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Potential of Detailed Environmental Data Produced by Information and Communication Technology Tools for Better Consideration of Microclimatology Issues in Urban Planning to Promote Active Mobility

Živa Ravnikar, Alfonso Bahillo Martinez, Barbara Goličnik Marušić

***Abstract*—**Climate change mitigation has been formally adopted and announced by countries over the globe, where cities are targeting carbon neutrality through various more or less successful, systematic, and fragmentary actions. The article is based on the fact that environmental conditions affect human comfort and the usage of space. Urban planning can, with its sustainable solutions, not only support climate mitigation in terms of a planet reduction of global warming but as well enabling natural processes that in the immediate vicinity produce environmental conditions that encourage people to walk or cycle. However, the article draws attention to the importance of integrating climate consideration into urban planning, where detailed environmental data play a key role, enabling urban planners to improve or monitor environmental conditions on cycle paths. In a practical aspect, this paper tests a particular ICT tool, a prototype used for environmental data. Data gathering was performed along the cycling lanes in Ljubljana (Slovenia), where the main objective was to assess the tool's data applicable value within the planning of comfortable cycling lanes. The results suggest that such transportable devices for in-situ measurements can help a researcher interpret detailed environmental information, characterized by fine granularity and precise data spatial and temporal resolution. Data can be interpreted within human comfort zones, where graphical representation is in the form of a map, enabling the link of the environmental conditions with a spatial context. The paper also provides preliminary results in terms of the potential of such tools for identifying the correlations between environmental conditions and different spatial settings, which can help urban planners to prioritize interventions in places. The paper contributes to multidisciplinary approaches as it demonstrates the usefulness of such fine-grained data for better consideration of microclimatology in urban planning, which is a prerequisite for creating climate-comfortable cycling lanes promoting active mobility.

***Keywords*—**Information and communication technology tools, urban planning, human comfort, microclimate, cycling lanes

I. Introduction

A. Carbon Neutrality

AWARENESS of climate change mitigation has become the mainstream in the research area within various disciplines, where in practice, cities all over the globe, are targeting climate and carbon neutrality through number of systematic or fragmentary actions. The transport sector represents over a quarter of Europe's greenhouse gas emissions, with passenger vehicles alone representing 11% [24] and is thus the main cause of air pollution in cities [7]. In that sense, the European Green Deal calls for net-zero economy-wide emissions and a 90% reduction in transport emissions by 2050, where low-emission mobility is an essential component of the broader shift to the low-carbon [7]. Active travel (walking or cycling for transport) is considered the most sustainable low carbon way of traveling, while changes in active travel have significant lifecycle carbon emissions benefits [5]. Some authors illustrate that if an average person cycled 1 trip/day more and drive 1 trip/day less for 200 days a year, it would decrease mobility-related lifecycle CO_2 emissions by about 0.5 tons of CO_2 over a year. In that sense, countries all over the world are implementing diverse policies and strategies trough different sectors and levels of government to influence active travel [28].

B. Influencing Cycling Behavior by Physical Environment

Individual's decisions to walk or cycle are not only determined by personal needs, personal preferences, and social environment, but as well depend on characteristics of the physical environments. By influencing physical environment, we can enhance and support cycling behavior. Wang et al. [26] described a range of environment components that promote cycling, including the availability and suitability of design of cycling lanes; increasing accessibility; improved safety; ensured residential density and land use mix which consequently reduce trip distance and finally influences on aesthetic appearance, comfort level and environmental quality. Referring to the environmental determinants, Wahlgren & Schantz [25] identified that green route environments have a stimulating effect on commute cycling and Lu et al. [15] associated cycling behavior with street greenness, cyclers' experience at the eye level. Another interesting research [12] indicated that cyclist choose even longer routes and are willing to make detours in order to use routes with more green areas. The benefits of green spaces for the society are well known and if designed with microclimate consideration in mind can as well enable natural processes producing pleasant microclimatic conditions.

Ž. R. is with the Faculty of Engineering, University of Deusto, Bilbao, Spain (phone: 38640512118; e-mail: zravnikar@deusto.es).

A. B. M. is with the Department of Signal Theory and Communications, University of Valladolid, Valladolid, Spain (e-mail: alfonso.bahillo@uva.es).

B. G. M. is with the Urban Planning Institute of the Republic of Slovenia, Ljubljana, Slovenia (e-mail: barbarag@uirs.si).

