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DOCTORAL THESIS

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THESIS

Contributions to the green energy harvesting (from wind and waves) in harbor areas

Summary

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Bucharest, 2022

CONTENT

List of publications (*01.09.2022)*

Internaționale Journals

1. **Katona C**., Safta C., Dumitrache A.,” Adjoint building design optimization coupled with a VAWT for wind energy harvesting through a sea coastal wind stream”, ICNAAM 2022 WORLD CONGRESS, AIP Conference Proceedings of the 20th International Conference of Numerical Analysis and Applied Mathematics, Volume XXX, Issue XXX, on-going, 2022

2. **Katona C**., Safta C., Frunzulica F., Goemans M., ”Numerical Simulations of Gaseous Flames in Combustion Chamber Applications”, IC-MSQUARE 2020 WORLD CONGRESS, Journal of Physics, Conference Series of the 9th International Conference on Mathematical Modeling in Physical Sciences, Volume 1730, Issue 1, doi:10.1088/1742-6596/1730/1/012110, 2021

3. **Katona C**., Safta C., Frunzulica F., ”Efficiency location of a VAWT based on the wind conditions around the buildings in a sea coastal region”, ICNPAA 2018 WORLD CONGRESS, AIP Conference Proceedings of the 12th International Conference on Mathematical Problems in Engineering, Aerospace and Sciences,, Volume 2046, Issue 1, https://doi.org/10.1063/1.5081560, 2018

4. **Katona C**., Safta C.” The effect of wind direction and building surroundings on a marina bay in the Black Sea”, ICNPAA 2016 WORLD CONGRESS, AIP Conference Proceedings of the 11th International Conference on Mathematical Problems in Engineering, Aerospace and Sciences,, Volume 1798, Issue 1, http://dx.doi.org/10.1063/1.4972665, 2017

5. Lupu S., Pocora A., Nicolae F., **Katona C**.,” The role of the maritime simulators in evaluating the practical competences of graduated students in order to accomplish officer of the watch duties onboard vessels”, Proceedings of the 12th International Scientific Conference „eLearning and Software for Education”, ISSN 2066-026X-16-031, vol. II, Bucharest, April 21 - 22, 2016, indexed by ISI Web Of SCIENCE, CEEOL, ProQuest, EBSCO HOST

6. Lupu S., Pocora A., Toma A., **Katona C**.,” Training of the Romanian Navy personnel for underway replenishment operations”, Proceedings of the 11th International Scientific Conference „eLearning and Software for Education”, ISSN 2066-026X, vol. II, Bucharest, April 23 - 24, 2015, indexed by ISI Web Of SCIENCE, CEEOL, ProQuest, EBSCO HOST

7. Lupu S., Pocora A., **Katona C**., Boșneagu R.,” Simulation techniques for training and coaching of navy officers in naval kinematics problems and fleet formations scenarios”, Proceedings of the 11th International Scientific Conference „eLearning and Software for Education”, ISSN 2066-026X, vol. II, Bucharest, April 23 - 24, 2015, indexed by ISI Web Of SCIENCE, CEEOL, ProQuest, EBSCO HOST

8. Lupu S., Pocora A., Toma A., **Katona C**.,” Software application for officers in charge of a navigational watch”, Proceedings of the 10th International Scientific Conference „eLearning and Software for Education”, ISSN 2066-026X, vol. I, Bucharest, April 24 - 25, 2014, indexed by ISI Web Of SCIENCE, CEEOL, ProQuest, EBSCO HOST

International Database

1. **Katona C.**, Safta C., Building effect assembly and urban surroundings on a helical wind turbine performance: A numerical perspective, Universitatea Politehnică București, Scientific Bulletin, Series D, vol. XX, issue XX, ISSN XXX-XXXX, on-going (în curs de publicare), 2022

2. Lupu S., Pocora A., Bosneagu R., **Katona C**., “Maritime traffic in the Romanian harbours”,” Mircea cel Batran” Naval Academy Scientific Bulletin, ISSN 1454 – 864X, vol XIX, issue 1, indexed by SciTech Journals, ProQuest, Constanța, 2016

3. Lupu S., Pocora A., Bosneagu R., **Katona C**., “The security and safety of maritime navigation through Romanian maritime harbors”,” Mircea cel Batran” Naval Academy Scientific Bulletin, ISSN 1454 – 864X, vol XIX, issue 2, indexed by SciTech Journals, ProQuest, Constanța, 2016

4. Pocora A., Lupu S., Toma A., **Katona C**., “Light pollution in Constanta: A case study”,” Mircea cel Batran” Naval Academy Scientific Bulletin, ISSN 1454 – 864X, vol XIX, issue 2, indexed by SciTech Journals, ProQuest, Constanța, 2016

5. **Katona C**., Toma A., “The cargo evolution transportation on romanian waterways Cernavodă – Agigea and Poarta Albă – Midia Năvodari”,” Mircea cel Batran” Naval Academy Scientific Bulletin, ISSN 1454 – 864X, vol XVIII, indexed by SciTech Journals, ProQuest, Constanța, 2015

6. Șerban Sergiu, **Katona Cosmin**, Valeriu Panaitescu, “The analysis of squat and underkeel clearance for different ship types in a trapezoidal cross-section channel”, Universitatea Politehnică București, Scientific Bulletin, Series D, vol. 77, issue 3, ISSN 1454-2358, 2015

7. **Katona Cosmin**., Toma Alecu., “The information management for maritime accident reconstruction using Voyage Data Recorder system,” Naval Academy Scientific Bulletin, ISSN 1454 – 864X, vol XVIII - issue 2, indexed by SciTech Journals, ProQuest, Constanța, 2015

8. Sergiu Șerban, **Katona Cosmin**, Valeriu Panaitescu, “Case study of ship-to-ship interaction using NTPRO 5000 navigational simulator, Mircea cel Bătrân” Naval Academy Scientific Bulletin, Volume XVII – 2014 – Issue 2, pag 31-35, ISSN 2392-8956, Constanta, 2014

9. **Katona Cosmin**, Sergiu Lupu, Andrei Pocora, Sergiu Șerban, "Adjusting the magnetic deviation table for MK 2000S compass outfit in educational purposes," Mircea cel Bătrân" Naval Academy Scientific Bulletin, Volume XVII – 2014 – Issue 2, pag 18-21, ISSN 2392-8956, Constanta, 2014

International Conferences

1. **Katona Cosmin**, Valeriu Panaitescu, Scurtu Cristian Ionuț, "Optimal parametric rudder shape based on numerical analysis using commercial software CFX", 7th International Conference on Energy and Environment, October 2015

2. **Katona Cosmin**, Șerban Sergiu," Storage, access, and processing of information within VDR system (Voyage Data Recorder)", Science and Engineering, International Conference "Professor Dorin Pavel – Romanian hydropower founder", ISSN 2067-7138, Sebeș, 2015

3. Șerban Sergiu, **Katona Cosmin**, Valeriu Panaitescu, "Modelarea planurilor de proiecție ale unei nave de tip tanc petrolier utilizând programul autoship", International conference "Energy, Efficiency, Ecology and Education", ISBN 978-9975-71-719-9, Chișinău, 2015

4. Șerban Sergiu, **Katona Cosmin**, Valeriu Panaitescu, "Ship squat for a theoretical hull model in trapezoidal variable cross-section canal", International conference "Current issues of urbanism and planning", vol. II, ISSN 987-9975-71-582-9, Chisinău, 2014

Proposed Patent

1. Petică C.C., Petică G.Al., **Katona C**., Safta C.A., "Device and method for monitoring the operation of fish ladders in small hydroelectric facilities", patent request OSIM A00660 from 18.10.2019

Membru în proiecte de cercetare

1. Modal course for practical training in integrated simulator ship for the officer of the watch in the Navy – positon 123 from R & D Sectorial Plan - 2014.
2. The use of waterways for efficient military actions in responsibility of the Romanian Navy - position 125 from R & D Sectorial Plan – 2014.
3. Modal course for training in integrated simulator ship for the Search and Rescue Operations - position 145 from R & D Sectorial Plan – 2015.
4. The dispersion of oil in case of accidental pollution aboard military ships using real time hydro-meteorological forecasts received - position 144 from R & D Sectorial Plan – 2015
5. Modernization study of the Astronomical Observatory from the Naval Academy "Mircea cel Bătrân" - position 143 from R & D Sectorial Plan – 2015

INTRODUCTION

CONTEXT OF THE PRESENT STUDY

Maritime transport is a significant component in the world transport system which gives freedom to diversified trade and offers competitive prices compared to other methods of transporting goods. Seaports that enable water transport have a major impact on the economic, social and natural environment. Port authorities show a growing awareness of the negative influences on the urban environment and thus simultaneously implement energy and ecological measures in accordance with the principles of sustainable development.

A key element in response to sustainable energy issues is the development and implementation of an energy independent port as a substantial part in the development of the green seaport concept.

Improving the energy production of a seaport involves enormous challenges and engineering efforts such that implementation at a macroscopic level becomes almost unfeasible in the short term [168]. Such a challenge can induce risks in the development of harbor structures as well as the reduction of maritime traffic due to the high financial implications, which reduces the macroscopic concept to a microscopic scale, otherwise perfectly adaptable for commercial harbors supporting small and medium-sized pleasure boats.

At the global level, the idea of the partly energy supported harbor is evolving due to the offshore energy potential, which achieves a substantial supply of electricity in the port proximity, but the installation costs for the purpose of supporting a small seaport do not amortize the actual investment in the short term [157, 164]. Moreover, it is realized that the green energy potential in the vicinity of the tourist ports is hardly exploited for any form of renewable resource.

OBJECTIVES AND MOTIVATIONS

The thesis entitled *Contributions to the green energy harvesting (wind and waves) in harbor areas* is an applied research that aims to establish local areas for the capture of renewable energies associated with the phenomena of disturbed dynamic flows.

The study of flow dynamics in the vicinity of urban structures as well as harbor basins has a high application potential, being a subject directly related to the fundamentals of fluid mechanics: the correct establishment of the boundary conditions imposed on the flow field in the quantification of the real micro-power potential for renewable energies .

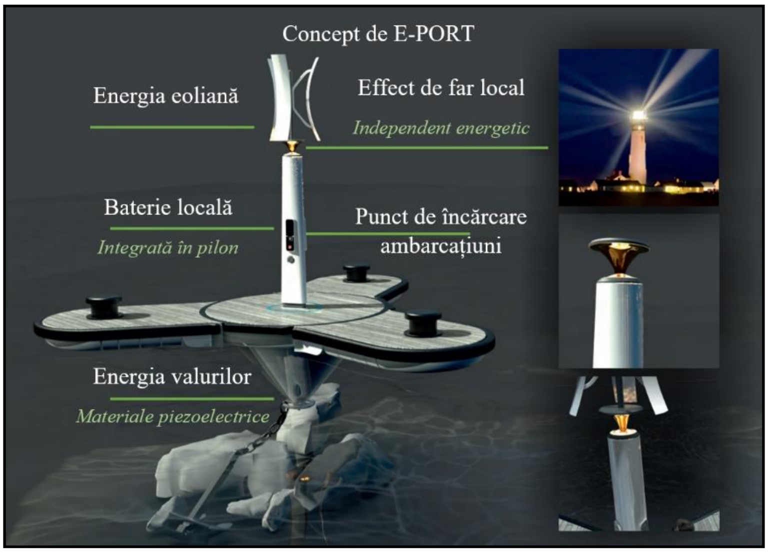


Fig. 0.1. Conceptul de e-Port în viziunea autorului

The present thesis deals with particular attention to the local aerodynamic flow of buildings, wind turbines and the hydrodynamics of flows with free surfaces in enclosed systems - mainly on the flow directions, the development of recirculation zones and vortex trails, the "*dam break*" type shock , the impact and distribution of hydrodynamic forces on a well-defined surface.

