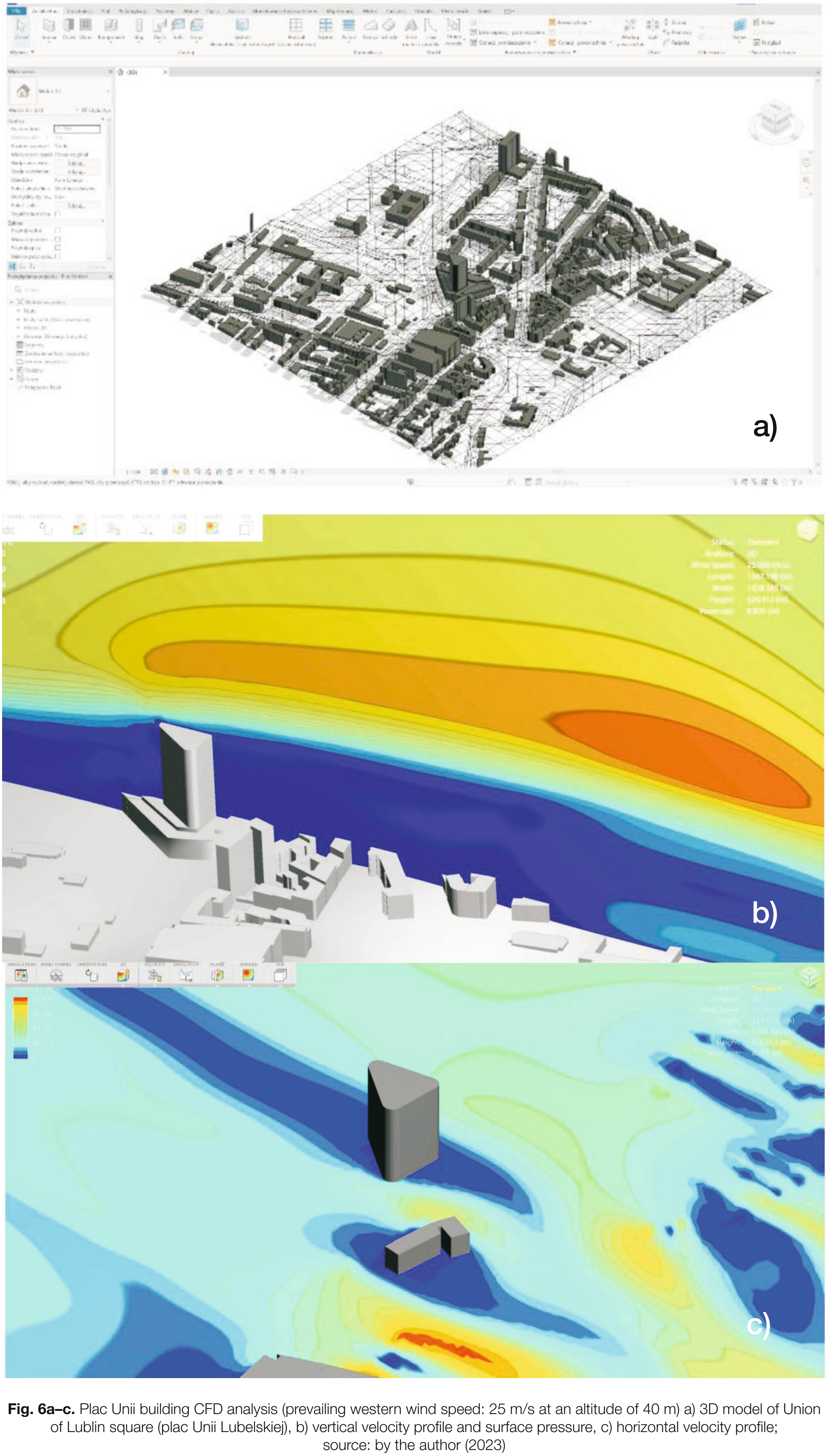
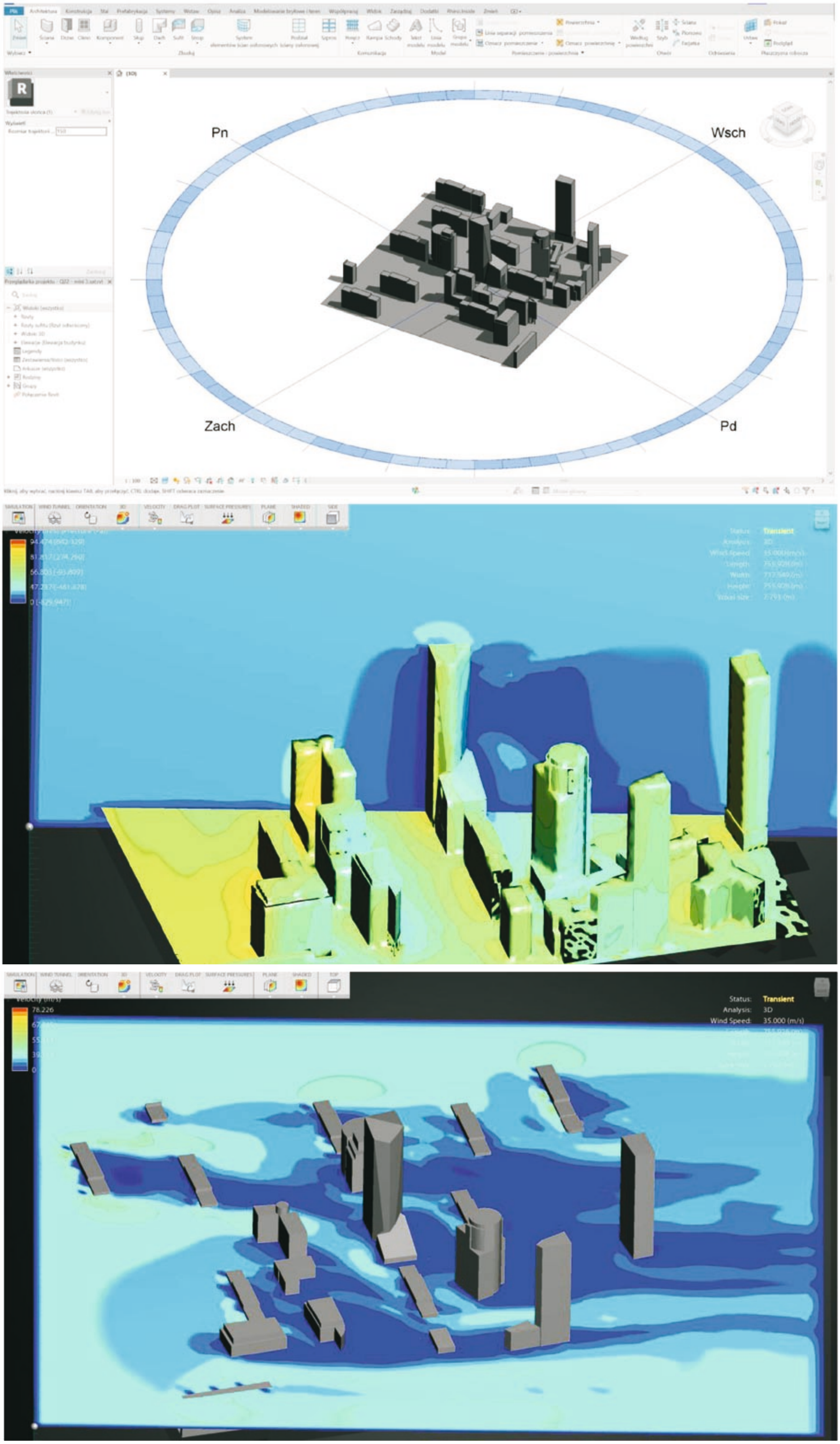


Fig. 6a–c. Plac Unii building CFD analysis (prevailing western wind speed: 25 m/s at an altitude of 40 m) a) 3D model of Union of Lublin square (plac Unii Lubelskiej), b) vertical velocity profile and surface pressure, c) horizontal velocity profile; source: by the author (2023)



a)

b)

c)

Fig. Fig.7a–c. Q22 building CFD analysis (prevailing western wind speed: 25 m/s at an altitude of 40 m)
a) Revit 3D model, b) vertical velocity profile and surface pressure, c) horizontal velocity profile;
source: by the author

- Potential for natural ventilation through various wind speed and pressures inside and outside the building,
- Wind hindrance at certain areas around the building, where wind speeds are too high,
- Renewable energy generation by optimizing the form of the building to harness wind energy.

CONCLUSIONS

Architectural design should aim at creating forms shaped to enable natural air circulation inside and around buildings. Modeling airflow, atmospheric phenomena and weather anomalies has an increasingly visible impact on the architectural form-finding process of a building that can be modeled both physically and virtually. The analysis results can also be used as input data for energy analyses when determining changes in the heat transfer caused by the impact of wind. Analysis can also be performed of pressure differences and aerodynamic phenomena of stagnations and vortices that can accumulate air pollution and play an important role in the convection and evaporation processes occurring both on the outer surface of the partitions and in their near-surface zones.

Application of CFD analysis tools in architectural design is crucial to counter the effects of climate change. Wind analysis accurately accounts for various project specific factors that include: aerodynamic influences associated with building shape, directionality of wind associated with regional wind climate and influence of neighboring buildings and land topography. Both physical wind tunnels and Computer Fluid Dynamics methodology provide the essential tools to examine airflow patterns. The dynamic model is used to simulate and model the behavior of both inner and external volumes of the building. It includes anomalies in weather model patterns and unexpected occurrences. Wind engineering is a combination of art and science, and it is important for architects to understand aerodynamics of buildings, therefore windflow analysis performed by CFD tools is worth implementing in academic curriculum.

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KRAKOW – A CITY BETWEEN TRADITION AND MODERNITY

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Own motto: Find a balance between own tradition, embodying a reaction to the peculiarities of the place, and the demands of modernity.

Abstract
The definition of the concept of the city forces us to think not only about the purpose of building and expanding the city, but also about the need to search for new ideas, to think about the benefits they should bring to the quality of the space and the quality of the newly created architecture in it. Not only in the context of climatic threats and challenges to the protection of natural environmental resources, there is a need to translate the quality of space into the needs of the modern and future user of the city, the integration of the new and transformed built environment in accordance with the spirit and identity of the city, with the nature of man and his natural earthly surroundings.
The purpose of this work is to demonstrate, based on self-reflection resulting from the analysis of the preliminary phase of the development of the Local Spatial Plan for the New Town in Krakow, the absence in the arrangements proposed in it of comprehensible principles of urban order, creating "fields of gravity" integrating spaces around them, that is, elements crystallizing the layout of the new district of the city creating at the same time threads of connections between tradition, legacy and experience of Krakow's history.

Keywords: city; traditions; urban form; integration; heritage; intellectual achievement

INTRODUCTION

Modern urban planning cannot be considered without remembering the publicly articulated imperatives of the strategy years of the first two decades of the 21st century. From these came the need to radically improve the urban offer both in terms of space, public facilities and to create public spaces equipped with important infrastructure to raise the level of attractiveness of the city, its healthiness, including, in cases such as, for example, a pandemic.

Newly created urban areas should provide residents with urban vitality mainly through animated streets, cultural and tourist attraction balancing the urbanity of office buildings and service and retail galleries tending to replace the residential function and related social infrastructure, science, education and recreation included.

There seems to be a need for a change of mindset offering the private sector "new projects", that is, new urban areas covered by large projects, profitable for the private sector, without guaranteeing certain concessions for the public use and subsequent maintenance of the buildings and their immediate surroundings, despite the fact that in some cases they carry the risk of opening the door to "selling" the city to the highest bidder.

Threatening the quality of urban space are urban designs that tear apart the network of urban nodes, returning to urbanism characterized by isolated towers, privatized collective use spaces that resemble suburban campuses, disrupting the historically achieved balance, rather than a "dense" city (Fig. 1).

Fig. 1. Example of isolated housing estate: Franciszkanskie Estate in Katowice, TDJ Estate; source: www.franciszkanskie.pl

Fig. 2. Example of user-friendly urban environment: Quicy Square, Boston, photo by N. Ares; source: www.wired.com

The task of modern urban planning is to eliminate the risk of turning the city into a single product of speculative urbanism, which may mean that the rest of the created urban structure will become a suburb, fragments "excluded" instead of included among the key dominants – significant elements of the historically shaped city. Nor should modern urbanism, dominant and innovative, be merely a continuation of the existing urbanization of the urban structure. The priority of today's and tomorrow's city planning should be to focus on the problem of quality in the broadest sense.

It is clear from the experience of history that not everything in the past was positive, even modernism did not provide a guarantee of quality. The turning point in Polish urban planning that occurred at the beginning of the 1990s prompts reflections that are difficult to assess due to the embryonic nature of the changes made. It does, however, allow us to ask some questions about the "new model" of the city created on the basis of the experience of the completed fragments of urban planning.

Concepts based on the principle of a sustainable hygienic environment, combined with concern for the problems associated with increased traffic, must offer urban and building-architectural solutions that aim to guarantee quality of life and opportunities for social interaction (Fig. 2).

The city's distinctive urban shape is considered an important contribution to the civilizational development of Krakow. Its basis was the location privilege issued by Prince Boleslaw the Chaste in 1257 with the participation of his mother Grzymislawa and wife Kinga, which gave the city a new organizational and legal form and a new urban shape. The location privilege framed Krakow in a plan, characterized by the scale and symmetry of the urban layout with the Market Square, one of the largest squares in Europe at the time. Freed from cramped backstreets, Krakow became the canvass - the beginning of its metropolitan development. The Magdeburg Law that underpinned its spatial development also laid the foundation for a pattern of legal and economic organization of urban life.

