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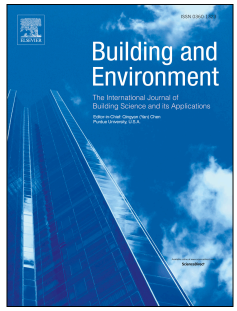

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Introduction of a Spatio-Temporal Mapping Based POE Method for Outdoor Spaces: Suburban University Campus as a Case Study

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1. Introduction

Buildings as filling elements and outdoor spaces as voids compose physical aspects of the architectural environment. While buildings as fills encase more limited and specialized functions (Velioğlu, 2013), serving as a ground for individuals' need to communicate to others is the most important function of outdoor spaces. Outdoor spaces as a place of delight and pleasure are often tied to urban life with memorable experiences via creating images of everyday life. The attached or particularly enclosed outdoor spaces are important to sustainable cities because they establish a common identity for social life through improving quality of urban living. These spaces can be used for social interaction, rest and relaxation, recreation, exchanging ideas and to support a sense of ownership and belonging (Herz, 2014). According to Gehl (2013), life between buildings (outdoor spaces) is a mix of outdoor activities in terms of necessary activities, optional activities and social activities. The transformation of outdoor spaces into socializing arenas through not only necessary activities, such as traveling between origins and destinations, but also optional and social activities depend on the design of these spaces as well as the convenience of user-oriented features that they house (Gehl, 2006).

In designing outdoor spaces, the needs of the users which consist of ecology, economics, technology, social and cultural concerns should be critical. According to Francis (2003) user needs are grouped in five major categories as; comfort (providing enough comfortable devices for performing activities), relaxation, passive and active engagement, discovery, and fun. Outdoor space should strongly articulate to the outdoor environment (natural or built environment in larger scale) both visually and functionally. In their comprehensive study, Matsuoka & Kaplan (2008) reviewed the studies published in *Landscape and Urban Planning* from 1991 to 2006 and classified user needs in two groups: (i) contact with nature, aesthetic preferences, recreation and play, and (ii) social interaction, citizen participation in the design process and community identity. Natural needs, directly linked with the physical features of environmental settings influence human activities to varying degrees and in many different ways. Whyte (1980) described successful outdoor space design as maintaining adequate seating, sunshine, wind protection, water and vegetation. The Project for Public Spaces (2000) identified four main factors in successful public space design: accessibility, activities, comfort and sociability.

In order to identify user needs in outdoor spaces as a way to assess if human use and design intentions are in fact successful, post occupancy evaluation (POE) is recommended as the most significant advanced method, which surpasses other methods such as archival research, observation, behavior mapping, interviews and environmental autobiography (Marcus & Francis, 1997). POE, as a way of systematically evaluating the performance of buildings, has earned increased attention in recent years (Hua et al., 2014). In spite of the increase in POE studies of indoor environments, there is a paucity of research about outdoor spaces. Having through much literature, it came to the conclusion that how little of research was applied on campus open spaces, although their critical role in learning and community life (Hanan, 2013).

University campuses create a unified sense of place with their buildings, outdoor spaces, social features and an effective spatial configuration. Apart from selected campus design models, campus plans are almost always arrangements of buildings with spaces created between them (Marcus & Francis, 1997). In campus planning, outdoor space is the key element with the potential to enhance well-being and quality of urban living. These outdoor spaces are the social and cultural activity places of university campuses not only for students and employees, but also the community. The relation between outdoor spaces and building groups, competence, usage periods, accessibility and interactions in the physical environment need to be investigated using a holistic approach. Although different aspects of outdoor space have been considered by many researchers since the 1960s, its critical role has yet to receive the attention it deserves. In the literature, to the best of our knowledge, a holistic POE study of outdoor spaces has not been published. The limited and narrowly focused POE studies make overall assessments without determining relations of causality. Other existing studies in outdoor spaces focus on (not limited with the selected studies): (i) user satisfaction (ii) space syntax and behavioral mapping, and (iii) biometeorological assessments have been given in Table 1. Descriptive information about the methodology, dataset, measure, analysis and findings of the studies has been included.

Table 1. Existing studies in outdoor spaces focus on (not limited with the selected studies): (i) user satisfaction (ii) space syntax and behavioral mapping, and (iii) biometeorological assessments

The aim of this study is to introduce a spatio-temporal mapping based POE method for outdoor spaces to extract both spatial and temporal knowledge from spatial processes and events. This comprehensive method is proposed to explore the users' spatial experiences in outdoor spaces within the context of the interaction between the conditions of the physical environment, users' behavior and activity, level of satisfaction and perception of comfort. The sub-objectives of the method are: enriching POE studies by including outdoor spaces, identifying important gaps in the existing approaches and emphasizing the importance of spatio-temporal data instead of the static view of geospatial phenomena.

A suburban university campus in Istanbul has been chosen as a case study, and the most highly used outdoor space, its main courtyard, has been mapped and discussed.

2. Method

Especially in post-2012 publications, POE studies of indoor environments have paid much attention to achieve goals of sustainability, increasing quality of life and creating more productive and inventive spaces for users. POE can be used effectively to improve building design by: (i) maintaining user satisfaction and productivity by identifying the real needs of users, (ii) increasing organizational efficiency by reducing time and energy loss, and (iii) providing benchmarking information for use in other projects to ensure sustainable development (Göçer et al., 2015).

While different POE methods and numerous applications in indoor environments are included in the literature, the limited methods and applications related to outdoor spaces show the crucial need for a comprehensive POE method for outdoor spaces. The proposed spatio-temporal mapping based POE method for outdoor spaces (Figure1) has the following purposes:

- New methods in POE research field will be provided by integrating issues such as user satisfaction, space syntax and behavioral mapping, biometeorological assessments, and user tracking.

- The integration of these issues will serve to enrich the content of POE studies of outdoor spaces.
- With the use of this leading methodology, the feedback loop for research on outdoor design will be closed.
- Spatio-temporal mapping will enhance the visualization technique in order to make gathered data easy to understand.

Figure 1. The purpose of the method

Survey Topics (STs)

The intention of this method is to integrate different studies focusing on various problems in outdoor spaces under the heading of POE. The survey topics take place in the method are user satisfaction, space syntax and behavioral mapping, biometeorological assessments, and user tracking (Table 2). In order to aggregate data, both qualitative and quantitative techniques and methods have been used. The POE method which governs all these survey topics gives the opportunity to understand the complex structure of spatial use explaining “why” and “how”. The steps listed in the survey topics below are not intentionally sequential. There are loops allow feedback, and some of steps can be repeated cyclically.

Table 2. Steps of surveyed topics

Integrating the Survey Topics: Spatio-temporal Mapping

Spatial data for topology and distance are related to objects that occupy space. A spatial database involves spatial data types that represent spatial objects and their spatial relationships. Current studies of data mining take a static view of geospatial phenomena, which captures only spatiality (Koperski et al., 1996) and cannot be used to infer cause and effect relationships because they overlook temporality. Temporal data mining that has the ability to determine the behavioral aspects of objects helps to understand why, rather than merely what (Roddick & Spiliopoulou, 2002). Integrating spatial and temporal data has received much attention in recent years and will help us to make better predictions for spatial processes or events.

In this study, spatio-temporal mapping is based on mapping user, environment and space-related data at that time into a single database using GIS software (Figure 2). The quantitative and qualitative data obtained from different sources are rearranged to form a database according to the identity number of their spatial origin. In spatio-temporal mapping, both the time and the space are located on each axis in the process of showing the change in the unit according to any variable (Miyamura et al., 2010). Both time and space represent a dimension on the map. All time-dependent interactions in the space are determined (López-Quilez & Munoz, 2009). This ensures that the data for the users and the environment at a specific time are converted into spatial data. Spatio-temporal analyses are the result of both a mutual interaction and a comprehensive association of factors related to users, environment and space and their interrelations. It is possible to evaluate these factors, each of which affects use value at various levels, as well as individual effects.

Figure 2. Integrating survey topics by using spatio-temporal mapping

3. Implementing the Method

Concomitant with the rapid increase in the number of suburban universities in Turkey, particularly in Istanbul, there is a great need for a comprehensive POE method to assess whether their outdoor space design solutions are successful and satisfactory. The proposed POE method has been applied to a suburban university campus in Istanbul, Turkey. Figure 3 shows the implementation flow chart, including data collection, evaluation tools and methods for each survey topic, and their integration in spatio-temporal maps.

Figure 3. The implementation flow chart

3.1 Case Study: Özyeğin University

In the last 10 years, more than 20 new universities have been established in Istanbul. Due to the limited and extremely expensive land in central Istanbul, recently founded universities have established their campuses in suburban areas to provide well-equipped and spatially adequate education facilities. As a newly established suburban university, Özyeğin University (OzU) was selected as a case study for the method. OzU is located within the boundaries of the city of Istanbul (Figure 4). OzU was founded in 2007 and began to offer classes at its Çekmeköy Campus in 2011. The campus is located close to the Yavuz Sultan Selim Bridge highway and the Şile highway (Figure 4). OzU's Çekmeköy Campus is situated on 280,000 m^2 and offers all the amenities and facilities necessary to foster students' academic development and expose them to social, sports and cultural events. The buildings are close to each other and the outdoor spaces between them are used as gathering areas to ensure continuity of movement between the buildings. The buildings are located on the main promenade that starts at the entrance and reaches the main courtyard, the heart of the campus.

