ENVIRONMENTAL PARAMETERS FOR CAMPUS OUTDOOR SPACE: A MICROCLIMATE ANALYSIS OF THE EASTERN MEDITERRANEAN UNIVERSITY (EMU) CAMPUS

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ABSTRACT

Open spaces—whether public, urban, or part of a campus—offer a variety of activities and opportunities to people. Therefore, open spaces should be considered a vital component of any built-up area and designed to meet the needs and address the comfort of potential users. Because of their presence in daily life and their preponderance of characteristics, open spaces have drawn the attention of many researchers, designers, and planners with varying perspectives. The current study takes a scientific approach to analyzing the environmental parameters of the Campus Outdoor Space (COS) in the case of the Eastern Mediterranean University (EMU). An extensive literature review supported the identification of seven important environmental parameters effective in the microscale analysis of a COS: geographical location, meteorological situation, urban form, surface materials, amount of vegetation and watershed, and anthropogenic pollution. Analysis of the environmental parameters called for a hybrid method that included a detailed field survey and the following set of simulations: sun-path, radiation, sky view factor, and turbulence analysis. The accuracy of the field survey directly contributed to the effectiveness of the simulations. Grasshopper® 3D software and Computational Fluid Dynamics were used to simulate the conditions of the EMU study area. The outcomes show that the spatial organization, building forms, and building orientation negatively affect the COS of EMU. In the Mediterranean climatic region of EMU, shade and flowing breezes greatly enhance comfort and usability of outdoor spaces from April to October. The massive form of buildings and minimal planning for effective building orientation to the sun increased heat storage capacity and neglected prevailing winds, resulting in flow separation and formation of eddies on the leeward side of buildings. These negatively influenced the microclimate, and thereby user comfort, at the core of the EMU's main COS.

KEYWORDS

Campus Outdoor Space; Computational Fluid Dynamics; Grasshopper® 3D; Microclimate

1. INTRODUCTION

The formation of a Campus Outdoor Space (COS) for any university is an important issue from both the planning and design points of view. As Lauder, Sari, Suwartha, and Tjahjono (2015) stated, campuses "have been conceptualized as 'small cities' in their quest to attain sustainability

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due to their size." COS characteristics are similar to those of Urban Open Space (UOS), since both are composed of buildings, open spaces, and paths. Environmentally, both are utilized with fixed and partially-fixed elements to enhance individual and social outdoor activities (Aydin & Ter, 2008; Hanan, 2013). These activities may include an array of sitting, resting, playing, cycling, walking, and watching for both types of spaces, and experiencing such activities in either space significantly contributes to the enhancement of physical and mental health (Aydin & Ter, 2008; Chen & Ng, 2012; Gehl, 2011; Hanan, 2013; Marcus & Wischemann, 1997; Woolley, 2003). Both outdoor environments are essential in achieving local sustainability and pair well with the notion of resilience for current developments (Leichenko, 2011; Meerow, Newell, & Stults, 2016). An exemplar of COS sustainability and resilience emerged from the Universitas Indonesia Green Metric in 2010, supporting green university development (Lauder et al., 2015; Suwartha & Sari, 2013). Universities function like a house of knowledge, by gathering smart and active researchers with a wide range of new knowledge; universities encounter innovative ideas, creative thinking, and tangible effects of human, social, and cultural life (Lau, Gou, & Liu, 2014).

As stated earlier, COS and UOS have common characteristics. However, educational concerns can distinguish COSs from UOSs. A COS becomes a host environment for the two to four years students and young adults who attend university and therefore has the potential for reducing stress and negative health impacts (Hipp, Gulwadi, Alves, & Sequeira, 2016). COSs quality is highly valued for enhancing student life (Hanan, 2013; Lau, Gou, & Liu, 2014; Xi, Li, Mochida, & Meng, 2012), and can facilitate psychological restoration and decrease observed stress in students (Hipp et al., 2016). Therefore, the quality of the COS should be thoroughly considered within the planning and design stages of the university. Regrettably, the majority of literature considered the fiscal issues and educational policies, while less attention was paid to COS design (Marcus & Wischemann, 1997, p. 176). Also, the shortage is seen in the size and location of COSs within universities' built-up areas (Maruani & Amit-Cohen, 2007). Besides the size and location, the qualities of a COS are important considerations. A large number of studies focused on the social dimensions of outdoor spaces (see Gehl, 2011; Thompson & Travlou, 2007; Woolley, 2003). Others considered the aesthetic dimensions of them (Miles, 1997; Portella, 2014). Some scholars had concerns about well-being, physical activity, and health in relation to open spaces (Abraham, Sommerhalder, & Abel, 2010; Koohsari et al., 2015; Villanueva et al., 2015) whereas proximity and accessibility were the important issues among other scholars (Giles-Corti et al., 2005; Koohsari, Kaczynski, Giles-Corti, & Karakiewicz, 2013).

Climatic concerns have been an important parameter for the thermal comfort of open space users (Ebrahimabadi, Johansson, Rizzo, & Nilsson, 2018). In addition, open space significantly affects urban ventilation and pollutant exposure (Sha et al., 2018). According to ASHRAE (2004) and ISO 7730:2005 (1984), psychological thermal comfort can be defined as the "condition of mind which expresses satisfaction with the thermal environment." According to the ISO 7730:2005 (1984), a human being's thermal feeling is linked to the body's thermal balance. There are many environmental parameters at the microscale which are involved in adjusting COS thermal comfort. The current study, in response to these dilemmas and after a broad literature review, tries to represent the significant environmental parameters needed to analyze a COS. It considers significant approaches including different techniques and methods for analyzing the environmental parameters at the microscale.

2. LITERATURE REVIEW

Thermal balance varies due to clothing, physical activity, and environmental parameters. In this context, environmental parameters are an array of geographical location (Mohajerani, Bakaric, & Jeffrey-Bailey, 2017; Robitu, Musy, Inard, & Groleau, 2006), meteorological situation (Chen & Ng, 2012), urban form (Andreou, 2013; Fuladlu, 2019, 2020; Fuladlu, Riza, & İlkan, 2018a, 2018b, 2021; Robitu et al., 2006), surface materials (Andreou, 2013; Fuladlu et al., 2018a; Jamei, Rajagopalan, Seyedmahmoudian, & Jamei, 2016; Mohajerani et al., 2017; Robitu et al., 2006), amount of vegetation and watershed (Andreou, 2013; Jamei et al., 2016; Mohajerani et al., 2017; Robitu et al., 2006), and anthropogenic pollution (Fuladlu & Altan, 2021; Fuladlu et al., 2018a; Marsh & Grossa, 1996; Robitu et al., 2006). The COS's microclimate is a combined response to these environmental parameters. Each of these parameters can be addressed within the early stages of design to improve microclimate conditions for user comfort. While Ebrahimabadi et al. (2018) noted there is less control between the outdoor environmental parameters, a set of tools is required to study these parameters during the design process.