According to Professor Jacek Purchla[1], Krakow harbors many contradictions that "have their own tradition". From a large European metropolis, economically prosperous and vibrant, it is turning into a provincial

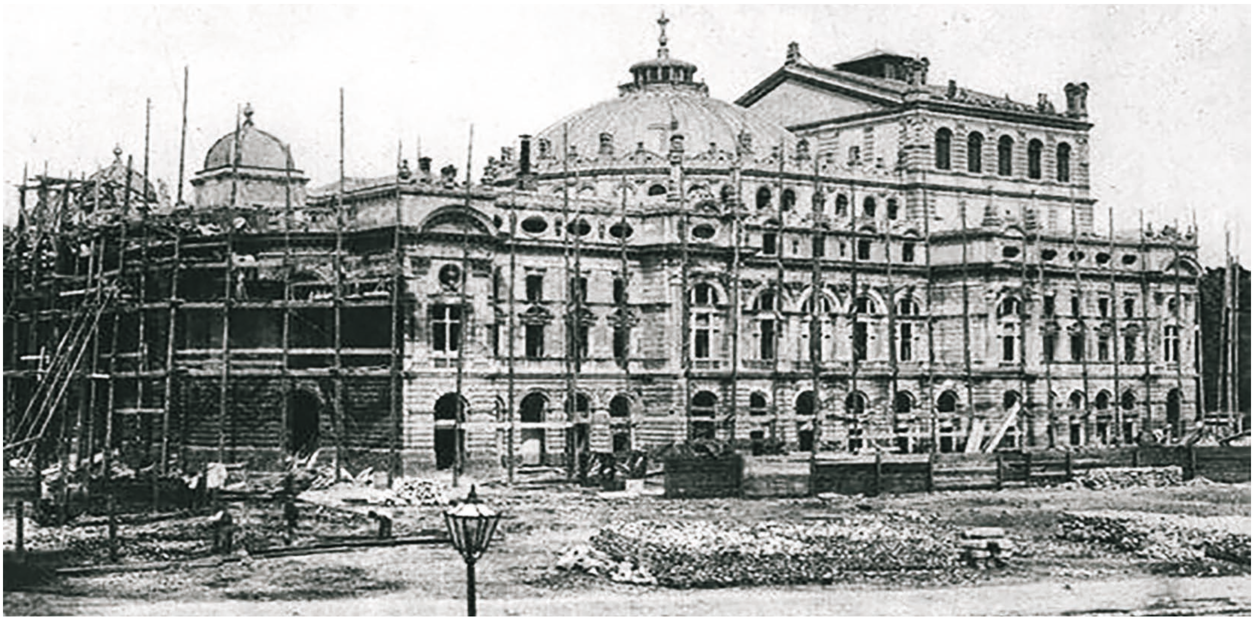


Fig. 3. Slowacki Theatre construction, Krakow 1891, Slowacki Theatre Archive; source: www.https://teatrwkrakowie/pl/poczatki

1. KRAKOW METROPOLIS

Medieval Krakow, spread out at the foot of Wawel Hill, marked a new dimension in the urbanization of the city. The urban shape of Krakow was not only the result of its capital functions. Built under Magdeburg law, the sprawling city was transformed into one of the largest emporiums of medieval Europe.

town. The city's crisis intensifies in the late 18th and early 19th centuries. The period of crisis is followed by the turn of the city's decline. Krakow begins to rise, gaining ground, trying to satisfy the exorbitant ambitions of its residents (Fig. 3).

Krakow's boom in the 1860s and 1870s was the result of far-sighted decisions by the city's authorities.

[1] Jacek Purchla (*1954) – Polish art historian and economist, professor of humanities, member of the PAU, specialist in cultural heritage, founder of the International Cultural Center in Krakow, chairman of the Polish Committee for UNESCO from 2015 to 2020.

At the beginning of Jozef Dietl's presidency, the city experienced a deep crisis, which de facto deprived Krakow of the chance to flourish. There were no opportunities for development using the typical rules of the 19th century, which were contained in the triad: industry, trade, communication. Krakow based its chance for development on assuming the role of a center of culture and science.

In the post-war years, after World War II, the projected development of the city was based on the belief that the only factor influencing the development of the city is industry and urbanization inherent in industrialization. It was Krakow that fell victim to such a view. The pre-war line of development based on the idea of a university center, a center of culture and science, allowed for the development of higher-order services, while the post-war practice deprived Krakow of its independence, harming it with the lack of opportunities for transformation on the basis of strategies and examples provided by other large, prosperous cities of Europe: Salzburg, Edinburgh, Strasbourg, which owed their development to culture, science and art.

Krakow at the turn of the 20th century was a very poor city, but it was the Krakow of Wyspianski, Matejko, and it was thanks to them that it became a metropolis - thanks to its culture. We can observe a similar phenomenon today. The number of cultural institutions, commercial and non-commercial galleries, theaters, cultural events, festivals, the new headquarters building of the Krakow Opera House, the Krakow Music Center planned for construction, the expansion of the National Museum, the International Cultural Center, testify to the fact that Krakow is on the rise.

It can be said of Krakow that it is an example of continuity of tradition, a social bond that has not been completely broken, according to Professor Jacek Purchla. The unique features of Krakow, its cultural tradition, create the potential of the city to foster development based on culture, science and art needed to face a difficult task - to create a concept of functioning and development within the framework of the old principles of management, which would allow harmonious development in accordance with free market principles, combining private and public capital. This does not mean that Krakow should be deprived of industry. What is needed "is its modernization and transformation into a high-tech industry." (Fig. 4) [J. Purchla 2011a].

An important political factor for the authorities of post-war Poland – the creation of a significant concentration of the so-called "working class," as Professor Stanislaw Juchnowicz[2] called it, the "vanguard of socialism," near Krakow, a city with aristocratic and

Fig. 4. Krakow Opera, arch. R.M. Loegler; source: Atelier Loegler Architekci Archive

[2] Stanisław Juchnowicz (*1923; +2020) – architect, urban planner, professor of technical sciences, co-author of the Nowa Huta spatial plan, UN expert at the Polytechnic University of Ibadan. Author of many theoretical works.

Fig. 5. Nowa Huta against the background of the Metallurgical Combine named after Lenin, photo by Sovfoto/UIG; source: www.dzieje.pl

bourgeois traditions, prevailed in locating the new city in close proximity to Krakow. The necessity of building a new ironworks was also supported by the needs of developing the national economy. Its establishment had to be accompanied by a decision to build a new city – Nowa Huta. This decision was accompanied by the conviction that the only factor influencing the development of the country, its prosperity, is industry.

With industrialization, naturally, urbanization was inextricably linked. In a way, Krakow became a victim of such a view. The city developed brilliantly without an industrial base. As a university city, a center of science and culture, Krakow influenced not only the region and the country. Professor Jacek Purchla notes that the establishment of the combine – the ironworks – disrupted the natural line of development of the city, despite the original assumption that the city of Nowa Huta would be an independent urban organism, whose social and cultural needs would be provided by the social and cultural institutions and facilities of Krakow. The policy of deliberate degradation of Krakow carried out since 1995 limited the independence of Krakow. Nowa Huta as an independent city grew on a symmetrical plan, often referring to Baroque assumptions, and the architecture drew inspiration from historical patterns, often changing their scale and spatial volume (Fig. 5).

The layout of the Nowa Huta city plan also resulted from the most characteristic features of the area, such as the wide arch of the 14-meter-high escarpment, a remnant of the former bank of the Vistula River. The escarpment became one of the main elements determining the composition of the plan with its central square, from which a network of main communication and composition routes emerges, connecting the most important centers located outside the layout with the city center (Fig. 6, Fig. 7).

The plan preserved and consolidated two basic, historically developed street layouts. A characteristic feature of the city's spatial composition in the design assumptions was the vision of piling up buildings – from two stories on the outskirts to six in the downtown zone. The social structure was to be shaped within four neighborhood complexes for about twenty thousand residents. The complex, with a block structure of buildings, included three or four settlements with a population between five and ten thousand. Such a plan allowed clear solutions to the spatial layout, and thanks to the services of commerce, education and basic public facilities, ensured that the basic needs of residents were met. The needs of the residents were also to be satisfied by the realization of a park foundation with a lagoon in the southern part, in the vicinity of Central Square. Unfortunately, it has not been realized to this day.

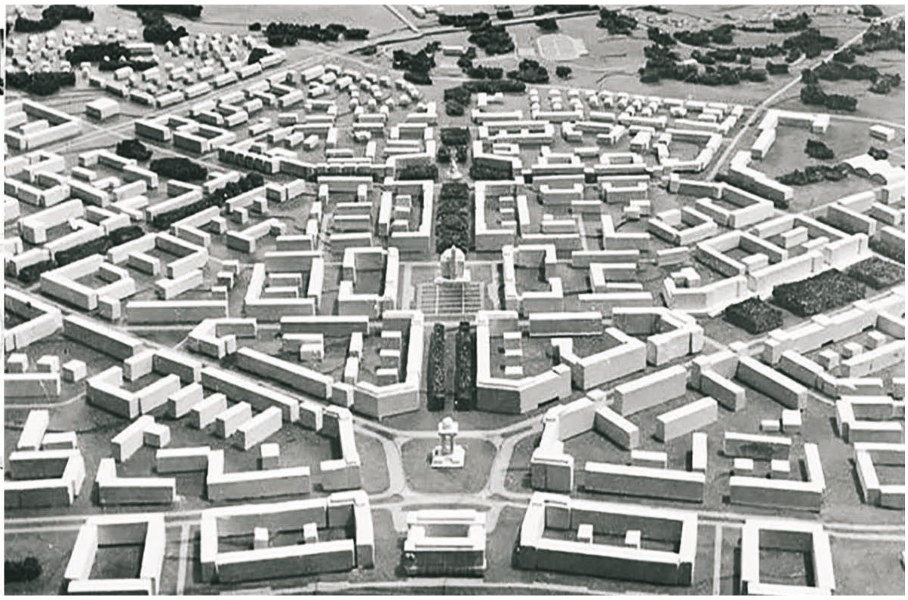


Fig. 6. Site plan of Nowa Huta by Tadeusz Ptaszycki, photo by INTI; source: “Architektura” No. 1 (429) 1986

Fig. 7. Master plan of Nowa Huta, 3D model 1951 by Miastoprojekt Krakow, W. Łozinski; source: www.repozytorium.ka.edu.pl

Planned as a new city, Nowa Huta – the “Polish Magnitogorsk” – is today also a symbol of the fourth phase of the great creation. Nowa Huta has undergone a metamorphosis. Its current face was best characterized by Professor Stanislaw Juchnowicz in a publication accompanying the presentation of the results in the competition for the design of the housing complex and program-spatial concept of Skarpa in Nowa Huta. “The Old Steelworks has a clear and legible layout with distinct crystallizing elements, and in today’s plan of Krakow it stands out among the many housing complexes realized in subsequent periods” (Fig. 8).

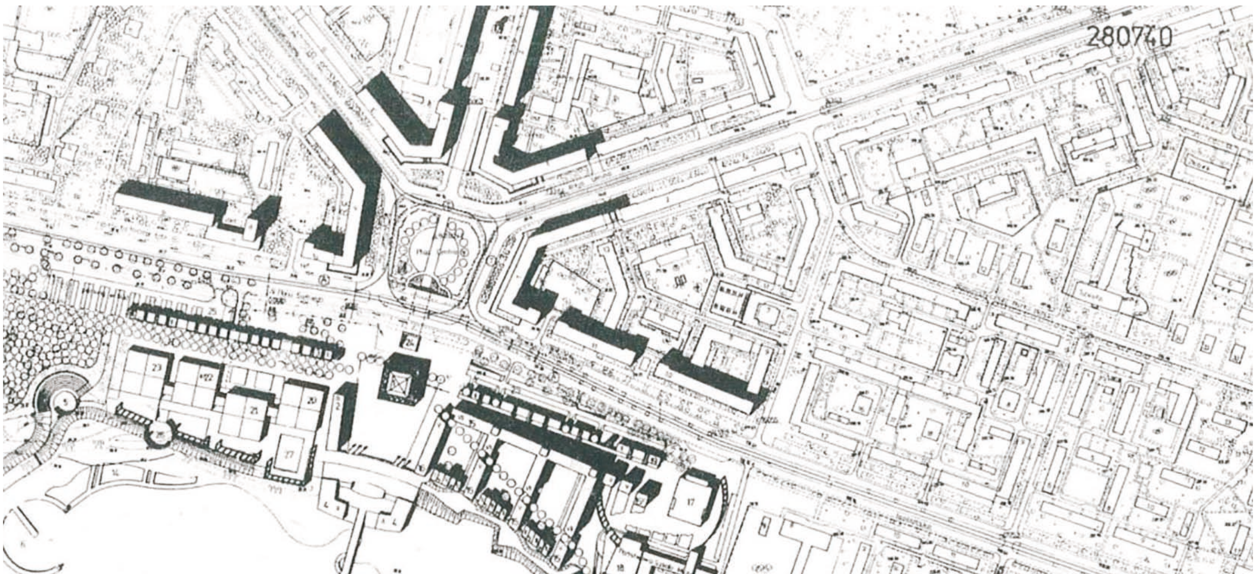


Fig. 8. Architectural competition project - Na Skarpie housing estate, author: arch. Romuald Loegler with Atelier Loegler Team; source: Atelier Loegler

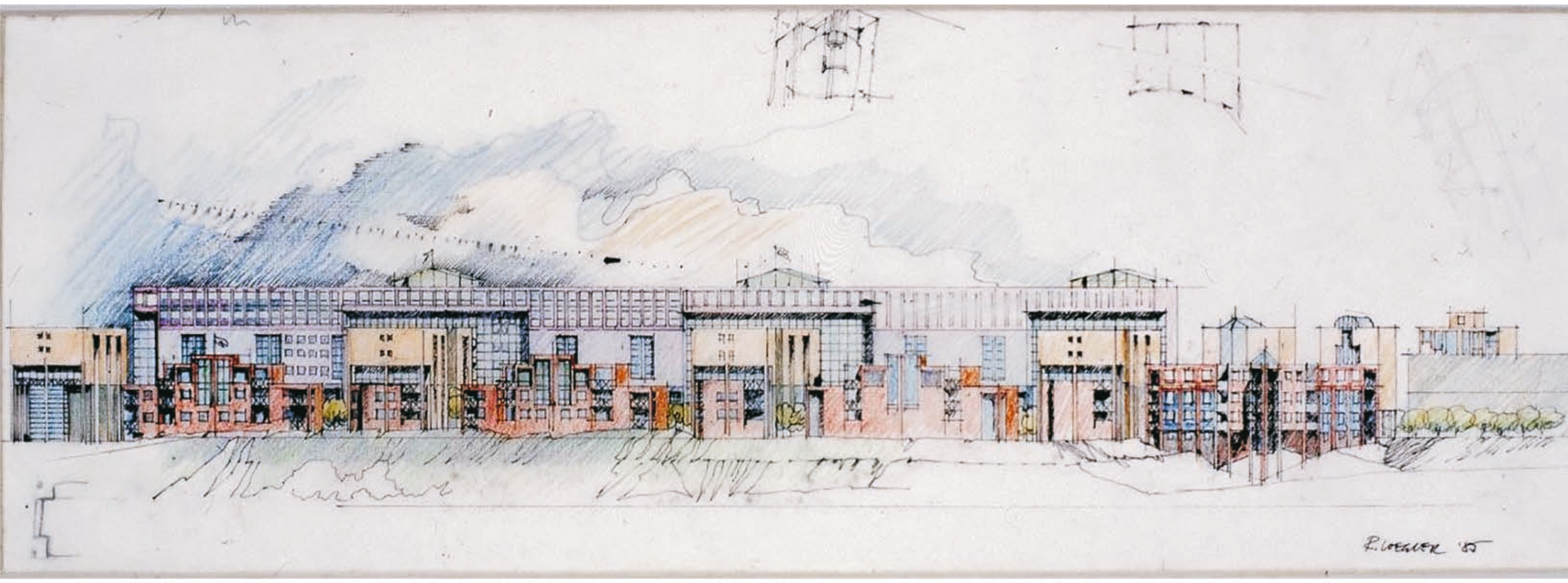


Fig. 9. Nowa Huta, Na Skarpie housing estate, panorama from the Vistula escarpment, author: arch. Romuald Loegler with Atelier Loegler; source: by the author

Fig. 10, 11, 12. Na Skarpie housing estate, author: arch. Romuald Loegler with Team Atelier; source: Atelier Loegler Architekci

Opinion of the Competition Jury: *"The work refers to the original concept of the spatial layout of the city, conceived during the period of the creation of the urban plan assumptions in a different architectural expression. The authors correctly propose to saturate the central part of Nowa Huta with downtown-type services. Particularly interesting is the proposal for the introduction of a shopping and service arcade, isolated from the busy artery, while constituting an acoustic barrier for the residential complex. The work, being a creative continuation of the existing layout, enriches the existing space"* (Fig. 9, Fig. 10, Fig. 11, Fig. 12).