I consider the main objectives of the thesis to be the following:

i. Capitalizing on the real power potential of the Tomis tourist harbor bay, Constanța, in order to create an energy-independent E-port;
ii. Conception, design and construction of architectural geometries in terrace areas of high buildings to improve dynamic flow in urban areas;
iii. Determination of a procedure to identify and improve urban structures to quantify the geometric influence on the area with energy potential;
iv. Development of a procedure for establishing the location of small power wind turbines in urban areas in the vicinity of tourist harbors;
v. Realization, validation and expansion of numerical simulations to extract relevant data in order to optimize the local micropotential energy;
vi. Numerical and experimental study of the physical instabilities of non-permanent flow with free surfaces of a "dam break" concept.

STATE OF ART

Producing energy from renewable sources in port proximity offers important advantages: a high number of operating hours, low variability, high flexibility, minimal cost maintenance and low balancing costs compared to offshore wind and photovoltaic energy. Thus, we identify the following aspects: urban wind energy does not require supporting structures because the structures of high buildings can be used as basic support, the terraces of buildings can be modified [56], with minimal costs, in order to improve the wind profile as well as the safety of pedestrian areas in in cases of gusts [129], the structures of the berths of boats can capture the energy of the waves and do not require considerable modifications, but on the contrary they integrate into the port architectural aspect.

One of the main difficulties in the analysis, modeling and implementation of renewable energies in urban harbor areas is the establishment of local spatial influences that characterize the field of disturbed flow on fluid dynamics. This subject remains a challenge not addressed by the specialized literature and risks the loss of the opportunity of energy prediction at the expense of the optimization and efficiency of energy capture systems from renewable sources.

Wind energy can become a pillar for reaching the objective of climate neutrality in the European context 2050 [164]. The technological advantage and significant wind resources in our country can contribute to a rapid development of the European strategic objective for renewable energy. A potential natural capacity of 94 GW is identified, of which 22 GW using fixed turbines according to the strategy of the European Union (*European Green Deal*).

At the present time, Romania is one of the leaders in the development of the energy potential of coastal wind energy in the south-eastern area of Europe, having installed a power of 3 GW according to the *National Integrated Plan in the Field of Energy and Climate Change 2021-2030* [55] but these facilities are outside urban areas.

Additionally, there is an increasing interest in the development of wind projects in different coastal areas defined following the study of the average wind speed, which in the winter period can reach up to 8 m/s [29, 38, 110, 142, 198] but the automatic meteorological stations (*Maritime Hydrographic Department of the Maritime Meteorological Surveillance Network of the Naval Forces*) in the urban and port proximity determine an average wind speed of only 5.5 m/s. Therefore, the reduction in wind speed as the difference between an open field and an urban area populated with high-rise buildings [44], discourages the market to introduce wind energy in urban planning.

The important implications that static urban bodies can have on dynamic flows represent opportunities for numerous investigations dedicated to passive [53, 114, 137] and active strategies to intensify this phenomenon [83, 136]. Passive strategies are realized based on local optimizations of body shapes and respectively, active strategies such as the use of local surfaces in generating ideal locations for the installation of wind turbines in the well-anchored urban context [14, 126, 183].

In recent years, various scenarios have been proposed in the fight for energy independence, mainly with wind and photovoltaic sources, but in order to achieve the 100% supply of renewable energies, other additional sources such as the energy generated by waves must also be considered [167]. Although the focus remains on coastal areas, some attention is also paid to the marine environment [185, 187 191].

The attractiveness of the marine environment increases significantly once we move away from the coastal area, but to remain competitive it is important to balance the existing energy potential and the characteristics of exploiting the energy potential, such as distance from the shore, water depth, CAPEX, OPEX , the connectivity grid, maritime traffic, aquatic environment and maintenance costs.

In most energy scenarios, the efficiency of energy utilization is defined offshore and the coastal area remains a particular case without interest. Marine energy capture projects are frequently encountered as macroscopic plans and involve large technological and financial efforts with the risk of failure of the implementation objective.

Thus, a microscopic plan (from a local point of view) can be highly successful by addressing relatively small areas with a significant concentration of marine energy resources such as the harbor basin or harbor proximities created for the purpose of harboring boats. Here, we identify an area of high energy micropotential, a continuous free surface flux, and a material basis of already present mooring structures. If the objective is kept at a microscopic level in the sense of powering electric boats, generating street lights or floating mooring platforms, the first infrastructural step in the conception of the energy independent port is achieved, Figure 0.1.

THESIS STRUCTURE

The thesis is structured in 6 chapters, preceded by the Introduction. The strategy for their realization aims to present an evolution of the cases studied, starting from current, theoretical aspects, numerical simulations and experimental studies in disturbed regime and continuing with investigations associated with the local energy micropotential.

The first chapter brings into consideration the current state of renewable sources as energy, socio-economic indicators, through innovation and competitiveness of the energy potential at the European, national and local level, as it emerges from the bibliographic study.

Chapter 2 presents the main theoretical notions regarding the effect of wind direction and buildings on a marina in the Dobrogean region, Constanța. Regional as well as local measurements are presented, in areas of interest determined according to general aspects and using numerical simulations. The concept of the atmospheric boundary layer is introduced, taken from the specialized literature, and a study of building embankments is carried out to improve the energy power potential.

The extension of the numerical simulations from the previous chapter is carried out in Chapter 3 as a continuation of the study of the buildings in the port proximity by transferring the results obtained in the study of the behavior of solid bodies to the action of air masses. The obtained results were transferred to initial conditions in the numerical study of the efficiency of the wind turbine. The concept of the neutral atmospheric boundary layer is introduced here, the position of the wind turbine is determined as well as its choice according to the particular case studied. Also, the chapter contains the achievable power ratio under disturbed conditions compared to the power curve provided by the wind turbine supplier.

Chapter 4 is dedicated to numerical simulations of free surfaces of the "dam break" type. Dealing with the dynamic instability of flows with free surfaces in a closed system are presented as numerical simulations of wave breaking. Dam break shock and impact with a first contact surface are highlighted in a two-dimensional domain. The power potential that can be captured from wave energy is presented by proposing the use of piezoelectric materials as integrated components in the contact surface.

The experimental results are the basis of the validation of some numerical cases, these being described in Chapter 5 and carried out under conditions similar to those of the experiment. Following the quantitative confirmation of the solutions resulting from the numerical simulation, they can be extended to cases of high complexity such as the three-dimensional domain.

Chapter 6 concludes the thesis by formulating the general conclusions resulting from the analysis of the obtained results and presents the original contributions made by the paper, focused on the three directions of research - theoretical, numerical and experimental - as well as perspectives for future research development.

The thesis ends with the bibliography and seven annexes, which include the formulation of the turbulence models used, the database of the hydro-meteorological situation from 2008-2019 of the Constanța region, the installation for measuring local parameters on the building of interest, the architectural profiles with the technical elevations related, the implementation code of the neutral atmospheric boundary layer in the numerical code Numeca – FineOpen (recently Cadence), the implementation code for the analysis of the convergence index of the discretization network and the commercial facilities used in the numerical studies.

A series of results presented in the thesis come from numerical simulations and the basis of these numerical methods are performed using the numerical code FluentTM version 12.1 developed by ANSYS for regional simulations of the urban area and the numerical code NUMECA FineOpen with OpenLabs version 6.2 (*Fidelity*, the new name of the code being taken over NUMECA company by CADENCE company in 2020) for detailed simulations of buildings, selected wind turbine and breaking waves.

All the experimental results presented in the thesis were carried out in the Department of Hydraulics, Hydraulic Machines and Environmental Engineering of the Faculty of Energy, Polytechnic University of Bucharest and the local measurements used the equipment from the material base of the "Mircea cel Batrân" Naval Academy Constanța. Exceptions will be the data and results mentioned in the bibliography of the specialized literature.

CHAPTER I
STATE OF ART REGARDING THE CONVERSION OF RENEWABLE ENERGY INTO ELECTRIC ENERGY

1.1. ENERGY INDICATORS

The year 2017 saw a record number of installations in the wind energy sector in the European Union, but the following year, 2018 saw far fewer wind installations. Eurostat reports that the EU added 10.5 GW of capacity compared to 14.1 GW in 2017 (i.e. a decrease of 26.7%) [171÷173]. The EU's maximum net wind electricity capacity expressed as maximum continuously deliverable active capacity increased to 179.1 GW by 31 December 2018. This overall trend is mainly attributed to the sharp decline from per year of new installed capacity in the three main markets of the European Union [184, 186], namely Germany (a decrease of 46.9% to 3263 MW), Great Britain (a decrease of 36.8% to 2 186 MW) and France (a decrease of 27.5% to 1401 MW).

However, not all EU Member States have followed this trend, as the levels of new installations of a significant number of Western and Northern European countries have clearly increased, some showing significant growth rates. This is true for Sweden (689 MW of additional capacity, 291.5% increase), Denmark (631 MW, 158.5% increase) and Spain (281 MW, 108.6% increase). Italy performed very well, with less substantial growth like Denmark and Spain (494 MW, 40.0% increase) [177].

The market decline is an underlying trend in many countries whose wind energy activity has been or has been nearly shut down for several years. About half of the wind turbine bases of the European Union member states have not expanded. One reason for this is that some states have already met their European renewable energy targets for 2020 (or are very close to doing so).