These parameters were studied on different climatic scales both vertically and horizontally. On the vertical axis, the lower part of the atmosphere is the mesoscale (urban boundary layer) and the lower part of the mesoscale is the microscale (urban canopy layer) (Erell, Pearlmutter, & Williamson, 2011; Oke, 1976, 1982, 2011). On the horizontal axis, the following classification is offered: micro (10^{-2} to 10^{3} m), local (10^{2} to 5×10^{4} m), meso (10^{4} to 2×10^{5} m), and macro (10^{5} to 10^{8} m) scales (Erell et al., 2011; Oke, 1987, 2006). Each scale is important for specific instances. Nonetheless, the microscale is weighted most significantly since microclimatic alterations directly affect the overall urban climate (Arnfield, 2003; Taha, 1997) and contribute to a building's energy efficiency (Allegrini, Dorer, & Carmeliet, 2012; Steemers, 2003). For example, Erell et al. (2011) stated that open space microclimate analysis is important for space improvements and to increase outdoor activity performance. Apart from that, microclimate modifications contribute to enhancing the human thermal comfort of the outdoor space (Auliciems, 1997; Höppe, 2002). Microclimate analysis is a challenging task due to the involvement of various parameters like street geometry, building orientation, wind speed, surface albedo, and trees (Andreou, 2013; Chen & Ng, 2012; Fuladlu et al., 2018a; Mohajerani et al., 2017) that form the COS microclimate. There are many approaches to climate analysis (see Mirzaei & Haghighat, 2010); however, from the microclimate point of view, classified approaches are observation and simulation. Each approach has advantages and disadvantages which will be discussed in detail.

2.1 Observational approach

An observational approach and employed field measurements was completed using several microdata logger station bases in the study area. Both fixed and mobile stations can be used for data collection (see Krüger, Minella, & Rasia, 2011; Shahrestani, Yao, Luo, Turkbeyler, & Davies, 2015) since sensors can be installed on airborne and aircraft platforms. Observation utilized a thermal sensing method and hemispherical photography. The thermal sensing method is known as thermography survey and captures the surface radiation of the mid- and long-wavelength infrared spectrum (3–14 μm) emitted by objects. This method has different applications in different disciplines (see Gade & Moeslund, 2014). Hemispherical photography, also known as fisheye or canopy photography, was used to estimate solar radiation and Sky View Factor (SVF). In many studies, this technique was integrated with data logger stations (see Hwang, Lin, & Matzarakis, 2011; Krüger et al., 2011). The disadvantages of this approach are related to the expense and time consumption, especially at the microclimate scale. A specific, high-resolution sensor device and standard is required to capture sufficient data for each parameter's measurement, which can become expensive. Because this approach is also a time consuming for management, installation, and maintenance of measurement devices, the costs and conditions have the potential of limiting the research.

2.2 Simulation approach

A simulation approach is also known as a mathematical model. One of the popular methods is the urban canopy model drive from the energy balance equation for a control volume between two adjacent buildings. This model simulates the energy exchange between ambient air and surfaces include buildings and pavements. However, a weakness of this model is the lack of air velocity to study flow patterns (Mirzaei & Haghighat, 2010). Another method, turbulence simulation, uses Computational Fluid Dynamics (CFD) to understand the airflow within the urban canyon and the effect of this turbulence on heat transfer. This method is highly important for microclimate analysis. Unlike the observational approach, CFD's advantage is its ability to perform comparative analysis based on different scenarios. CFD in comparison to the energy balance model can couple velocity and temperature fields (Mirzaei & Haghighat, 2010; Toparlar et al., 2015). Much commercial and open-source software have been developed for simulation approaches. Naboni, Meloni, Coccolo, Kaempf, and Scartezzini (2017) tried to summarize the scope of each software in detail. According to them, ENVI-met has more capability compared with CitySim Pro, RayMan, Grasshopper® 3D components, and Autodesk® CFD, but ENVI-met has a disadvantage. For instance, Krüger et al. (2011) found, in comparing field measurements, that ENVI-met tends to overestimate wind speed; Sharmin, Steemers, and Matzarakis (2017) concluded, ENVI-met is unable to distinguish between detailed urban-geometry features. Mackey, Galanos, Norford, and Roudsari (2017) stated that ENVI-met required several days to produce accurate results based on volume size. Besides these, ENVI-met is raster-based which decreases the volume accuracy. Lack of conversion from vector made it time-consuming to re-draw from the beginning. In summary, Bouyer, Inard, and Musy (2011) classified mathematical models under:

a. microclimate simulation tools, and
b. building energy simulation tools.

According to their study, a comprehensive solution to overcome the calculation difficulties could be to use microclimate and building energy simulation tools that are complementary and that take advantage of each other. Feasibility relies on establishing a coupling between microclimate and building energy simulation with a proper approach that keeps the model's capabilities and maintains a reasonable simulation time. The other advantages of the coupling are:

a. the evaluation of the mutual impacts of the urban microclimate and building energy,
b. the capture of the direct/indirect consequences of the selected adaptation methods, and
c. the acquisition of a better estimate of energy expenses connected with the human control of indoor spaces since they are affected by the outdoor microclimate (Malys, Musy, & Inard, 2015).

It was found that the coupling of CFD and radiative models enhance urban microclimate simulations because it permits a better evaluation of external surface temperatures (Qu, Milliez, Musson-Genon, & Carissimo, 2012).

2.3 Selection of methods and software

Perhaps each of these approaches is useful for a specific scope, scale, or focus that can account for some of the weaknesses and strengths. It is difficult to find a common approach for all studies. The combination of different methods to analyze the various parameters can lead any study to result in high accuracy. Consequently, following the literature review, this study concludes that a combination of different methods as a hybrid method will be a practical solution for analyzing the environmental parameters. To support green university development, a broad set of tools is required to simulate the environmental parameters of the COS from the early stage of its development. To choose the most appropriate toolset, the advantages and disadvantages of each of the methods and techniques are discussed briefly. The use of a hybrid simulation method in the current case of Eastern Mediterranean University (EMU) aims to analyze the environmental parameters to figure out the microclimatic situation and indicate the performance of the main COS. In addition, the current study with its use of simple yet comprehensive tools provide a guideline for analysis of the microscale environmental parameters in any COS. The hope for this study is that a new approach will highlight the value of the COS microclimatic analysis for urban design and architecture.