In a short time, Nowa Huta ceased to be an independent city and formally became a district of Krakow. Its scale far exceeded the initial assumptions (100,000 residents). Today, Nowa Huta has a population of about 200,000. Almost from the beginning of the realization of Nowa Huta, the necessity to integrate the entire complex with Krakow became an urban and technical problem. Years later, it should be noted that the subsequent piecemeal design and realization of Nowa Huta, as loosely interconnected settlements, reflected negatively on the integration process, including in the sphere of creating a local community with a sense of being Krakowians.

2. KRAKOW – THE FIELD OF CONFRONTATION BETWEEN MODERNITY AND THE HERITAGE OF THE PAST

The box of confrontation between the heritage of the past and the present is often reduced to a polemic between creative architects, architecture critics and art historians on the topic: context and tradition! Do they all understand tradition and context in the same way? What do we even understand by tradition? Does tradition mean the transmission of knowledge, experience, beliefs, principles? We can pose many such questions, but it is certain that we build our civilizational progress on the experiences of the past, spontaneously, in spite of ourselves. It is certain that we are enriching and creating further traditions through new experiences, also by building cities and houses. The current urban planning of Krakow is not just a continuation of the urban planning in force based on the canons of the 1980s and 1990s, in which the priority was certainly not the "qualitative leap" that seems to suit today's city. It can be noted that even modernism did not guarantee qualitative development of the city. The turning point, which was the change of Poland's political status in 1989, did not become a real test of the quality of Krakow's urban planning.

Rather, this new urbanism of the late 20th century had an embryonic character and openness to change – it belonged to the scale and network of the "city of action" instead of making the spatial order of the city paramount over the chaotic sprawl of closed developer housing estates, excluded from the authentic spatial structure of the city. This urbanism, which was concretized in the late 20th century, is difficult to appreciate because of its embryonic nature and openness to various possible changes. Many of these urban designs of grand structures interrupt networks of urban nodes, reverting to an urbanism characterized by isolated towers and privatized private spaces that resemble suburban campuses rather than a dense city implanted in its historically shaped structure. They form not cities, but rather individual creations of speculative urban planning, and others have turned into theme parks. It seems that the local government and planners have forgotten what Krakow is, which has made it desirable to understand its needs, to understand whether planning for its development will maintain its multi-faceted attractiveness. For the sake of the city, it is necessary to consider whether the continuation of the strategy of urban tradition will give Krakow, with regard to public spaces and facilities located in all areas equipped with centers, important infrastructure, to make the city much more attractive, including for the high-quality service sector.

The city of Krakow has not lost its urban vitality, which has been improved by the strengthening and multiplication of streets and the emergence of new cultural initiatives and tourist attractions. Despite fairly well-functioning infrastructure such as the ring road, traffic in central areas of the city is still a nuisance. In a nearly saturated urban area, housing prices have risen, and urban planning of office buildings and service activities tends to replace housing. Planners have not abandoned the most essential elements of the city's "model," while offering the private sector attractive urban areas covered by design assumptions that ensure profitability (Nowa Pawia, Plac Dworcowy) (Fig. 13, 14, 15).

City planners have forgotten that the first things in a city are streets and squares, collective spaces and only then buildings. The history of cities, not just Krakow, has proven that public space determines the quality of life and sense of belonging determines the quality of a city, as it shows the quality of life and sense of belonging as perceived by its inhabitants [A. Jacobs[3] 1993; J. Gehl 2014].

Allan Jacobs' book *Streets of Cities* analyzes the city in terms of the aesthetic, cultural, functional, social, symbolic and modern quality of city streets. Ildefons Cerdá[4] – the creator of the spatial plan of the Eixample district in Barcelona, considered the father of urban planning of the modernist era, said: *"city streets are not roads!"* In his book *General Theory of Urbanization*, he outlined a philosophy of rational urban development, noting the phenomenon of industrialization and transportation development and their impact on the transformation of cities. He pointed out that the Latin concept of civitas placed more emphasis on the rights of citizens, as opposed to the Roman concept of urbus, which refers to a material collection of buildings and infrastructure. Reinforced by the success of Bar-

[3] Allan Jacobs (*1928) – U.S. urban planner professor emeritus, known for his publications and research on urban planning (*Toward an Urban Design Manifesto*), Author of urban planning projects in California, Oregon and Brazil.
[4] Ildefons Cerdá (*1815; +1876) – Spanish engineer and politician considered the father of urban planning in the modern era. Creator of the spatial plan for the Eixemple district in Barcelona.

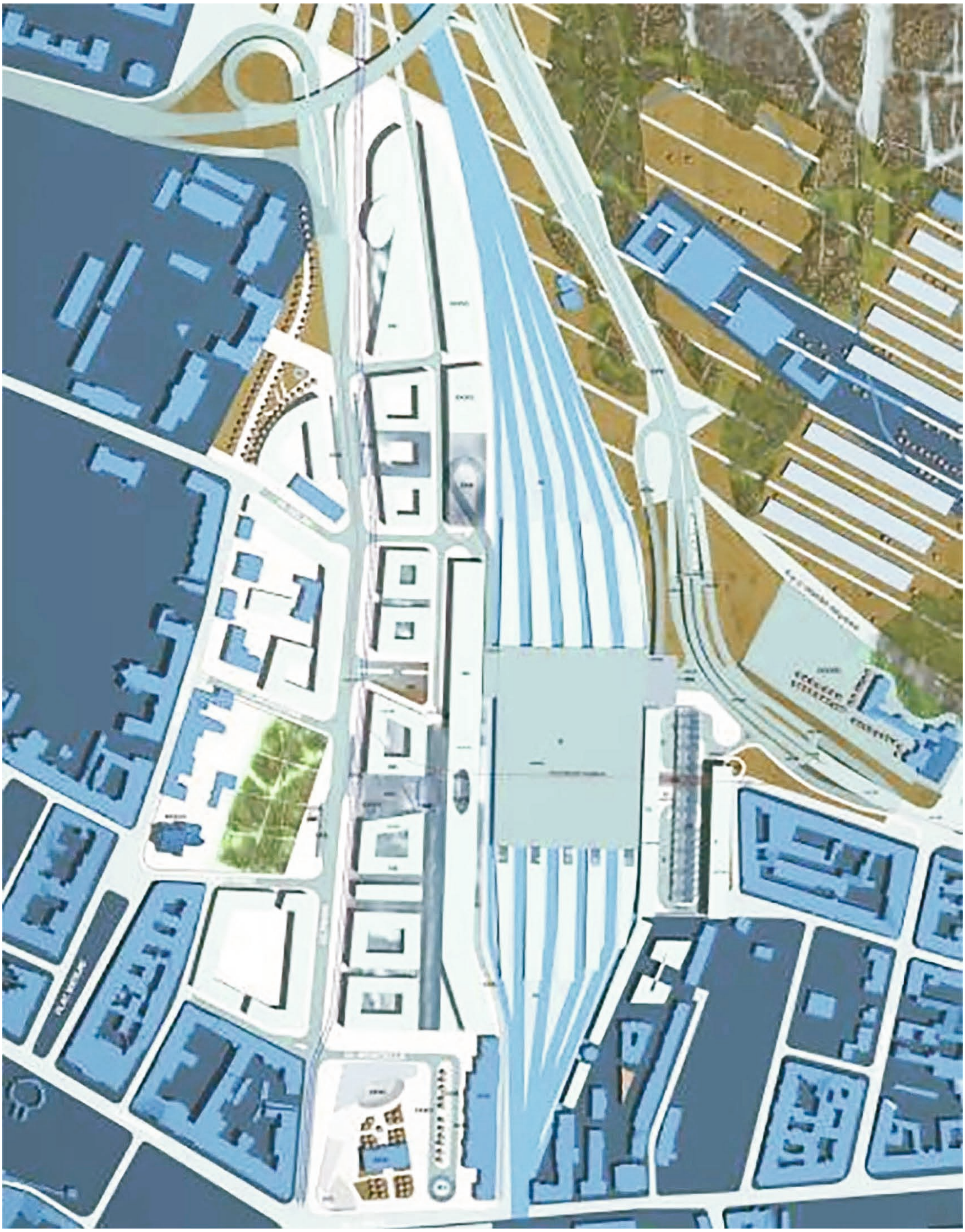
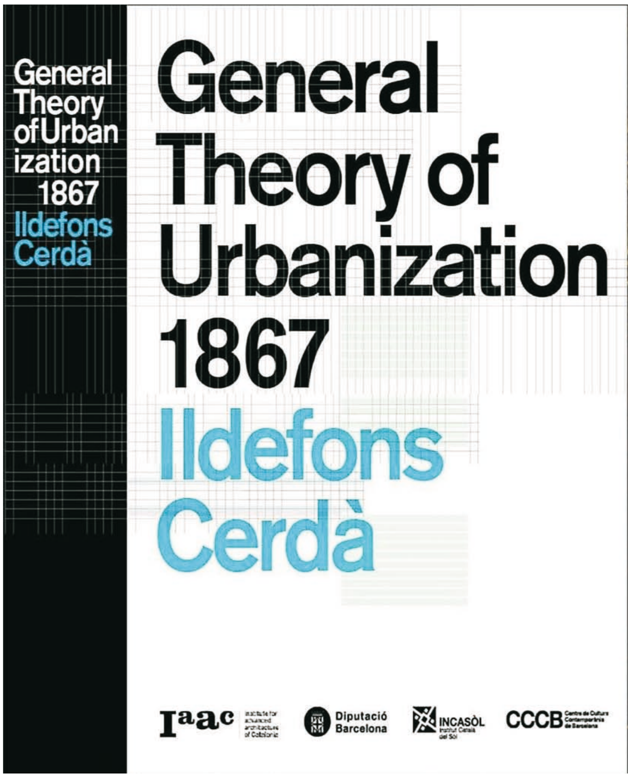


Fig. 13. Project of Krakow Traffic Center, author: arch. Romuald Loegler; source: Atelier Loegler Architekci archive



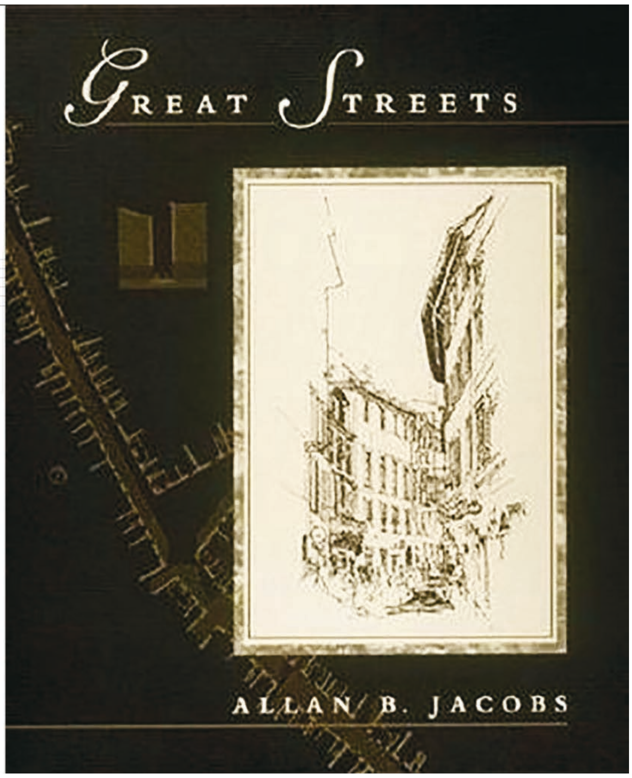


Fig. 14. Allan B. Jacobs, *Great Streets*, MIT Press, Cambridge, MA 1995; source: www.amazon.pl

Fig. 15. Ildefons Cerdá, *General Theory of Urbanization 1867*, Actar 2018; source: www.amazon.pl

celona's transformation, Cerdá's considerations gave rise to the development and transformation of cities, which greatly influenced the social, economic and cultural living conditions of residents in many cities around the world. Urbanism and urbanization have permanently entered the catalog of standard terms used around the world (Fig. 14, 15).

Transformation of the urban fabric today often refers to the expansion of cities into new areas, to expand them. In these processes, architects and urban planners are now collaborating with experts from many fields, trying to adapt existing cities to the world's climate change by revitalizing abandoned infrastructure, creating new public spaces from neglected areas, spaces open to the needs of global citizens. These processes also point to the fact that solutions to urban structures are not universal and cannot be imposed a priori. They are deeply relative, contextual Interventions that involve making large-scale changes to the fabric of the city. On the other hand, however, urban revitalization, its development, does not necessarily mean replacing the old with the new. Fixed in history, its traditions of places and their features, with memory and innate energy, have great potential to define local identity, and the architectural aspects fixed in them, although they do not literally build urban reality, their appearance has the ability to shape large social, cultural and political visions of the city.

3. LOCAL DEVELOPMENT PLAN – NOWE MIASTO

Krakow is spilling beyond its administrative borders – Mogilany, Zielonki, Zabierzów and many other suburban municipalities are building an image of a new "Greater Krakow." After 1989, the city began to enter the phase of metropolitan development – an organism based on the civilization of the car.

Today, the city is an agglomeration with the municipality of Krakow at its center. During the presidency of Juliusz Leo[5], the city's development policy consisted of both grand urban creations and strict control of space. The current image of the city and its size is the result of post-war industrialization and sprawl in Krakow. The construction of Nowa Huta required the in-

[5] Juliusz Leo (*1861; +1928) – politician, professor of economics and law at the Jagiellonian University, Mayor of the City of Krakow from 1901 to 1904, and in the following three terms until his death. Creator of the so-called Greater Krakow Plan – he annexed 14 boroughs to Krakow municipality, including Podgórze.

Fig. 16–19. Nowe Miasto in Krakow; source: Krakow Municipality, Departament of Spatial Planning

tegration of urban development of the very core that is the Municipality of Krakow. This need for integration is met by the idea of creating a "New City," a new urbanization remaining within the borders of the Municipality (Fig. 16, 17, 18, 19).

Six hundred and eighty hectares of land in the southeastern part of Krakow, according to the assumptions of the Study of Conditions and Directions of Development of Krakow and the Local Spatial Development Plan, the Municipality of Krakow is to create a New City – a district of high-rise buildings. About one hundred thousand new residents are to live in the district. Thus, the Municipality, by designating the area of Rybitwy and Płaszów for transformation and development, is to realize the city's development strategy planned for 2030. A new multifunctional district is to be created in the designated area, offering investment opportunities for the construction of tall buildings – from one hundred to one hundred and fifty meters.

Raising many doubts with its proposed arrangements, the draft of the Local Land Use Plan seems to take no account whatsoever of the mission of urban planning and architecture and the art of city building. The Vitruvian triad: expediency and utility, individuality and the city's own characteristics – is not enough. *"A city created for utilitarian purposes satisfying the livelihood needs of man, should produce a link with its spiritual content. The spiritual 'service field' of urban space, created by works of architecture, is also a reflection of the spirit of time and the time of the city's existence."* [R.M. Loegler 2011]. It should also create timeless cultural values, a force that is difficult to recognize, but affects the majority.

