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Design for wind comfort.
The CFD assessment over a future outdoor public space

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Abstract

People's comfort depends also on the wind condition, which is strongly guided by urban spatial design. This paper focuses on climatic conditions and pedestrian behavior in an urban area. These studies emphasize the connection of people's attitudes with physical and climatic ambiance. The challenge of urban designers is to consider the surrounding structures and the topography to design a comfortable outdoor public space. Two criteria are used to assess the wind in a public space domain. The CFD was used as an instrument to analyze pedestrian wind comfort in the outlined environment. This study has come to important findings related to the air movement in and around the studied domain: High-velocity wind can be a nuisance for most creative activities in the outdoor public space. This paper provided a velocity map for future recreational activities inside the current building pattern. The effects of these architectural patterns were discussed.

Keywords: Outdoor public space, building configuration, wind velocity, CFD, comfort

1. Introduction

Nowadays, the concern in urban safety is raised globally, since the population living inside the urban area is increasing dramatically. More than half of the world population is living in cities or towns with a growing tendency in the upcoming years [1]. In the past 50 years it is observed an increase in cites and town population. By 2050 around 7 billion people or over 2/3 of the world population will be living in urban areas, consequently to the rapid economic growth [2]. Much research is focused on urban environment climate, finding solutions to improve the conditions to a better living habitat. Wind condition is also related to the performance of buildings in an urban area [3]. People's comfort also depends on the wind condition, which is strongly guided by man-made barriers and the urban spatial morphology [4]. City authorities are often obliged to find immediate and long-term solutions to improve microclimate quality in the physical layout of existing high-density cities. Particularly in new urban areas, they often order aerodynamic studies focused on wind comfort to the pedestrian level. Recently, many authorities have given permission to new development areas after wind comfort studies, focusing on pedestrian levels. Therefore, wind safety has always been an issue to consider for people's comfort, typically those living in cities influenced by high-speed wind.

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Every season, people living inside cities enjoy outdoor public areas hence, urban designers are interested in confronting their concepts also with microclimate issues. An interesting domain remains the implementation of comfortable spaces for people living in urban areas. Regularly, outdoor public spaces are conceived as places to walk, relax, interact, and perform between people. Cities reflect the societies that have shaped them, and they participate in shaping human behavior [5]. Often, is distinguished a symbiotic relationship of outdoor public spaces and high-rise buildings, particularly in new urban developments. These buildings in many ways influence the public spaces close to their basement. High-rise buildings often show fascinating elegant shapes, but they are liable for significant changes in the urban area's environmental conditions. The challenge of urban designers is to consider the surrounding structures and the topography in order to design a comfortable outdoor public space. It is also known that wind speed increases in open spaces. This study analyzes people's comfort and public space in order to suggest an outdoor environment with a framework to counter the desired wind conditions.

Much research is done over the years, focused on the urban space's configuration concerning people's comfort. The future of urban public space configuration is directly affected, particularly by wind speed and other environmental elements [6]. The unpleasant environmental conditions generated in an area in San Francisco, principally wind and sunlight, derived by the presence of multistory buildings [7, 8]. These studies emphasized the importance of the design under regional climatic elements. Also, environmental elements and architectural design altogether, affect the user's perception, related to distinctive places [9]. Other studies used real measurements to quantify the relationship between wind conditions and pedestrian behavior [10]. Other studies were focused in personal behavior toward rapid change in wind speed [11]. Other researchers emphasize that people comfort is related not only to environmental factors, but also to other external elements such as clothing, age, and gender, [12]. People's comfort and healthy life in public space areas is yet a major concern to many researchers [13-16]. All these researchers are focused on climatic conditions and patterns of behavior in an urban area. These studies emphasize the direct connection of people's behavior not only with physical and climatic ambiance but also to other social aspects. Hence, urban design impacts people's quality of life.

The wind is an invisible fluid hence, it is difficult predict. Therefore, the wind is widely being factorized in the urban environment by using computational tools. Several techniques have been used to assess wind flow, but it seems that only one, above all methods, prevailed over the last 50 years. If it is considered the affordability, accuracy and information availability, computational fluid dynamics (CFD) is one of the most effective methods to evaluate the building environment design [17]. On-site analysis and wind tunnel methods present incomplete information in comparison to CFD. Wind tunnel evaluates only few areas in a physical model, and it doesn't cover the whole flow field at once [18]. Because of these advantages, CFD simulations are commonly applied to analyze the wind flow in environmental sensitive domains [19]. The CFD has been used for partial information and rarely as part of a complete study on pedestrian safe and comfort [20, 21].