3. METHODOLOGY

The microclimate analysis of the COS of EMU revealed the following environmental parameters: geographical location, meteorological situation, urban form, surface materials, and amount of vegetation and watershed. The SVF, radiation, sun-path, and turbulence simulations are comprehensive enough as parameters to demonstrate the microclimate situation. The current study is limited to the analysis of anthropogenic pollution. The reasons for choosing these parameters were that they are comprehensive enough to demonstrate the microclimate situation, and unlike most of the other tools, these are less complex to use, easier to perform and understand, and less time-consuming for calculation. EMU was established in 1979 and as of 2018, it had eleven faculties and six schools with about 20,000 students and employees (Fuladlu et al., 2021). The EMU campus is not limited to educational facilities; it also has dormitories, restaurants, a health center, sports facilities, workshops, and administrative offices which together occupy a large area. The current study selected the main COS of EMU's campus as a case for studying environmental parameters. The case study area is located at 35°08′32″N, 33°54′42″E in the northwest part of Famagusta, a city on the eastern coast of Cyprus (Figure 1).

The reasoning for limiting the study to the main COS involved the size appropriate for microclimate analysis and simulation and the lack of a supercomputer to perform the calculations. At first, the whole EMU campus is over-sized for microclimate simulation/analysis, since the horizontal range for microclimate study is 0.01–1,000 meters. Therefore, a small site had to be selected. As a case study, it is large enough. Finally, the selected COS is significant in terms of history (EMU developed and grew starting from this COS), location (proximity to the main entrance of EMU increases its value), applications (Atatürk Plaza hosts many events, competitions, and exhibitions), and facilities (adjacency to Özay Oral Library (ÖOL), the campus bookstore, and the Central Lecture Halls (CLH)). Together with the ÖOL and CLH buildings, the buildings of the School of Computing and Technology (SCT), the Department of Mechanical Engineering and Fine Arts Education (DME&FAE) enclose the study area and occupy about 51,392 square meters (Figure 1 and Figure 3).

The core of this study is composed of three phases (Figure 2). In the first phase, the study area was carefully surveyed and all the required data was collected to establish the drawing.

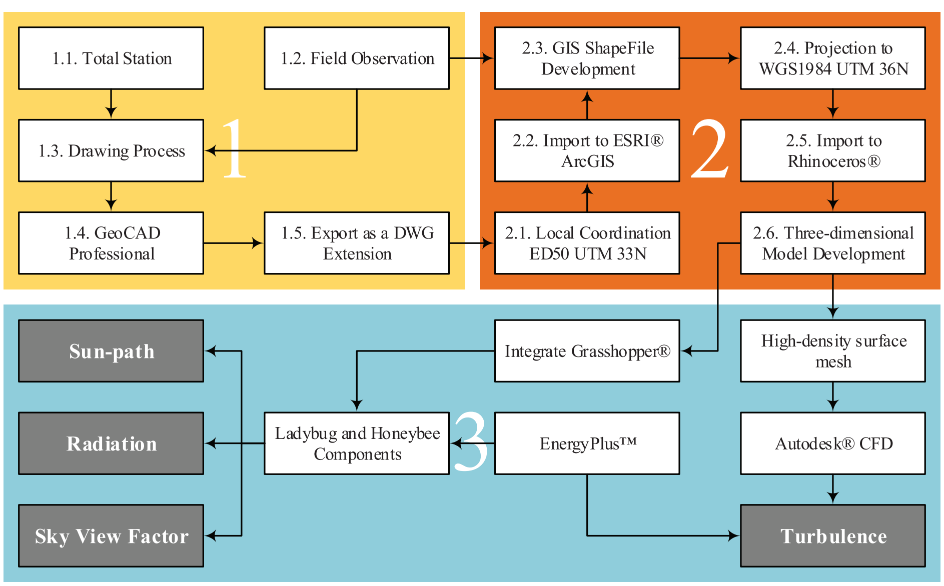
FIGURE 1. A bird's eye view of the main COS of EMU.

Secondly, the drawing was imported to the GIS, and observed attributes were assigned to the drawing. Additionally, a three-dimensional model was developed from the GIS in Rhinoceros®. Thirdly, the prepared model was integrated with the EnergyPlus™ metrological dataset to simulate the SVF, radiation, sun-path, and wind turbulence.

3.1 Study Area Field Survey

To have a precise and reliable analysis, eight students under the supervision of the author performed a detailed field survey of the study area over 28 days. The field survey progressed from two coordinate points based on the ED50 UTM Zone 33 North (local coordinate system) inside

FIGURE 2. Methodology Flowchart.