While the EU saw declines in the deployment of new onshore wind connections, offshore wind presented a different picture [156]. According to Eurostat [171], the EU's maximum net offshore wind electricity capacity in 2018 was 18,731.9 MW, which means an additional 2,964.4 MW, similar to the achievement in 2017 (3174.6 MW). Seven European Union countries, Table 1.1, operate full offshore wind turbine capacity. Offshore wind thus accounted for 28.1% of additional connected capacity in 2018, compared to 22.1% in 2017

Table 1.1. Maximum electricity capacity from wind energy at EU level

	2017	of which offshore	2018	of which offshore
Germany	55 580.0	*5 406.0*	58 843.0	*6 396.0*
Spain	23 124.5		23 405.1	

United Kingdom	19 584.8	*6 987.9*	21 770.4	*8 216.5*
France	13 499.4		14 900.1	
Italy	9 736.6		10 230.2	
Sweden	6 611.0	*203.0*	7 300.0	*203.0*
Denmark	5 489.6	*1 263.8*	6 120.6	*1 700.8*
Poland	5 759.4		5 766.1	
Portugal	5 124.1		5 172.4	
Netherlands	4 202.0	*957.0*	4 393.0	*957.0*
Ireland	3 318.0		3 676.1	
Belgium	2 796.5	*877.2*	3 260.7	*1 185.9*
Austria	2 886.7		3 132.7	
Romania	3 029.8		3 032.3	
Greece	2 624.0		2 877.5	
Finland	2 044.0	*72.7*	2 041.0	*72.7*
Bulgaria	698.4		698.9	
Croatia	576.1		586.3	
Lithuania	518.0		533.0	
Hungary	329.0		329.0	
Czechia	308.2		316.2	
Estonia	311.8		310.0	
Cyprus	157.7		157.7	
Luxembourg	119.7		122.9	
Latvia	77.1		78.2	
Slovenia	5.0		5.2	
Slovakia	4.0		3.0	
Malta	0.1		0.1	
Total EU 28	168 515.3	*15 767.6*	179 061.7	*18 731.9*

** Net maximum electrical capacity. Source: Eurostat*

The UK and Germany again had the highest number of new offshore installations. According to data published by BEIS (Department for Business, Energy and Industrial Strategy) cited by Eurostat, the UK added 1228.7 MW of capacity in 2018 (1694.5 MW in 2017), bringing the country's wind power volume to 8 216.5 MW at the end of 2018 [181]. The fully connected wind farms include Walney 3 Extensions Phase 1 – West (66 MW) and Phase 2 – East (329 MW), Galloper (277.2 MW), Rampion (220.8 MW), Race Bank (50.4 MW) , EOWDC (93.2 MW) as well as the partial connection of Beatrice Wind Farm 2 (273 MW). Germany was the second most active country with 990 MW connected in 2018 (1275 MW in 2017), bringing offshore wind farm capacity to 6396 MW. This additional capacity is equivalent to the full or partial commissioning of the Borkum Riffgrund 2 (450 MW) and Merkur (396 MW) wind farms in the North Sea and the Wikinger (350 MW) and Arkona (384 MW) wind farms in the Baltic Sea. Denmark ranked third, with 437 MW connected in 2018, according to the Danish Energy Agency. In 2018, offshore wind capacity was a record 1,700.8 MW, thanks to the commissioning of the Horns Rev 3 wind farm (407 MW).

Belgium stood out by connecting the Rentel wind farm (309 MW), making it the fourth EU country to exceed the 1 GW offshore connected threshold with 1185.9 MW, surpassing the Netherlands (957 MW), which did not connect no additional new installation.

Hydropower is also a small field in terms of public investment in research and development compared to solar power. In this area, the US has the largest public investment in research and development of all the countries considered in this analysis. It is followed by Turkey, Switzerland, Canada and Norway, which all have significant hydropower resources. The EU as a whole has investment values for research and development in the hydropower sector between Canada and Norway. In the EU, the UK, Austria, France and Germany show the highest values. The GDP shares show that the highest shares are found in Switzerland, Norway, Canada, the USA and Korea.

1.2. PATENT FILLINGS

In wind power, China has the largest number of patent applications. Comparatively, the EU has only a third of China's filing figures, although the number of EU filings has increased slightly since 2014. China, however, has also increased its patenting activities in wind technologies.

Germany ranks third, followed by Korea, Japan, the United States and Denmark. This strong position of Europe is largely supported by the strong position of two European countries, namely Germany and Denmark, which together are responsible for more than 70% of all European patents in the field of wind energy. However, Spain, France, Great Britain, the Netherlands and Poland also filed a significant number of patents in this field in 2015.

In terms of the contribution to GDP brought by patents filed with wind energy topics, Denmark is the leading country with the highest value. It is followed by Korea, China, Latvia, Germany and Japan. In terms of wind patent specialization, Denmark in particular shows a high value, implying that wind energy can be seen as an important factor in its domestic energy technology portfolio. High values can also be found for Latvia, Lithuania and Spain. Germany also shows above-average specialization, but it is not as pronounced as in Denmark and the other countries mentioned. This is because Germany generally files a large number of patents in energy technologies, so the effect of wind power patents on its portfolio is not so pronounced.

In hydropower, patenting figures are lower than in wind or solar power. Again, it is China in particular that displays a large number of patents. Japan, the EU and Korea follow, but at a lower level than China. China, the EU 28 and Japan managed an increase in patent filings between 2014 and 2015, while the figures for Korea fell. In Europe, Germany is responsible for 30% of all patent filings in this field, while France is responsible for 15%. Poland, Italy, Romania, Finland, the Netherlands, Great Britain, Slovakia, Austria, Sweden and Belgium also filed more than one patent in the hydropower sector in 2015.

Relative to its economic size, China and Korea reveal the highest patent filing figures per GDP, followed by Slovakia, Romania, Poland and Japan. However, it should be emphasized again that these patents also include single national patent applications, an interpretation in terms of international competitiveness is therefore difficult. The RPA (Revelead Patent Advantage) indicator shows high specialization for Romania, Slovakia and Poland. However, the number of submissions is very low.

CHAPTER II

EFECTUL DIRECȚIEI VÂNTULUI ȘI AL CLĂDIRILOR ADIACENTE ASUPRA UNUI PORT DE AGREMENT DIN MAREA NEAGRĂ

2.1. INTRODUCTION

Wind action is a major factor in achieving a commercial marina integrated into an urban area. These locations represent an interaction between tourism and commercial activities, requiring detailed studies to define the dynamics of air currents in the port area. Numerical simulations have been used in an integrated way in the research of the urban maritime environment. However, literature studies show that harbors are evaluated by air current dynamics only for a limited number of wind directions and/or without considering the effects on surrounding buildings. This chapter discusses the numerical simulation results obtained for different wind directions and speeds. The obtained results show the urban effect on the wind profile in a semi-enclosed maritime area [56]. Thus, the importance of wind effects on the harbor bay is highlighted in terms of the safety of the mooring of boats and, at the same time, determines the potential of renewable energy for a green port.

Romania benefits, through the Black Sea, from an important strategic position having a historical connection with a commercial route from Europe to the Middle East. Energy security is a priority for any nation, but energy independence is a must for Romania, both economically and politically. Under these conditions, a development of technologies for the conversion of renewable energy sources is required, even in the area of Romanian ports.

Romania's theoretical wind potential is the largest in South-Eastern Europe, assessed at 23 TW annual energy potential, and the Dobrogea region has the largest operational technical wind potential in Romania [143, 200]. At the end of 2015, Romania was in 11th place on the European wind energy market with a total installed capacity of 3.2 GW. Also, from the analysis of the wind energy potential in the south-east of Romania over a period of 40 years (1965÷2004) based on meteorological data, it appears that the wind energy potential of Dobrogea is 2.0 GW [110].

Constanța Port is the main Romanian port on the Black Sea. One of the infrastructure development projects promoted within the large infrastructure operational program 2014÷2020 is the modernization of the energy system in the Port of Constanța. The modernization consists in improving the quality of electricity and thermal energy, and the value of the investment is estimated at 29.5 million Euros [142].

2.2. PROBLEM STATEMENT AND URBAN AREA

Port Tomis is a tourist port in Constanța. The harbor was built in 1958 and was achieved by enclosing the bay with two dams: the northern, Y-shaped, 400 m long, and the eastern bluff, 500 m long. Three of the four sides of its (east, south and west) are provided with pillars. The depth is between 0.5 m in the southern part of the bay and 3÷5 m in the northeastern part of the basin. Figure 2.1.a) shows an aerial view of Tomis Bay from the north side and Figure 2.1.b) shows an aerial view from the south side of the bay.

a) b) c) d)

Figure 2.1. Tomis Harbor – Constanța

Figure 2.1c) shows an east view of the bay and Figure 2.1d) a top view of the bay and the Y-shaped design of the harbour. Starting from the eastern part of the bay, the length of the jetty is 320 m. The southern part of the bay is divided into two sections, the first as the south-east part with a length of 100 m and the second as the south-west part with a length of 200m. The last is the western part of the bay, also divided into two sections, the first to the west with a length of 160 m and the second upper and to the north with a length of 100 m as shown in Figure 2.2.

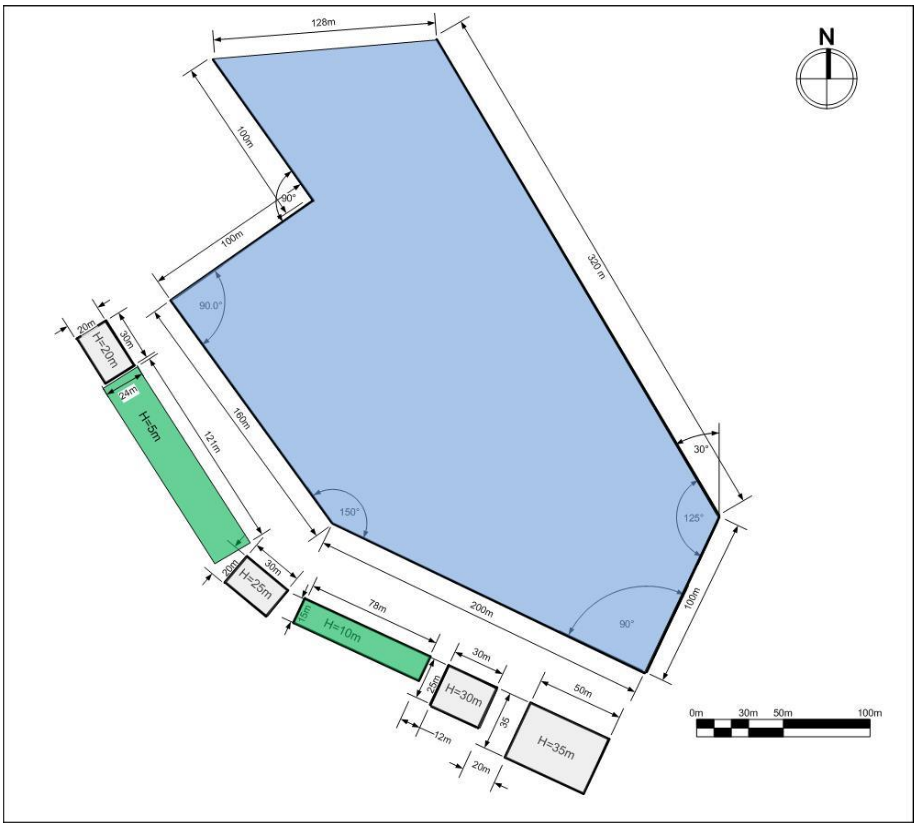


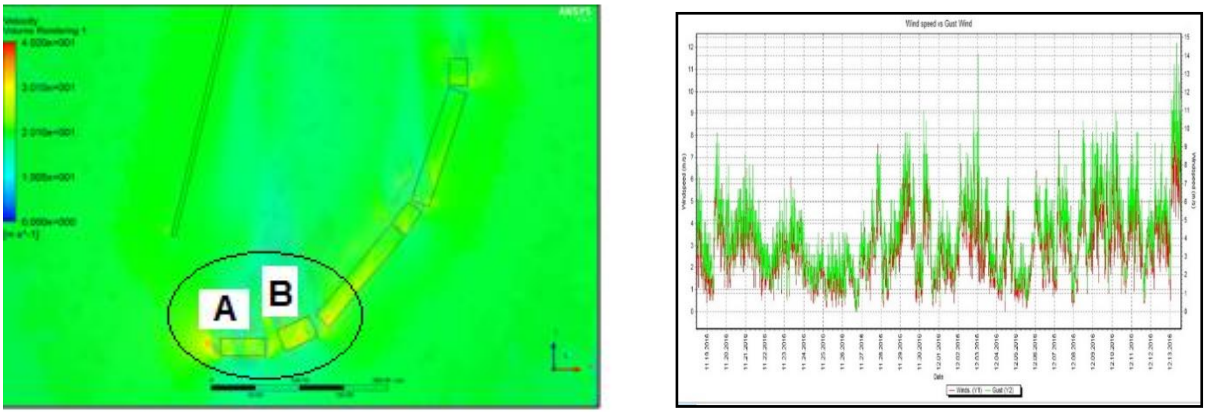
Figure 2.2. Harbor sketch

For the present study, a northern portion of the bay was established, divided into two sections, one right on the edge of the green part of the harbor (Figure 2.2) and the second as a closing portion of the bay with a length of 128m. The area of the bay we set for analysis is 77260 m^2. Also in Figure 2.2 are presented the most important buildings in the harbor bay, colored in gray and a height elevation, colored in green.