Several researchers highlight the Raynold-Averaged Navier-Strokes (RANS) as a CFD mathematical model [22]. RANS model is also used to determine the wind flow pattern to evaluate the influence of the domain's geometry [23]. RANS CFD simulations are an effective method to assess pedestrian wind comfort and safety in urban areas [24].

1.1 Case study.

Rapid urbanization also affected Tirana due to fast economic changes. The urban development is often chaotic, and the green space is decreasing constantly, giving space to buildings and concrete pavements. The local authorities intended to expand the future development of the city by extending the main boulevard in the northern part of it, renovating the banks of the river Tirana and the rest of the area. That part of the city presents a lot of environmental challenges such as air and water pollution, urban sprawl, waste disposal, etc. The area close to the river provides an open corridor for the wind to penetrate at high speed. In most cases, areas affected by strong wind are located along the seaside or close to riverbanks [32]. There were several proposals, but the winning one suggested a pattern of public spaces extended along the newly designed boulevard. One of the most discussed domains was the new central park positioning. This public area will be surrounded in all its contour by tall buildings adjacent to the riverbanks, (Figure 1). During the project presentation, the designers provided environmental studies by showing an ambitious urban design, but we couldn't find any study focused on wind flow.

Urban areas, above all, should provide safety and comfort to their occupants. We focus this paper on pedestrian comfort, involved in various activities in this newly suggested development. The purpose is to merge the existing terrain and the future design geometry into wind comfort assessed by CFD.

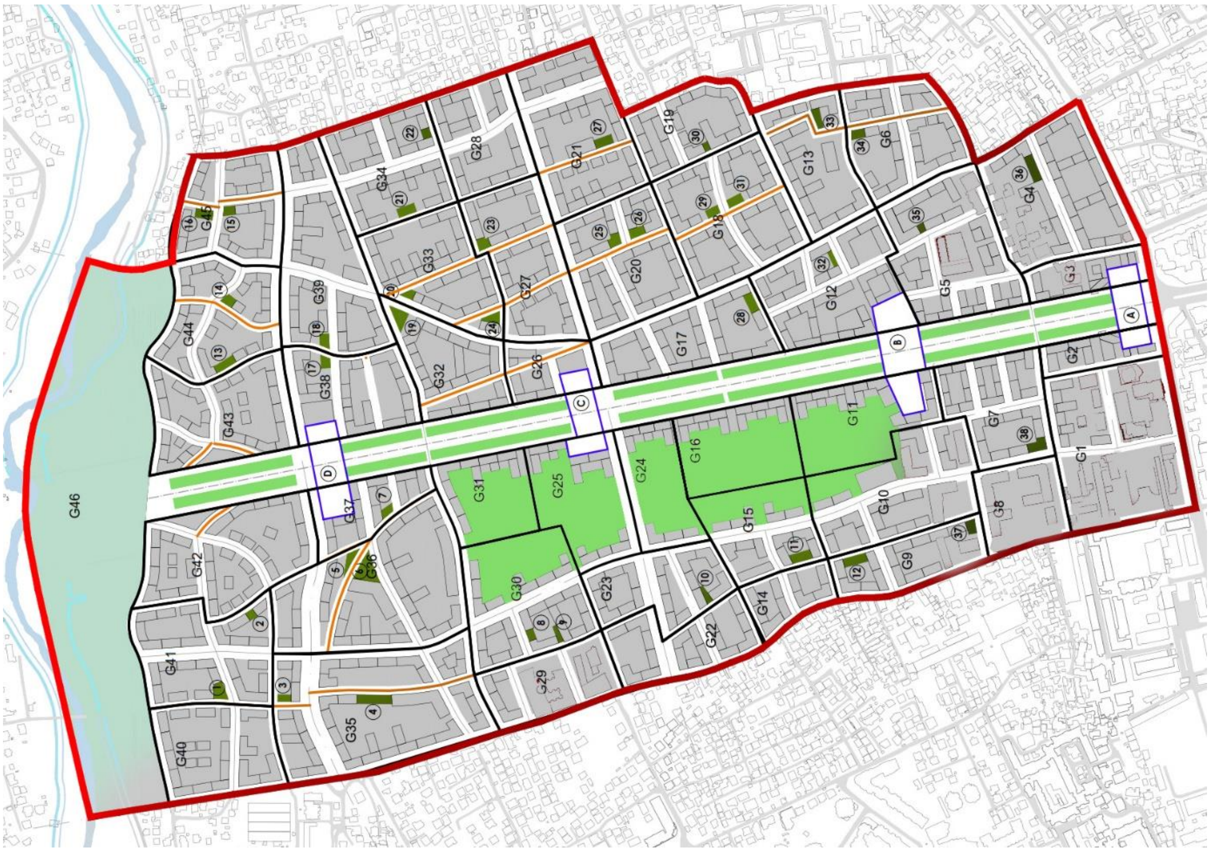

Figure 1. The winning masterplan (future park).