II. Addressing Comfortable Environmental Conditions within Urban Planning and the Importance of Integrating the Microclimatic Aspect

Pleasant environmental conditions affect human comfort, which can directly be reflected in human behavior and the usage of space [22], [13], [11]. Human comfort is usually defined with a combination of different environmental parameters such as air temperature, solar radiation, humidity, wind velocity [30], [16], [23], air quality, acoustic [4], [20] and should not be a neglected aspect when addressing cycling infrastructure and carbon neutrality.

Within urban planning we can address comfortable environmental conditions with designing sustainable solutions, using different, not necessarily green (vegetation) and living spatial components. Green infrastructure is usually correlated with cooling effect [1], Simčič et al. [19] identified that forest land use has a statistically significant negative effect on temperature in urban areas. Urban geometry of buildings and their height can influence the wind speed [18] while planting vegetation barrier along the traffic road can improve the air quality, [6], and mitigate the level of noise [17]. The usage of reflective material can reflect incoming solar radiation and reduce the warming effects in urban areas [31], and water features can improve pedestrian thermal comfort, through decreasing air temperature in warm city-built environments [18]. However, if we want to influence the environmental conditions and provide human comfort on cycling lanes, it is necessary to include, often neglected, microclimate aspect in the urban planning and consider climate-environmental outcome in the design decision. This is especially important in urban areas, characterized with limited available space for implementing new solutions. However, to obtain a certain environmental outcome, we must address the prospect of utilizing the appropriate natural processes to provide functions which achieve these benefits [10].

A. The Importance of Microclimate Data in Urban Planning of Comfortable Cycling Lanes

To produce or maintain pleasant environmental conditions on cycling lanes, site analysis as part of urban planning process, should represent a key step. However, to assess site characteristics, it is important to operate with microclimatological data, which enable the understanding of the correlation between environmental conditions and spatial settlement, and enable urban planner to interpret environmental conditions, from a human comfort perspective. Data characteristics play an important role, especially when interpreting environmental conditions, as cyclers might have different experiences in different locations and different times of the day, data must have detailed spatial and temporal resolution. In relation to human comfort aspect, it is also crucial that data should enable urban planner to interpret conditions related to most of the environmental parameters that affect human comfort while cycling. Finally, there is also a practical aspect and it is related to the medium through which urban planning operates. Lin & Brown [14] argue that mapping of microclimates links the necessary information with spatial information effectively and represents the resulting information clearly. In that sense in urban planning, it is important to operate with map based, graphically geolocated data which enables to allocate environmental data within a particular spatial setting and helps better understand the correlations between environmental conditions and spatial characteristics.

B. ICT Tools and Detailed Data

In the process of analyzing environmental site characterizes, ICT tools represent a potential for gathering and interpreting locally-based information. Here we are especially referring to ICT transportable devices for obtaining detailed environmental data with the potential of understanding of the often-hidden dynamics between environmental characteristic and spatial context.

The literature review shows that new technologies with different transportable devices are emerging and trying to assess detailed-climate spatial and temporal variations within cities, with as much accuracy as possible [9], [29], [30]. However, tools and their data characteristics need to be further explored in terms of their applicability in urban planning. In that sense this paper tests one particular ICT tool to explore its data potential and focuses on the following research question: Whether the tool and its detailed data enable a researcher to interpret environmental conditions from human comfort perspective and assure the interpretation of correlations between environmental conditions and different spatial settings.

III. Methodology

The paper follows case study approach. The fieldwork was done by data gathering performed along the cycling lanes in Ljubljana (Slovenia). In order to address the research question, we explored the potential of this ICT tool considering the following data characteristics:

- Spatial resolution,
- Temporal resolution,
- The interpretation of environmental data through human comfort parameters,
- The interpretation of environmental data within different levels of comfort zones,
- Map-making and linking environmental conditions with a spatial setting,
- Identification of correlation between environmental conditions and different spatial settings.

Those data characteristics were identified as important when addressing human comfort of cycling lanes in urban planning and are important also for the process of identifying correlations between environmental conditions and different spatial settings.

A. Work Field

Data gathering was performed with the usage of the protocol for environmental street assessment, consisting of several steps.