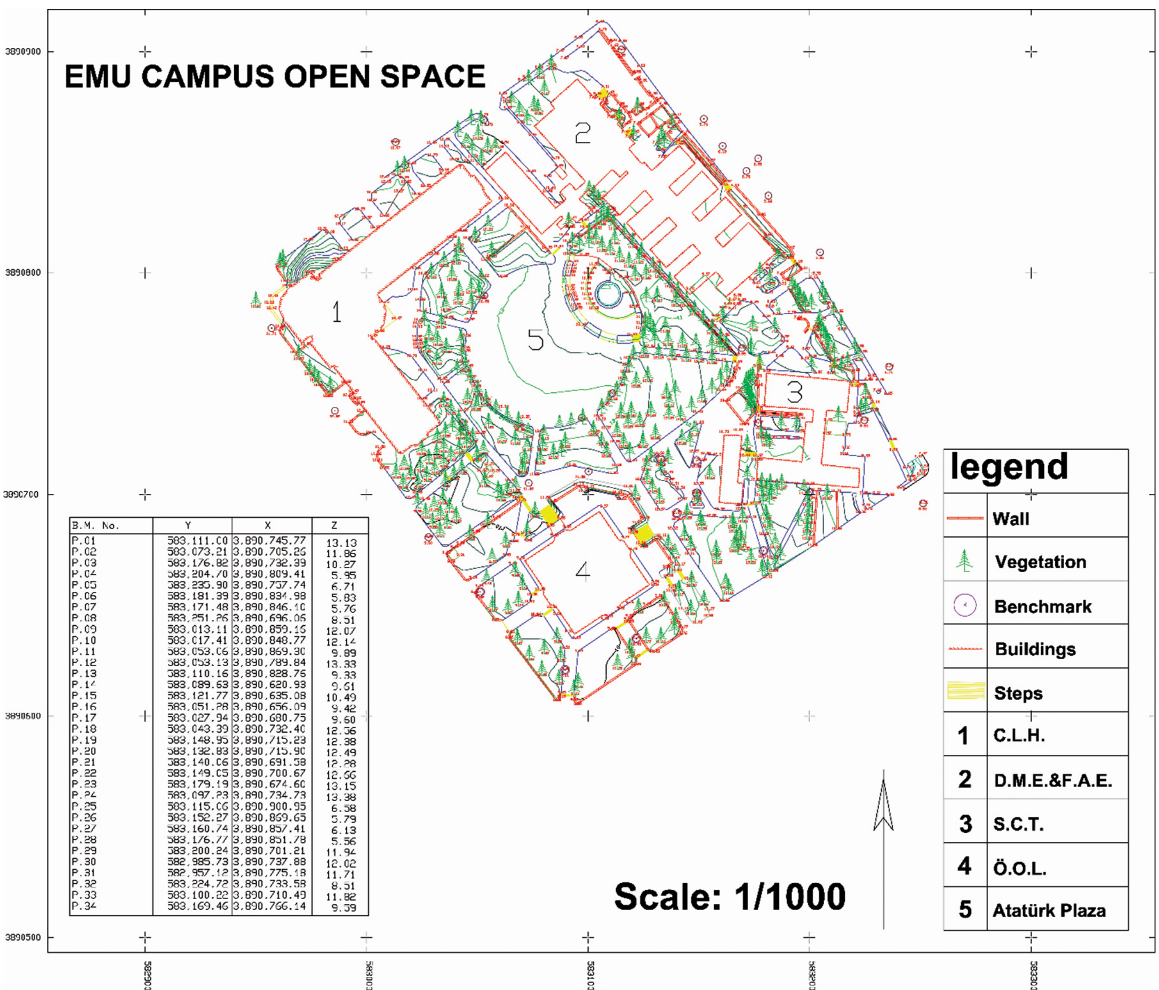


the COS area. The students used a SOUTH Total Station Model N4 and a Leica GPH1 Single Prism System. During the field survey, the building forms, building heights, façade materials, and building details such as eaves, shading elements, and roof materials were recorded along with positions, materials, and heights of landscape elements, including ground covers (pavements or vegetation), vegetation (tree) heights, site topography, and watersheds were fully considered and recorded as attribute data. The daily survey was drawn and digitized using GeoCAD Professional software. The drawing was classified under specific layers and each day's entries were completed by adding new survey points.

3.2 Study Area Three-dimensional Model

The final, complete spatial map was exported with a DWG extension for importing into ESRI® ArcGIS (Figure 3). For the purpose of simulation, all observed attribute data, such as materials, details, et cetera, were assigned to the document. Thereafter, to integrate the attribute data with the spatial data, the DWG file was imported to the ESRI® ArcGIS software and converted into a spatial GIS-ShapeFile. All recorded attributes were assigned to this dataset and the local coordinate system was converted to the WGS1984 UTM Zone 36 North for the subsequent

FIGURE 3. The EMU case study field survey.



steps. The GIS ShapeFile was imported to the Rhinoceros® 3D software to develop a three-dimensional model using the poly-surface tool. After the modeling process, all bad surfaces were extracted and various tests such as curvature, angle, naked edge, and direction analysis were applied to the model. Based on these tests, relevant corrections were applied to the model. Every element of vegetation more than one meter in height was modeled. The reasons for filtration of the vegetation were because the shadows of vegetation of less than one meter are minor, and elimination of that vegetation increased the simulation performance. For the terrain modeling, a highly accurate surface UV Spanes 70x70 experimentally was distributed over the ground survey point clouds to obtain a detailed terrain model.

3.3 Study Area Simulation

Finally, each group of objects including terrain, buildings, and vegetation was imported as a Brep to Grasshopper® 3D. According to the simulation aims, the EnergyPlus™, Ladybug, and Honeybee components were then added to the Grasshopper® canvas (Figure 4).

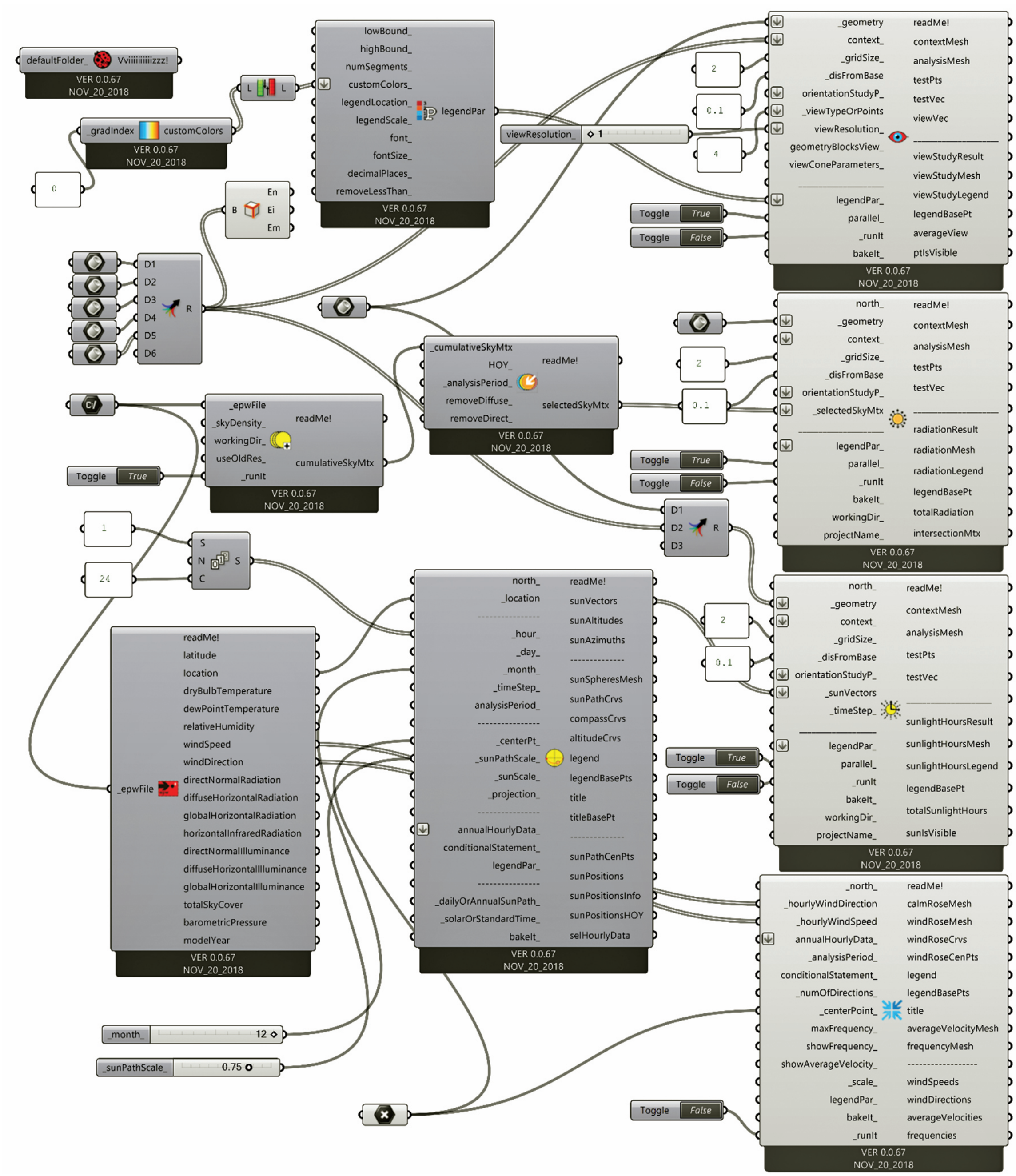
Sun-path has been known as an informative diagram for many years. It remains highly effective for environmental analysis, especially at the micro/building scales for analyzing the geographical location, urban form, and amount of vegetation. The diagram not only represented the sun position according to the geographical location, it even described whether shading was desirable at a given moment and simulated cast-shadow. It also indicated how sunlight reaches the buildings and the roof-mounted solar panels (Olgyay, 1962; Ritchie, 2009; Roudsari, Pak, & Smith, 2013).