2. Method

2.1 Three-dimensional model and RANS Computational parameters

After being supplied with the future urban development drawing, we could create a three-dimensional model in real scale 1:1 using computer-aided design (CAD) software package. Since urban development covers a large area, we have provided none building details. Our model was not limited only to the building's main geometry but also to the surrounding buildings nearby the studied area. The CAD file is considered being topologically incorrect due to the participles (triangles) that constitute a mesh surface. These participles easily intersect with other meshes, resulting in missing geometries. That is why the 3-D model is exported as an STL file, to be used by ANSYS CFX 12.0 software package. CFD software adopts a special "shrink-wrapping" mesh topologically correct and can be therefore used as a model boundary for the simulation.

Two transport equations were used to explain the RANS turbulence parameters: the first equation is focused on kinetic energy k and it is called the transport equation. The second equation controls the transport of the dissipation rate Ɛ of K. The turbulence parameters for the model were: Model of turbulence=k-epsilon. Turbulent kinetic energy=0.015, Turbulent dissipation rate Ɛ = 1.7029E-06 and Specific Dissipation rate ῳ = 0.00126143. The wind tunnel parameters were: Kinematic Viscosity:1.5e-005m²/s. Density 1.25kg/m³. Convergence criterion (P-Residual) =0.001.

2.2 Simulation; wind speed

Studies of wind comfort are a collection of three types of data: statistical meteorological data, aerodynamic information's and wind safety and wind comfort criteria [18]. The wind climate is recorded in the standards by local institutions and then broadcast to different media. The wind meteorological data was available at the Weather Spark website. This website represents the mean wind data determined over time for Tirana city. Over the course of the year, the windy days are more frequent along late Autumn, Winter, and Spring. The calmer time lasts for almost 6 months from April to October. Mean wind speed at the chosen site throughout the year varies from 0 km/h to 22km/h. Occasionally the maximum speed exceeds 35km/h approximately (10m/s).

The wind from the north at (10m/s) was chosen as the worst-case scenario. This direction coincides with the open riverbank's corridors responsible for high-speed wind gusts. Hence, this parameter was applied in the CFD simulation as a north vector. This scenario is more likely to happen from November to February. To have a fundamental understating the model was analyzed also from the other directions (East, West, South), but at a lower wind speed 5m/s. Therefore, the model was tested four times in different directions: North 0º-10m/s; East 90º-5m/s; South 180º-5m/s; West 270º-5m/s. After obtaining all the graphs and data, we can increase the awareness of the risky areas and those where comfort is provided during any season. Since the project is not yet implemented the field survey was unavailable. Albania doesn't adopt it is own standards on wind comfort and wind safety, hence we have decided to control the results accordingly [30], [28].

Various societies use different standards to set the limit values for wind comfort and wind safety. The criteria to be used for assessment of pedestrian wind conditions have been developed through research and practice. Most of these criteria try to set a limit wind speed over a probability to happen [25]. Despite the fact that many studies are made in wind comfort criteria over the years [26, 27, 28, 29, 30, 31]. Albania doesn't apply its own standards on wind comfort yet.

3. Results

3.1 Wind tunnel parameters

Since the model uses a unique geometry, every simulation had the same fine grid in the wind tunnel made by 784,470 cells and 917,448 nodes. This grid has been proven to be efficient in terms of accuracy and computational time. For computational purposes, was used a thicker grid. The results of this model were not considered. The wind assessment is recoded mostly from a horizontal plan 1.7m high. Undoubtedly, the wind speed changes at different altitudes, but our concern was only for the pedestrian level. After the first results, we were able to place also vertical plans to have a better evaluation of the entire area of the future park. Tunnel parameters were: Dimensions: Dx=6540m; Dy= 2955m; Dz=577m; Original model drag force sum: Fx=1341kN, Fy=115kN, Fz=2937kN. Simplified model drag force sum: Fx=1455kN, Fy=167kN, Fz=2398kN. Flow parameters were in the following terms: Inlet velocity 5m/s to 10m/s; Kinematic viscosity 1.5E-005m²/s; Density 1.25kg/m³.