The marina bay and surrounding buildings are located on flat land with a maximum height difference of 5 m, and the buildings built on the edge of the bay consist of mid-rise and high-rise hotels. The height ranges from 5 m to 45 m. Numerical simulations need the surrounding aerodynamic roughness height y_0, which was determined based on the updated Davenport roughness classification for an upstream distance of about 10 km [140].

2.3. STUDIUL UNUI ANSAMBLU DE CLĂDIRI

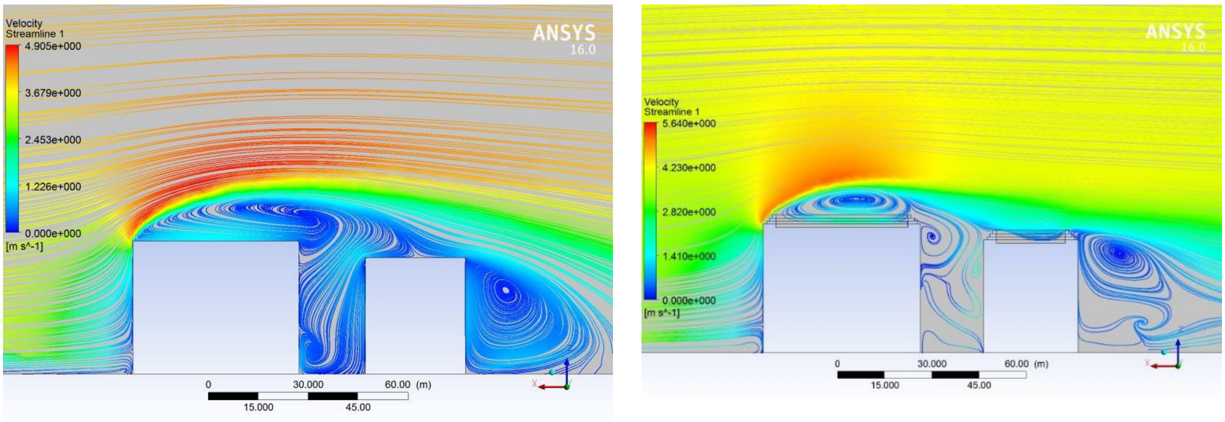
The port domain, from the study above [56] presents a local micro-energy potential with a relatively high velocity profile along the tallest buildings in the domain, $H = 40m$ building A and respectively $H = 35m$ building B, (Figure 2.8.a). From this point of view, this region was isolated and further a local analysis was performed along the structure of the two buildings.



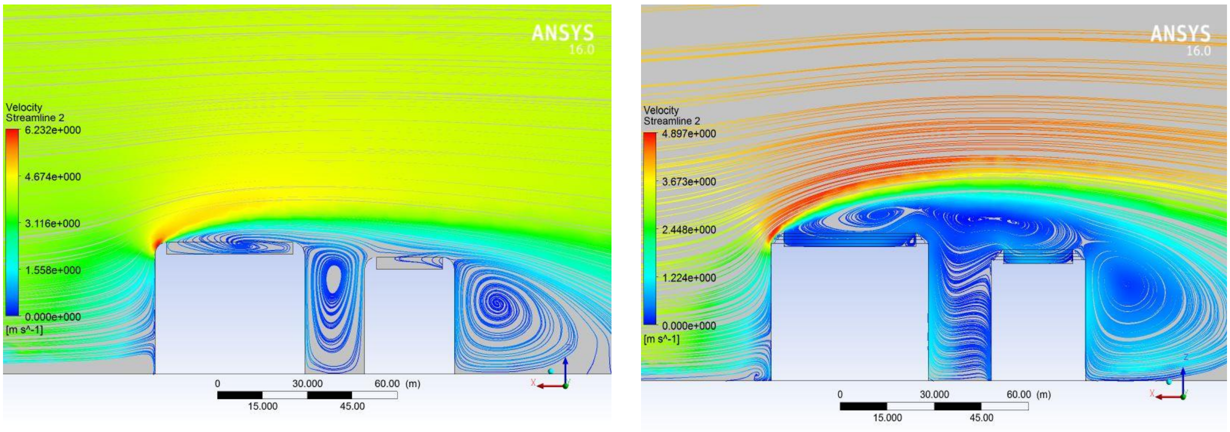
a) b)

Figure 2.8. The location proposed for the wind measurement devices

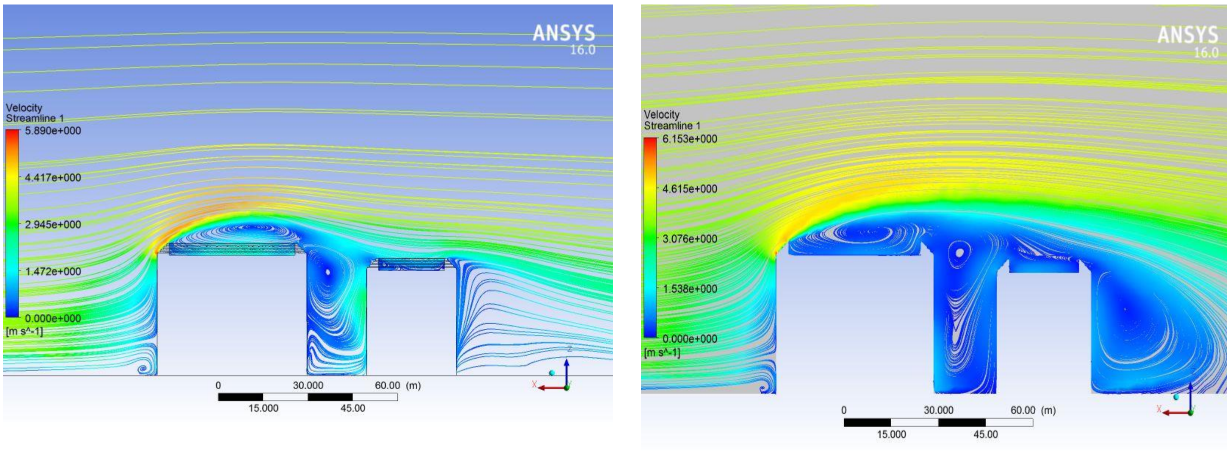
The database of the automatic meteorological station Constanța was used, being a component of the Constanța Maritime Hydrographic Directorate of the Maritime Meteorological Surveillance Network of the Naval Forces regarding the speed and general directions of the wind in the Constanța area (Annex A 2). The measurements give us values of relative air pressure, temperature, wind speed and wind gust. The measurements at the front of the premises (Figure 2.8.b) revealed that the minimum wind speed is 2 m/s, and the maximum wind speed is 8 m/s. The average speed near the sea and the harbor was 4 m/s, and the stable direction was east (90°).



a) case 0 b) case 1



c) case 2 d) case 3



e) case 4

f) case 5

Figure 2.11. Wind streamlines over the buidlings – horizontal sections.

CHAPTER III

NUMERICAL MODELING OF A WIND TURBINE IN A COASTAL URBAN ENVIRONMENT

3.1. INTRODUCTION

Research and investments in the energy sector are increasingly concentrated in renewable energy, in a framework where decentralization plays an important role [1, 35, 79, 80, 86, 144]. In this scenario, low power wind turbines are one of the most promising solutions [48]; Currently, small vertical axis wind turbines (SVAWT) by their simplicity and good performance in disturbed flow fields compared to small horizontal axis wind turbines (SHAWT)), are a good alternative for "green" type buildings (eco friendly) in the urban environment.

Computational Fluid Dynamics, frequently abbreviated CFD, has become a very useful means of scientific investigation to provide detailed information about the flow of air masses in complex geometries, such as the flow domain described by urban architecture [117, 128]. In this regard, RANS (Reynolds-averaged Navier-Stokes) models offer a balanced trade-off between solution accuracy and computational time [111, 124, 125]. Conventional wind profiles (as input data) proposed by *Richard and Hoxey* [107] suffer from horizontal inhomogeneities once the boundary layer is applied under standard conditions. One of the reasons for the breakdown of turbulence models (used in numerical simulation methods) is the lack of consistency between the fully developed input profiles and the boundary layer formulation method [74, 97, 103]. Thus, the geometric architecture of urban buildings introduce swirling and recirculation zones that are not reproduced by standard two-equation models [34, 39, 69, 76, 97].

3.2. URBAN MODELING GUIDE

A number of general recommendations for sizing the discretization domain can be listed by [44, 45, 130]. This study considered the following:

a. Surrounding urban environment: tall buildings, H_n, of the skyscraper type if their height exceeds the distance of 6H_n from the local area of interest;
b. Vertical extension: a maximum extension of 5H_max above the tallest building in the interest group to avoid artificial acceleration of fluid flow;
c. Downstream extension: exit condition located at a distance of 15H_max from the last building in the interest group.

The purpose of this paper considers a general wind-dominated direction because the influences of different wind directions have been evaluated and exploited in the previous chapter. Thus this dominant direction highlights the maximum energy potential reached in the determined location as well as the maximum efficiency of the wind turbine in conditions of maximum power.

In Figure 3.1 the coastal area related to the port of Tomis is marked by the aerial view, the area of local interest is marked with a red border and the target buildings are marked with a green border. These general coastal areas and local buildings of interest were printed in a terrain sketch that followed the standard numerical simulation process according to the software used.

The next step consisted in evaluating the wind resources by using a wind speed recording meterological station, Figure 3.2, and Annex 3. The results of the local records could be validated with data from the automatic meteorological station of the Constanta Maritime Hydrographic Directorate from the local section of the National Administration of Meteorology, Annex 2. The general direction of detailed analysis for the purpose of determining the energy potential found as follows: the dominant wind direction is 135° (South East) with an average entry speed of 5m/s at a height of 44m compared to sea level representing the most frequent direction during the measured period with an average gust variation of 6m/s.

The results of the analysis are as follows:

$$GCI_{12,TKE} = 1{,}64\% \qquad GCI_{23,TKE} = 0{,}46\%$$

$$GCI_{12,U} = 3{,}14\% \qquad GCI_{23,U} = 1{,}19\%$$

Due to the high computational effort for the upper grid, the medium grid discretization was chosen for the study of the wind turbine location considering the differences with the upper grid.

Also, the dimensionless wall distance y^+ is between 35 ÷ 400 around the buildings for the middle grid and between 30 ÷ 250 for the upper grid, ensuring a fine resolution for the chosen turbulence model.