Radiation is the main energy source observed at the urban canopy surface layer. Radiation is an important parameter to adjust for thermal comfort and building energy consumption. Urban geometry plays a very important role in absorbing radiation. In principle, radiation is absorbed in a complex way in the urban area. The amount of radiation absorbed varies due to urban density, building orientation, building height, and urban latitude. (Erell et al., 2011, p. 29; Fuladlu et al., 2018a; Oke, 1987, p. 232; Roudsari et al., 2013). Therefore, radiation measurement tools are useful to analyze the geographical location, urban form, surface materials, and amount of vegetation, and/or watershed. The radiation simulation was limited to daytime because the COS is inactive during the night.

Sky View Factor (SVF) refers to the visibility of the sky; it can be defined as "the ratio of the amount of the sky 'seen' from a given point on a surface to that potentially available" (Oke, 1987). The SVF depends on the aspect ratio factor, which is a ratio of the street width to adjacent buildings heights. The SVF is significantly associated with the solar radiation and air movement (Erell et al., 2011, pp. 19–20; Fuladlu et al., 2018a; Jamei et al., 2016; Oke, 1988). It was adequate to analyze the meteorological situation, urban form, and amount of vegetation.

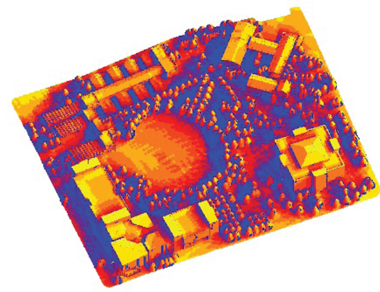
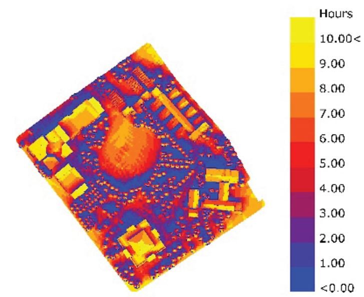
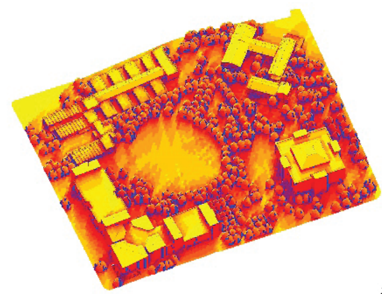
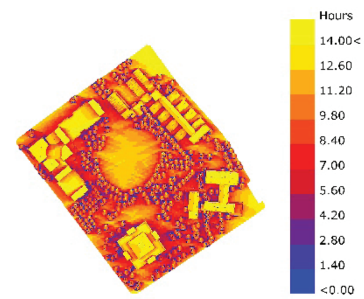
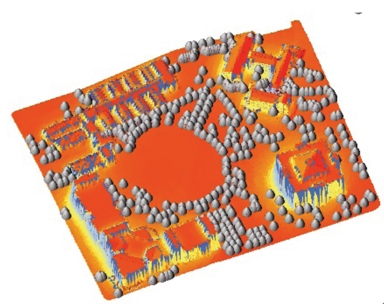
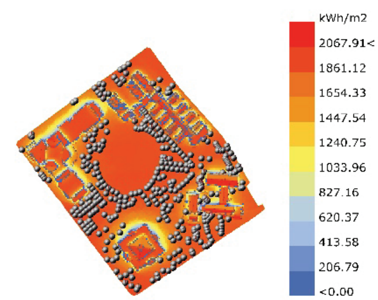
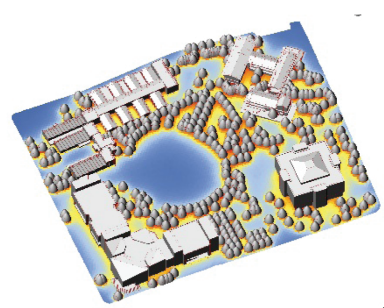
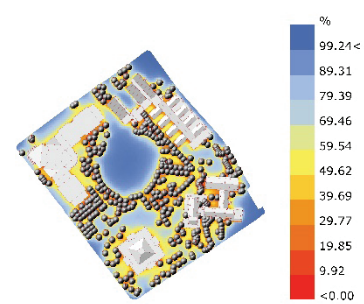
The sun-path, radiation, and SVF analyses were run with the use of meteorological data. The required data was obtained via integration with the EnergyPlus™ metrological dataset. The Larnaca International Airport (CYP Larnaca 176090 IWEC) is the nearest metrological station to EMU at approximately 40 km to the southwest. The height of the station is about 2 meters (7 ft.). The dataset, with an EPW extension, was imported to the Grasshopper® canvas. The geographical location is automatically obtained from the model coordinates and the simulation was run for 1976 test points. The sun-path was simulated for 21 December, since that is the winter solstice and the shortest day, and for 21 June, since that is the summer solstice and the longest day of the year in the northern hemisphere. The simulation, using the EnergyPlus™ dataset, was run on Grasshopper®, and the results of the site plan and bird's eye view are displayed in Table 1.