Figure 4. The location of the university campus

3.2 Data Collection

The data collection procedure for each survey topic is explained briefly below.

3.2.1 User Satisfaction

A total of 1,041 students participated in the survey. The number of questionnaires is statistically acceptable with an error rate of 0.03 samples. Of the students who participated in the questionnaire, 48.8% were female, 46.6% were male. A total of 304 employees participated in the survey with a statistical error rate of 0.05. 68.4% of all the participants were female respondents. The employees were 42% administrative and 58.0% academic staff. The university has a very young profile. Of the employees, 74.2% were under 40 years of age, and 18.2% were between the ages of 41 and 50 (Table 3).

Table 3. User profile

The questionnaire was specifically selected to collect data from a large group of users. There were 23 questions: 3 Likert type questions (5-point), 13 multiple-choice questions and 7 open-ended demographic questions. The aim was to collect information about the users' profile, habits, overall outdoor environment satisfaction, activity-oriented behaviors and perceptions of campus sufficiency. This survey made it possible to gain an understanding of the users' satisfaction with the outdoor spaces on campus.

3.2.2 Space Syntax and Behavioral Mapping

Behavioral mapping methodology helps to identify the used and under-used outdoor spaces on campus. Behavior mapping within intensively used areas of the campus was measured through direct observations within 10-minute intervals using the methodology developed by Goličnik & Marušić (2012). Spatial behavior mapping was conducted for both passive (sitting, standing, lying down) and active (walking, running) occupancies within the campus during a typical weekday, repeated over 5 time intervals (8:00-10:00, 10:00-12:00, 12:00-14:00, 14:00-16:00, 16:00,18:00). In addition, behavioral mapping was repeated over 4 seasons (autumn, winter, spring, summer) to identify how the campus was occupied during an entire year. The duration and location of the observed activities were also noted. Only 12:00-14:00 time interval observations are presented in this study.

The use of space syntax analysis allows us to describe the visibility and accessibility levels of the physical environment and determine the integrated and segregated spaces on campus. The results from the user behavior maps and the spatial analyses were overlapped to show the role of spatial organization and behavioral patterns. Overlapping these two methods made it possible to identify the strengths and weaknesses of the campus design and to develop design strategies for potential improvements.

3.2.3 Biometeorological Assessments

Psychological factors (preferences, environmental stimuli, thermal memory, anticipations) as well as physical factors are highly determinant in outdoor comfort conditions (Nikolopoulou & Lykoudis, 2006). For this reason, while the microclimate data were measured, perceptions of comfort were also measured using questionnaires (Hwang & Lin, 2007). This data was collected using: (i) questionnaires and (ii) biometeorological measurements of weather parameters.

Outdoor thermal comfort surveys:

The survey was designed in two parts. The first part was used to collect descriptive information about the users such as gender, age, attire and activity, reason for visiting and time of outdoor exposure (relation between indoor and outdoor places). These characteristics are significant because thermal comfort is perceived subjectively. Most of the interviewees were students between 18 and 22 years of age, although there were a number of older staff members.

The second part of the survey refers to EN ISO 10551 (1995) and ASHRAEE 55 (2010) standards. Considering the conditions, the PMV method was used with questions about comfort, preferences, perception of weather parameters and satisfaction levels.

Meteorological Measurements:

These measurements were done using three different devices: (i) a portable mini-weather station used to measure sunlight, wind speed and direction, humidity and temperature, (ii) a portable CFM (cubic feet per meter) thermo-anemometer and (iii) a humidity meter. The portable mini-weather station was set at a height of 1.1 m. The height of portable devices was set at 0.6 and

1.1m, the human body’s center of gravity for sitting and standing subjects (Johansson et al., 2014). These portable devices were used to measuring conditions for interviewees during the survey.

CFD Analysis:

With CFD analysis, the wind patterns with a dominant effect on outdoor thermal comfort levels were simulated using StarCCM+ software. Even though the capabilities of the modern simulation software are very developed, uncertainties related to wind conditions, geometry and other numerical modeling approaches necessitate the validation of the numerical results with the experimental measurements. Wind measurements were thus conducted in the main courtyard of the university campus using the portable meteorological weather station at the locations shown in Figure 5. Wind speed and direction were recorded for 5 seconds at every measurement location, and the average wind speed and main wind direction were calculated in the post-processing step. The data was collected on a typical windy fall day in Istanbul, and the wind was from the northeast at about 10 m/s.

Figure 5. Measurement locations at the main courtyard

The base of the domain was formed using the digital elevation map data for an area of 4.6 km x 3.5 km. The university campus was positioned in the middle of the domain as shown in the figure. The height of the domain was selected as 1.5 km. At the inlet of the computational domain, wind speed and direction were set to the meteorological wind condition measurements. On both sides of the domain, the periodic flow condition was applied. The terrain and the buildings were set as walls with no slip condition, and the upper boundary of the domain was set as a wall with slip condition. Steady, three-dimensional RANS equations were solved using StarCCM+ software. The turbulence was modeled using the SST k-ω model. For convergence, the equations' residuals were monitored. The residuals dropped to as low as 10^{-6} for the momentum equations and 10^{-5} for the continuity equations.

3.2.4 User Tracking

Five CCTV cameras were placed at specified points on campus for user tracking. The images collected from the cameras with 2MP resolution, 32x optical zoom and 25fps were stored in an external hard disk. The CCTV software's own codec was used in the security center due to hard disk capacity.

The pedestrian detection pipeline yields detection coordinates on the campus map with their respective times and dates. This pipeline has two stages, detection and projection. The detection stage finds pedestrians in the video coordinate system to project onto the campus map and combine the detections with the weather data over the campus. The inception-residual network (inception-ResNet) (Szegedy et al., 2017) and structured faster-region based convolutional neural network architecture (faster-RCNN) (Ren et al., 2015), which achieved outstanding results in the ImageNet challenge (Russakovsky et al., 2015), were used for detecting pedestrians. The network was trained on the COCO dataset (Hays et al., 2014), which consists of 80 object categories involving pedestrians. During the detection stage, all objects except pedestrians were disregarded, and bounding boxes that exceeded a certain size were filtered out. Detected bounding boxes for a sample video frame are shown in Figure 6. Detections were made every 10 seconds, and the center coordinates of the detected bounding boxes were passed to the projection stage.

Figure 6. Sample output of the neural network

3.3 Data Processing: Spatio-temporal Mapping

Data aggregated from each survey topic was collected in different formats. Figure 7 shows that each survey topic required different data collection methods and tools. In order to use these data in the GIS environment, the data had to be converted into the required format (geographical data) that would later be overlapped on a spatial and/or spatio-temporal map. This was the most challenging step of the method. It enabled us to visualize data for the mutual relationships between user-space and environment at once on a map.

In order to create spatial and spatio-temporal maps, the outputs for each survey topic were organized in .csv format and then these non-geographical data were converted into geographical data by creating point clouds with the aggregated data using Grasshopper, a parametric design program. Then Rhino software was used to convert these point clouds into a CAD file since ArcGIS can only open them in .dwg format. The user tracking data were suitable to be visualized as point data, but the process of converting the environmental data into geographical data was completed by converting point data into .tin files, converting .tin files into raster data and then converting raster data into line data. Raster data were obtained from .tin files using spatial analysis methods in ArcGIS software. Using this method, the contours of environmental data such as wind speed, humidity and temperature were created so that both environmental datasets and user-related data could be visualized by overlapping them on a map in the GIS environment (as Figure 7 shows).

Although this new method has been structured to cover 4 groups of studies on outdoor spaces, the method can be applied for each topic individually or in a combination of the two or three of them according to the capabilities and limits of research team and/or interest. The programs such as Rhino, Grasshopper, ArcGIS are extensively used in architecture and urban design make the method more advantageous. For the transformation process of aggregated data (both qualitative and quantitative) into a database needed for GIS analysis is not complicated and can be achieved without skilled workers.

Figure 7. Converting non-geographical data into geographical data

3.4 Results

According to the survey results, both the staff and students were satisfied and had positive assessments of campus safety, attractiveness and identity (Table 4). The staff's lowest score was on the statement that the campus offers opportunities to meet others (3.01), and for students, it was on the statement that the campus encourages users to spend more time there (3.00).