1. Definition of the Measurement Area

In this step, the area of data gathering is defined. Data

gathering was performed on cycling lanes in Ljubljana (Slovenia) in a radius of approximately 2 km, where people most often use cycling lanes for their daily commute. In terms of performing urban analyses and identifying possible correlation between environmental conditions and spatial setting, it is important to include spatial analysis from different perspectives related to space characteristics. In that sense in this protocol step the following criteria were considered: Type of place related to usage of place, type of place in terms of the presence of the natural morphological elements, the planned land use and urban morphology.

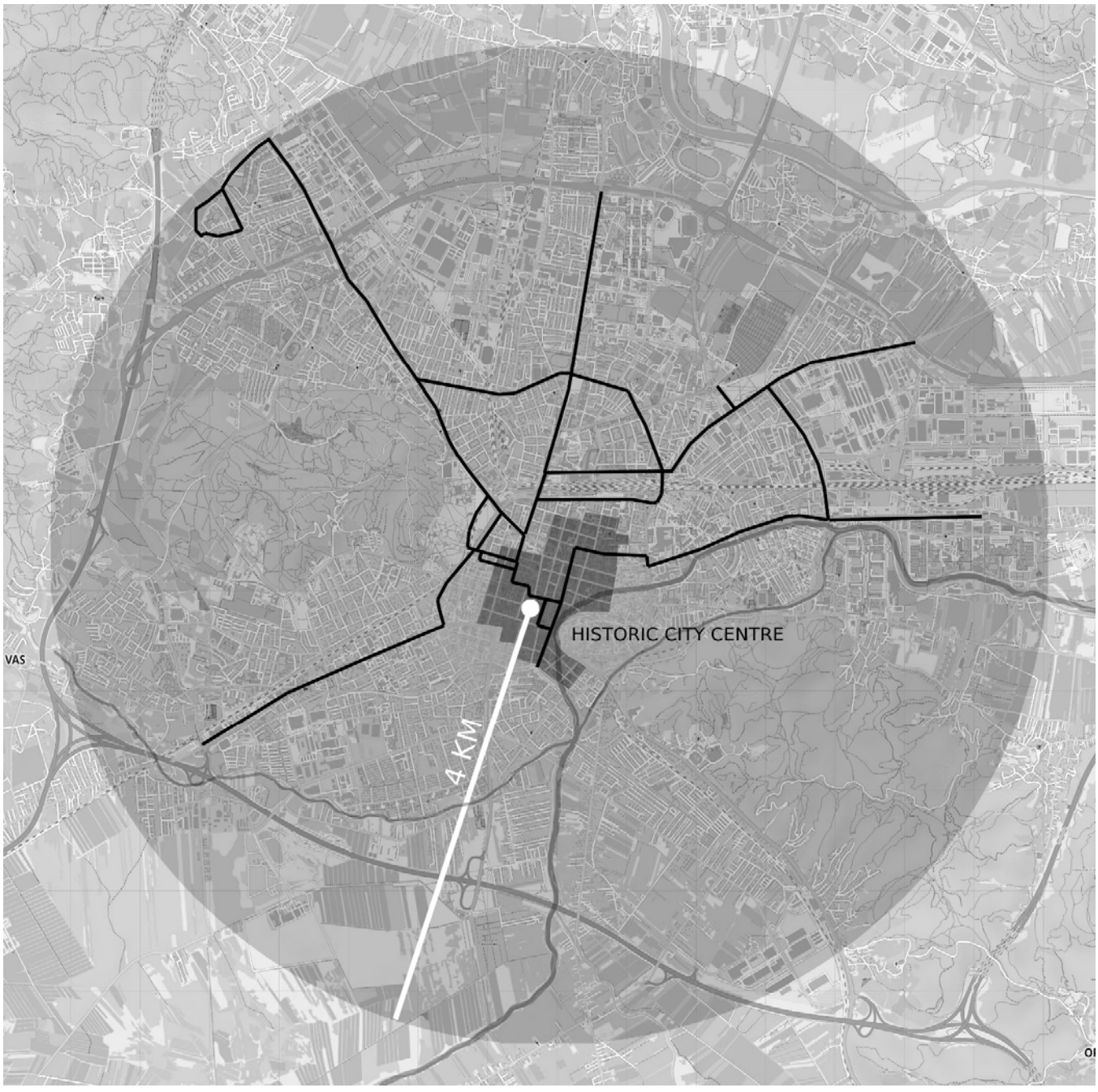

Fig. 1 Area of data gathering

2. Selection of Parameters Measured and Evaluated

The parameters that were selected for the environmental assessment are temperature, humidity, level of noise and air quality.