The emergence of myth means that the newly created city districts and their residents are to live in continuity with their own history. "*The physical building structure, urban spaces that create life events, regulations and legal norms are only a part of the city. Ne-*

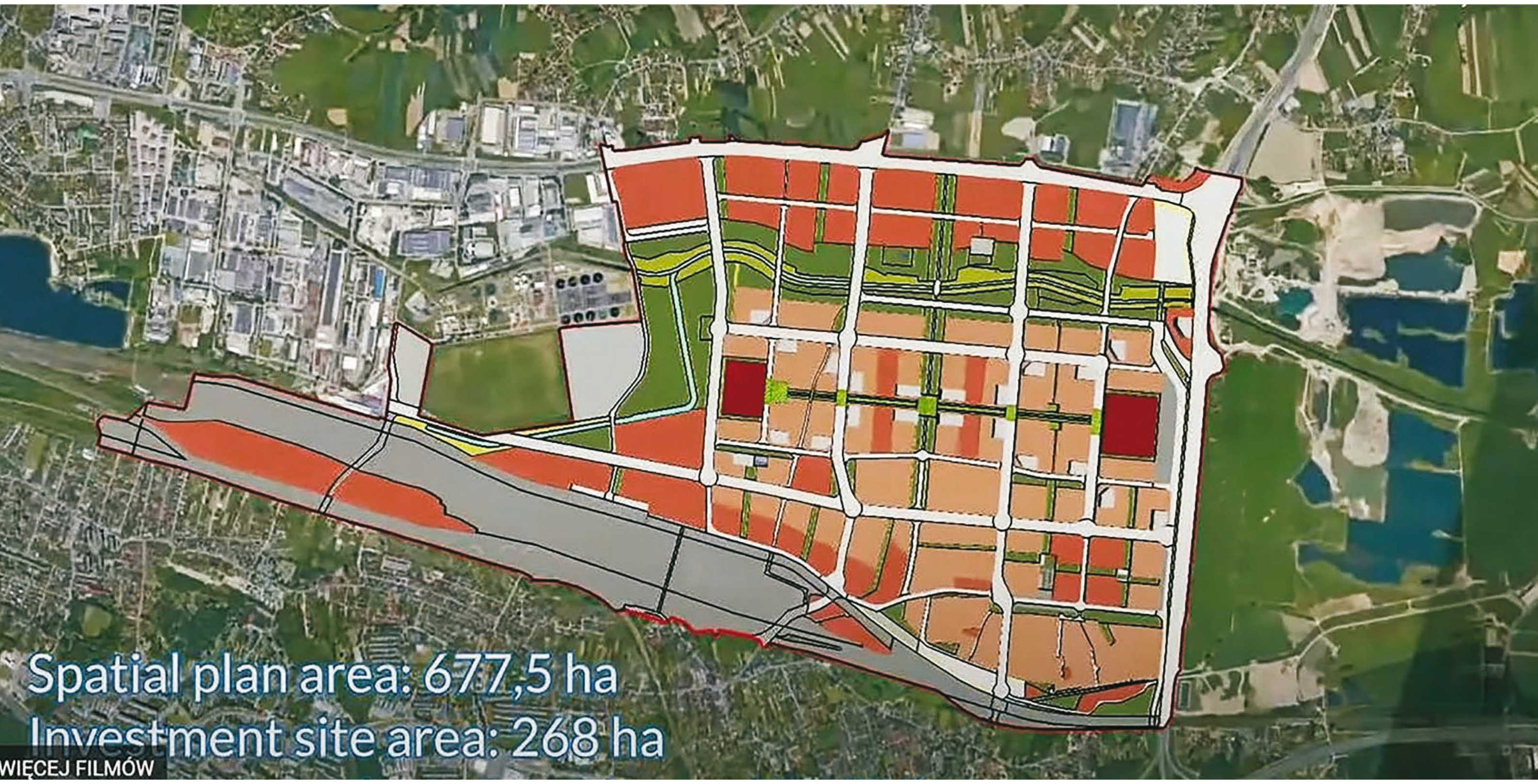


Fig. 20. Project of Nowe Miasto – Local Spatial Development Plan; source: Krakow Municipality, Departament of Spatial Planning

cessary or even essential, but not sufficient factors for a city to exist. Often the myth of history and events associated with a particular space means more to a city than a useful but anonymous building" [R.M. Loegler 2011]. This is proved, among other things, by Krakow's innate myths integrating into its history with its real existence of urban space. The struggle between the myth of the traditional city and the modernist city continues, although in truth the slogan to live in the continuation of a long history was also preached by modernists.

German urban planner Hans-Reiner Miller-Roemisch[6] claims that it is a lie and a deception if someone *"...supposes and promises that through buildings and not through the awakening of humanity and spirit in urbanization, it will be possible to live"* [R.M. Loegler 2011]. The development of a city does not only mean the expansion of its functioning mechanism. For it is physically shaped by the architectural forms of space in which the dreams, experiences and memories of successive generations of its inhabitants are to be recorded. The creation of a new section of the city is writing the script for its material and immaterial existence, the entities that define its structure, monumental buildings, recreational spaces, residential areas, transportation bloodstream, as well as monuments to the future and memories of its residents. The above-mentioned principals of creating development are difficult to find in the presented proposals for the vision of the Local Plan for the New City district.

Illustrated by a physical model, the visions recorded in the draft local plan Nowe Miasto do not reveal the idea to bring out and emphasize the existing qualities and values at the site, which Krakow has enshrined in the tradition of its development in successive stages, the achievements of previous generations (Fig. 20, 21).

Professor Jacek Purchla notes that "*today the metropolitanity of Krakow on the map of Europe is still determined more by its history than by the present. The challenge for all of us is to change this situation and turn to the future." [J. Purchla 2011b]* The need to perpetuate Krakow's metropolitanity must mean creating its future with a projection of modernity that does not threaten the city's tradition, but enriches it and at the same time saves the existing values that previous eras have written into the city's fabric. The vision of modern Krakow, in Professor Purchla's view, should not *"slavishly imitate a model that is inadequate to our entire thousand-year history."* [J. Purchla 2011b] President Leo was aware of this view a century ago.

In the plan of Great Krakow of that time there is no tall building, although at that time the world began to build skyscrapers. The Great Krakow plan focused on the creation of large complexes of public greenery and included freely composed assumptions of relati-

[6] Hans-Reiner Müller Raemisch (*1923; +2018) – German architect and urban planner. Head of the planning commission, author of many publications on urban planning, promoter of citizen participation in city planning.

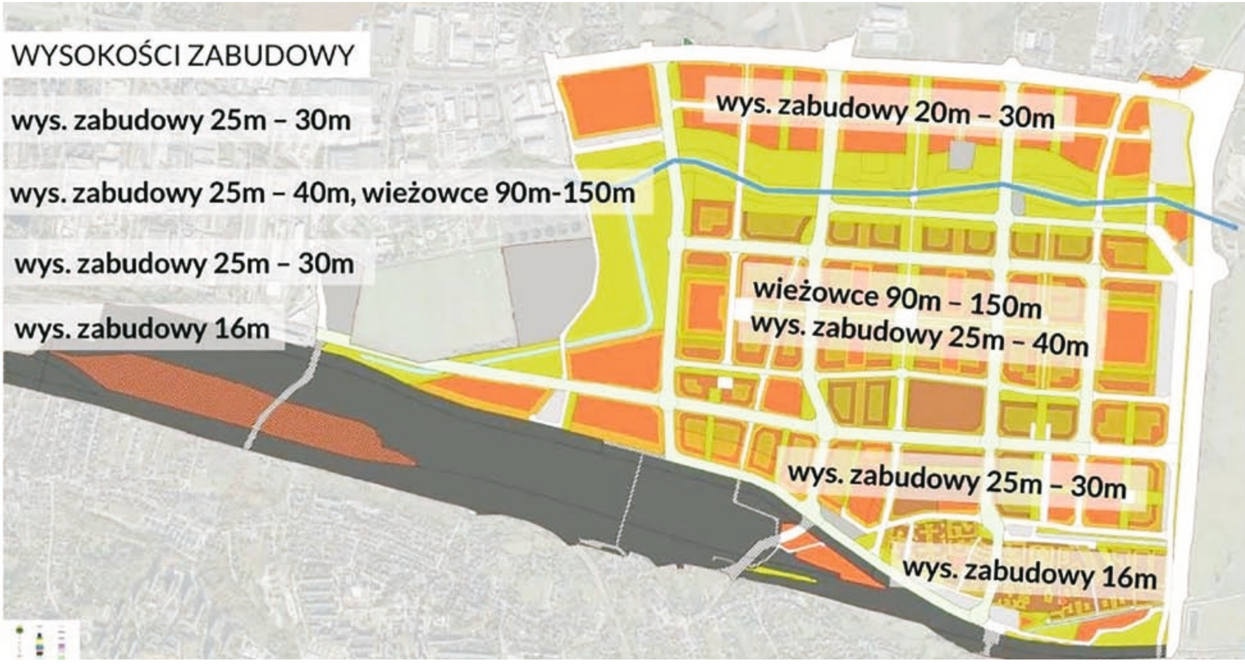


Fig. 21. Project of Nowe Miasto – Zoning of building heights; source: Krakow Municipality, Departament of Spatial Planning

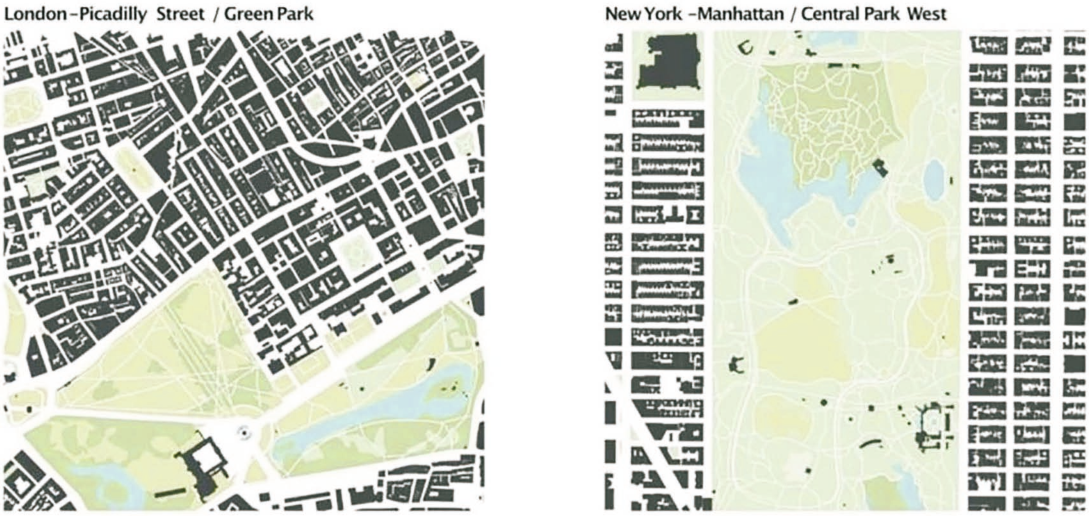


Fig. 22. Comparison of building density – the projected New Town (Nowe Miasto) in Krakow with London, New York and Sydney; source: study by prof. arch. Artur Jasinski

Fig. 23. Map of "Greater Krakow", 1905; source: Budownictwo Miejskie Miasta Krakowa (Municipal Construction of the City of Krakow)

vely low-rise buildings with comfortable healthy apartments. Even then, the value of the medieval city silhouette was appreciated. Also today, Krakow does not need to imitate and duplicate the ideas and models of global urbanization, models that blur the differences in identity of the vast majority of the world's metropolises. With its individuality, which defines its identity, Krakow should be an inspiration to create its development based on ideas that protect against the emergence of city districts devoid of tectonic logic and a sense of architectural materiality that places future residents in an internal and external space tailored in human terms, so that its users will be able to live in it and understand it!

The centuries-long history of mankind shows an unwavering desire to create something unique, unchanged. These efforts were expressed by the creation, among other things, of monumental buildings and the mythological city of the future "Tower of Babel", which signified the need to concentrate people, to create agglomerations. Today we are witnessing the need for change in the creation of a new vision of the city. The creation of city centers today is no longer defined by churches, city halls, town halls and the like. Our view of complex transportation systems and their planning methods are undergoing changes. They are having a huge impact on traditional urban institutions and other components of the city. The relationship between cities and their landscape is becoming important, affecting our understanding of planning, development and changing needs, including the need to compete with other cities: compete to attract citizens and investment (Fig. 24).

Foreseeing the future is a task for architects and urban planners who create spatial constellations that demonstrate the potential of architecture by inducing future patterns of living conditions. Their new visions, protecting both the tangible and intangible cultural legacy at the same time, the new urbanization is to ensure the comfort and security of life for the communities of future generations, thus facilitating the animation of life events. Manifesting the necessity of preserving the unique original features found in the location, the newly created urban spaces enrich their identification and identity with authentic traces of the past.

What, then, is the city of the future, the city of tomorrow, supposed to be? Is it only a functional reflection of the political system, social and economic circumstances? Is it the result of anticipated events that will be "clothed" in a specific form and will be the psychic dimension of that form? Or a form that arises only as a result of the necessities of existence of its inhabitants and users? A city is not a collection of architectural objects. It is not recognizable by their functional programs and technical qualities. The city is a space delineated by architecture, shaped in a creative act that connects the past of a place with the present. It is the product of the art of building, the art of creating a framework for the network of connections between the many manifestations of social life.

The creation of the city is a result inspired by many pretexts. The obvious pretext is utility. For the construction of its form, the pretext is also the context understood as a play with the environment, not only architectural, but also cultural milieu of the place of its future existence. In the case of the planned, tentatively named "Nowe Miasto" (The New City), the peculiarity of the area of its location is the stream flowing out of the Piaski Nowe estate – since the 20th century it has borne the name Drwinka (formerly: Czarna). Flowing through Kozlowek, Prokocim, Biezanow, Jerzmanowskis Park, it ends its course flowing into Drwinka on the other side of the tracks. Its valley is home to several species of birds, including the green woodpecker and the northern spotted owl.