3.2 CFD simulations

The first simulation on the above grid was performed for the prevailing north wind direction (0º) at 10m/s. Inlet velocity 10m/s. The wind speed ratio inside the future public park areas varies from 0.1m/s-8m/s. Investigating the velocity field plan, is shown that 64% of the future park area is affected by wind high-velocity 4-6m/s with a peak wind velocity at 8.98m/s. Dangerous high wind velocities appear at these areas; (a1=8.98m/s); (a2=6.32m/s). (Figure 2a). This simulation was also supplied with a vertical plan registry showing the wind velocity at different highs. The vertical plan shows that the air moves much faster above the ground due to the absence of the obstacles. (Figure 3a).

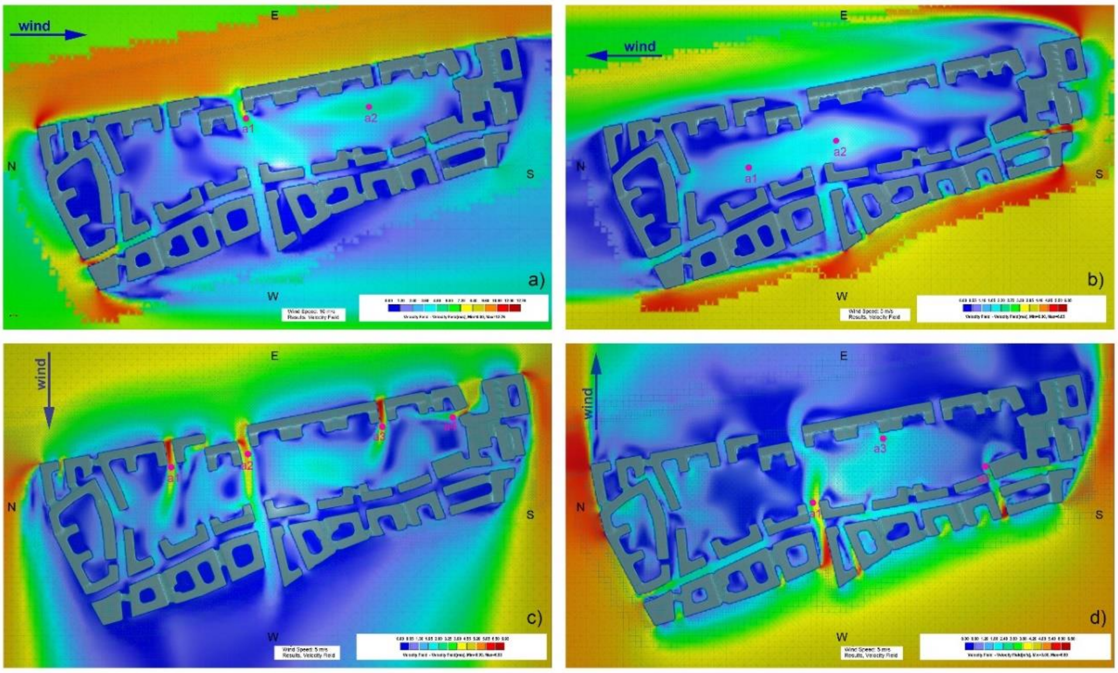

Figure 2. Wind velocity field; (a. north at 10m/s; b. south at 5m/s; c. east at 5m/s; d. west at 5m/s).

In the second simulation, was applied a lower wind speed at 5m/s prevailing from the south direction (180º). The tested speed was diminished since according to the prevailing wind in this direction and the probability it happens. Inlet velocity 5m/s. From this direction, the wind encounters other buildings with almost the same high suggested in the master-plan. Wind speed ratio inside the future public park areas varies from 0.1m/s-1.9 m/s. Investigating the velocity field plan the results show 53% of the future park area is affected by wind high-velocity 1-2m/s with a peak wind velocity at 1.92m/s. The rest of the area is affected by wind speed lower than 1m/s. High wind velocities occur at these areas; (a1=1.92m/s); (a2=1.85m/s). (Figure 2b).

The third simulation adopted the same wind speed as above (5m/s), except the prevailing direction from the east (90º). Wind speed ratio inside the future public park areas varies from 0.1m/s-6m/s. Investigating the velocity field plan the results show 81% of the future park area is affected by wind high-velocity 1-2m/s with a peak wind velocity at 6.11m/s. The outer buildings barrier seems to have several gaps in this direction. The increase of speed at these passageways happens due to a decrease in static pressure or a decrease in potential energy (Bernoulli principle on fluids). Severe wind velocities are recorded at these passages; (a1=6.11m/s); (a2=5.83m/s); (a3=5.94m/s) (a4=4.18m/s). (Figure 2c). A considerable vortex is created in this simulation (Figure 4c).