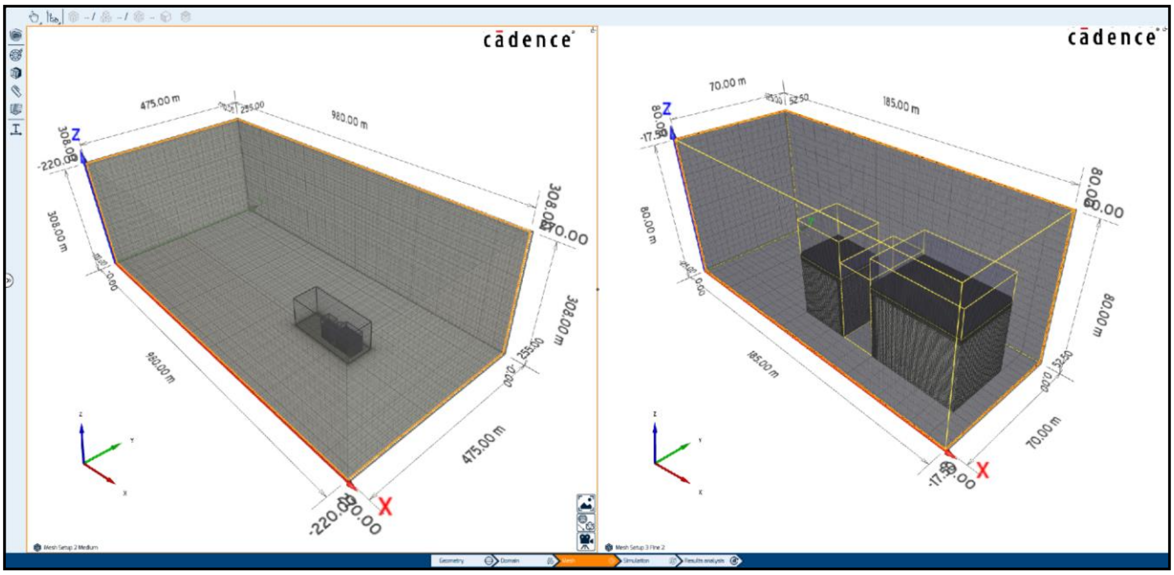


Figure 3.5 Grid domain of the local buildings

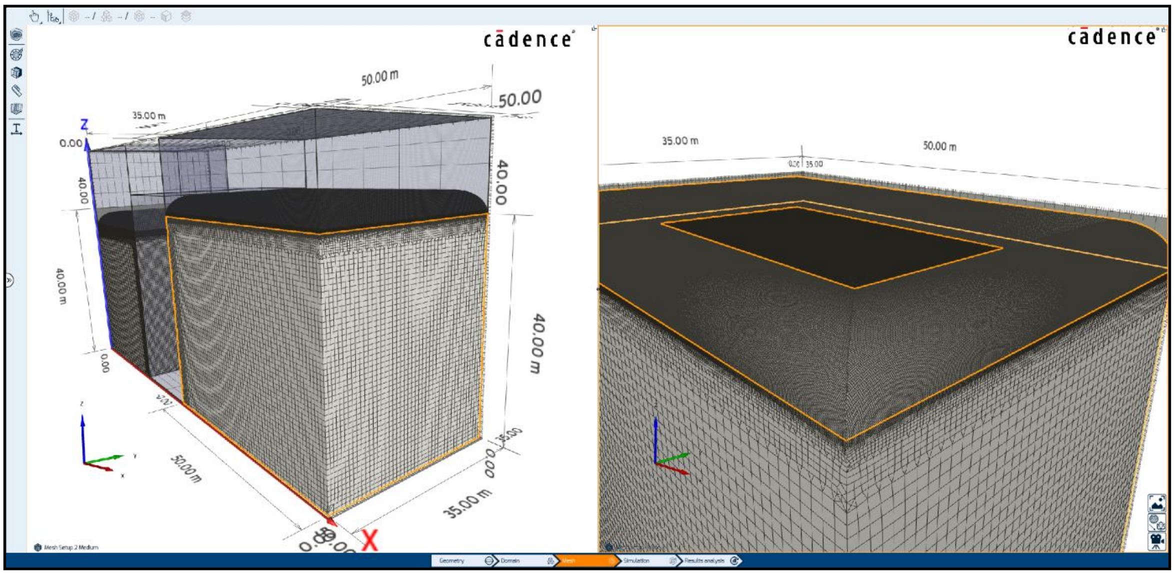


Figure 3.6 Grid domain of the local position of the vertical wind turbines

Figure 3.11 shows the configuration of the velocity field at the entrance to the numerical simulation of the behavior of the wind turbine.

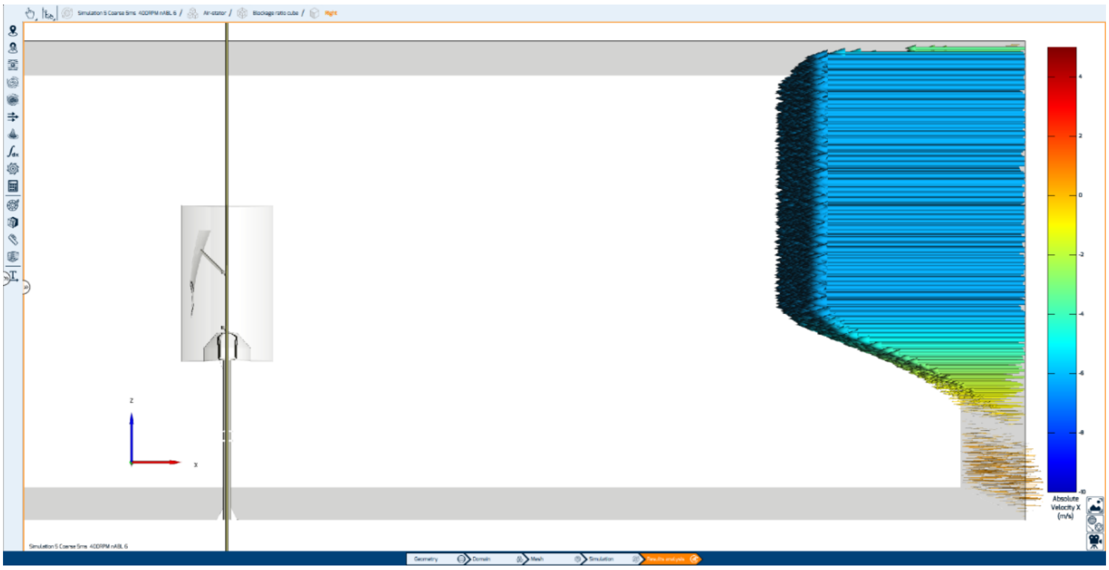


Figure 3.11. Initial conditions for the wind turbine domain with the wind profile resulted from the neutral ABL study

The analysis shows that the energy potential available in the study area can be doubled by installing two wind turbines whose operation will be influenced by the profiled walls of the terrace of the building where the turbines are installed, see Chapter II.

A three-dimensional exposure of the air mass in the flow domain is shown in Figure 3.12.

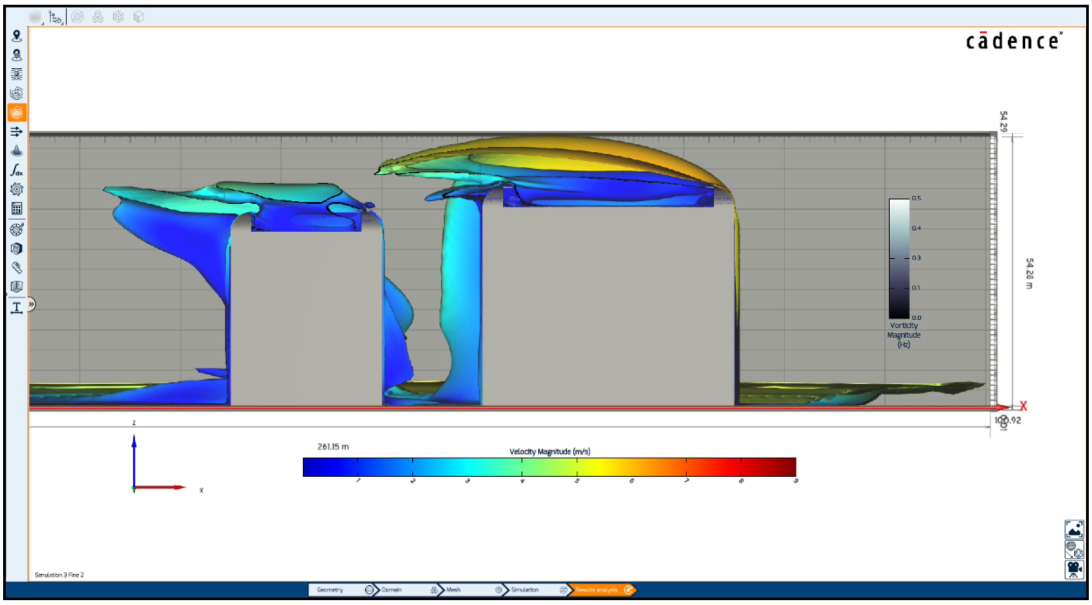
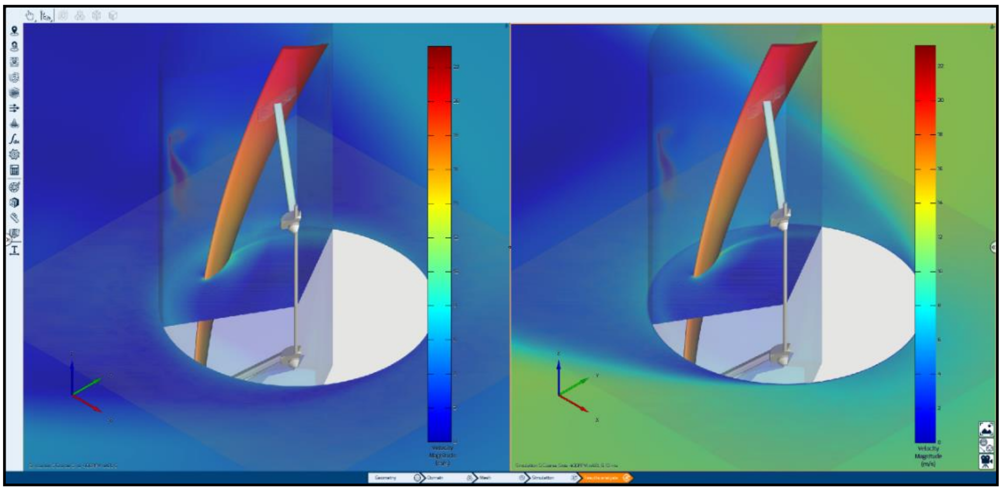


Figure 3.12 Contour of the relative velocity over the vorticity iso-surface

The results of the numerical simulations are represented as velocity profiles both in the stationary domain and in the rotating domain. These are highlighted as streamlines, isolated volume surfaces, and contours of the entire domain.