FIGURE 4. EnergyPlus™, Ladybug, and Honeybee components added to the Grasshopper® canvas.



For the wind turbulence simulation, Autodesk® CFD was used. As stated before, CFD is considered a very important tool for air velocity and flow pattern analysis though it is missed in most of the mathematical models (Mirzaei & Haghighat, 2010). This study used CFD to figure out wind flow pattern within the urban canyon and its effects (Toparlar et al., 2015). With the use of CFD, the following environmental parameters can be addressed: meteorological situation,

TABLE 1. The Grasshopper® 3D Simulation Output.

Simulation Type	Bird View	Site Plan
Sun-path (21st December)		
Sun-path (21st June)		
Radiation		
SVF		

urban form, surface materials, and amount of vegetation and watershed. Perhaps CFD depicts how this pattern transfers the heat within the urban canyon.

For the turbulence simulation, a high-density surface mesh was draped onto the model in Rhinoceros®. This step significantly contributed to decreasing future mesh errors and increased simulation performance. The surface geometry was then converted to an accurate triangle mesh, which enhanced the simulation quality. The mesh errors were fully inspected and any error was reviewed and treated accordingly. Autodesk® CFD 2019 software was used for the simulation purpose and the following logarithmic mean wind profile equation (1) for smooth surfaces was used (Oke, 1987; Wiernga, 1993).

$$\bar{U}_{(Z)} = \frac{u^*}{K}\ln\left(\frac{Z}{Z_0}\right), \tag{1}$$

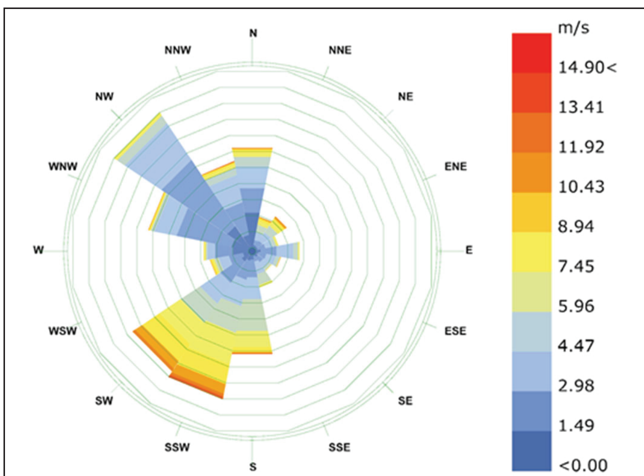
Where:

$\bar{U}_{(Z)}$ is the mean of wind speed at height Z (m/s);
u^* is the atmospheric boundary layer friction velocity (m/s);
K is the Von Kármán constant (≈0.40 ± 0.01);
Z is the height coordinate (m); and
Z_0 is the roughness parameter (aerodynamic roughness) length (m).

The reason to use this equation was that the metrological data—due to the impact of terrain and the built environment—are from a site different from the urban site. The required data for Equation (1) was obtained as follows. The mean of the meteorological data for the simulation inlet was extracted from EnergyPlus™ by use of the wind-rose component of the Grasshopper®. The resulting 16 directions included mean velocities and frequencies were extracted (Figure 5). Based on the frequency, the prevailing wind for the study area blew predominantly from the NW with 13.52 frequency and the SW with 11.67 and 12.23 frequencies. Therefore, NW and SW wind directions were used to define the two scenarios for the CFD simulation.

Based on the wind direction, for scenario one the mean velocities of 5.42 m/s for SW, and for scenario two 2.65 m/s for NW direction were assigned. For the roughness parameter

FIGURE 5. Wind-Rose Component extracted Direction and Frequency from the CYP Larnaca 176090 IWEC station.



Direction	Velocities (m/s)	Frequencies
N	1.79	8.42
NNE	4.57	2.6
NE	4.76	3.17
ENE	3.47	1.94
E	3.09	3.7
ESE	3.33	2.15
SE	3.17	1.69
SSE	4.04	2.8
S	4.65	8.39
SSW	5.65	12.23
SW	5.2	11.67
WSW	3.35	3.31
W	2.32	3.8
WNW	2.56	8.52
NW	2.65	13.52
NNW	3.11	7.28

(aerodynamic roughness) Z_0 = 0.4, since the area is dense with low-rise buildings (Wiernga, 1993) and the height coordinate of 2 m (U2) was used. The computational domain for this simulation was developed according to Franke, Hellsten, Schlünzen, and Carissimo (2007), besides that the situation model was considered for the computational domain dimensions.

The warp generation was done with a 1000-resolution factor and the count surface element (mesh size of the CFD model) became 78,742. The mesh sizes were chosen according to the computer performances, therefore the effect of mesh size on the CFD performance was ignored. Beforehand, the geometry and computational domain material were defined, and afterward, the inlet and outlet of the computational domain for each scenario were defined. The K-epsilon (k-ε) turbulence model was used for the CFD and is defined by equations (2) and (3):

$$k = \frac{2}{3}\left(I_U U\right)^2, \tag{2}$$

Where:

k is the turbulent kinetic energy (m^2/s^2);
I_U is the inlet longitudinal turbulence intensity; and
U is the logarithmic inlet velocity.

$$\varepsilon = \frac{\left(U^*_{ABL}\right)^3}{k\left(Z + Z_0\right)} \tag{3}$$

Where:

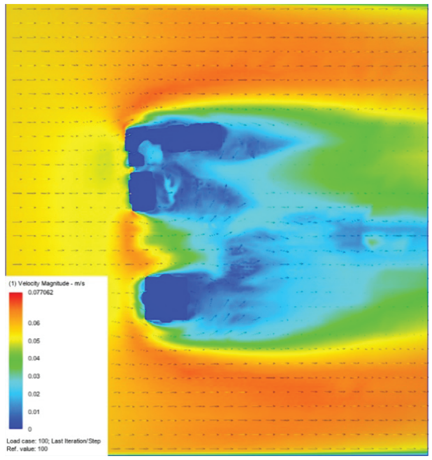
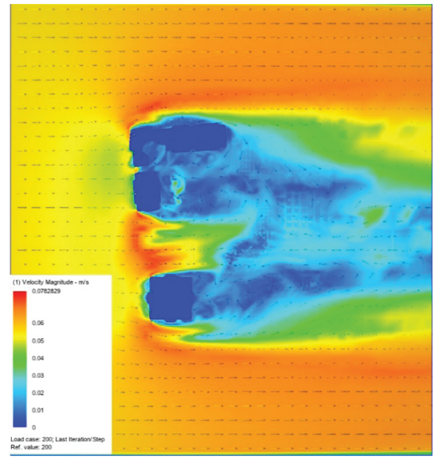
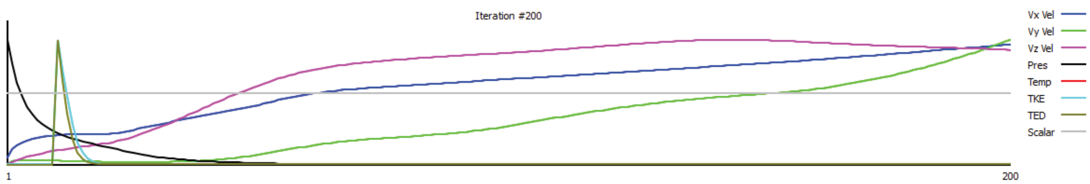
ε is the dissipation rate of turbulent kinetic energy (m^2/s^3);
U^*_{ABL} is the atmospheric boundary layer friction velocity (m/s);
Z is the height coordinate (m); and
Z_0 is the roughness parameter (aerodynamic roughness) length (m).

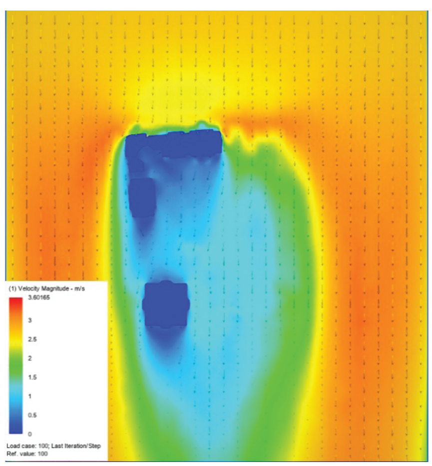
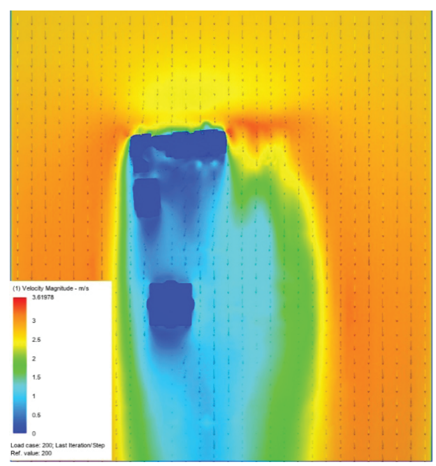
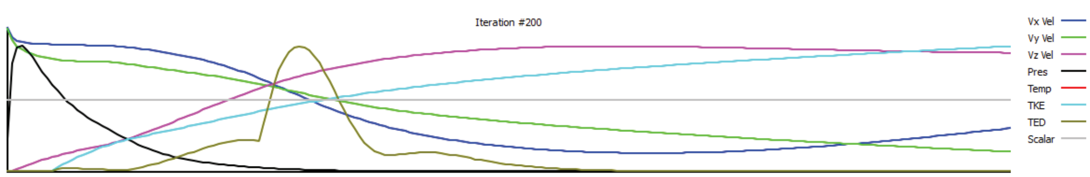
The CFD simulation for both scenarios initially was calculated for 50 iterations, and then it was continued three more times for up to 200 iterations each. The main reason to stop in 200 iterations was the smooth repetitions in the convergence plot. The horizontal convergence lines in the convergence plot indicate when the results stop changing and that the solution is converged (Table 2).

4. RESULT AND DISCUSSION

According to the analysis outcomes (Table 1 and Table 2), half of the study area—composed of ÖOL, the CLH, and Atatürk Plaza—is in an objectionable condition from the microclimatic perspective. Since the microclimatic formation of the COS is highly dependent on the surrounding building conditions, and to have a better awareness of the results of the study area, assessment of the situation is divided into buildings and open space.

TABLE 2 CFD Simulation Output.

<table>
<tr><th>Direction</th><th>100 Iterations</th><th>200 Iterations</th></tr>
<tr><td>Southwest</td><td></td><td></td></tr>
<tr><td colspan="3">

Convergence Plot</td></tr>
<tr><td>Northwest</td><td></td><td></td></tr>
<tr><td colspan="3">

Convergence Plot</td></tr>
</table>

4.1 Buildings

Buildings conclusively shape the urban form; so, to understand how urban form fits in this study, all the building typologies were studied in terms of form, spatial organization, and orientation. Following Ching (2014), the buildings in Figure 1 and Figure 3 were classified according to form—which can be square or linear, and according to the spatial organization—which may be centralized, linear, or radial. According to this classification system, ÖOL is a compact square form with a centralized organization. The SCT, as well as the DME&FAE, are linear in both form and organization, and the CLH building is a linear form with a radial organization. The orientation of all the buildings is to the NW-SE and NE-SW without regard for the sun-path, except the SCT, which is prominently oriented to the sun-path (N-S and E-W) directions. Besides the SCT, the buildings appear to have been developed without considering their geographical location.

According to Table 1, the ÖOL gets maximum radiation during the sunny hours. Lack of vegetation around this building is an issue because the building cannot be protected from direct sun radiation. The massive form of the CLH may result in increasing the building's heat storage capability. However, the linear form and massive volume of this building, in comparison to the library, results in the generation of shadows on different edges of the building. Besides that, the location of vegetation to the SE and NE was distant from the building and unable to protect the building from solar radiation; therefore, the heat storage capability is valid for the CLH as well. Apart from the SCT, the other buildings exhibit less respect for sun orientation on the one hand and on the other hand their massive forms result in minimization of the shadow on their southern edges and maximization of shadow on their northern edges.

The situation of the building occupied by the DME&FAE is different. Although these buildings are not sun-oriented, the narrow linear form of these buildings together with the repetition of the same linear elements in a pattern of solid and void minimizes the heat storage capability and radiation observed by the building. Moreover, the SW edge of this building is fully covered by rows of trees hiding this building from sun radiation. Furthermore, this building's placement on the site means that it is partially in a low area of the site topography. The SCT has a better situation in comparison to the other buildings since this building form is linear and sun-oriented. Additionally, one side of the SCT building is compatible with the site topography, and on another side, a high amount of vegetation prevents the building from experiencing the direct sun. Finally, the radiation simulation depicts high amounts of radiation on the roofs of ÖOL and CLH buildings in comparison to the other buildings The primary reasons for this last distinction are their low albedo materials and flat roof systems.