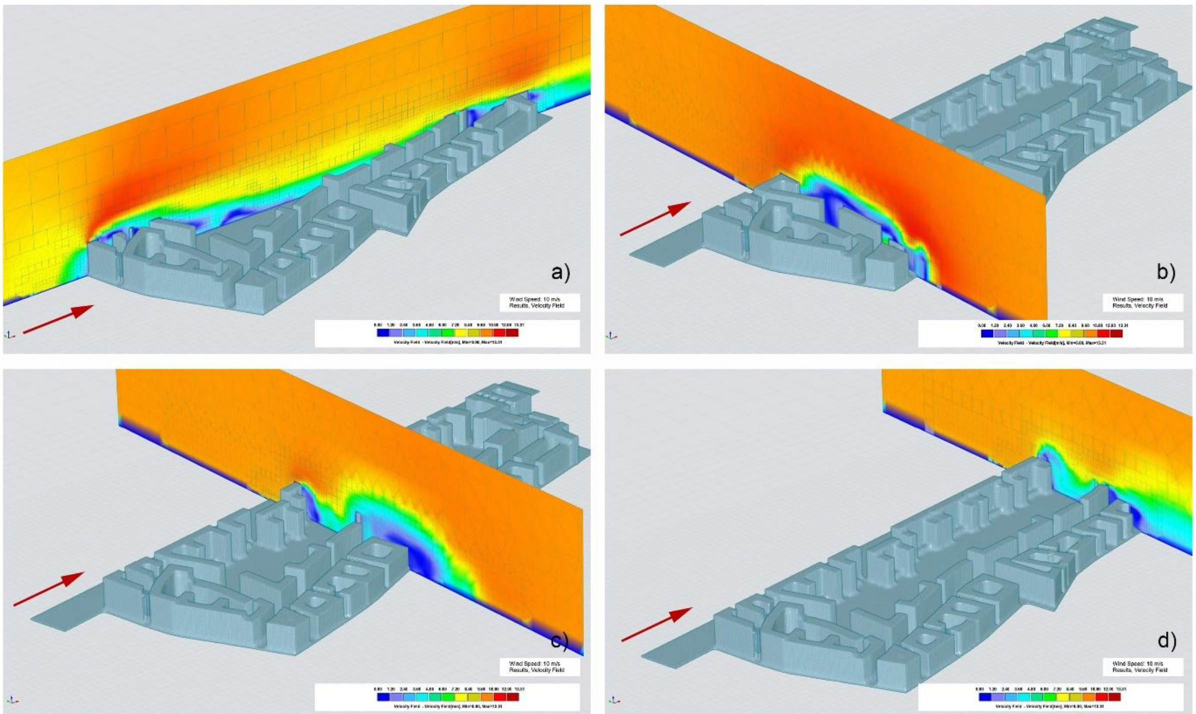

Figure 3. Wind velocity field (north at 10m/s).

As mentioned above the last simulation preserve the same wind speed at 5m/s prevailing from the west (270º). Wind speed ratio inside the future public park areas varies from 0.1m/s-4m/s. Investigating the velocity field plan the results show 58% of the future park area is affected by wind high-velocity 1-2m/s with a peak wind velocity at 4.47m/s. Critical high wind velocities appear at these areas; (a1=4.47m/s); (a2=3.20m/s); (a3=2.76m/s) (Figure 2d). Several vortexes are created in this simulation (Figure 4c).