Table 4. Survey results

Since the campus has a long rectangular shape, the academic buildings and the other facilities are situated on a linear axis (Figure 4). The outdoor spaces between buildings face the forest on the west side. Although buildings were constructed in different years, colored perforated metal mesh on their façades creates a harmonic integrity. The campus, built with a flexible and modular approach, is an example of sustainability through the economic use of resource and operating costs. The academic buildings are designed to be eco-friendly and sustainable. The campus is located in the periphery of the city and surrounded by city's north forest. This gives the campus the feeling of being in a green and peaceful zone. Although the campus is located on a sloped topography, the linear axis connects the buildings on different levels. This smooth axis and eventual convergence in the central courtyard provide both accessibility and prevent the buildings from reaching heights that exceed a human scale. Contemporary architecture style buildings surrounded by the existing green pattern give the campus a specific identity. This claim was also supported by the survey respondents.

For the other survey topics, as the largest outdoor space on campus surrounded by educational facilities and the student center, the main courtyard was mapped and discussed. Due to the facilities and services it provides, it is the area used most. The main courtyard is surrounded by academic buildings and the student center. The forest west of the campus creates natural scenery. The main courtyard's purpose is to accommodate leisure and recreational activities as well as large-scale events such as concerts and meetings. A map of pedestrian behavior shows which areas are used the most. Passive activities occur by the corner of the student center and on the main courtyard where benches are located. The Café Shop provides a significant number of seating as well as shading elements, with food and drink that also attracts people. However, the high occupancy of main courtyard is also due to the recreational factor of people enjoying its green open area with a view of the forest. The use of square is not very pleasurable for long-term passive activities because its trees are still saplings that do not provide enough shade. The trees on the main courtyard are also saplings, but unlike from square, it has umbrellas for shade. In this area, two more activities occur: lying down and running. The grass on the courtyard encourages people to spend time on it. In the evening, the area is well-lit.

Active users walk along the pathways in the courtyard and the area leading to the main promenade and other areas on campus. Although the user occupancy is at its highest on campus, the visibility level is 8.951. Café Shop and its surrounding shaded areas have a high user density during the autumn and winter months (Table 5). In the spring and summer months, the number of users in the green area increases. In the summer, shading elements are placed in these green areas. Since the benches under these shading elements are fixed, the shading elements are not effective when their shadows do not fall on the benches.

Table 5. Space syntax and behavioral mapping analysis of the main courtyard

For presenting biometeorological assessments (measurements, outdoor thermal comfort surveys and CFD simulations) and user tracking results, a representative date, October 20, was chosen. Figure 8 shows the results of the outdoor thermal comfort surveys with the biometeorological data for 2:00 pm on October 20. The survey respondents confirmed the findings of CFD simulations (Figure 9). According to biometeorological data, there was more sunshine in the area between the student center and academic building 2, and accordingly, the recorded temperatures were high. The temperature varies between min. 21.3 °C to max. 23.6 °C. At the same time, the wind corridor increases wind speed. The users indicated that, although the outdoor air temperature averaged 21.5^{o}C, they felt cold due to wind speed (ranges between min. 0.02 m/s and max. 6.0 m/s). Humidity percentage diverges from 72.3% to 78.3%, being highly related to solar radiation.

Figure 8. Biometeorological data and outdoor thermal comfort survey results in the main courtyard on October 20 at 14.00

There are also users who say they feel "cool" due to the significant increase in wind speed despite the increase in temperature during noon hours. Even though they are experiencing the same space, users' evaluation of the environment in a very different way from each other is also an indicator of how much the sense of comfort is connected to the other issues such as gender, exposure time and user related characteristics. It is seen that the longer exposure time cause feeling colder. The gender is also another factor should be considered in outdoor thermal comfort. Under the same environmental factors, although having higher clo index the female occupant feels colder than male occupant.

CFD simulation predicted that the main courtyard of the campus is largely protected from the wind. However, gusting winds are generated in the north of the area where two buildings approach each other as Figure 9 shows. Except for that location, the wind speed distribution shows a relatively uniform distribution in the area. CFD simulation predicted a velocity of approximately 8m/s. Even though the measurements agree on the presence of a high wind zone in the north of the main courtyard, CFD simulation overestimated the wind speed by approximately 3 m/s.

Figure 9. CFD and measurements results in the main courtyard on October 20 at 14.00

With the use of user tracking based on aggregated data from camera surveillance, systematic observation of users providing specific information, such as who, where and what is being done can be possible. This valuable information can be used for spatial statistical analyses such as standard deviational ellipse (SDE). SDE which was initially propounded by Lefever (1926) refers to the area covering about 68% of the variance standardized around the mean center. The more the ellipse overlaps the area of analysis, the more homogeneous the data distribution (www.arcgis.com).

In order to analyze the distribution of occupants, the SDE method was used. In this method, the size and shape of the ellipse determine the degree of dispersion of occupants in the main courtyard, and the orientation of their extension display the direction of the distribution. SDE analysis helps capturing occupation patterns and pedestrian routes in outdoor spaces, as well as to determine the configurational properties of the campus layout.

The analyses were done for the main courtyard during a day to identify micro-climatic effects related to diurnal changes on the usage value of space and occupation pattern (Figure 10). Figure 10 shows the user tracking maps from 8:00 am to 5:35 pm. Classes begin 8:40 am, so early in the morning the main courtyard houses users were having their breakfast and drinking coffee, and around 9.00 am the number of users in the area fell. It peaked at midday, and at 1:30 and at 5:35 pm when the shuttle bus returns, the number of users in the area fell again. Each red point represents a user on the map.

Figure 10. The SDE of the distribution of the occupants in the main courtyard on October 20

The results of the SDE analysis in the courtyard (Figure 10 and Table 6) indicate that the dominant direction of the SDE of occupant pattern has a northwest-southeast trend in the morning hours, with the standard distance of 0.209067m in the x axis and 0.125275m in the y axis and a rotation angle of 173.88° at 8.00-8.05am. But the dominant direction trend changes to northeast-southwest direction after lunch hours and the dominant distribution of the courtyard use shows that the standard deviation had the standard distance of 0.127053m in the X axis and of 0.139094m in the Y axis, and a rotation angle of 70.06° at 17.00-17.35am. The spatial distribution of the occupation pattern is clustered. The heavily used Café Shop and intensive use of the Student Center play an important role in differentiation of dominant direction by creating an attractive meeting point for the users.

Table 6. Results of analysis of SDE in the courtyard of the campus from 8.00-17.35

4. Discussion

Spatial design of learning environments is restructuring in accordance with the developments in information and communications systems, changing demographics, increased focus on student engagement, and demand for sustainability (Whitmer, 2009). In response to new ways of learning, innovative solutions in 'learning environment design' have been introduced, and the solutions lead to increased flexibility both use of space and time, resulting in higher quality of learning outcomes and satisfaction through the implementation of creative and innovative learning environments. Rodrigues et al. (2009) emphasized the relationship between multitasking ability of space functions and learning process indicating that at least twice the total amount of time spent by students in learning activities occurs outside the classroom. With the statement of the direct correlation between the physical aspects of the learning environment and learning activity (Salama, 2009), the role of places outside the classroom has become more very important. Moreover, given the fact that students spend a large amount of their time on university campuses, there is a need to provide a livable and pleasant environment where they can spend their free time comfortably and engage in leisure activities. This need is usually met by open and green areas, which are essential parts of university campuses. The comprehensive POE method for outdoor spaces is proposed to meet the crucial requirement for completing the missing link in outdoor design process. The following original value (s) are obtained as a result of the study;

- In the literature, to the best of our knowledge, a holistic POE study (above-mentioned content) for outdoor spaces has not been published. The POE method governs the survey topics such as user satisfaction, space syntax and behavioral mapping, biometeorological assessments and user tracking which were studied separately before to give the opportunity for understanding the complex structure of spatial use through explaining “why” and “how”.
- With this method, the importance of POE studies for outdoor spaces, which are at least as important as the interiors and serving as a unifying element between the external environment and the internal environment, has been emphasized and the gap in this area has been aimed to be eliminated.

- In literature, the use of spatial mapping for the visualization of POE results and transformation of aggregated data into a database has been applied on different POE studies (Hua et al., 2014; Göçer et al., 2015; Göçer et al., 2016; Göçer et al., 2018). In this study, the use of spatial mapping has been revised for outdoor POE studies and enriched as "spatio-temporal mapping" method.

- This method will not only fulfill the need to investigate the synchronous spatial and temporal relations indicated in the literature, but also help outdoor POE studies get the attention they deserve.
- This method will also lead to the widespread use of POE for urban life quality research while closing feedback loop in outdoor design.

- Despite the fact that research on POE studies has been carried out in urban settlements, such studies are lacking in university campuses. This study has contributed to the literature with a case study on suburban university campus.

- The study includes various survey topics to reveal underlying reasons in explaining space use. This will not only serve to enrich the content of the POE studies, but will also guide the cause-effect relationship works carried out in the social sciences.

5. Conclusion

In POE studies, visualization takes on more importance, and with the use of GIS in spatial data mining, the data is able to be visualized through spatial and spatio-temporal maps. This makes it possible to understand the complex structure of relationships and to connect various stakeholders involved in the process. This visualization would be particularly valuable as a tool for managing building information in the design and construction sector.