By the decision of the Krakow City Council, the Drwinka is to be protected through the implementation of a project entitled Drwinka River Park. The fact of Drwinka's existence is a cultural and landscape aspect that should motivate and inspire us to find an answer to the question of how to write a scenario for the continu-

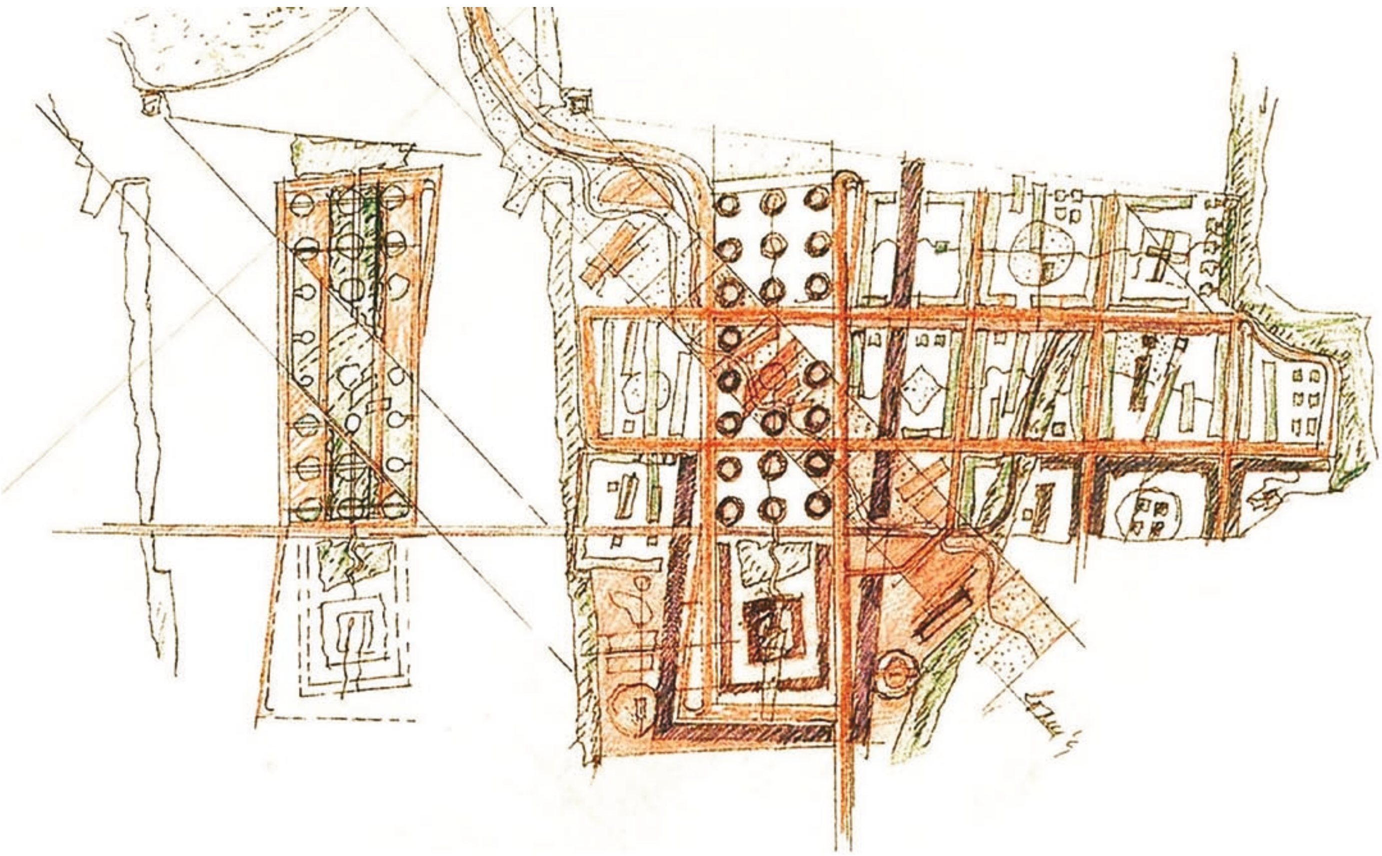


Fig. 24. The project for the revitalization of the former Bangour Hospital grounds in Edinburgh – sketch for the competition design by arch. Romuald Loegler; source: Atelier Loegler Archive

ation of the story of the symbiosis of utility, functionality and beauty of the planned, future revitalization of the area located in the area adjacent to Christo Botewa and Tadeusza Śliwiaka streets towards Bieżanowska street. This scenario should take into account the challenges of managing the diverse character of large cities, the phenomenon of climate change and the need to find an answer to the question: how should the green profile of the new city fit into the trend of pro-ecological urbanization to protect the air and natural environment?

The ideological message directing the scenario of analysis of the proposed solutions for the New City is the creation of a "Sustainable Green City" – green in its symbolic and real layers. Understood and accepted idea and actions within its framework, will allow urban planners and architects to move in the world of contemporary forms, and Krakow to come out with an investment offer showing potential investors Krakow as a city of science, culture, a city aware of the climatic threat, looking for exemplary and inspiring solutions in the current, difficult global climatic reality, not only in Europe. Today, in a new conceptually broadened approach, solutions should also include reference to the spirit of the place – genius loci, tradition, ecology, the idea of sustainable development, sustainability and "green" energy.

The Local Development Plan for the area of Rybitwy - Nowe Miasto, is a unique plan of exceptional importance for Krakow. It is to become the basis for Krakow to make an investment offer, increasing its competitiveness for potential investors.

The draft of the local plan, which is the subject of this analysis, does little to convince the reader of how its proposals fit into the vision of a quality urban landscape of a city seducing its residents, affecting emotions. Nor does it convince the reader of the investment attractiveness of the New City, which was to be, among other things, the oversized public space of a pedestrian "square" proposed in the first design assumptions, equal in size to several Red Squares in Moscow. Clad with high-rise buildings, it was more of a harbinger of a space of sensory deprivation[7].

The attractiveness of the vision of the New City is also not convincing in view of its other proposals: quarters of urban development with a lost human scale, lack of definition of requirements for the creation of individual features of individual quarters. The omission of an appropriate location compatible with nature, respecting its natural peculiarity, which is the Drwina stream, is surprising. Also surprising is the lack of an unambiguous preference for pedestrian traffic, pedestrian routes and a clear limit of streets with intensive vehicular traffic allowed. Also overlooked is the need to create orientation-serving public spaces, diverse in form, allowing for easy identification. The planning arrangements do not compositionally crystallize the elements that integrate the spaces around them. Like the original version of the Plan's findings, the next edition of the Plan does not specify the disposition and location of utility programs in the field of municipal services, administration, education in proper relation to residential zones, health, sports, culture, religious worship (e.g., in connection with park greenery), environmental protection, security, etc. Many more doubts could be enumerated. These include the lack of indication of the possibility of locating programs that interact with the higher education community: scientific research facilities/institutes, etc., as well as the lack of proposals for programs and functions adequate to the location of the agglomeration rail stop.

Serious objections are raised by the failure to define a strategy for releasing land currently used by plants and enterprises in the field of manufacturing, industry, transportation, and waste disposal services. Omission of this very important issue may become a reason for conflicts between entrepreneurs and the city.

According to Bruno Taut: *"You can't build a city merely according to plans that define only building lines, which define nothing de facto in a spatial sense."* How and where buildings are to stand can only be decided by a provision that defines their specific location, three-dimensional form, scale and volume. Only with this understanding of urban planning can there be "a relativization of the value of architecture and urban planning." And this means that planning a "Sustainable Green New City in Krakow" is only possible with the help of an architectural vision. Although, on the other hand, it should be stated that the city, which is subjected to constant processes of transformation, must provide for a certain margin of permissible modifications of urban planning while ensuring the preservation of its basic features. The layout of the city, its space, is common property. So, to create a city is to create a concept for the formation of public space independent of architectural fashion. Such a point of view is obvious, if only for the reason that the realization of urban plan-

[7] Sensory deprivation of space – leading residents to reduce stimuli positively affecting the senses, a reduction resulting in anxiety, intensive thoughts, depression and negative social behavior. "*This is a consequence of, among other things, the separation of physical spaces by abstract spaces, mathematical spaces. A result of this process is more abstract spatial relations, leading to a rupture of man's emotional connection with his surroundings...*" [J Gądecki 2005, p. 45].

ning should be situated in a time perspective of several decades. Urban structures, thoughtfully and holistically spatially defined, are subjected to a constant process of "interpretation" in the various phases of implementation, referring to individual fragments of places and buildings. This means that the basic structure should bear the characteristics of a clear, timeless "skeleton", easily understood, recognizable not only to professionals, but legible to every user of the city, and especially to decision-makers. The urban spatial structure understood in this way should not be subject to transformations forced by architectural fashion or the spectacular interests of a developer. Urban planning should be understood not only as the creation of an image of space justified by the provisions of the local plan, but also anticipating the future development of a given area of the city.

The areas defined by the local zoning plan are a kind of pattern based on a typology of abstract forms of buildings of various types: residential dwellings, offices, service buildings, commercial, educational, cultural spaces, etc. Such a picture of space becomes a metaphor for current architectural possibilities, while indicating future proposals for shaping building forms that remain valid in the short term, from five to ten years.

The role of the creator of urban space means that he creates functional spatial connections that can be filled by contemporary architecture, up-to-date at a particular time, which is created as the fulfillment of urban rules written in urban author's decisions by form. The space created on the basis of the findings of the Local Plan should be the result of a certain order and the social values preferred in it, as well as those being the result of the architect's/urbanist's creative idea. The proposed spatial order of the "New Town" could draw inspiration from the experience of the original - the layout of the Old Town, while going beyond its sentimental and aesthetic framework. For many, the above-mentioned inspiration, could have the meaning of a symbolic bond between Krakow and its contemporaneity, to be identified as a determinant of the bond of future generations of residents with the past and their identification – with KraKow's history!

The shape of objects, buildings, their arrangement and distribution of accents influence human behavior, their way of covering social distances – "... first we shape cities, then they shape us..." (Jan Gehl). The New City, as a new district of Krakow, should be planned in a spatial and functional structure that stimulates the attitudes and activity of its future residents – both the individual and his community (Fig. 25).

High-rise buildings are not places with hostile fortresses – islands implanted in residential quarters lowering the quality of life of residents. The zone of high-rise buildings located in the vicinity of the S7 expressway eliminates the negative impact on the quality of life for inhabitants, while creating conditions for the penetration of public life into their multifunctional interiors: offices, collective housing, hotels, stores functions of culture, art, etc.

The result of the rules, graphic and textual arrangements of the local plan in force should also be the creation of spatial structures and spaces, positively influencing the quality and cultural values of social processes. Consciously composed, with easily readable and understandable public space, should provide social groups of residents and users with the opportunity to fulfill their basic biological and emotional functions, in a rational and harmonious manner. The rules written in the plan for the creation of public spaces that form the framework of the built environment for the future residents of this new district of the city, must use the contemporary language of architecture, its quality and

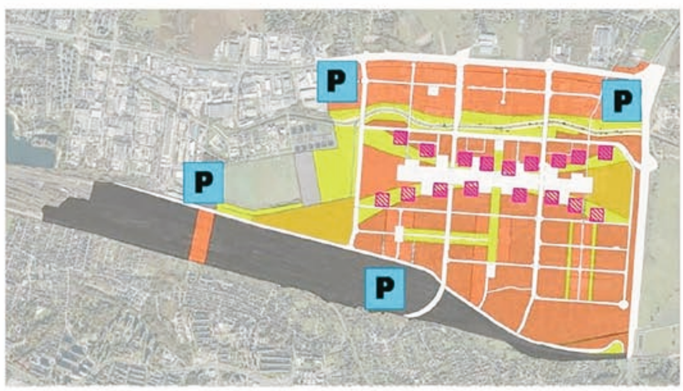


Fig. 25, 26. Establishment of public space - square; source: Krakow Municipality, Department of Spatial Planning

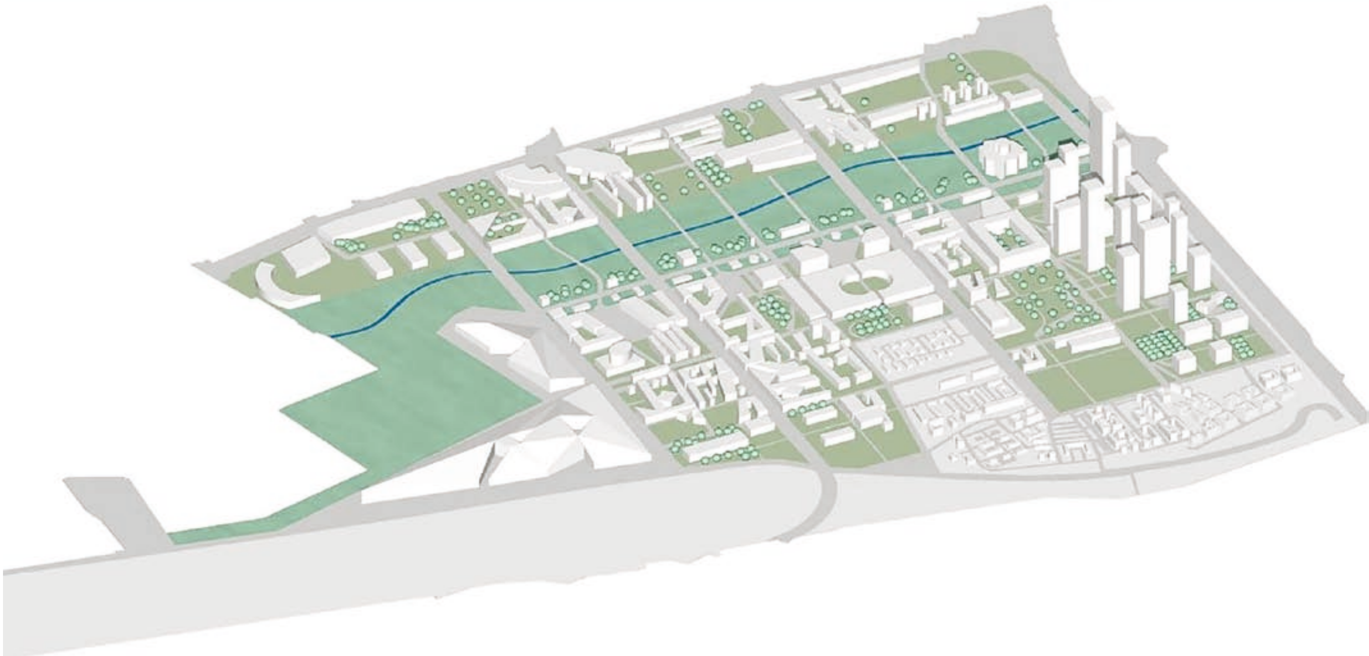


Fig. 27, 28. The concept of the Green City in Krakow by arch. Romuald Loegler; source: own archive

aesthetic qualities, and indicate the need to refer to the intellectual, cultural and aesthetic values that characterize historical and contemporary Krakow. The proposals for the rules of creating urbanism, included in the material of this work, are based on the conviction that the future of the city must follow the needs of climate protection and healthy conditions for the existence of present and future generations; on the conviction that quality is the most important thing, quality in a broad sense, including in the way of energy management, its pro-ecological acquisition, distribution, sensible and rational use. The findings of the plan, regardless of state standards and requirements, should be linked to the possibility of investing in the area of the New City – a Green City with the condition of using "green" energy from available alternative sources. A consequence of the above should be the provision of a location for the installation for the acquisition of energy, for example, in the HDR system ("Hot Dry Rock"). A new range of guidelines and recommendations is needed, expanded to include such provisions as:

– "sun on the roof" (photovoltaics);
– "green" roofs;
– windows that let in maximum daylight, providing natural ventilation and maintaining a friendly interior climate;
– connection to the smart grid;
– insulation of residential homes with a type of aerogel or dry ice (a nanotechnology miracle), allowing to make homes economical and energy-efficient while reducing carbon dioxide emissions;
– a city for bicycles in connection with the main street system, with parking close to residences and technical infrastructure located below them;
– walking distances to basic services: 300–600 meters to an environmentally friendly public transport system.

The idea and spatial organization of the city, growing out of the urban vision of the New City, should be the answer to the question of a compact, multifunctional, friendly and vibrant city. For it, the most rational core should be defined. The principle should be a clear layout with urban characteristics, providing good orientation and easy accessibility to buildings thanks to the right hierarchy of streets, rational designation of the location of functional and utility zones of the city/district, their connection with the public transport system, with the system of public spaces: streets, squares, parks!

They are the opportunity and condition for the existence of activity in the city, necessary for its existence. A prerequisite for the emergence of a well-functioning created city is the unambiguous definition of zones for private sector investment and the designation of areas for the location of objects realized by the public sector: offices, headquarters of public institutions, municipal services, public health services, police, post office, education, etc. The framework for the formation of development by the private sector, the provisions of the plan should not leave unlimited freedom to create individual solutions. Determining the requirements of special care and compliance with the rules that determine the aesthetic quality of public spaces, forming in each city places of interaction - creates a kind of skeleton of connections between its various parts.