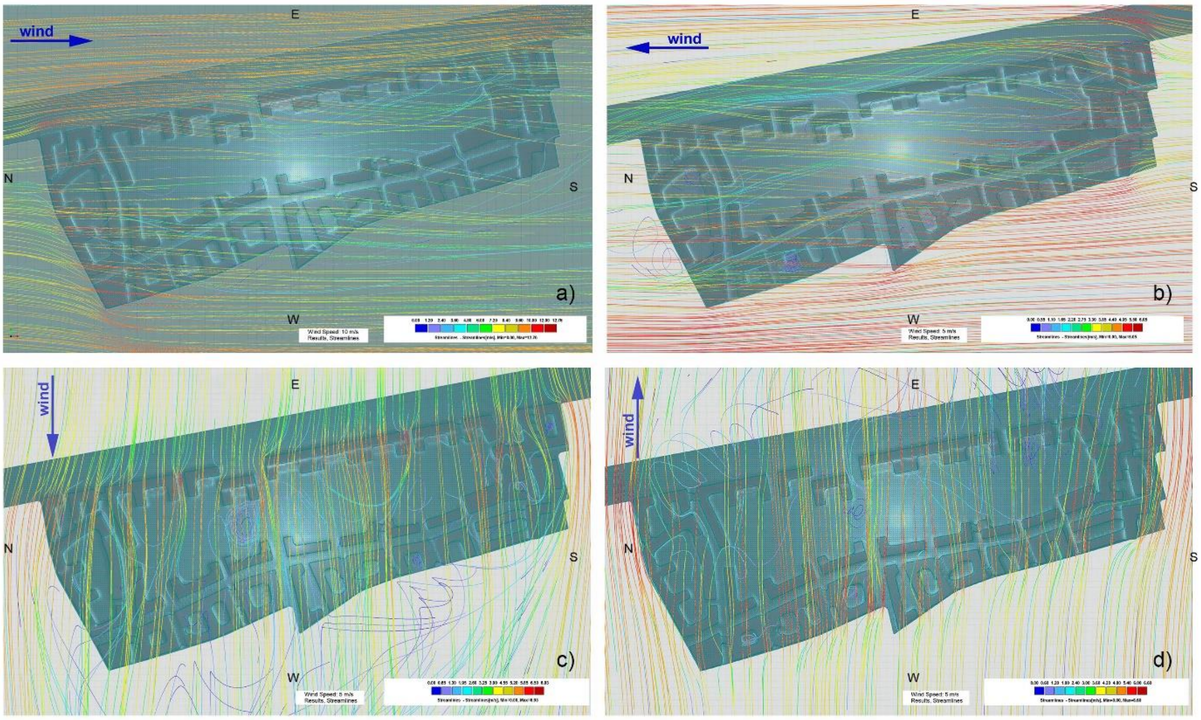

Figure 4. Wind streamlines (a. north at 10m/s; b. south at 5m/s; c. east at 5m/s; d. west at 5m/s).

3.3 Pressure field

In the pressure field graphs, the playing area is created in the simulation b-(wind blowing from the south) and d-(wind blowing from the west). For tests running at 10m/s, results show the maximum dynamic pressure of 51.3Pa and the minimum -96.5Pa. (Figure 5a). It also reveals the lowest pressure field is also in the model-b with a maximum dynamic pressure of 12.7Pa and a minimum of -20.0Pa. (Figure 5b). The surface pressure in the building facades does not reveal any useful information to be used for evaluating the wind flow inside studied area.

4. Discussions

This paper has analyzed the wind speed generated in a public ambiance. The studied area was unconventionally surrounded by tall buildings, and this fact raise our concern about wind flow issues. As mentioned above, the architectural proposal has not presented any study focused on the wind flow hence, we have been able to develop CFD as a method of evaluating the wind flow in the future public park area. Therefore, the short-term on-site investigation wasn't able since the master-plan we have evaluated is not yet been implemented. This study has come to important findings related to the air movement in and around the studied domain:

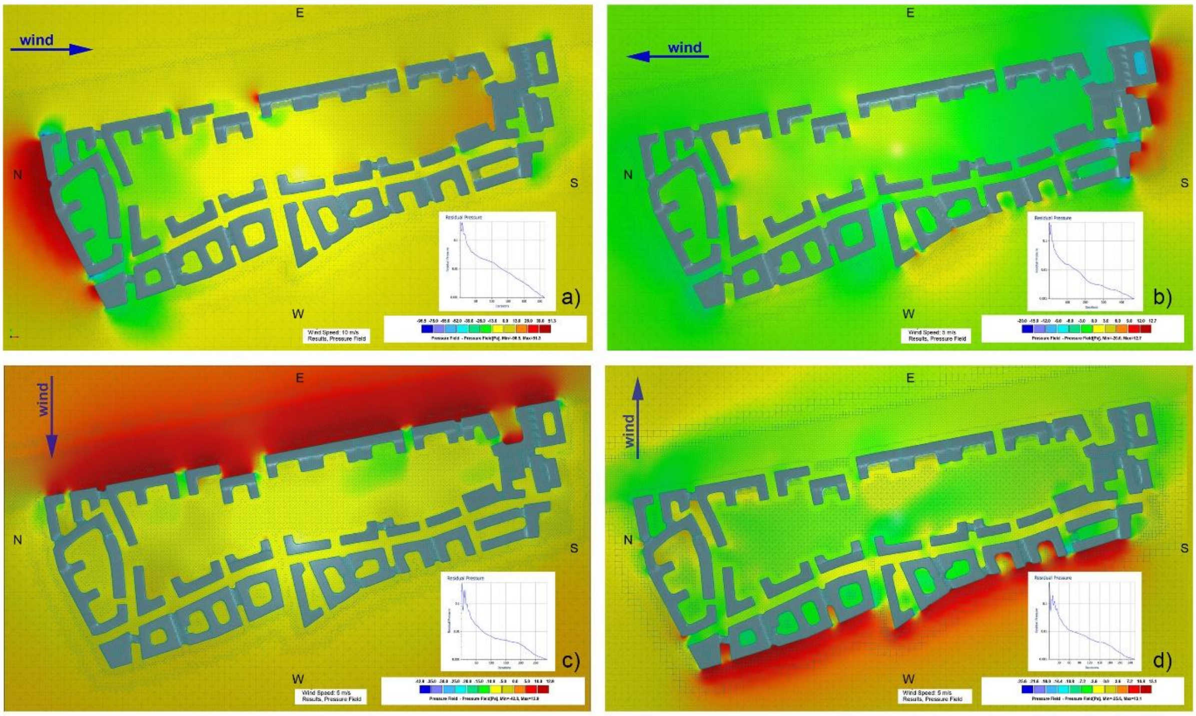

Figure 5. Dynamic pressure field (a. north at 10m/s; b. south at 5m/s; c. east at 5m/s; d. west at 5m/s).

1. The worst-case scenario is more likely to happen in winter from November to February when the wind blows from the north (10m/s), (Figure)2a In almost half of the area, the wind was 4-6m/s considered definitely unpleasant for sitting, moderated for strolling and good for traversing [30]. This means in most cases the area is not suitable for people seeking to relax. One of the most important factors that affect people's behavior seems to be the urban wind environment [33, 34]. As wind speeds increase, some variations can become more abrupt and of greater amplitude, such as "wind gusts" [35]. The wind gusts are defined as a short-duration (seconds) maximum of the fluctuating wind speed [36]. Hence, in the first scenario, we could discover also wind ate high velocities (9m/s) but these were limited areas hence, considered a nuisance for most creative activity [28]. In this scenario, the leaves would sway creating unpleasant conditions for people standing nearby.

2. In every environmental condition and direction, the wind is not distributed in a uniform pattern, (Figure 2a). The way the air mass moves over and around the urban context is a complex fluid flow phenomenon [37]. Probably the reason for this variable is the presence of nonlinear building layout suggested in the master-plan. The difference is visible mostly in the first scenario when the wind blows from the north at 10m/s. Hence, two different approaches must be considered in the design concept for the same public park.

3. The presence of tall buildings in the park boundary was not common at these distances. These buildings direct the air at high velocity inward the public park. Tall buildings often show captivating elegant profiles, but the higher they are, the stronger the wind blows on their top, [35]. Many studies emphasize the down-draught effect generated on high-rise buildings therefore, they are strongly influencing the wind flow causing discomfort at the pedestrian level [38]. Inspecting (Figure 3a) we could find a faster movement of the air above the ground because of the absence of the obstacles. The higher the building, the more wind ate high velocity is captured and guided beneath the base of the building causing discomfort to pedestrians.