This paper shares findings from a case study, Özyeğin University in Istanbul, that focuses on a POE approach for outdoor spaces in a case study of. In order to evaluate outdoor spaces on campus, a spatio-temporal mapping method integrating outdoor thermal comfort, biometeorological analysis, and user tracking has been proposed. The spatio-temporal mapping method extends the use of GIS, a powerful tool for analyzing and visualizing spatial and temporal relations at the same time. Variables of different qualities related to users, environment and space were systematically processed and analyzed to be transformed into valuable information in order to evaluate whether the design intentions were successful. A database for all the quantitative and qualitative data on users, environment and space was used to create the maps. Spatial statistical analyses were conducted based on the spatio-temporal maps on October 20 to determine occupation patterns and pedestrian routes in main courtyard university campus. By transferring the pedestrian tracking data from camera surveillance into the GIS environment, it is possible to process, digitize and visualize a large amount of data more accurately. Explanations and deductions can be made on the spatio-temporal maps by using spatial statistical analyses such as mean center and standard deviational ellipse. This paper focused on a single case in order to do an in-depth analysis. Multiple-case studies should be conducted. Doing so will enable us to make comparisons that will further increase our knowledge about outdoor design and how to evaluate its effects on user behavior, satisfaction and comfort.

This study's findings reveal the importance of designing outdoor spaces as areas of social and cultural activity of university campuses. Suburban campuses need to be addressed as urban settlements because they meet the basic functions of housing, work, recreation and transportation, and because the population density (around 10,000 people on medium-sized campuses) is high. These campuses do not consist only of various social and educational structures, but involve outdoor spaces that generate interacting communities and balance the inward focus of learning.

In the design and planning of university campuses, it is essential that outdoor spaces ought not to be treated as left-over areas. Careful consideration should be given to the overall spatial configuration of the buildings and outdoor spaces defined by these structures, location of building entrances and the detailing of outdoor spaces for a comfortable and delightful urban living. In addition, the main congregational areas should be supported with user-oriented features, such as benches, shading devices, and catering services for maintaining passive and active engagements. During campus planning process, as in any other site planning process, it is critical to conduct a participatory process by including prospective users in the decision-making process from the start. Similarly, it is important to do some sort of evaluation –evaluating the occupancy patterns and investigating the underlying reasons of these patterns– once the design is implemented so that changes or additions to an existing campus can be planned strategically. The proposed POE model can be used to identify user practices accurately and understand whether design intentions are in fact successful. The conclusions discussed here can guide both practicing architects and landscape architects in the design of new university campuses.

ACKNOWLEDGEMENT

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Table 1. Existing studies in outdoor spaces focus on (not limited with the selected studies): (i) user satisfaction (ii) space syntax and behavioral mapping, and (iii) biometeorological assessments

	References	Methodology	Participants	Case study	Dataset	Measures	Analysis	Findings
(i) User Satisfaction	Abu-Ghazzeh, 1999	interview and photographing of outdoor space use (summer)	a total of 140 participants (students, faculty, admin staff)	a suburban campus in Jordan	qualitative dataset	physical attributes of outdoor spaces (i.e. sitting places, trees and shading)	qualitative analysis (reviewing the results)	In socializing the size of the space, the presence of sitting opportunities, and the type of landscape are important.
	Lau &Yang, 2009	site observation & questionnaire	a total of 33 participants (students & staff)	a city campus in Hong-Kong	self-reports on perception and usage patterns of green spaces and resting points	green space usage and perception	qualitative analysis (reviewing the results)	In the perception of the space and usage shading elements, natural views, aspect ratio of green open space is critical.
	Ercevik & Onal, 2011	questionnaire	total of 150 students	a suburban & 2 in-town campuses in Turkey	self-reports on outdoor spaces of campuses	physical and social characteristics of campus outdoor spaces	quantitative analysis (descriptive analysis)	Suburban universities' outdoor spaces should be designed strategically.
	Isitan, 2011	a POE survey	a total of 93 students	2 suburban campuses in Turkey	self-reports on outdoor spaces & individual physical activity	physical qualities of accessibility, size, safety, aesthetics, landscape and noise	quantitative analysis (descriptive analysis)	There is a correlation between evaluation of campus and the time spent in the campus
	Hanan, 2013	site observation & questionnaire	a total of 230 students	an in-town campus in Indonesia	self-reports on outdoor spaces of campuses and individual physical activity	physical (materials and outdoor space) and spatial aspects of campus outdoor spaces	qualitative analysis (reviewing the results)	Shaded areas, comfortable seating to the side of the main pedestrian axes, variety of open spaces in proximity to classrooms are the primary attraction factors for students.
	Wei et al., 2014	questionnaire	A total of 89 students (domestic & international students)	a campus in Korea	questionnaire and in-depth students' interviews	space usage & activities in the campus	quantitative analysis (descriptive analysis) qualitative analysis (reviewing the results)	Higher education space organizations and facilities have to be designed for the needs of domestic and international students.
	Lau et al., 2014	site observation of students` behaviors	–	an urban & a suburban campus in Australia & Hong Kong	observations	green space usage and morphology	qualitative analysis (reviewing the observations and assessments)	A healthy campus must encompass open spaces in diverse scales for different purposes.

	References	Methodology	Participants	Case study	Dataset	Measures	Analysis	Findings
(ii) Space Syntax and Behavioral Mapping	Salama, 2008	behavioral mapping, observation and questionnaire	a total of 58 students	a suburban campus in Qatar	self-reports on perception of physical and spatial attributes + observations	physical (massing, shading, seating) and spatial aspects (wayfinding) of campus outdoor spaces	qualitative analysis (reviewing the observations) and quantitative analysis (descriptive analysis)	Lack of shading and seating devices along with way finding barriers hinder the efficient utilization of outdoor spaces.
	Aydin & Ter, 2008	survey, behavioral mapping and observation	a total of 243 students	a suburban campus in Turkey	self-reports on perception of physical & behavioral attributes + behavioral mapping	physical (outdoor space appearance and accessory elements) aspects of outdoor spaces	quantitative analysis (descriptive and correlational analysis)	The higher the quality of the physical landscape components of the space, the higher the perceived level of that space.
	Yildiz & Sener, 2010	field survey, behavioral mapping and questionnaire	a total of 209 users	an in-town campus in Turkey	self-reports on outdoor spaces of campuses	physical and social characteristics of campus outdoor spaces	quantitative analysis (regression and factorial analysis)	Enclosed spaces, spatial configuration and physical attributes are significant for the use of outdoor spaces.
	Yaylali-Yildiz et al., 2013	space syntax analysis, observation of stationary activity and survey	a total of 97 students	a suburban campus in Turkey	spatial configuration syntactic analysis + self-reports of students` choices of spatial practices	syntactic measures of accessibility + self-reported socio-psychological public practices	quantitative analysis (visual comparison of syntactic and behavioral patterns)	In campus design, furniture and activity supporting stationary uses need to be considered.
	Heitor et al., 2013	space syntax analysis, interview and space-use observation	a total of 10 participants (students and staff)	an in-town university in Lisbon	spatial configuration syntactic analysis of the campus	syntactic measures of accessibility + self-reported information regarding accessibility on campus	qualitative analysis	The car parking harms pedestrian traffic and eliminates the natural property of spaces to allow movement or conviviality.
	Ozbil et al., 2018	space syntax analysis, space-use observation, survey and behavioral mapping	a total of 1345 participants (students and staff)	a suburban campus in Turkey	spatial configuration syntactic analysis of the campus & behavioral attributes + behavioral mapping	physical (massing, shading, seating) and spatial aspects (wayfinding) of campus outdoor spaces	quantitative analysis (visual comparison of syntactic and behavioral patterns)	Pedestrian quality attributes in outdoor spaces with high visibility and accessibility levels would increase rates and types of activities in a campus.