Finally, the power of the wind turbine is analyzed to determine if the power described by the supplier coincides with the results of the numerical simulations. The power of the wind turbine is compared with the available sources: the documentation of the commercial wind turbine (Appendix 7); the generalized empirical formulas regarding the power generated by the wind and the results of the numerical simulations.



a) viteza vântului 5 $\mathrm{m/s}$ b) viteza vântului 10 $\mathrm{m/s}$

Figure 3.15 Angular velocity of wind turbine, wind velocity profile and the edddies generated by the blade contour

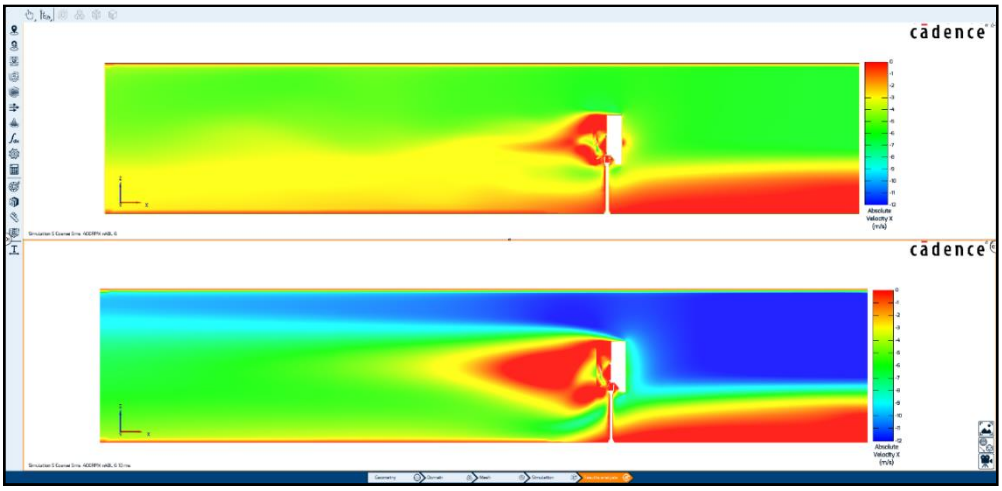


Figure 3.16 Velocity profile V_x in longitudinal section – above with wind profile of 5 $\mathrm{m/s}$ și below wiht wind profile of 10 $\mathrm{m/s}$

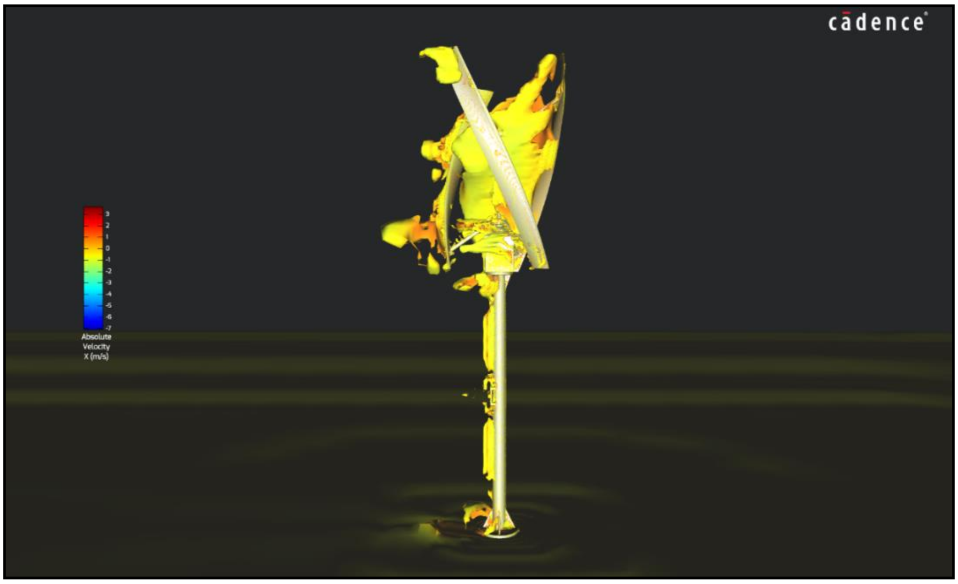


Figure 3.18 Vortices generated by wind the profile, 5 m/s, in respect with non-rotating wind turbine

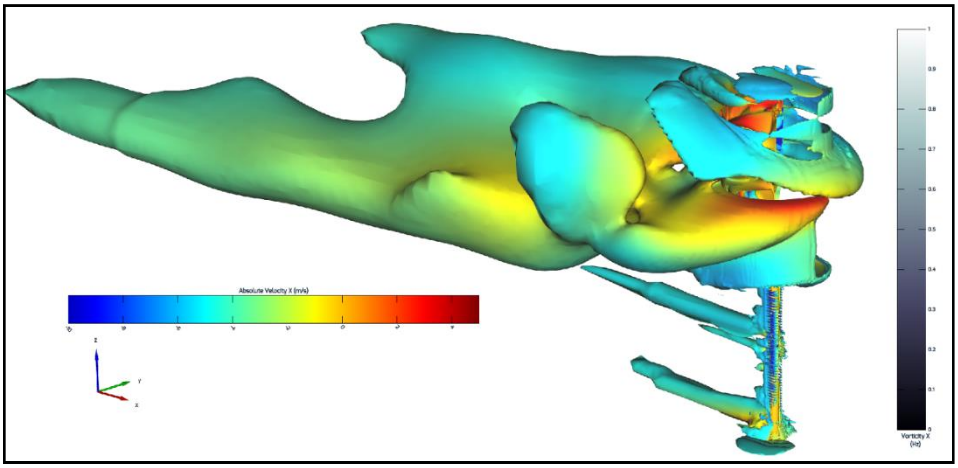


Fig. 3.19 Vortices generated by the wind profiles, 5 m/s, in respect with rotaitng wind turbine

Figures 3.18 and 3.19 highlight two distinctly different cases with respect to the bearing surface of the wind turbine. The first figure shows the vortex shedding when the wind turbine is non-operational, non-rotating, and the 2nd figure shows the vortex trail when the wind turbine is operational at full capacity. This comparison suggests the required space available between turbines, in cases of urban wind farm implementation.

CHAPTER IV

CONTRIBUTION TO THE WAVE ENERGY HARVESTING BY MODELING A WAVE IMPACT OVER A FLAT SURFACE

4.1. INTRODUCTION

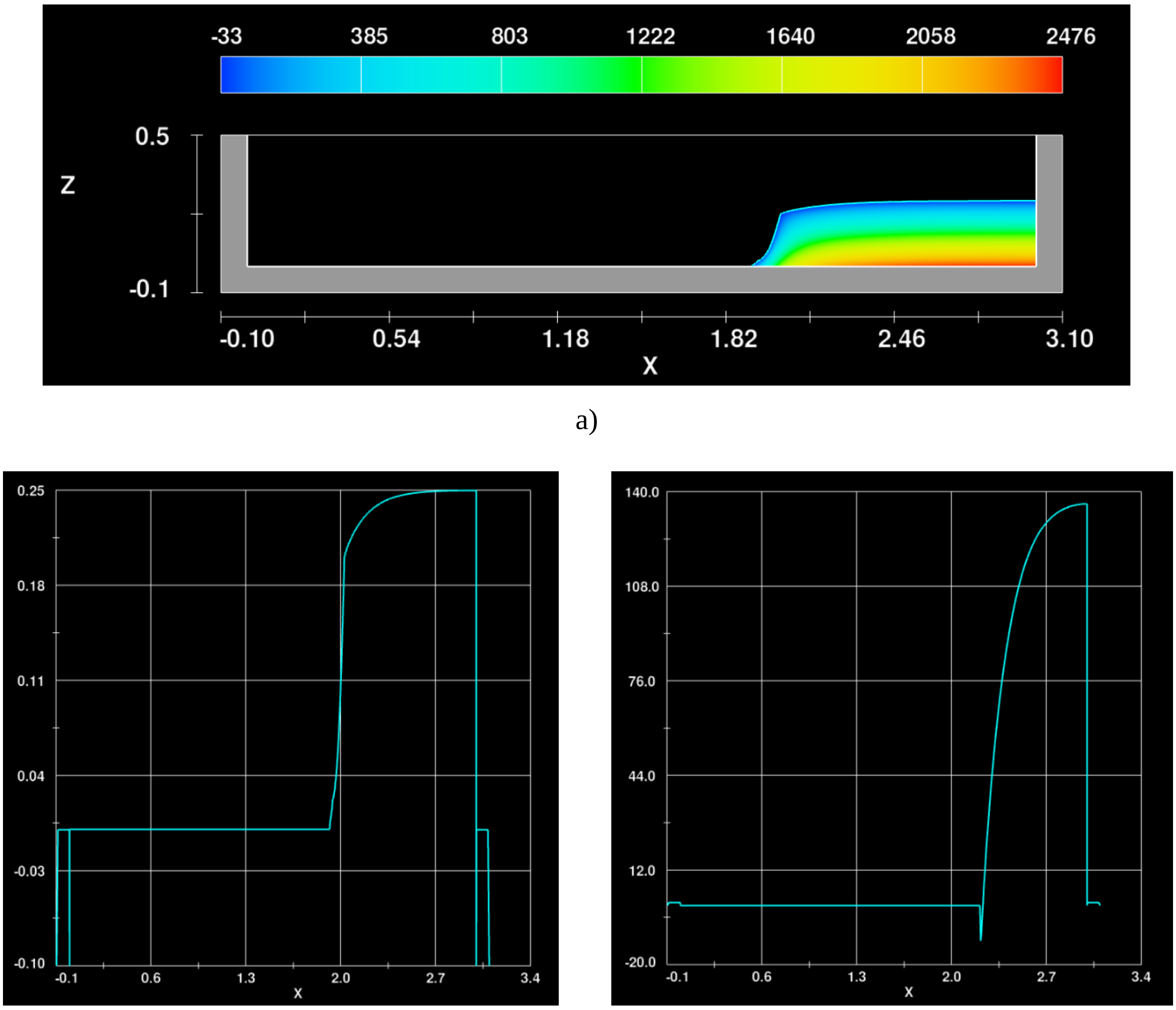
The sea has always exerted its inescapable fascination on man. Waves breaking on rocks or a beach allow one to understand the power available in this continuous movement of them. This continuous power, globally distributed and relatively easy to access, makes wave energy an interesting phenomenon, so that it counts among the most promising renewable energies [165]. Precisely from the comparison with other forms of energy, exploiting the potential of this form of energy can generate a motivational challenge [6, 18, 141]. The different power densities of some of the most well-known renewable energies can be explained by the process of wave formation: waves are mainly generated by the interaction between the wind and the sea surface. The constant mechanical action of the wind, which acts as a tangential stress, leads to the formation of waves [201]. Wind itself is a derivative of solar energy.

The evolution of these physical phenomena develops an increase in the energy potential so that the energy density can be expressed as a linear available resource power [25, 31]. Depending on the geographical distribution, we can distinguish the following two types of renewable energy resources:

a) On the one hand, on-shore devices, such as wind energy potential, solar and other hybrid type systems that offer the possibility of having the source of energy generation close to the place of use.
b) On the other hand, wave energy that reduces land use (on-shore) and eliminates human visual impact.

Another comparison factor concerns predictability: the wave energy resource is characterized by a high degree of predictive reliability compared to solar and wind resources [26, 28]. To this end, several theoretical aspects related to the statistical estimation of wave energy have been developed to represent the source in terms of average wave power and the return value of typical and extreme events in different coastal areas [7, 33, 65]. This facilitates the integration of renewable energy into the continental or island power grid and consists of a reliable generation node in smart grids [37].