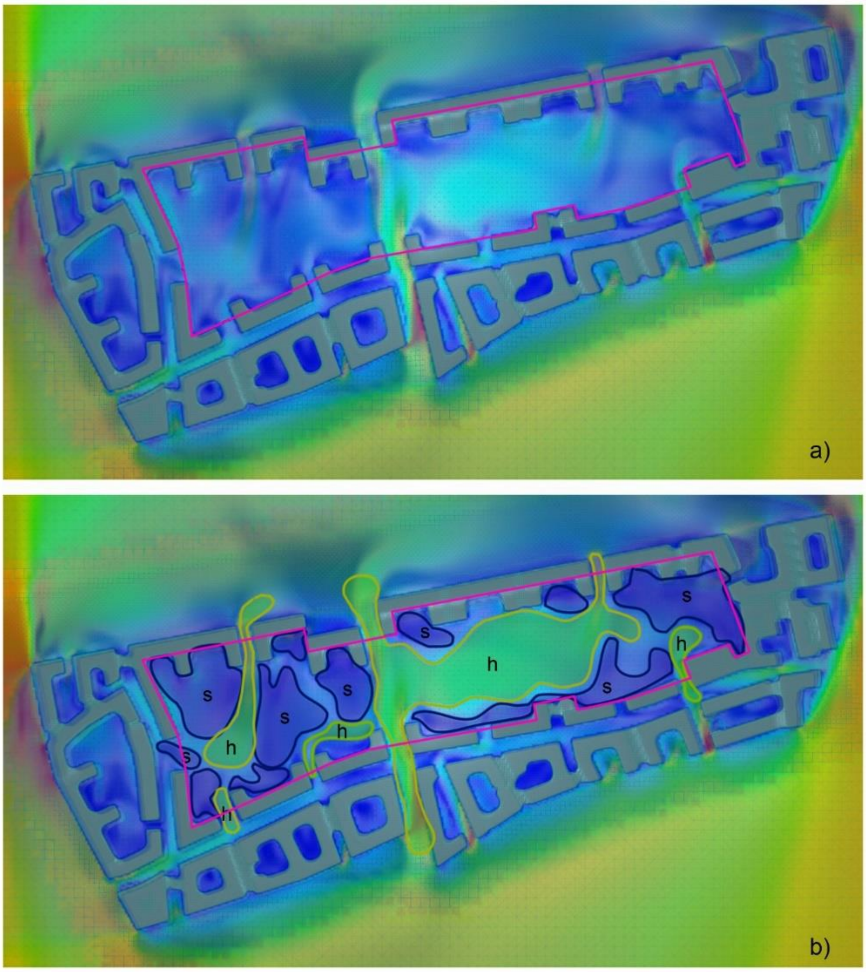

Figure 6. A hypothetical model of the park design. (h) – high speed areas; (s) – slow speed areas.

4. Wind at high velocities is obtained when the wind blows from the east, even at a lower speed (5m/s). The highest speed is generated in-between the buildings gap's (Figure 2c). The wind gains speed in the gaps due to the high pressure created in the building's facades [4]. (Figure 5c). (Figure 6c), reveal this increase in wind's pressure at the east, considering the wind finds no nearby barriers at that direction. High speed wind currents are created in the channel mostly by parallel facades and the sudden drop of pressure. The wind speed generated in the gaps wouldn't be difficult to people traversing, jogging or running but not comfortable for people sitting or resting [30], [28]. But channeling needs to be considered in higher speed prevailing winds.

5. This study provides design recommendations to avoid pedestrian discomfort. After picking up all the result, we could overlay all the graphs taken in all four scenarios in order to identify a hypothetical best-case scenario. In the (Figure 6), we have identified the high-velocity areas. Inside the green areas labeled "h" sitting and standing is unpleasant unless mitigation strategies (such as tree plants), are implemented. The blue areas labeled "s" show the slow speed areas in every wind condition. The following area reports a wind speed of 0.1m/s to 2m/s, which is considered relevant to most creative activity [28]. Our simulations revealed in all cases, the absence of any dangerous area for pedestrians. The top speed observed in specific areas is 9m/s.

5. Conclusions

This paper was focused on wind conditions and pedestrian behavior in a public urban area. The urban context impact dramatically on urban wind patterns. Moreover, the urban wind is influencing pedestrians' wind comfort and safety. The purpose of this study was to analyze people's comfort and public space to suggest a pleasant outdoor environment. The CFD was used as an instrument to evaluate the wind impact on a public domain, included inside the pattern of the buildings. The effects of these architectural patterns in the wind conditions were discussed.

The architectural shapes are capable to impact at large the local wind by different aspects such as building dimensions, their orientation, urban density, structure articulations, etc. The study indicates that high velocity wind can be a nuisance for most creative activities in the outdoor public space. A decrease in wind speed, particularly during winter, would help urban habitants to extend their recreation time in the future park domain. This study attempts to provide urban designers with planning instruments to consider pedestrian safety and wind comfort during their creative process.

This paper provided a velocity map, (Figure 6b), for future recreational activities inside the current building pattern. Activities in the park could be designed according to the tolerated wind speed in this map. Hence, urban design impacts people's life quality.

Future research

Mitigation strategies are typically recommended to improve the safety and comfort of pedestrians. Tree planting in the areas where wind speed exceeds 7-8m/s might be one of the mitigation strategies. Also, the mitigation strategies might consider a different design concept of the building units, with pedestrian comfort in mind. Other research must be done in order to improve the microclimate through trees plant typologies. They can both be used for mitigation strategies during winter and at the same time to enhance ventilation during the summer. Hence a study focusing on local season must be done in order to better evaluate the people's comfort.

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