Public spaces, being socially owned, form the core that organizes the spatial layout of the city, determining the fields of investment activity of public and private investors.

CONCLUSIONS

The vision of the New City district, outlined in the local plan, is to define the principles of shaping public spaces, which should be created in cooperation between the private investor and the local government. While the local government is to be responsible for defining the geometry of public spaces, as well as for shaping and equipping streets, squares and parks, it is the buildings erected by the private sector that are mainly to create the atmosphere of the city. This special public space in the vision of the New City, should be the main compositional axis, defined by the Promenade and adjacent urban squares, connecting Drwinka Park with the zone of new urbanization.

Drwinka Park conceived as a cultural park – an island of positive divergence – should serve the multidirectional formation of creative personalities involved in sustainable development projects. Clearly defined rules for the creation of public spaces should determine the convention of the entire premise.

In his latest book *How to study public life*, Jan Gehl writes: *"look and learn – go out into the city, see how it works, use your common sense, your senses and ask if this is the city we want in the twenty-first century."* The life of a great city is complex, with simple tools and systematic observation it becomes clearer. City planning is not about focusing on individual buildings or technical issues, it is the result of understanding the status of city life, focusing on the future life of the city, creating a framework for the scenario of human events in public space, the interaction between life and public space [J. Gehl, S. Brigitte 2021].

Addressing the problem of public life requires political will and professional leadership, directing the development or planning of a city towards making it more people-friendly.

Proper understanding of city planning tools by urban planners, architects and authorities-councillors responsible for the joy of living in our cities, will address pressing issues such as environmental issues, climate, growing urban population, social and health challenges, and is a prerequisite for creating city plans!

A good, thoughtful and creative city plan is the basis of decision-making processes! The aspect of public life should be taken into account in all phases of city planning and construction. "*Life is difficult to predict just like the weather, nevertheless meteorologists have developed tools to predict the weather – similarly, planning needs tools."* (J. Gehl)

Taking into account the nature of the area of the future location of the Green City, setting the rules of the game for future urbanization should reflect the main challenges in our common global situation - the need to build sustainable communities in a world of constraints.

Self-reflection resulting from the analysis of the created New Town – a local plan for a new district of Krakow, does not augur the emergence of an urban quality, different from the newly implemented and established in the city space. We have many urban planners and many urban-architectural assumptions of our time, which with their anonymity, lack of references to emotional involvement with historically formed places and buildings, are not conducive to the integration of communities living in them, with the myth and space of Krakow.

Self-reflection from this analysis suggests referring more broadly to the current state of Polish urban planning in recent years, especially in the context of the struggle for a broadly defined "healthy city." Urban transformations with the chief slogan of a city for people provoke a combination of spatial and urban planning with high quality architecture and pro-ecological solutions – synonymous with the ideal city. It is not difficult to notice that modern thinking about the ideal city of the future is dominated by such concepts as "smart city", and "green – healthy" – dependent on the implementation of ever new information technologies and environmental-energy, zero-emission matters. In a word, a city in a sustainable balance.

A third utopia is also emerging: the "inclusive city." This is a city without social, racial, cultural segregation, a city of citizen movements with participatory governance, multicultural, without fences and barriers. A city with a "right to the city." Each of these ideas abstracts from the spatial shape, the urban landscape, from its aesthetics. Digging into the depths of the ideological assumptions of the so-called ideal cities of the future, one can notice the absence of a fundamental message in their ideology: reference to heritage, created by their spatial structure, architecture, culture, intellectual output as well as by spirituality. It is worth considering whether heritage as a necessary condition for the city's development potential is sufficient for successive new layers of urban space to remain in symbiosis with its history, re-interpreted and re-developed heritage. However, this entire heritage: space, objects, cultural landscape, lifestyle should appear as a useful starting point not limiting the final solutions of form, space and use of architecture giving rise to the true identity of the new urbanization. While past memories become the seed of a new idea, the spatial outcome as a traditional tool defining social order will inevitably be the result of a process of architectural evolution based on historical references adapted to contemporary phenomena, uses and needs.

Architecture and urban planning is the art of giving a framework to our lives, building to open up to new possibilities to create cohesive communities.

The original expression of creativity implies finding, inventing, arriving at something new by experiencing the grandeur of what exiss. It means adding what is new to what is old and familiar. Finding involves risk, namely the risk of one's own ego. But the conditions for creativity can be systematically exercised: i.e. impartiality, flexibility, curiosity, passion discipline. In this context, experience means thinking of many possibilities, systematic changes of perspective, not following the same path!

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DŁUGOSIODŁO – A PAINTED VILLAGE

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Abstract
Mural paintings in Długosiodło, a village in Wyszki commune, the Mazovia Province, N-E Poland, have been surveyed, as well as other types of public art in that village. Such semi-vernacular art is a remarkable phenomenon that had arisen from the local culture but is absent in surrounding villages and towns, thus deserving recognition and research from a cultural and sociological viewpoint.

Keywords: countryside architecture; vernacular architectural ornamentations; painted cottages; graffiti; N-E Poland

INTRODUCTION

Fancy painted cottages or such were an infrequent sight in the old Polish countryside, but in some regions and neighborhoods, such as near Lowicz (in the area of the former so-called "Duchy of Lowicz") and near Tarnów (in the so-called "Powiśle Dabrowskie"), painting the logs of cottages became a custom in the past, and even inspired talented individuals to creative expression that grew even further beyond this local custom, as was the case with the cottages in Zalipie near Tarnów, painted by Felicja Curyłowa.

All the more noteworthy are today's country houses, whose aesthetics their owners or users want to improve with thoughtful painting compositions. However, this is not pop-culture graffiti (which is born most often without the knowledge and consent of the homeowner), but paintings applied to the walls of buildings and to objects of small architecture with the aim of aestheticizing them and with respect for the aesthetics of the surroundings, and not to sound subcultural slogans or street protest.

In cities, the relatively tolerated place of pop-culture or subculture graffiti has become undeveloped walls and temporary fences, although for half a century there has also flourished an intolerated and combated mural art that crosses the boundaries of vandalism, which is an expression of rebellion, an occasion for manifestos or even private display (in fact, it has existed since the dawn of mankind, and certainly since the existence of cities, as evidenced by drawings and inscriptions, sometimes vulgar, on the walls of Pompeian buildings). On the other hand, architectural painting techniques are, as it were, returning in glory in the exterior polychromes of cities, created by reliable and experienced artists. These works, sometimes huge in scale and artistically superb, are sometimes called murals. Examples include the so-called Midtown Story with a trumpeter on the roof and a cat in the background - a monumental work by arch. Radoslaw Barek, a professor at Poznan University of Technology, created in 2015 on the wall of a Poznan tenement on the corner of Śródka and Rynek Śródecki streets, as well as the same author's mural in Gorzow (2020) and several other, minor ones. In recent years, groups and communities of mural promoters and contractors have been emerging, such as Grupa RW – MalujemyMurale.pl (www.malujemymurale.pl) and Grupa Murall (www.facebook.com/murall.studio).

The countryside, however, is a very different mural environment from the big cities – different as to scale, including the space available for wall or fence painting. The degree of social consent to outdoor painting (murals)[1], the scale of creativity, the subject matter of the works, and their longevity are different there.

Thus, if in a village or small town a nice façade polychrome is created, which arouses curiosity, later – social recognition, and then it finds imitators, gives rise to a local decorative fashion and induces autochthons to care about the landscape of this village or town – such a case is worthy of research attention from a threefold perspective: artistic, architectural-landscape and sociological. At least in part, the communal village of Długosiodło in the Wyszków district of the Mazovian voivodeship is becoming just such a case.

Thus, this article is a contribution to a broader multi-faceted view of the phenomenon of façade painting in the rural landscape of villages and small towns, using the example of the aforementioned village of Długosiodło. The origins and development of façade painting in the said village are discussed, and the effects of this phenomenon are pointed out on the rights of hypothesis. The need for the preservation of Dlugosiodlo's malatures is substantiated.

1. DŁUGOSIODŁO VILLAGE

Długosiodło is a communal village with a population of about 1,400 people [Czajkowska H. et al. 2018], located on the edge of the former Biała Forest, which is an area with distinct ethnographic characteristics. Długosiodło already existed in the 13th century as a private bishop's village[2] But at the end of the 17th century, after the Swedish invasion and other historical cataclysms, it was largely depopulated, as were the surrounding villages. Therefore, in the years 1730–1790, the Plock bishops resettled new landowners, mainly Kurpies from the nearby Puszcza Zielona, to the Biala Forest, in the number of about 300 families, and closer inter-village resettlements were also allowed. Part of today's population of Długosiodło is thus made up of descendants of these 18th-century settlers. In the 19th century and as late as the beginning of the 20th century, they were identified as Kurpies[3], while over time the Kurpie self-identification of a sizable part of this society disappeared, and it is only in the last few decades that awareness of their ethno-historical identity has been returning among the local population.

Dozens or more old wooden houses have survived in the village and its surroundings, including a dozen with ornamentation characteristic of the folk architecture of the Kurpie Białe region, and a dozen more with ornamentation characteristic of small-town wooden architecture of the early 20th century. (including Jewish, as before World War II the Jewish population made up almost half of Długosiodło's population). However, only one wooden house (at 6 Poniatowskiego Street) in Długosiodło is included in the municipal register of historical monuments, while in the entire municipality – about 30 wooden houses[4]. On the other hand, only six objects from the area of Długosiodło municipality have been entered in the register kept by the Provincial Conservator of Monuments, including only one old house, namely a 19th-century wooden cottage in Stary Bosewo. Protection of the relics of old buildings is therefore rudimentary here, although other villages and towns in the region are no better off in this regard.

The desirability and urgency of preserving old wooden village houses in this municipality, including Długosiodlo itself, is a topic for a separate study, while here the subject of consideration is a slightly different, rather new phenomenon – namely, elevation painting

[1] In reference to this category of art, the word malatures was used by Roman Reinfuss (1949), paintings – by Wladyslaw Hickel (1906) and Adam Bartosz (1983), among others, and paintings – by Anna Germel (2015), with the above-mentioned authors, so to speak, intuitively taking these words from the folk artists of these polychromies. Nowadays, media publicity favors the use of the words mural and graffiti, with the former seeming to refer to monumental, large-scale, professionally executed works and to grow positive associations, and the latter acquiring a pejorative meaning and referring to ad hoc painting activities, often vandalism. In view of this, neither the word mural nor graffiti accurately captures the essence of the rural architectural painting discussed in this article. There is also the word polychromy, technically appropriate, but less commonly used today, except by art historians. So we remain here with the word *malatura*.

[2] 1381 people according to the National Population and Housing Census of 2021.

[3] At the beginning of the thirteenth century, Konrad Mazowiecki gave the White Forest to the bishops of Płock. Długosiodło became a private bishop's village around 1203. It is also known that in 1262 one of the battles of the Masovian knighthood took place at Długosiodło against the army of the Grand Duke of Lithuania Mindaugas, during his expedition to Masovia.

[4] Adam Zakrzewski, the author of a commentary to the encyclopaedic entry *Kurpie* in the Great Universal Illustrated Encyclopaedia [1909, p. 543], wrote: "The Kurpie population currently forms two separate, non-touching ethnographic islands: the northern one north of the Narew River and the southern one along the right bank of the Bug River. In the first of these groups, the ethnographic distinctiveness has so far been preserved quite clearly and can now be considered typical Kurpie. (...) The second, southern group of Ks is located in today's Ostrów County, in the vicinity of Brok and Ostrów, between Brańszczyk, Długosiodło and Naguszew, but it is currently impossible to distinguish the Kurpie population in this area. (...) Only in the municipalities of Brańszczyk, Orło, Komorowo, Długosiodło and Poręba the Kurpie population still forms even more significant separate groups."

from the 21st century. Complementing this research issue is painting on frames and fences and other manifestations of artistic culture, visible in the rural landscape of Długosiodło.

2. MURALS IN DŁUGOSIODŁO

Probably a remnant of the proper care for the external aesthetics of houses in Kurpie Białe is the cleanliness and orderliness visible here on properties and in front gardens, as well as the aesthetics of fences and the care visible on the street facades of buildings. Attention to the aesthetics of buildings and fences is also evident in places in their decorative painting. Although facade and fence paintings are few in relation to the total number of about a thousand buildings in the village, but still much more numerous than in other villages known to us, and visible, visually exposed. What is lacking is the sloppy pop-culture graffiti that is so common in larger cities.

2.1 Elevation murals

The attention of passing travelers is especially attracted by several buildings on the main Królowa Jadwigi Street (former Dąbrowszczaków Street), whose facades are covered with paintings. These are wooden houses No. 6, 7 and 10. Until recently, paintings also covered the facade of house No. 4, but this one has now been repainted in a uniform light color. An old wooden house at 1 Mickiewicza Street and another wooden house, now defunct, at Królowej Jadwigi Street, formerly located between the current buildings No. 20 and 22, were covered with paintings. Paintings decorated the shutters and doors of the "Dziupla" store at 21 Królowej Jadwigi Street. A closer look at the village allowed us to notice more such buildings and murals even in more secluded places, sometimes quite large, like the mural on the blind wall of the brick building at 7 Kościuszko Street, sometimes smaller, like the mural on the wall of the pub at Józef Poniatowski Street (Fig. 1) or in several places on the walls of the building that is the headquarters of the Communal Information, Culture, Sports and Recreation Center. Meanwhile, behind the church, in the city park, framed by the arm of Kościuszko Street, which bends here, we find racks set up with several huge panoramic painting compositions, each about ten meters long and almost three meters high. A mini open-air museum was separated from part of the park, whose wooden building and entrance gate are also covered with paintings. We will talk about the paintings on the frames further on, because their genesis is a bit different than strictly facade paintings, nevertheless all these works of painting give Długosiodło a specific expression, create a unique atmosphere of a painted village. This climate would be even more pronounced if it were not for the fact that some of the paintings have already been destroyed. Until recently (until December 2022), some of the already invisible facade paintings, now faded or destroyed, could still be viewed online in the Google Maps portal (Street View option).

The murals in question were generally created in the first years of the 21st century. Some of them no longer exist or are faded and barely visible. Fading and destruction happen fastest on old wooden walls. It is the vividness of the colors, or on the contrary, the fading and faded, that allow the fastest dating of the paintings, or at least testify to whether they were restored or allowed to gradually deteriorate.

Of course, most of the several hundred buildings in Długosiodło do not have paintings, but these dozen or so polychromed objects (also including polychromes on fences and freestanding frames) attract attention and have become an interesting and original rural-landscape, artistic, architectural and probably also sociological phenomenon. Questions arise, of course: where and how did these paintings appear? Who created them? Are the Longosiodla polychromes the work of only a few talented individuals, perhaps a few visual artists - or has the fashion for creating them begun to spread? Does this fashion inspire public recognition and find more imitators, or does it die out when the artists performing it run out? Does it prompt indigenous people to care for the landscape? Are the paintings being restored?