The ICT tool enables a researcher to interpret data within human comfort zones, where different symbols follow the threshold classification of comfort zones. The classification was based on European environmental context.

The definition of threshold classification of comfort zones (bolded text) for temperature bases on average temperature

values of Spain [21], level noise parameter thresholds are based on the environmental noise guidelines for the European Region [27], air quality parameter thresholds are based on European Air Quality Index [8], while humidity levels are based on general recommendations for indoor and outdoor humidity in European climate.

TABLE I
LEGEND TO BETTER INTERPRET ENVIRONMENTAL DATA IN RELATION TO HUMAN COMFORT VALUES

Temperature (°C)	Level of Noise (dB)	Air Quality (PM2.5)	Humidity (%)
> 40	> 100	75	< 15
35-40	80-100	50-75	15-30
25-35	70-80	25-50	**30-60**
15-25	60-70	**20-25**	60-75
5-15	**40-60**	10-20	75-90
0-5	**< 40**	< 10	> 90
< 0			

3. Definition of Measurement Time Intervals

In this step, time intervals for data gathering were set up. Since environmental conditions can change within a couple of hours, while active travel (commute cyclers) usually occupies space twice per day, it is important to test if the ICT tool enables to gather data on working days (Monday to Friday), between 7.30–9.00 and 15.00–17.30.

4. Analyzing the Gathered Data

This is the most complex step of the protocol. It is composed of two levels: 1. Initial descriptive analysis enabling to identify areas that are comfortable or uncomfortable for their users, and 2. Analyzed data interpretation to identify a correlation between environmental conditions and different spatial setting.

B Description of the ICT Tool for Data Gathering and Analyzing

Data gathering was performed by ICT tool developed by the University of Deusto in Bilbao, Spain, whose main purpose is to gather and analyze detailed and locally based environmental data. The tool consists of two main components: hardware and software. Hardware consists of sensors for collecting Air temperature (°C), Relative Humidity (%), Noise level (dBA) and Particulate Matter PM 2.5 (μg/m^3), and is connected to user interfaces (software), a platform called Bike Intelligent Centre, which provides feedback to the user and is publicly accessible [3]. The platform provides feedback to the user and allows a variety of functions which can help us analyze different environmental parameters, where individual parameter values are defined by thresholds, represented by different symbols.

IV. RESULTS

In the following section, the results of data gathering are presented. The practical performance of the protocol is presented following the analysis of the pilot cases in Ljubljana (Slovenia).

Data gathered are commented on the potential of ICT tool in terms of data characteristics that are important for interpreting environmental conditions from the human comfort perspective and for identifying correlations between environmental conditions and different spatial settings.

The results are related to the quality of data, ranging from data spatial and temporal resolution, data characteristics related to interpretation within human comfort zones, and the ability related to map-making to identify and interpret the correlations between space and environmental conditions.

A. The Practical Testing of the ICT Tool

ICT tool enabled data gathering on cycling lanes that led through different parts of the city. Considering the city's morphology, the path passed by a variety of urban structures, such as densely built-up historic urban area, wider city center area with densely built-up structures, and a relatively compact urban pattern with low-density of private housing. Regarding the land use plan, the cycling path mostly crossed residential areas, areas of central activities, green spaces, and agricultural land. The natural morphological elements were most often related to flat terrain, open spaces, and artificial green areas, such as urban tree lines, a cluster of trees, shrubs, and middle-sized green surfaces.

Since the paper is focused on the ICT testing for obtaining detailed data, the sampling does not reflect on fully fledged investigation but provides rather some illustrative preliminary examples of correlation between environmental conditions and different spatial settings.

a. Comparison of the Environmental Conditions on Left and Right Cycling Lane on Three Different Sections of the Afternoon

According to Fig. 2, the temperature on both sides of the road is slightly above comfortable zone, whereas on the left side the temperature can be up to 2 °C lower. Pleasant environmental conditions of temperature and level of noise, on the left cycling lane, could be correlated with spatial elements of a row of trees, unpaved surface, and physical orientation of the buildings, which provides an additional shade. However, on the same cycling lane, the humidity level is a bit higher (58-59%) compared to the right one (54-56%). Yet, humidity, on both sides, is still interpreted within with comfortable human level. Data related to the level of noise are on the right cycling lane indicating uncomfortable conditions (around 73 dBA). On the left cycling lane, the level of noise is lower, data indicating comfortable conditions between 54-57 dBA. The last parameter, air quality, at the proximity of green elements, on the left cycling lane, varies from 23-24 μg/m^3, indicating comfortable conditions. Yet on the right-side conditions are uncomfortable.