Another important aspect is the availability of the resource: wave energy can be harmoniously integrated with solar and wind systems. Indeed, a very rough sea usually does not coincide with a day of intense sunshine and frequently comes as a result of a phase of intense wind. This allows the creation of an integrated, time-distributed energy mixture [190, 197].



a)

b) c)

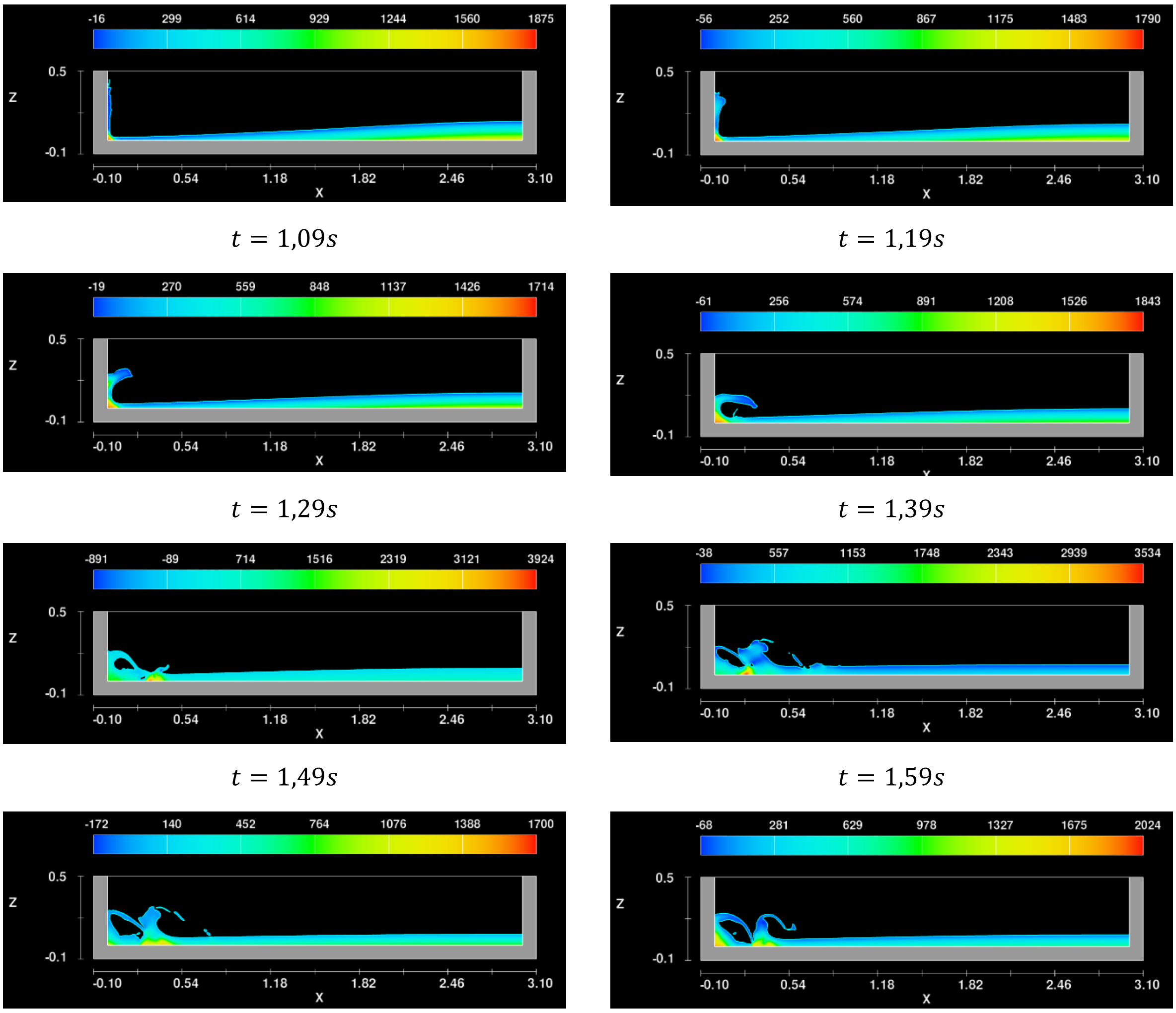
Figure 4.10. Dynamic reprezentation of the dam break ar $t = 0{,}1$ s: a) pressure b) free surface graph c) pressure graph

The "dam break" type case can be highlighted in Figure 4.10. This physical phenomenon, encountered in hydropower, describes a shock of an inverse negative wave as the exposition of a parabola with the vertical axis of the profile of the given free surface. This shock can be visualized in the pressure and free surface plot. The plot of the free surface shows a fast type void that evolves over time.

The following representations will describe the time evolution of this voiding phenomenon with rapid fluid removal by choosing the most significant points in the unsteady flow.

The flow transition to the opposite end of the domain takes 0.8s. The contact with the wall describes a form of pressure (like a damping one) and an energy transfer between the two domains is also realized. The impact can be characterized as a devastating impact because comparing the hydrostatic pressure from the point of initial condition to the point of wave run-up a pressure increase of a second order of magnitude is observed. The slope of the fluid flow and its drift in the opposite wall is observed in the free surface plot. The maximum height point at impact reaches 0.49 m and the pressure distributed at the point is 389 Pa.

A technical configuration for achieving this capture is represented by piezoelectric materials [71, 134, 138, 146]. According to [159, 163], the maximum power achieved by the best performing piezoelectric material is 120 mW. The contact surface available in the numerical simulation setup is up to 3 piezoelectric materials. But the optimal micropotential capture space will only be limited to the contact of 2 piezoelectric materials [168]. Thus, the total maximum power generated will be 840 mW.



$t = 1{,}09s$ $t = 1{,}19s$

$t = 1{,}29s$ $t = 1{,}39s$

$t = 1{,}49s$ $t = 1{,}59s$

$t = 1{,}69s$ $t = 1{,}79s$

Figure 4.14. Time evolution of the dam break between the first shock wave and several bounces in the domain in an enclosed system, $t = 1{,}09 \div 1{,}79$ s

CHAPTER V

VALIDATION OF THE NUMERICAL RESULTS

5.1. GENERAL

The analysis of numerical simulations involves the evaluation and validation of the results by well-established experimental methods. The parameters of the initial conditions have a very important role in the description and evaluation of the physical phenomenon subjected to the experiment. Thus, the roughness of the surfaces involved in the experiment must be well defined to have similar initial boundary conditions between the test bench and the parameters of the numerical algorithm used.

The process of defining the dimensions of the stand required a numerical error reduction study done by simple numerical simulations to detect the occurrence of numerical errors due to the dimensions of the test stand. This numerical procedure reduces the errors of the stand dimensioning by the rounding method by using iterative calculations of precision up to 16 significant tenths.

In the present case, it is proposed to dimension a wave generation pool in two configurations, one involving the simplicity of negative wave breaking in a finite domain so that the domain then has the possibility of installing a wave generation flap through a camelar structure managed by an electric motor. If the dimensions of the pool are too small, the effect of rolling the wave from a static position generates permanent shocks in the field that will lead to the composition of new waves. If the dimensioning of the basin is too large, the opposite effect appears in the numerical relation – experiment imposing a very large discretization domain that will lead to a much too large and inefficient calculation effort.

5.2. QUANTITATIVE VALIDATION OF EXPERIMENTS

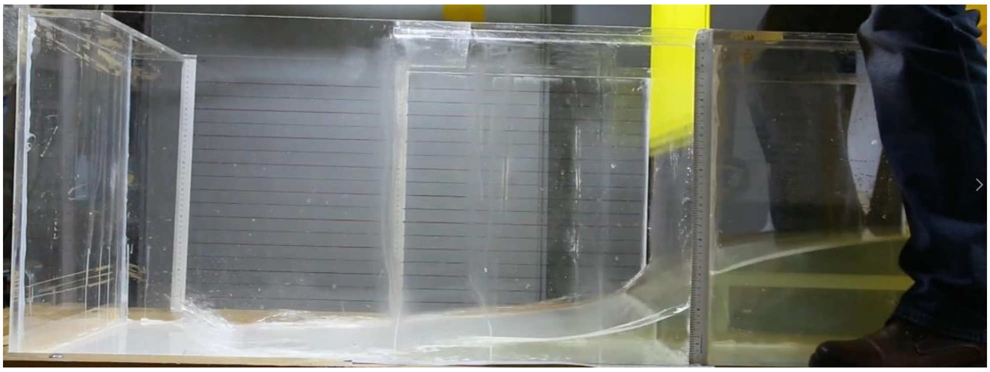
The method of direct visualizations requires the comparison at different time points of the fluid flow trajectories. Digital elements were used to eliminate the synchronization errors between the numerical result and the experiment and the modern effect of slowing down the recordings was taken into account.

The drilldown sequences, consistent with the way the vertical panel is handled between the two basins, are selected as follows:

1. The fast emptying wave breaking sequence.
2. The sequence given by the maximum impact of the wave with the wall opposite the dividing plane wall in the direction of initial positive movement of the wave.

3. The sequence given by the impact of the wave with the wall opposite the dividing plane wall in the direction of wave retreat (negative wave).

$h_{12} = 0{,}25$ m



$h_{21} = 0{,}30$ m

$h_{21} = 0{,}35$ m

$h_{21} = 0{,}40$ m

Figure 5.3 The experimental cases of dam breaking from the small section to the large section and vice versa at the specified static heights

$t_{12} = 1{,}4\ s$

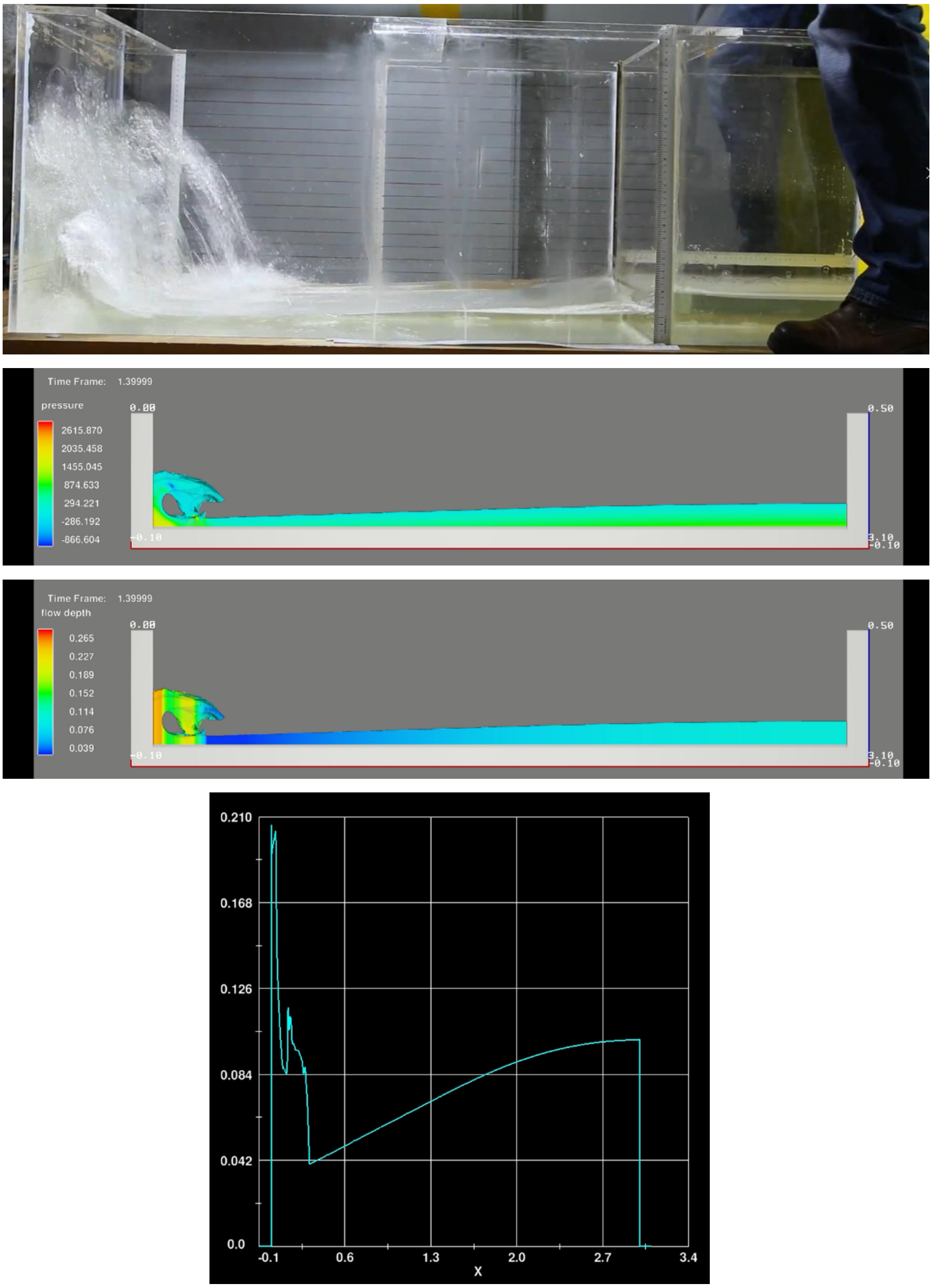


Figure 5.7 The experimental case of the dam break from the small section to the large section and for the static height $h_{12} = 0{,}25$ m and $t_{12} = 1.4$ s