	References	Methodology	Participants	Case study	Measures	Analysis	Findings
(iii) **Biometeorological Assessments**	Lin et al., 2010	field experiments, survey and RayMan	1644 interviews for survey	a campus in central Taiwan	air temperature in the shade, horizontal solar, wind speed, relative humidity and the surrounding ground surface temperature	using 10-year period meteorological data Rayman model run to assess the shading effect on annual thermal comfort with PET index	Beside the importance of sky view factor, thermal requirements of residents and characteristics of the local climate must be considered when creating shaded outdoor areas.
	Cheng et al., 2012	longitudinal experiments	subject group of 8 participants	a campus in Hong Kong	four experimental conditions microclimatic conditions	examines the use of pmv and illustrates the use of PET index	Developed formulas help determine the standard needed to achieve neutral thermal sensation in Hong Kong.
	Marakemi et al., 2012	field experiments and survey	200 students	a campus in Malaysia	air temperature, relative humidity, wind speed and mean radiant temperature in shaded outdoor spaces, and subjective assessment of thermal comfort	thermal comfort assessment with pet & perceived thermal comfort analysis	PET index in the selected shaded outdoor spaces of the campus were higher than the comfort range defined for tropical climate.
	Srivanit & Hokao, 2013	on-site measurement & a numerical simulation model ENVI-met		a campus in Japan	air temperature, relative humidity, wind speed and mean radiant temperature in field to validate simulation model	based on the current conditions of the simulation model, the cooling potential of 3 different greening modifications were compared	Decision support tools are particularly useful for modeling the urban thermal impacts of different scenarios and for analyzing greening performance.
	Niu et al., 2015	on-site measurement		a campus in Hong Kong	continuous monitoring of the pedestrian level winds and thermal parameters at two sample days in summer, which includes air temperature, globe temperature, wind speed & humidity	the effect of building design on urban heat island has been assessed with PET index	Wind amplification combined with shading effects can generate thermally comfortable conditions in the open ground floor beneath an elevated building.
	Taleghani et al., 2015	on-site measurement & a numerical simulation model ENVI-met		a campus in USA	air temperature, globe temperature and wind, spectral reflectivity and albedo of surface materials	courtyard vegetation, ponds and high albedo surfaces were investigated as potential heat mitigation strategies	In the temperate climate, vegetation and water bodies can reduce air temperature and significantly mean radiant temperature in canyons.
	Bakovic & Gocer, 2017	Field measurement, questionnaire & a numerical simulation model ENVI_met	13 students	a suburban campus in Turkey	air temperature, solar radiation, wind speed and humidity; perception of the thermal environment (PMV)	effects of roof terrace flooring materials on microclimate and outdoor thermal comfort	Proper use of trees and grass can improve outdoor thermal comfort; still the role of the building geometry and tree presence are essential.

Table 2. Steps of surveyed topics

ST1-User Satisfaction	ST2- Space Syntax & Behavioral Mapping
• Determining the user profile (selecting a set of samples), • Conducting surveys and observations to identify user behaviors and patterns of spatial use with behavioral mapping, • Analyzing the data statistically, making complex structures simple and perceptible with factor and variance analysis, and t-tests, • Using these analyses to identify differences in user groups.	• Determining the functions of buildings and function analysis, distance between buildings and modeling spatial organization, • Digitizing outdoor space patterns with space syntax, • Determining visibility and accessibility values of outdoor spaces, • Determining how people use outdoor spaces by observing their movement and behavior.
ST3-Biometeorological Assessments	**ST4-User Tracking**
• Measuring year round microclimatic factors in designated areas, • Performing wind and temperature analyses using CFD software, • Conducting outdoor thermal comfort surveys, • Determining outdoor thermal comfort zones using indices such as PMV.	• Creating a database from images recorded by cameras, • Designing & implementing tracking algorithms for moving people, • Designing & implementing algorithms for the calibration of data from geographic information systems (GIS) using cameras, • Algorithms for digitizing images, • Regulating data on critical days for microclimate data.

Table 3. Participant profile

	Total number of users	The number of surveyed users	%
Students in undergraduate programs	5315	1041	**19.6**
Academic and administrative staff	698	304	**43.6**

Table 4. Survey results

I agree with the opinion that….		campus is attractive	campus is well-organized	campus is safe at daytime	campus is safe at night	campus has an identity	campus encourages spending more time	campus give opportunities to make friendships	campus supplies privacy
Student	Mean	3.72	3.48	3.95	3.61	3.74	3.00	3.04	3.05
	N	1031	1025	1021	1020	1021	1027	1025	1027
	Std. Deviation	.861	.945	.988	1.171	.900	1.147	1.104	1.225
Staff	Mean	3.72	3.08	4.17	3.41	3.87	3.04	3.01	3.35
	N	319	321	321	306	316	316	317	318
	Std. Deviation	.861	1.034	.822	1.008	.784	.962	.934	1.054

Table 5. Space syntax and behavioral mapping analysis of main courtyard

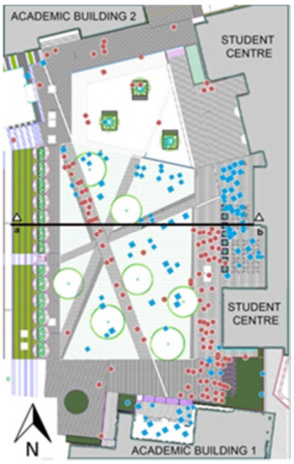
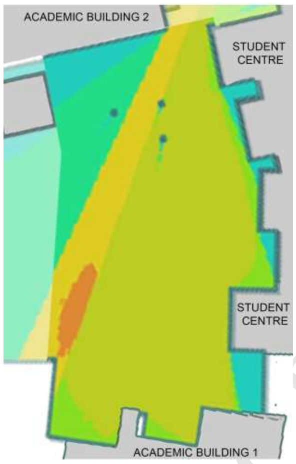
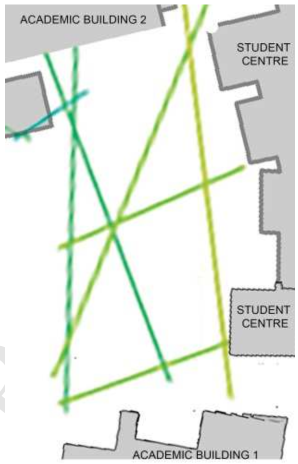
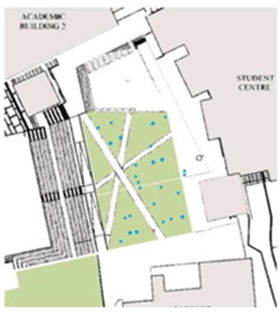
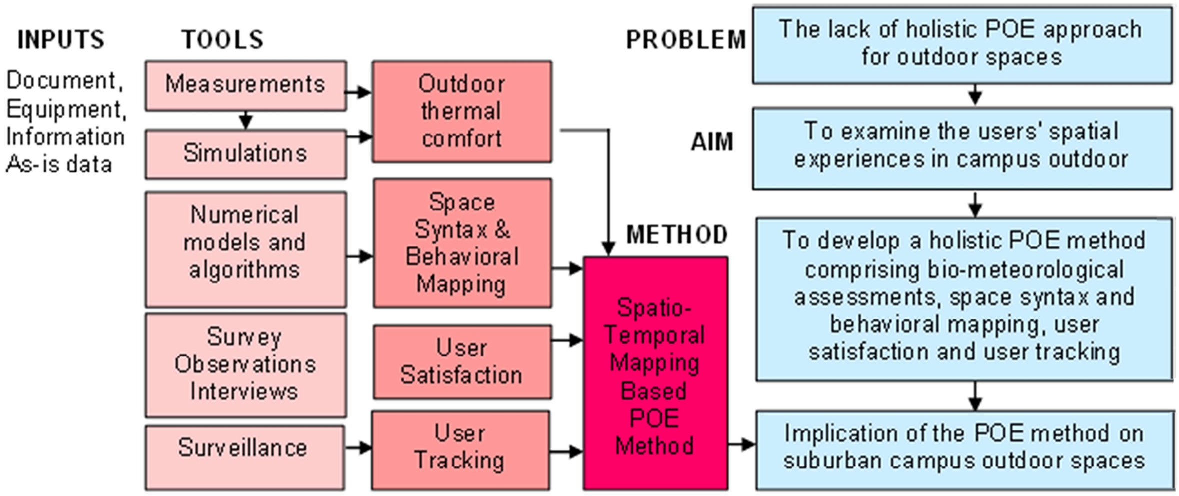
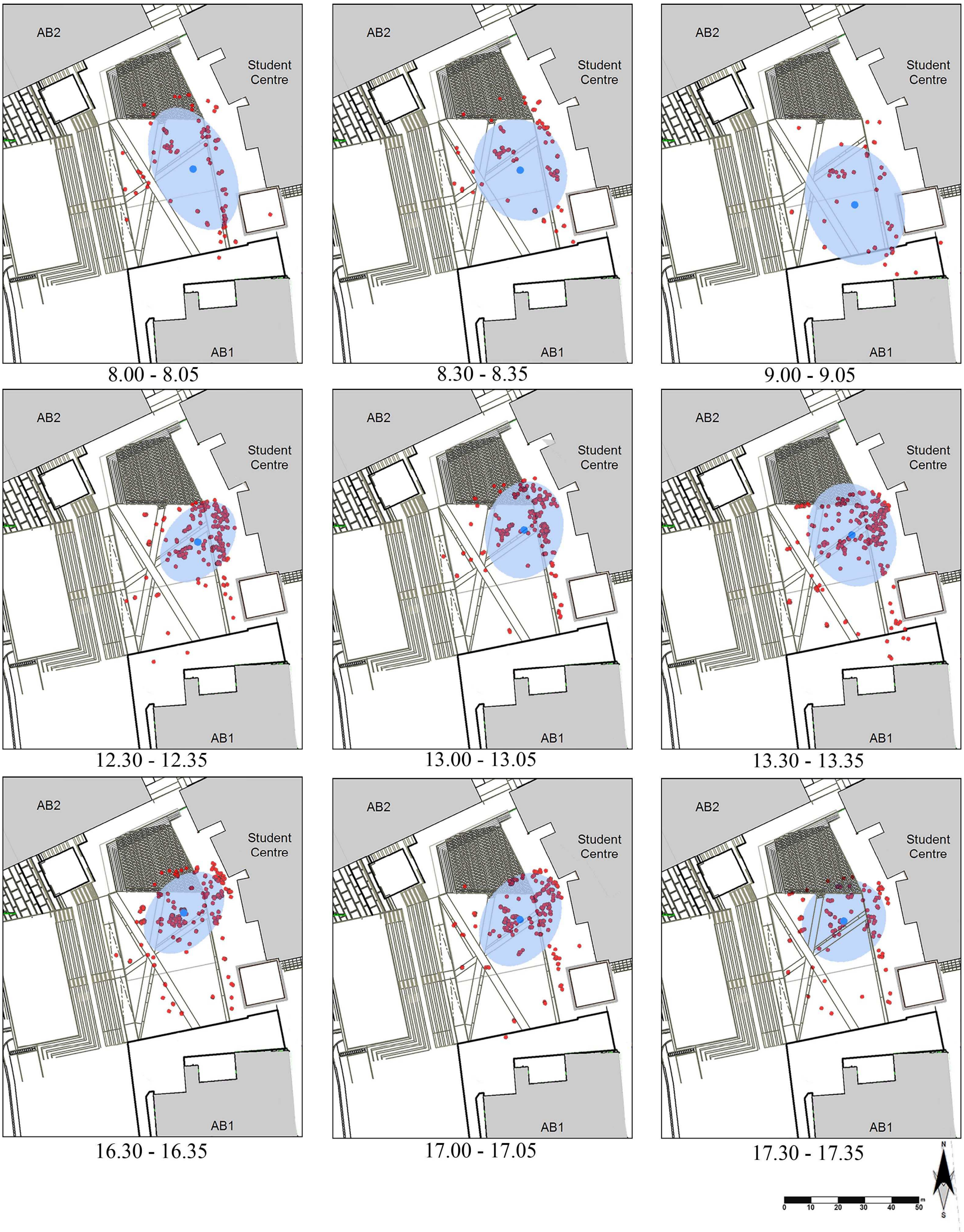
<table>
<tr><th>Site View</th><th>Site Plan</th><th>Integrity</th><th>Axial connectivity</th></tr>
<tr><td>
</td><td>
</td><td>
</td><td>
</td></tr>
<tr><th>Observed activities</th><th>Spatial function</th><th>Ground surface</th><th>Green design</th></tr>
<tr><td>Standing Sitting
Walking Running
Lying down</td><td>A large open space for leisure as well as organizational activities</td><td>Natural stone cladding
Granite cube stone
Ebony granite stone
Lawn area</td><td>Shrubs
Decoration plants
Sapling trees</td></tr>
<tr><th colspan="2">Existing Spaces and Successful Qualities</th><th colspan="2">Missing / Inadequate Spaces and Failed Attributes</th></tr>
<tr><td colspan="2">•The area with large courtyards and has the main recreational area
• Esthetic, visual objects (sculpture, etc.) are available
• Forest land in the west of the campus creates natural scenery.
• Eating / drinking facilities are available
• Walking divergence from other areas
• The area has average integration value</td><td colspan="2">• Inadequate seating and shading equipment
• Cafe Nero users prefer to sit in tables under the shaded area
• The walking path on the west side of the courtyard and the sitting elements on the edge of the walking path are rarely used
• Some green areas of the courtyard are not used due to lack of seating / shading equipment
• No flowers to color the place</td></tr>
<tr><td colspan="4">
</td></tr>
<tr><th colspan="4">4 Seasonal behavioral mapping</th></tr>
<tr><td colspan="4">FALL WINTER SPRING SUMMER
12.00-14.00
   </td></tr>
</table>