According to the available information[5], the first large-scale paintings on old houses were created in 2004 during an open-air painting workshop under the project called "Return to Eden." The project was carried out by a group of visual artists and young art enthusiasts under the artistic direction of painter Małgorzata Ewa Czernik and with the support of the Homo Homini Cultural Foundation in Długosiodło. The elevations were also painted later, during subsequent

[5] The organization of these and other open-air workshops was also supported by the Public Junior High School in Stary Bosewo, the Municipal Cultural Center in Długosiodło and the "Praga" Cultural Center in Warsaw (in October 2005, the Długosiodło municipality signed a cooperation agreement with the "Praga" Cultural Center in Warsaw, which joined in the organization of artistic open-air workshops and the Polish Championships of Actors and Journalists in Mushroom Picking organized in Długosiodło).

openair painting and sculpture workshops[6], especially during the open-air event "Touching Eden" in 2008 and the open-air event "Artistic Gardens of Eden" in 2009. Some paintings came from the brush of another artist Urszula Pogwizd-Balcerzak. There have been more open-airs organized in Długosiodło (practically every year since the beginning of the 21st century), but the above-mentioned three had the strongest impact on the local architecture and landscape, leaving flower-painted facades of houses. At that time (i.e., from around 2002), separate open-air paintings were also organized for schoolchildren in Długosiodło and nearby Stary Bosew, carried out by the Association for the Development of Długosiodło Municipality under the direction of Ewa Urszula Krysiak, director of the Municipal Center for Information, Culture, Sports and Recreation in Długosiodło. Thus, although most of the local facade paintings are related to the person of painter Małgorzata Ewa Czernik, the entirety of facade painting in Długosiodło should already be treated as a broader phenomenon.

2.2. Murals on fences

As already mentioned, a few small painting compositions on wooden fences have also appeared in the landscape of Długosiodło, for example, on the entrance gate to the mini-skansen on the eastern side (from Kosciuszko Street). Their genesis is similar to that of façade murals. However, the actual impact of fence murals on the landscape of this village is negligible, as they are exceptions, but we mention them for the sake of completeness of the argument, and also because, in a way, they are an intermediate category between facade paintings and the next category described below, i.e. murals on frames.

2.3. Murals on racks

In addition to facade murals, murals made on panels mounted on freestanding racks in the city park on Kosciuszko Street have been created in Długosiodło since 2012. Their originator and designer was, and still is (as every year there are new mural additions on the attached racks), visual artist Wieńczysław Pyrzanowski, and the contractors – a group of visual artists and students[7]. Wienczysław Pyrzanowski was also the artistic commissioner of previous open-air events.

Before the huge outdoor murals began to be created in the city park in 2012, in August 2011, during the 13th open-air painting event, its participants painted a large-format painting measuring one and a half by three meters, entitled "The Legend of Długosiodło." The painting was donated to the Długosiodło Municipality Office. The successful group painting encouraged the participants to continue the team creative work. With support from the Gmina Office, the LAG Równina Wołomińska, the mayor of Długosiodło and the Homo Homini Culture Foundation (run by Urszula and Maciej Zaleg, the de facto organizers of the aforementioned plein-air workshop), another plein-air workshop in 2012, under the artistic direction of Wieńczysław Pyrzanowski, produced a mural measuring 2.7 × 7.5 m, depicting a genre scene in a rural homestead. A year later (2013) another mural panel of 5 m was added, depicting villagers working together to pickle cabbage. A five-meter panel depicting village washerwomen was also added the following year (2014). In 2015, a seven-meter-long panel with a harvest scene was painted, and in 2016, a 2.7 × 5-meter scene of the autumn cabbage harvest was painted. This resulted in a 270 cm high and very long, almost 30 m long mural depicting various scenes of rural life. Residents call it "Four Seasons," although this is an unofficial and somewhat misleading title.

In 2017, the participants of the open-air event, still under the artistic direction of Wienczysław Pyrzanowski, painted another panel, filling it with a scene of mushrooming. The artists referred to a local cyclic (annual) promotional event – "The Great Mushrooming" (in autumn 2017 its fifteenth edition was held, and at the time of writing this article, in 2022 – the nineteenth edition). The event is accompanied by the Polish Actors' and Journalists' Mushrooming Championships.

A year later (2018), the total length of all mural panels, set up in the city park, had already reached 47.5 meters. At that time, a mural was created depicting the entry of Michal Belina-Prażmowski's cavalry unit into Długosiodło. The content of the painting corresponds to the actual events. The pretext for the historical theme was the centennial of Poland's regaining of independence. This mural marked the beginning of another mural series, this time battle-historical. In 2020, a painting composition of a lost painting by Maximilian Gierymski, "Alarm in the Uprising Camp", was recreated

[6] Grażyna Bany, Anna Bojas, Łukasz Dymiński, Ola Jamiołkowska, Marek Konatkowski, Dominika Małgowska, Dominika Nasiadko, Julia Pyrzanowska, Matylda Pyrzanowska, Katarzyna Słowikowska, Julian Sulikowski, Zuzanna Trzcińska, Helena Wieczorek and Joanna Żaboklicka. Some of them participated in the painting work only sporadically, others regularly (especially Dominika Małgowska, Matylda Pyrzanowska and Łukasz Dymiński, co-creators of murals from the historical series).

[7] 7,853 people in 2017.

Fig. 1. Examples of murals in Długosiodło (Królowej Jadwigi St.); photos by K.M. and E. Krysiak

Fig. 2. Examples of murals in Długosiodło (Królowej Jadwigi St.); photos by K.M. and E. Krysiak

on the next large-format panel. In 2021, a battle scene from the November Uprising was painted, depicting the Battle of Ostroleka on May 26, 1831 (this battle was preceded by two smaller skirmishes, including one at Długosiodło). In 2022 a mural was made commemorating and showing the passage in 1794 of a detachment of the 1st Wielkopolska National Cavalry Brigade under the command of Brigadier Antoni Madalinski. It is known that the unit moved near Długosiodło.

2.4. Summary of architectural painting in Długosiodło

In summary, the architectural paintings visible now (late 2022 and early 2023) or until recently in the public spaces of Długosiodło village include a dozen or so facade paintings in various parts of the village (most in the center) and 10 "murals" on free-standing frames with a total area of about 150-180 m² (more than 60 running meters) in the municipal park. These works are overwhelmingly the result of individual artistic initiatives and were created during open-air painting workshops: in 2004-2009, under the artistic direction of Małgorzata Ewa Czernik, the facades of houses in the center of the village were painted, and in 2012–2016, under the direction of Wieńczysław Pyrzanowski, free-standing rack compositions of the "Four Seasons" series were created in the city park, complemented in 2017 by a mural with mushroom picking, and in subsequent years (2018–2022) by murals with historical and battle scenes. It is likely that several minor facade and fence paintings may have been created outside of the above-mentioned outdoor projects. The paintings are generally not renovated, so the older (facade) ones are gradually fading and deteriorating, and some, like on house No. 4 on Królowej Jadwigi Street, have been repainted and covered up. Currently, there is a lack of willingness on the part of residents to make their buildings available for new paintings. Perhaps this is due to the association of the murals with old neglected houses, as the first Longosiodla facade paintings were created on older wooden houses and by now (after more than a decade and a half) they have fallen into neglect.

3. OTHER MANIFESTATIONS OF ARTISTIC CREATIVITY IN THE DŁUGOSIODŁO LANDSCAPE

Nevertheless, there is a noticeable saturation of public space with fine arts creations, which should be considered with the scale of a given settlement unit in mind. As already mentioned, Długosiodło has a population of 1,400 people, and the entire municipality – about 7800–7900 people[8]. This is not much, considering that the statistical Polish municipality has twice as many residents[9]. However, the village of Dlugosiodlo has in its public space not only the murals described above, but also more than a dozen monuments and sculptures and other works of art.

3.1. Historical monuments, contemporary sculptures and other art forms

At Królowej Jadwigi Street (Dąbrowszczaków) on property No. 5 there is a monument to Tadeusz Kosciuszko erected on October 15, 1917, on the 100th anniversary of Kościuszko's death, so the monument itself is now more than a century old. In 1977, a second monument to Tadeusz Kościuszko was erected at the intersection of Królowej Jadwigi and Mickiewicza streets. This monument, too, still stands today, and was renovated a few years ago.

In more recent times, over the past two decades, wooden sculptures have appeared in Długosiodło's landscape, made by Kazimierz Sikorski, a local sculptor (a graduate of the State High School of Arts and Crafts in Kielce), who has his own studio and gallery in Długosiodło. Some of his works are outdoor sculptures: a few stand near the market square, some in the park, and a few – on private properties. Kazimierz Sikorski is also the author of sculptures exhibited occasionally, such as elements of New Year's nativity scenes.

Sculpture-painting compositions also adorn several newer buildings, including the top of the house at 22 Królowej Jadwigi Street (decorated with compositions alluding to Kurpie cut-outs) and buildings on a private property on Prince Józef Poniatowski Street 34.

The public space of Długosiodło also sometimes exhibits paintings on boards, painted by Iwona Rychlik, an artist from nearby Stare Bosewo, 3 kilometers away to the northwest. Permanently standing in the center of Długosiodło is Iwona Rychlik's composition entitled "Kurpianeczki. "Kurpianeczki".

3.2. Temporary Art Installations

The aforementioned open-air artistic events for professionals, as well as smaller open-air events for young people and some other cultural events in the village of Długosiodło attract artists from outside

[8] In 2023, the population of Poland was 37,750,000 inhabitants, and the number of municipalities was 2477, which gives an average of 15,240 inhabitants per municipality.
[9] Own calculations based on publicly available satellite images.

or bring together local art amateurs, so that open-air artistic activity then becomes part of the local landscape. This activity has in the past also included art installations, performances and other manifestations of art temporarily shaping the landscape. For example, in 2015, the aforementioned Margaret Czernik held an open art workshop culminating in an outdoor show with performance elements entitled ‘Margaret’s Dancing Gardens’.

Some promotional initiatives work in a similar way, such as Przystanek Rękodzieło, which is – according to its creators – *“a social initiative of Długosiodło commune inhabitants, promoting the culture and tradition of the Biała Forest”*[10]. It has been ongoing since around 2015 and also includes artistic activities.

3.3. Summary of landscape impact of art that is not ‘murals’

Monuments, sculptures, sculpture-painting compositions, paintings on boards, temporary installations, performative works and outdoor participation by local and outside artists have all had a significant impact on the landscape of Długosiodło, although this impact is most evident during celebrations, workshops and open-air art events.

This raises questions about the degree of social acceptance of artistic activity. After all, art is, in a way, an attempt to overcome routine, life’s schematism, habits and blind rules - an attempt necessary to produce aesthetic values that rise above the everyday and the banal. This is why artistic activity can, to some extent, clash with the habits, values and rules that have united small communities for generations. Is this the case with Długosiodło? An answer to this question is beyond the scope of this article, as it would require sociological research, nevertheless such a question should at least be posed, noting the strength and scale of the artistic ferment initiated by artists coming from outside.

4 DISCUSSION

As already mentioned, there is a “Mini-Skansen” in Długosiodło[11] with old cottages with old furnishings, and 14 km south of Długosiodło in the village of Brańszczyk there is a small open-air museum named after Maria Żywirska. It was established as a local government initiative[12], thus, probably to some extent, it testifies to the appreciation of their own architectural traditions by the inhabitants of the region (by the way, the patron of the open-air museum, ethnographer Maria Byczynska-Żywirska, was born in Brańszczyk, some of her publications were even devoted to the surrounding area of the Kurpie Białe Forest, e.g., *The Kurpie Białe Forest* [M. Żywirska 1949; M. Żywirska 1967].

It seems tempting, then, to hypothesize that the aesthetic sensitivity and cultural awareness of the residents of Długosiodło and the surrounding villages is greater than elsewhere, which could be indicated by open-air museum initiatives, artistic initiatives and culture and art creators operating here, as well as the presence in Długosiodło’s urban space of the aforementioned sculptures, frame murals and painted elevations.

However, not everything supports such an interpretation. In Długosiodło, the old wooden buildings are quickly disappearing, the facade paintings from a dozen years ago are not being restored, while the most active artists and cultural activists (including organizers and participants of professional open-air painting workshops) do not come from Długosiodło, but from outside. Most of the manifestations of artistic activity are imported, so to speak.

Arguably, however, there is a process of gradually increasing self-identification of rural residents with the art around them in the built space. This is partly attested to by discussions on the Internet; moreover, it would also be expected, since analogous processes have occurred in the past in cities, where murals with high artistic values have appeared. One of the best-known examples of cities identifying themselves with mural art is the London neighborhood of Brixton, where murals have been created since 1982, and the stimulating factor of this art were the unresolved social problems (including a series of strikes and protests in 1981), as if reactivated by mural art. Fortunately, local artists rather than youth subcultures were involved in composing the murals in Brixton, which protected the urban space from aesthetic vandalism.

We also have positive examples of mural art from the Długosiodło area: murals in Ostrołęka (35 km north of Długosiodło) by Anastasia Drabot, a graduate of the Faculty of Architecture at the Warsaw University of Technology; murals in Ostrow Mazowiecka (20 km east of Długosiodło), or murals in Pułtusk. They prove that it is possible to internalize mural art by the local community. Here, it is worth noting factors unfavorable for community integration, including: the creation of

[10] According to http://rekodzielodlugosiodlo.blogspot.com (accessed 1.1.2023).
[11] The open-air museum was established in 2015 from the funds of the Rural Development Program, as part of the project Protection of cultural heritage through the creation of an open-air museum in Brańszczyk at the planned route of St. James to Łomża.
[12] This initially informal name has already begun to be used in [Plan... 2014, p. 15].