CHAPTER VI
FINAL CONCLUSIONS

6.1. GENERAL CONCLUSIONS

The fundamental purpose of the research in this doctoral thesis was to investigate, analyze and model the energy micropotential from renewable sources in sustainable urban development, under the conditions of changes in the direction of flow and formation of eddies.

The doctoral research project carried out the following applied and numerical studies:

- The real power potential of the bay of Tomis port, Constanța, for sustainable energies in view of the conceptual realization of an energy-independent E-port.
- Conception, design and construction of architectural profiles to study the performance of structured profile flows to improve flow.
- Identification of recirculation and reattachment lines from the flow field in order to increase efficiency in relation to energy production.
- Realization of numerical simulations using three-dimensional working geometries for cases of flow with a vortex line.
- Extending the numerical results obtained for architectural profiles by arranging walls with straight, curved and combined edges.
- Realization of the wind profile in the atmospheric boundary layer through numerical simulations based on local urban hydrometeorological measurements.
- Delineation of areas of interest with high energy capture potential for the location of specific wind structures.
- Numerical analysis of the wind turbine performance in relation to the eddy currents resulting from the segmentation of the area delimited by the local atmospheric boundary layer.
- Extraction of relevant quantitative data in order to determine the optimization parameters of the control of wind turbines in the induced resistance reduction regime.
- Realization of a procedure for evaluating the influence of the urban structure on the determination of the local energy micropotential in the E-port concept.
- Engaging the physical instability of unsteady free-surface flow of the "dam break" type in a reliable two-dimensional numerical simulation.
- Evaluation of the breaking shock, the propagation of the discharge wave and the impact with a contact surface in the non-permanent flow regime.

- Experimental measurements and numerical simulations in non-permanent flow regime aiming at the modification of the breaking parameters of the negative emptying wave at different height levels.
- Experimental measurements, through direct visualizations, of the evolution of a negative discharge wave in a limited time.
- Evaluation of the energy micropotential in the repetitive contact points with the local constructive design of some finite piezoelectric materials.
- the creation of a procedure for evaluating the influence of the urban port water area on the transfer of micropotential energy captured by the shape of the waves through a high degree of predictive reliability.

6.2. ORIGINAL CONTRIBUTIONS

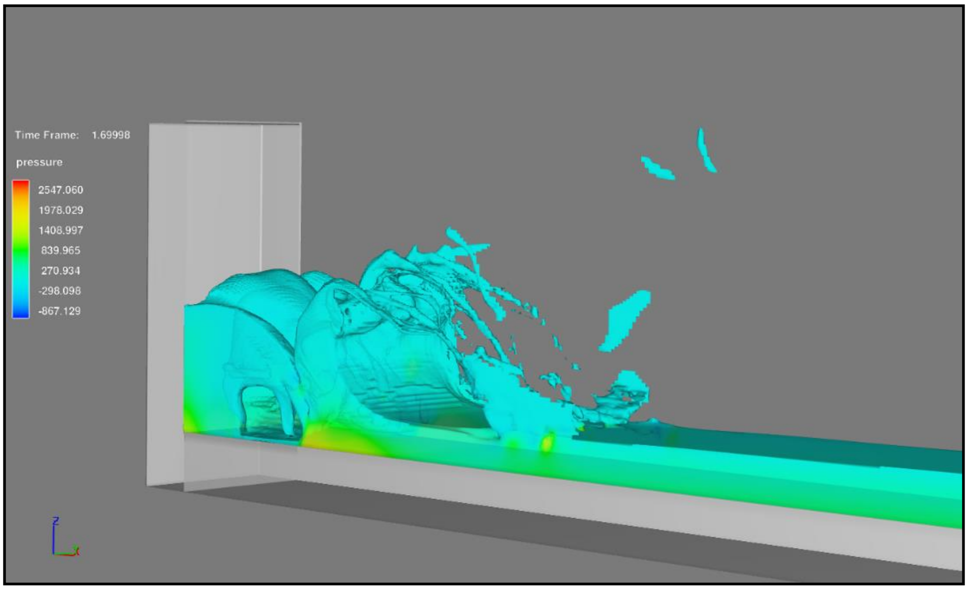
The present work makes original contributions to the experimental and numerical study of local urban vorticity flows:

- Design of architectural constructions with an attractive aesthetic impact and the loss of the spectrum of visual integration of the turbine support structures in relation to the pedestrian walkways.
- The arrangement of a set of wind turbines in the urban environment with the possibility of increasing energy production in the points of low performance of classic wind turbines.
- Proposing a wind energy capture system under passive control through a mechanism that can change its rotation pitch to cover a wide spectrum of wind speeds in order to achieve a high energy potential.
- Proposing an aerodynamic blade profile with "winglet" type deformation to reduce vortex trails in the macroscopic assembly of the building roof configuration in order to optimize the interference created by the assembly of vertical axis and horizontal axis turbines.
- Uncertainty analysis of numerical simulations by highlighting numerical discrepancies in different calculation algorithms performed.
- Qualitative validation of numerical simulations.
- The proposal for the placement of piezoelectric materials on the hull of the ship in order to create micro-energy potential for the purpose of independent coupling to the local current distribution grid.
- The integration of piezoelectric materials offers the opportunity to improve survival procedures at sea in extreme conditions of failure of the operational support facilities of boats and protect human life at sea.
- The integration of piezoelectric materials in the port water area by placing on the construction of the boat mooring berth a sector dedicated to capturing energy through the transport of wave energy.

6.3. PERSPECTIVES

Fundamental research in the field of vorticity flows represents the basic pillar for the development of engineering applications and procedures and the main results highlighted in this thesis show feasible extensions with prospects for further development.

- The consideration of the urban case in the determination of the wind profile in the atmospheric boundary layer can lead to higher quality results for the aspect of numerical simulations on 3D domains by applying proximity porting on a domain in a wider field.
- The expansion of the numerical discretization domain and the short imposed time step (server having a processor with 320 cores and 1024 GB of RAM memory) led to a higher computational effort. Thus, higher calculation procedures were used in parallel. |A finer domain discretization in order to realize the non-stationary flow, will overload the computing power and the storage space so that the efficiency of parallel type calculations and storage methods will become a primary necessity in the implementation of engineering practices in the industrial field.
- The domain and the discretization methods require the user to pay special attention in the areas of interest with high precision and thus the time allocated to this step in numerical simulation subjects the engineer to a high time effort. The automation of certain steps in the discretization methods are becoming a main direction of development in the amortization of the time allocated to the industrial platform.
- Implementation of the concept of the *neutral boundary layer* in the procedures for determining the energy micropotential as well as in the architecture of the calculation algorithms of commercial numerical simulation platformers.
- The extension of the research related to the building in the present study can also be developed on the extended energy micropotential, in the case of a set of obstacles.
- It is also required to make the performance curve of the Gorlov type wind turbine also in the case of positioning the turbine axis in the horizontal plane and compare it with the catalog data for the vertical position (recommended as the operating position, usually).
- The present work uses classical turbulence models in RANS-type simulations, which often present challenges in obtaining accurate results for specific cases. The implementation of numerical simulations such as DES or LES can correct certain deficiencies of these classical models. It is recommended to develop the study for complex flow domains, in which case the performance of RANS-type simulations may change.
- The nature of two-dimensional simulations of "dam break" type flows causes the expansion into the three-dimensional domain for the study of some cases of flows of negative flow waves. The three-dimensional development of the shock, flow front and wall impact will describe different spectra than plane flow thus inspiring additional information regarding the contact front on the surface of piezoelectric materials (Fig. 6.1). It is recommended to continue this study for 3D flow domains.



➢ **Fig. 6.1.** Spectrul deferlării de val în domeniul de lucru tridimensional

- In the case of numerical simulations of the negative emptying wave, certain numerical anomalies were identified that could not be categorized as physical or numerical status. The development of this study remains as a main research direction for the future.

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Figure A3.1 Ultrasonic anemometer type WindMaster 3 - testing and calibrating

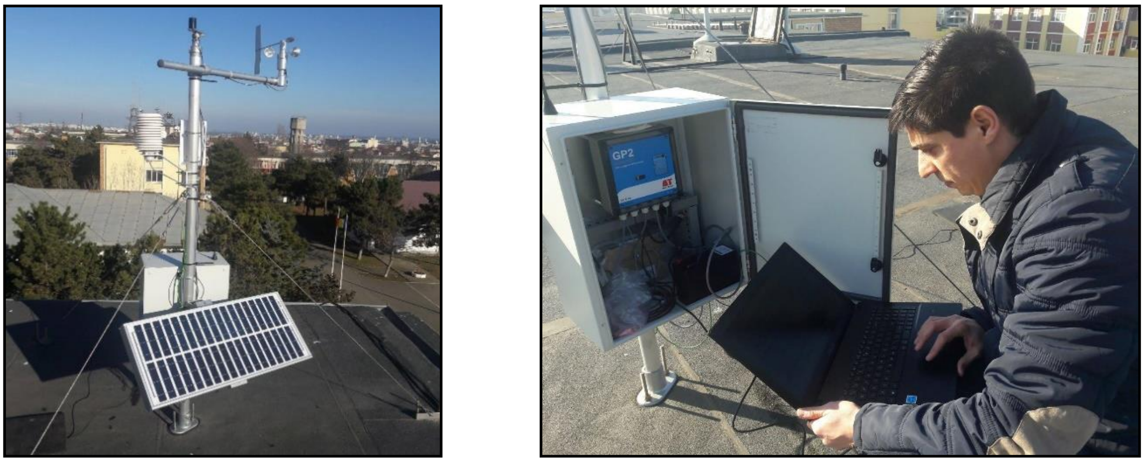

Figure A3.2 The hydrometeorological installation type WS-GP2 - testing and calibrating