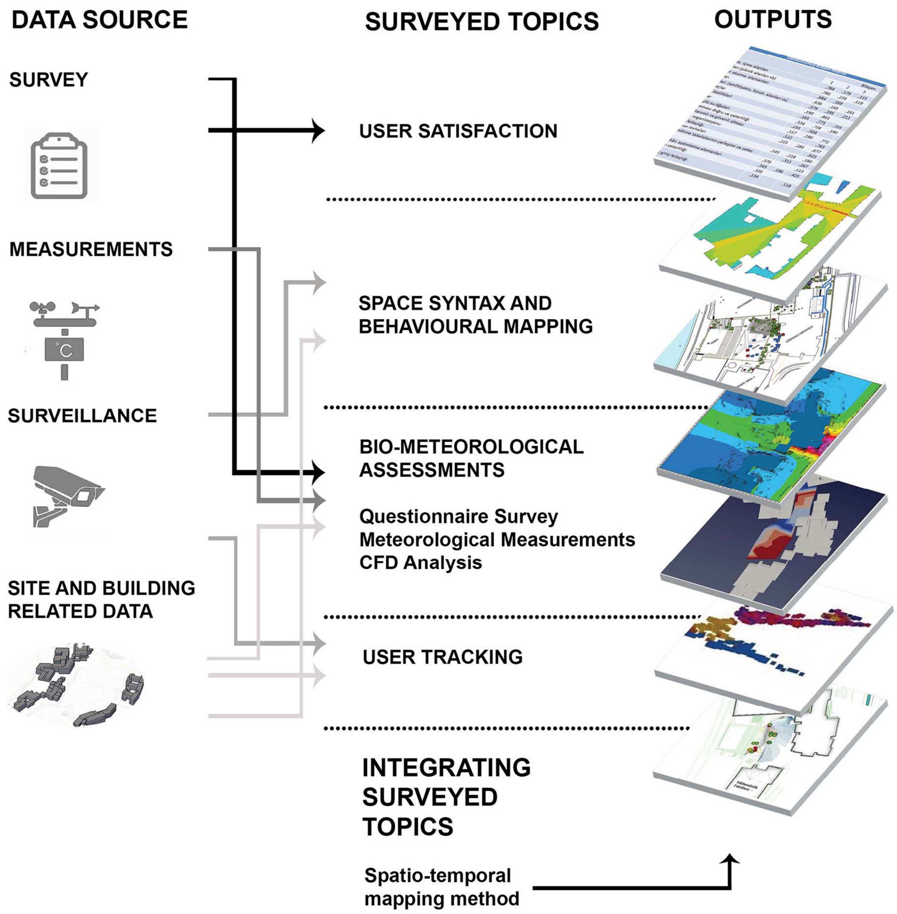
Table 6. Results of analysis of SDE in the courtyard of the campus from 8.00-17.35

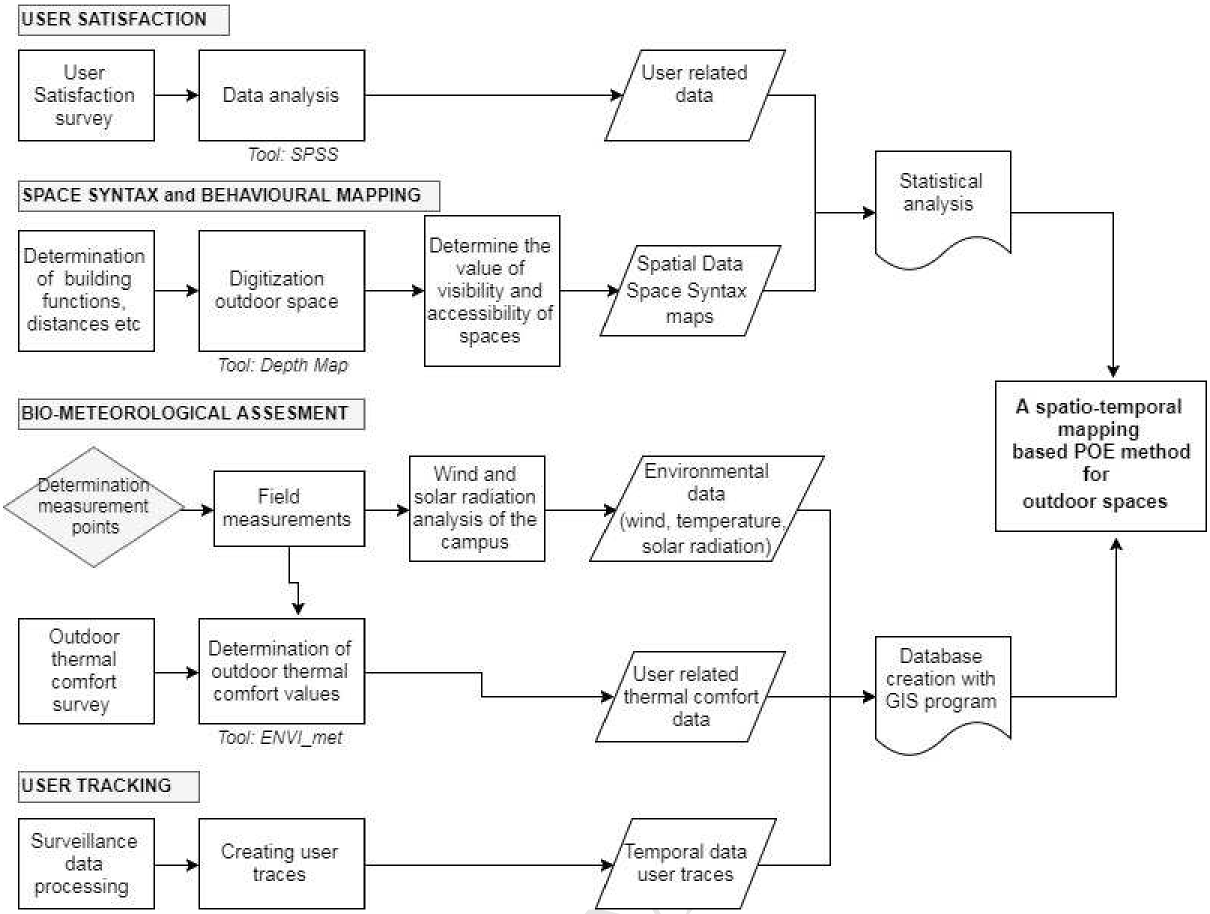
Time	Center X	Center Y	XStdDist	YStdDist	Rotation
08.00-08.05	8.384257	0.985409	0.209067	0.125275	173.88
08.30-08.35	8.352218	0.991088	0.16575	0.145418	175.75
09.00-09.05	8.353832	0.951096	0.197933	0.152864	177.37
12.30-12.35	8.40568	1.098257	0.101248	0.145181	59.54
13.00-13.05	8.407738	1.064077	0.123677	0.15609	31.50
13.30-13.35	8.390174	1.098335	0.13804	0.167947	0.38
16.30-16.35	8.372026	1.087493	0.104934	0.150884	62.32
17.00-17.05	8.383852	1.080769	0.119258	0.159636	51.19
17.30-17.35	8.379148	1.091701	0.127053	0.139094	70.06