Fig. 3. Examples of murals in Długosiodło; photo E. Krysiak

Fig. 4. Examples of murals in Długosiodło; photo: K.M. and E. Krysiak

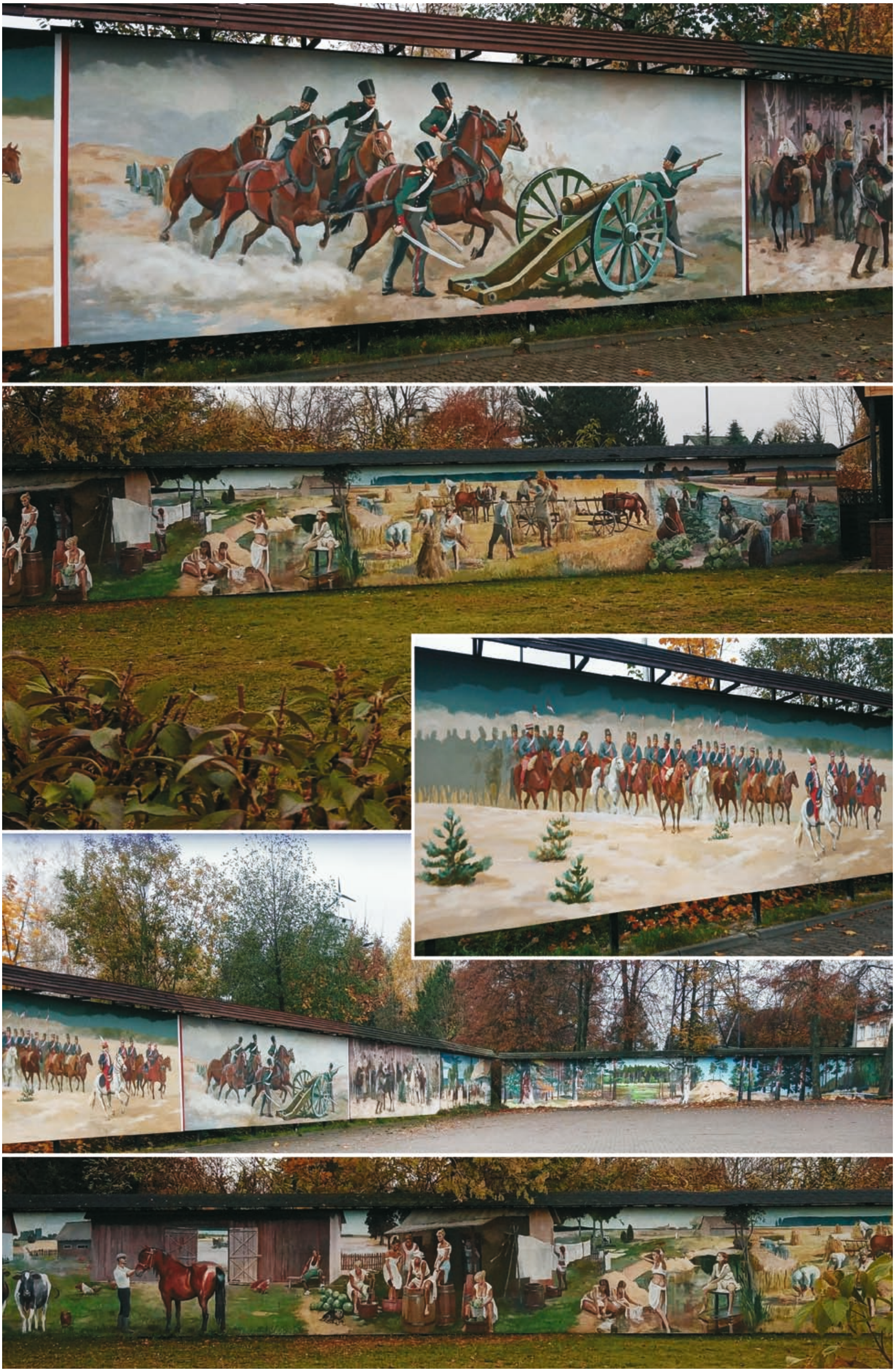

Fig. 5. Examples of murals in Długosiodło; photo: K.M.

Fig. 6. Examples of murals in Długosiodło; photo: K.M.

murals with political, martyrological or religious messages, or with accentuated symbolism in general, as well as naive compositions – but also overly ambitious works. Such murals polarize local communities, and their perception changes over time – viewed for the first time, they arouse interest; viewed again, they cause weariness; viewed repeatedly, they arouse irritation in some viewers. Not surprisingly, murals created not by visual artists, but by architects, sensitive to the specificity of urban space, are often the best received – here positive examples are the already mentioned Anastasia Drabot, as well as Radosław Barek, architect and professor at Poznań University of Technology, author of, among others, the so-called Śródek Mural (2015) or the mural on Jagiełły Street in Gorzów Wielkopolski (2020).

In turn, when considering the influence of creative circles on the space of small towns and communal villages, or when looking for references (seeking comparisons with Długosiodło), it is worth remembering the examples of towns with visual arts high schools.. Artur Grottger State High School of Visual Arts in Suprasl (founded in 1944), J. Chelmonski State High School of Visual Arts in Naleczow (actually functioning since 1947) and, to a lesser extent, the State High School of Visual Arts in Kościelec (functioning since 1979), which all enrich the urban space with the creative activities of their students and teachers. Other examples of the influence of artists on small towns include Rudnik nad Sanem and Nowy Tomyśl (west of Poznań), where open-air wicker workshops are held, and wicker sculptures and land-art works have been an integral part of the aesthetics of these towns for decades. These examples show that in the social dimension, the integration of art into architectural space (its acceptance) takes time, takes place gradually, and at the same time is two-way: residents also learn aesthetic sensitivity, and the sowers of the seeds of such sensitivity are the visual artists.

A community center can also be an activator of artistic creativity. An interesting study of the impact of creative community centers on local communities in the Mazovian Voivodeship was conducted in 2022 (the study was carried out by the Association of Creative Initiatives *"ę"* with a team of sociologists under the direction of Dr. Maria Theiss; it resulted in the report *Zoom na domy kultury – diagnoza mazowieckich domów kultury*). Among other things, they sought answers to the questions: *"Does the operation of community centers enable participation, activation and creativity of residents? What is the social range and diversity of the community center's program, including activities to reach different groups? With the help of programs and other activities, how do community centers contribute to the integration of the local community, the creation of ties between residents and the networking of local institutions? Who are the community center employees and how do they work as a team?"* [Zoom... 2022, p. 33]. *"Is the purpose of the community center's activity art education – to increase the competence of participants in a particular field (e.g., playing an instrument), or to stimulate creativity, which is a feature of everyone? (...) What form should mass events take? (...) Can they also be an element of community identity building? Is their role to provide a product or to integrate the community?"* [ibid, p. 39]. *"Who should be the main audience for community center activities? Is their role to provide a product or to integrate the community?"* [ibid, p. 39]. *"Who should be the main audience for community center activities? Are community centers elitist places whose proposal is aimed at narrow groups of sophisticated audiences? Rather, is a community center a place that invites various social groups and is not afraid to involve them in joint activities?"* [ibid, p. 41]. It concluded that *"the identification by the community center of uncooperative groups of residents and comprehensive attempts to include them in the activities of the community center are, in our view, a good indicator of the integrative role of the community center"* [ibid]. It seems that, by analogy, the key to raising the aesthetics of downtown spaces in towns may be "the recognition of uncooperative groups of residents and comprehensive attempts to include them in the activities" of the creative, and that the success of activities such as those in Długosiodło is due, among other things, to the charisma of those involved in culture and art there, and their ability to involve others in joint activities.

CONCLUSIONS

The architectural landscape of Długosiodło abounds (for such a small village, with a population of 1,381 in 2021) in monuments, sculptures, sculpture-painting compositions, paintings exhibited in public space, temporary installations, performative works, and, above all, architectural façade and frame paintings, including more than a dozen façade paintings in various parts of the village (most in the centre) and 10 'murals' on freestanding frames with a total surface area of approximately 150–180 m² (over 60 linear metres) in the city park. The works in question were created between 2004 and 2022 as part of open-air art events with the participation of outside visual artists, and some also as a result of local artists and young people participating in minor open-air painting events organised by the local community centre (the contribution of young people has not been accurately estimated here, however). Facade paintings are generally not renovated; there is a lack of willingness on the part of local residents to make their buildings available for new paintings. In spite of this, the artistic activity of local and visiting creative circles constantly enriches the space of Długosiodło with works of art. However, the boundary of public support behind which such works would also be created by 'ordinary' residents has not yet been broken. Nevertheless, Długosiodło has become, and still remains, a kind of ruralist phenomenon – the authors have called it here a 'painted village' with deliberate exaggeration to suggest the need for appreciation and scientific monitoring of the phenomenon of the emergence and persistence in its rural space of a wide range of artistic works (especially large-format murals), for it is an interesting socio-cultural, artistic, ruralist-architectural phenomenon, perhaps already worthy of protection.

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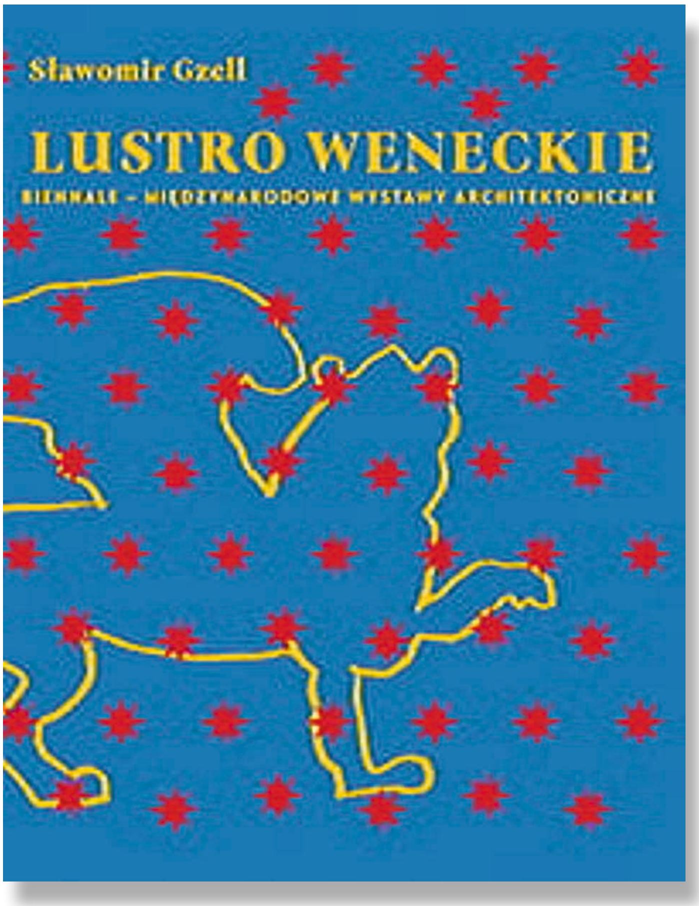
Reviews


Sławomir Gzell
LUSTRO WENECKIE
BIENNALE – MIĘDZYNARODOWE WYSTAWY ARCHITEKTONICZNE

Bartosz Czarnecki

Professor Slawomir Gzell's *Venetian Mirror*

Professor Slawomir Gzell is an undisputed authority and mentor of the Polish architectural community. Admittedly, by virtue of the specialty he pursues, he is an urban planner, but endowed with architectural sensitivity and with a consistently holistic view of space. He is also absolutely knowledgeable about the Venice Biennale, as he is its regular *in situ* observer. Hence, it is understandable that the book is richly illustrated with the author's drawings and photographs from Venice and the Biennale itself.

With the book's title, the Professor does not refer to a classic Venetian mirror, but to one observed in a Venetian (by the way) hotel room, where, with the use of a remote control, the mirror image could be turned into a TV screen image. Similarly, the author proposes two layers to the book content: an overview of the Venice Architecture Biennale edition as a pretext for reflecting on the condition of architecture in general. The professor writes: *"We look at the exhibits, evaluate them, describe them, remember them or not, and at the same time, especially we architects, we look through them - at other people's achievements - and can compare at once the presentation and afterimages of our own work."* Prof. Slawomir Gzell looks at the condition of architecture especially in the mirror of Polish exhibitions in the Polish Pavilion of the Venice International Architecture Biennale, but not only.

The book is divided into six chapters. Chapter 1, is factography: a brief characterization of each of the editions of the Biennale to date. Chapter 2 talks about the urban landscape of Venice, especially during the Biennale period. Chapter 3 discusses the relationship of technology, science and art shown during the Biennale, especially devoting a lot of space to green. Chapter 4 talks about the portrayal of the countryside in Biennale exhibitions. Chapter 5 deals with attitudes toward scientific research in architecture and urbanism. Chapter 6, is about architecture as art and the language of art in architecture.

The author does not rely solely on his own experience of Venice and the Biennale. He quotes quite abundantly from past (Goethe) as well as contemporary (Koolhas) visitors to Venice and, in the case of the latter, Biennale exhibitions. He even cites medieval travelers, such as the Venetian Marco Polo, seeking different contexts of Venice's specificity.

Reflections and digressions are an excuse to evoke various places in Venice and architectural events related to them, not necessarily in the context of the Biennale, although in fact almost everything related to architecture in Venice is also related to the Biennale. Analyzing a selection of the works presented, based on their most common property of ambiguity, the author poses questions, mostly addressing them to the readers.

The book is worth allocating a place on the shelf for it, preferably next to the rich set of items authored by Prof. Slawomir Gzell.

Sławomir Gzell, *Lustro weneckie. Biennale – Międzynarodowe Wystawy Architektoniczne [Venetian Mirror. Biennial – International Architectural Exhibitions]*, Warsaw Univ. of Tech. Publishing House, Warsaw 2023, p. 174.

Bartosz Czarnecki

Lustro Weneckie prof. Sławomira Gzella

Profesor Sławomir Gzell to niekwestionowany autorytet i mentor polskiego środowiska architektonicznego. Co prawda z racji realizowanej specjalności urbanista, ale obdarzony wrażliwością architektoniczną i z konsekwentnie holistycznym spojrzeniem na przestrzeń. Jest też absolutnie kompetentny w zakresie Biennale weneckiego, ponieważ jest jego regularnym obserwatorem *in situ*. Stąd też zrozumiałe, że książka jest bogato ilustrowana autorskimi rysunkami i fotografiami z Wenecji i z samego Biennale.

Tytułem książki Profesor nie nawiązuje do klasycznego lustra weneckiego, lecz do zaobserwowanego w weneckim (a jakże) pokoju hotelowym, gdzie za użyciem pilota lustrzane odbicie można było zmienić w obraz z ekranu telewizora. Podobnie Autor proponuje dwie warstwy treści książki: przegląd edycji weneckiego Biennale Architektury jako pretekst do refleksji nad kondycją architektury w ogóle. Prof. pisze: *„Oglądamy eksponaty, oceniamy je, opisujemy, zapamiętujemy albo i nie, a jednocześnie, zwłaszcza my architekci, przeglądamy się w nich – w cudzych osiągnięciach – i możemy porównywać od razu prezentację i powidoki własnych prac.”* Prof. Sławomir Gzell przygląda się kondycji architektury szczególnie w zwierciadle polskich ekspozycji w Pawilonie Polskim Międzynarodowego Biennale Architektury w Wenecji, lecz nie tylko.

Książka podzielona jest na sześć rozdziałów. Rozdział 1, to faktografia: krótka charakterystyka każdej z dotychczasowych edycji Biennale. Rozdział 2 mówi o krajobrazie miejskim Wenecji, zwłaszcza w okresie Biennale, szczególnie wiele miejsca poświęcając zieleni. Rozdział 3 omawia związki technologii, nauki i sztuki pokazywanych podczas Biennale. Rozdział 4 mówi o ukazywaniu wsi w ekspozycjach Biennale. Rozdział 5 traktuje o stosunku do badań naukowych w architekturze i urbanistyce. Rozdział 6, to architektura jako sztuka i język sztuki w architekturze.

Autor nie bazuje wyłącznie na własnym doświadczaniu Wenecji i Biennale. Dość obficie przytacza dawnych (Goethe), jak i współczesnych (Koolhas) odwiedzających Wenecję i, w przypadku tych drugich – wystawy Biennale. Przywołuje nawet średniowiecznych podróżników, jak Wenecjanin Marco Polo, poszukując różnych kontekstów specyfiki Wenecji.

Refleksje i dygresje są pretekstem do przywoływania różnych miejsc w Wenecji i zdarzeń architektonicznych z nimi związanych, niekoniecznie w kontekście Biennale, choć właściwie prawie wszystko, co wiąże się z architekturą w Wenecji, wiąże się też z Biennale. Analizując wybrane z prezentowanych prac, bazując na ich najczęstszej właściwości jaką jest niejednoznaczność, Autor stawia pytania, przeważnie kierując je do Czytelników.

Książka jest warta, aby przeznaczyć dla niej miejsce na półce, najlepiej obok bogatego zestawu pozycji autorstwa prof. Sławomira Gzella.

Sławomir Gzell, *Lustro weneckie. Biennale – Międzynarodowe Wystawy Architektoniczne*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2023, s. 174.