SVF factor was another tool used to assess an environmental parameter in this study. According to Table 1, the ÖOL has a large amount of SVF because of the building form. However, this situation in the case of the CLH partially decreases because of its linear form. The SVF is highly related to the building form and its height-width ratio. Therefore, the linear forms and spatial organizations of the SCT and the DME&FAE positively enhance the SVF. This may help to cover façades with buildings shadows. Moreover, the linear form of the buildings significantly contributes to the enhancement of the air flow in skimming over the buildings.

Besides the SVF tool, the turbulence simulation was used. According to Table 2, the square and massive form of the ÖOL and CLH buildings from one side and from another side the orientation of these buildings toward the prevailing winds (SW and NW) resulted in flow separation, which negatively affected the free flow movement. In this situation, a low-pressure zone was created on the leeward side of the buildings and this situation resulted in the formation of large eddies in this low-pressure zone due to the pressure differences. In fact, both buildings served as obstacles and resulted in the detachment of wind flow. In comparison to the ÖOL and CLH buildings, the other buildings are low-rise, have linear forms, and their altitudes, especially in the case of the DME&FAE, are located at a lower level of the topography which resulted in the flow skimming over the buildings without the formation of other eddies.

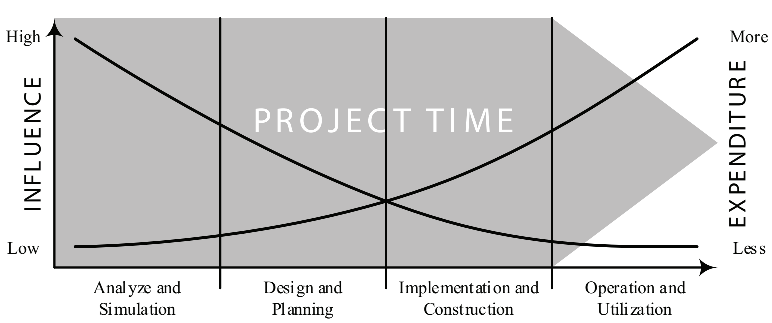
4.2 Open Space

The Atatürk Plaza is a central gathering plaza of the campus; it is enclosed by the four buildings. The plaza's altitude is partially depressed in comparison to the surrounding areas. Although the plaza is enclosed by surrounding buildings, the buildings are far away from each other and the plaza creates a relatively broad height-width ratio for COS. Because of the height-width ratio, the SVF is significantly increased. The high SVF combined with an absence of vegetative cover in this area (Figure 3) lent to increased hours of sun exposure and thereby absorption of radiation in the plaza (Table 1). In addition, the plaza's pavement material with low albedo vastly contributes to its minimal reflectance and maximum heat storage capability.

The turbulence analysis (Table 2) of the COS depicted that the square is located in a low-pressure zone. Therefore, the airflow from both directions (SW and NW), after stroke to the ÖOL and CLH buildings and because of the flow separation, results in the formation of the large eddies in the Atatürk Plaza. It is apparent that the absence of vegetation in this area emphasizes this effect on the Atatürk Plaza. As stated earlier (Table 1) both buildings (ÖOL and CLH) work as heat storage, the air flowing past these buildings carries a significant amount of heat into the Atatürk Plaza. Based on the environmental parameters and the analysis, it can be concluded that the COS of EMU temperature increase in comparison to the other area.

According to the COS assessment, it can be stated that the main COS on EMU campus is dealing with microclimatic problems which were very much driven by the rapid development of the campus without consideration for the environmental parameters. Hence, the design and planning process should integrate simulation and analysis stages to increase process performance. Following along with Paulson Jr (1976) efforts, this study proposes integration of the analysis and simulations within the project timeline (Figure 6). The proposal places the analysis and simulation phase at the beginning of the project, so it has maximum influence on the subsequent stages and a project outcome with minimum expenditure.

FIGURE 6. The early stage analysis and simulation highly influences the project expenditure (after Paulson Jr (1976).



Architects and urban designers should take a series of actions to improve the microclimate of the COS of EMU by addressing environmental issues directly in the design of new buildings and spaces. These actions could be the use of individual elements to protect the buildings from direct solar radiation, especially for the Mediterranean climate. Alternately, increasing vegetation, expanding the watershed, and replacing low-albedo materials with high-albedo materials may significantly contribute to improvement of the COS microclimate (Erell et al., 2011, pp. 17–18; Fuladlu et al., 2018a; Mohajerani et al., 2017; Oke, 1987; Rosenfeld et al., 1995).

5. CONCLUSION

The current study, using a broad review of literature, took a close look at the environmental parameters and offered a simple yet comprehensive method of microclimate analysis using the case of the COS of EMU. This study combined a field survey and the computer simulations of sun-path, radiation, SVF, and turbulence to offer a hybrid analysis method. As an addition to the existing literature, the current study provides a fundamental guideline for analyzing outdoor environmental parameters at the microscale. The methodology can be applied to any outdoor space since it is cost and time efficient, and it can be applied with an ordinary computer.

The results depict that Atatürk Plaza, as the main COS of EMU, faces an unacceptable situation from a microclimate point of view. The primary problems were found in the form, organization, and orientation of the surrounding buildings. The massive and square form of ÖOL and CLH may increase their heat storage capacity in Mediterranean climates. Besides, massive forms work as barriers to airflow and cause the formation of eddies on the leeward side of buildings; the main COS of EMU was especially affected in this way. Therefore, linear forms oriented to the sun-path and with respect for the prevailing winds are highly recommended during times when the wind flow is pleasant. The absence of vegetation especially at the center of the COS and the use of low-albedo pavement material minimized reflectance and maximized heat storage capability. The combination of these factors may negatively affect the human comfort of the COS. Although this study was restricted from providing specific solutions, the following recommendations are suggested:

a. design individual elements to protect buildings from direct solar radiation;
b. design individual elements on building edges to avoid wind flow separation;
c. conduct a study on vegetation type, height, and location; and
d. study the effect of material albedo on the overall microclimate conditions of the COS.

Additional study is required to consider more about the COS. For instance, the current study is limited from including the role of anthropogenic pollutants; therefore, subsequent studies should integrate the effects of pollutants on the microclimate of the COS. In the future, dynamic methods should be used to analyze and simulate campus design and any changes from the early stages of development.

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Availability of Data and Materials

All data generated or analyzed during this research are included in this manuscript.

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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