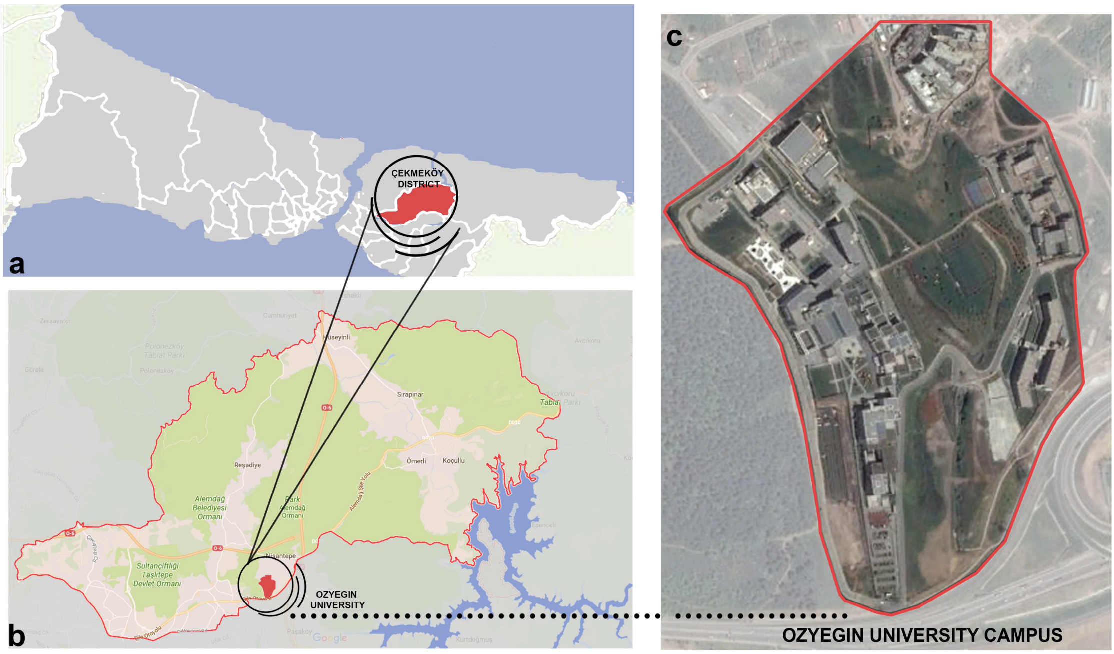

INPUTS
TOOLS
Document,
Equipment,
Information
As-is data
Measurements
Simulations
Numerical models and algorithms
Survey
Observations
Interviews
Surveillance
Outdoor thermal comfort
Space Syntax & Behavioral Mapping
User Satisfaction
User Tracking
METHOD
Spatio-Temporal Mapping Based POE Method
PROBLEM
The lack of holistic POE approach for outdoor spaces
AIM
To examine the users' spatial experiences in campus outdoor
To develop a holistic POE method comprising bio-meteorological assessments, space syntax and behavioral mapping, user satisfaction and user tracking
Implication of the POE method on suburban campus outdoor spaces



AB2
Student Centre
AB1
8.00 - 8.05
8.30 - 8.35
9.00 - 9.05
12.30 - 12.35
13.00 - 13.05
13.30 - 13.35
16.30 - 16.35
17.00 - 17.05
17.30 - 17.35
N
S
0
10
20
30
40
50
m

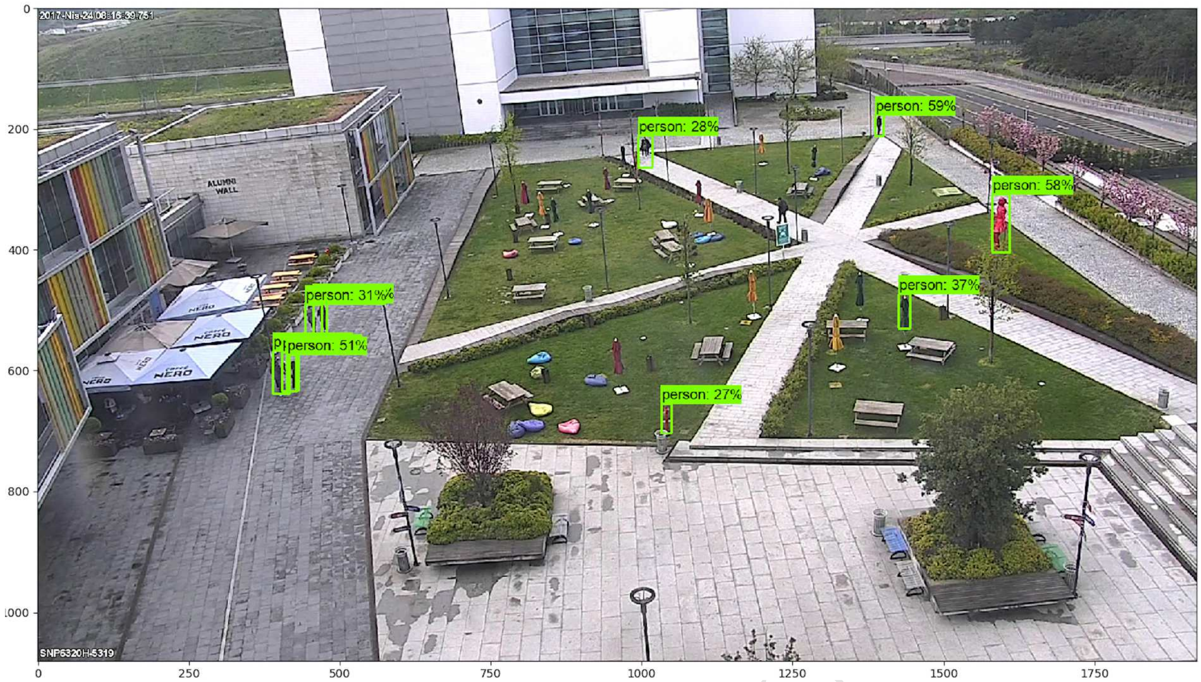

DATA SOURCE
SURVEYED TOPICS
OUTPUTS
SURVEY
MEASUREMENTS
SURVEILLANCE
SITE AND BUILDING RELATED DATA
USER SATISFACTION
SPACE SYNTAX AND BEHAVIOURAL MAPPING
BIO-METEOROLOGICAL ASSESSMENTS
Questionnaire Survey
Meteorological Measurements
CFD Analysis
USER TRACKING
INTEGRATING SURVEYED TOPICS
Spatio-temporal mapping method


USER SATISFACTION
User Satisfaction survey
Data analysis
Tool: SPSS
User related data
Statistical analysis
SPACE SYNTAX and BEHAVIOURAL MAPPING
Determination of building functions, distances etc
Digitization outdoor space
Tool: Depth Map
Determine the value of visibility and accessibility of spaces
Spatial Data Space Syntax maps
A spatio-temporal mapping based POE method for outdoor spaces
BIO-METEOROLOGICAL ASSESMENT
Determination measurement points
Field measurements
Wind and solar radiation analysis of the campus
Environmental data (wind, temperature, solar radiation)
Outdoor thermal comfort survey
Determination of outdoor thermal comfort values
Tool: ENVI_met
User related thermal comfort data
Database creation with GIS program
USER TRACKING
Surveillance data processing
Creating user traces
Temporal data user traces

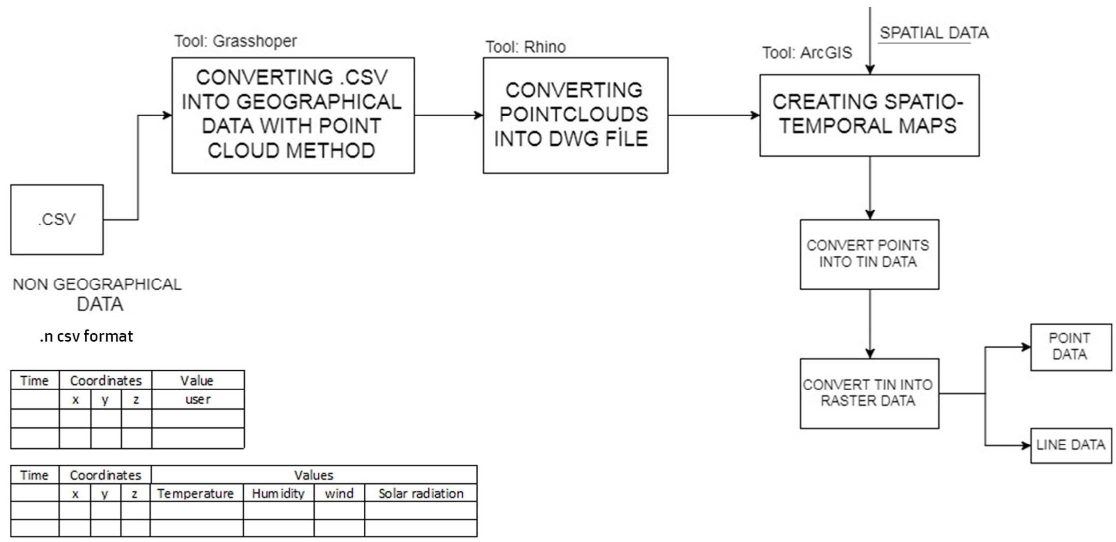


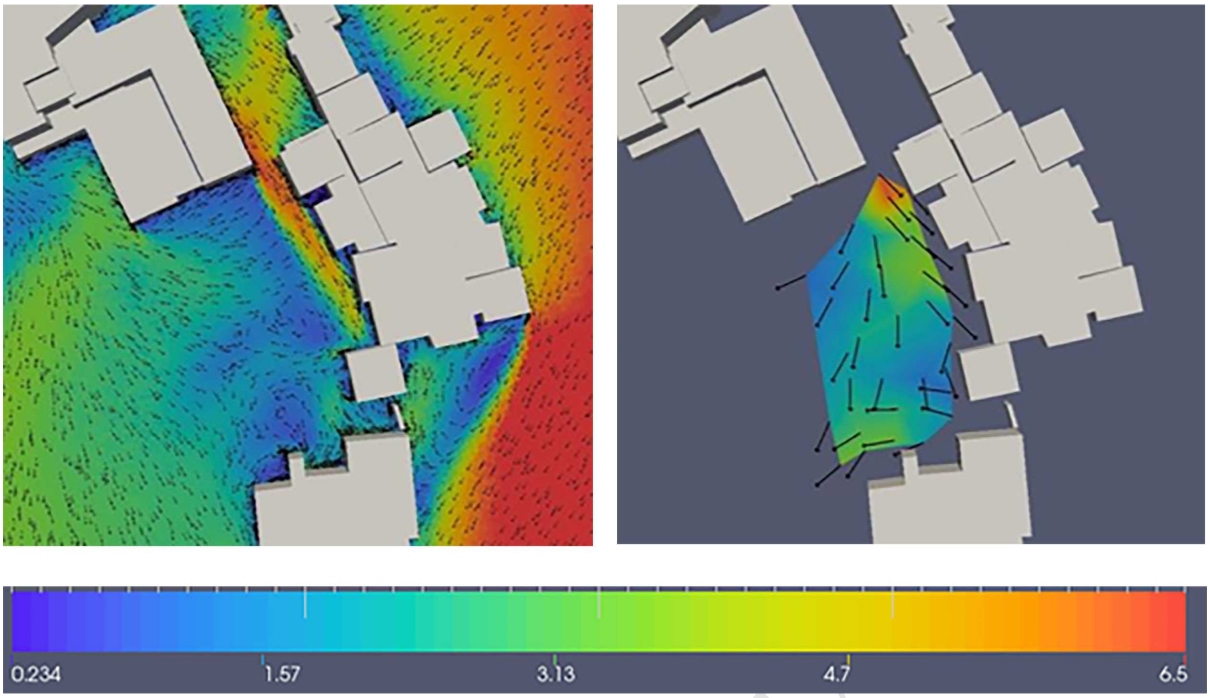
ACCEPTED MANUSCRIPT


X11
X33
X28
X27
X10
X9
X30
X12
X26
X8
X29
X7
Özyeğin Univers
X21
X6
X5
X31
X13
X4
X3
X32
X2
X14
X1
X25
X34
X20
X15
X16
X18
X23
X24
X22
X17
X19



person: 28%
person: 59%
person: 58%
person: 31%
person: 51%
person: 37%
person: 27%
0
200
400
600
800
1000
0
250
500
750
1000
1250
1500
1750


Tool: Grasshoper
CONVERTING .CSV INTO GEOGRAPHICAL DATA WITH POINT CLOUD METHOD
Tool: Rhino
CONVERTING POINTCLOUDS INTO DWG FİLE
SPATIAL DATA
Tool: ArcGIS
CREATING SPATIO-TEMPORAL MAPS
.CSV
NON GEOGRAPHICAL DATA
.n csv format
CONVERT POINTS INTO TIN DATA
CONVERT TIN INTO RASTER DATA
POINT DATA
LINE DATA
Time
Coordinates
x
y
z
Value
user
Time
Coordinates
x
y
z
Values
Temperature
Humidity
wind
Solar radiation


0.234
1.57
3.13
4.7
6.5


RADIATION
FACULTY OF SOCIAL SCIENCES
STUDENT CENTRE
FACULTY OF ENGINEERING
RADIATION
110-130
130-180
180-220
220-260
260-310
310-360
360-400
400-440
440-490
490-540
0
50 m
100 m
AIR TEMPERATURE
FACULTY OF SOCIAL SCIENCES
STUDENT CENTRE
FACULTY OF ENGINEERING
AIR TEMPERATURE
21.30-21.60
21.60-22.00
22.00-22.50
22.50-22.90
22.90-23.30
23.30-23.60
0
50 m
100 m
HUMIDITY
FACULTY OF SOCIAL SCIENCES
STUDENT CENTRE
FACULTY OF ENGINEERING
HUMIDITY
72.30-74.40
74.40-76.20
76.20-78.30
0
50 m
100 m
WIND SPEED
FACULTY OF SOCIAL SCIENCES
STUDENT CENTRE
FACULTY OF ENGINEERING
WIND SPEED
1.5-2.18
2.18-2.86
2.86-3.54
3.54-4.22
4.22-4.90
0
50 m
100 m
SURVEY RESULTS
FACULTY OF SOCIAL SCIENCES
STUDENT CENTRE
FACULTY OF ENGINEERING
SURVEY RESULTS
-3 (COLD)
-2 (COOL)
-1 (SLIGHTLY COOL)
0 (NEUTRAL)
+1 (SLIGHTLY WARM)
+2 (WARM)
+3(HOT)
0
50 m
100 m
Air temp: 19.8 Humidity:44.1 Wind: 0.62 Radiation: 175 G: Female Clo: 1.5 Activity: sitting Exposure: 15-20 min
Air temp: 19.8 Humidity:45.7 Wind: 0.8 Radiation: 182 G: Male Clo: 1.0 Activity: sitting Exposure: 15-20 min
Air temp: 19.8 Humidity:44.1 Wind: 0.62 Radiation: 175 G: Male Clo: 1.0 Activity: sitting Exposure: 10-15 min
Air temp: 21.8 Humidity:42.7 Wind: 0.57 Radiation: 233 G: Male Clo: 1.0 Activity: sitting Exposure: 15-20 min
Air temp: 18.5 Humidity:51.8 Wind: 1.55 Radiation: 385 G: Male Clo: 0.5 Activity: sitting Exposure: >60 min
Air temp: 18.5 Humidity:51.8 Wind: 1.55 Radiation: 385 G: Male Clo: 0.5 Activity: sitting Exposure: 10-15 min
STUDENT CENTRE
0
50 m
100 m

Highlights

- Outdoor spaces create a common identity for social life enabling communication and socialization.
- There is a paucity of research on campus outdoor spaces.
- Proposal of a new POE approach for outdoor spaces.
- The POE method integrates different studies on various problems in outdoor spaces.
- The POE method will complete the missing link in outdoor space design process.