Fig. 3 is referring to data gathering performed on a cycling lane along a heavy traffic road. The right cycling lane is characterized by close proximity to a double row of trees and an unpaved surface in a form of grass, whereas on the left cycling lane there are no natural elements, except a narrow strip of grass, separating the cycling lane from a heavy road. The preliminary results indicate that both cycling lanes are slightly above temperature comfortable zone, yet the left lane has a lower temperature. Pleasant environmental conditions of the

left lane are correlated with the built element, where height and the orientation of buildings are providing shade and 3 °C temperature reduction. Continuing with humidity parameter, indicating that both cycling lanes are as well comfortable, yet surprisingly the right cycling lane characterized, with more green elements has an 8% lower level of humidity. Air quality, on both sides, ranges between 9-13 μg/m^3, representing the comfortable level of air pollution, yet on the right cycling lane, comfortable conditions are correlated with natural elements offering 3 μg/m^3 lower value of particular matter. And the level of noise parameter does not offer any possible correlation, yet more measurements must be performed.

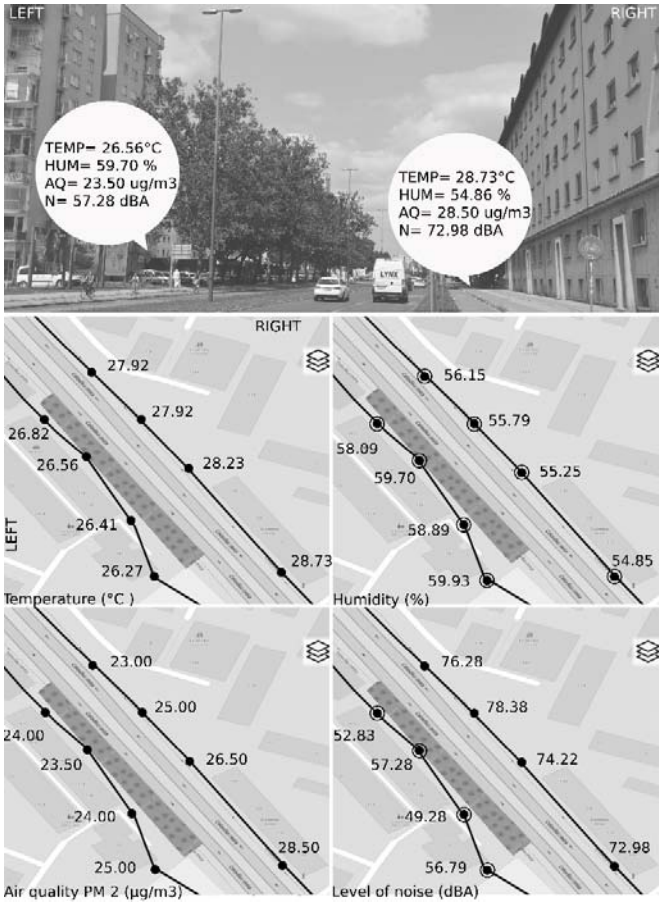

Fig. 2 Comparison of the environmental conditions on left and right cycling lane; Ljubljana, Friday, 23.7.2021 between 15.00-16.00, where comfortable conditions are represented with double circle symbol

Fig. 4 is referring to data gathering performed on cycling lanes in Ljubljana, where the left cycling lane is characterized mostly by the proximity of high buildings and sealed surfaces with only one row of trees. As a contrast, the right cycling lane is passing by two large green areas, with clusters of trees, shrubs, and a larger surface of the grass. Both cycling lanes are slightly above temperature comfortable zone, yet the temperature on the right cycling lane can be 2 °C lower and is correlated with a dense cluster of trees and unsealed surfaces of grass. The humidity parameter indicates that both cycling lanes are comfortable, whereas right cycling lanes with natural elements are correlated with up to 6% higher humidity. Air quality data do not offer any correlations. Level of noise on the left side is on average 73.56 dBA and on the right cycling lane is 61.06 dBA. Noise reduction could be correlated with open green space in a combination of high vegetation (clusters of trees and shrubs).

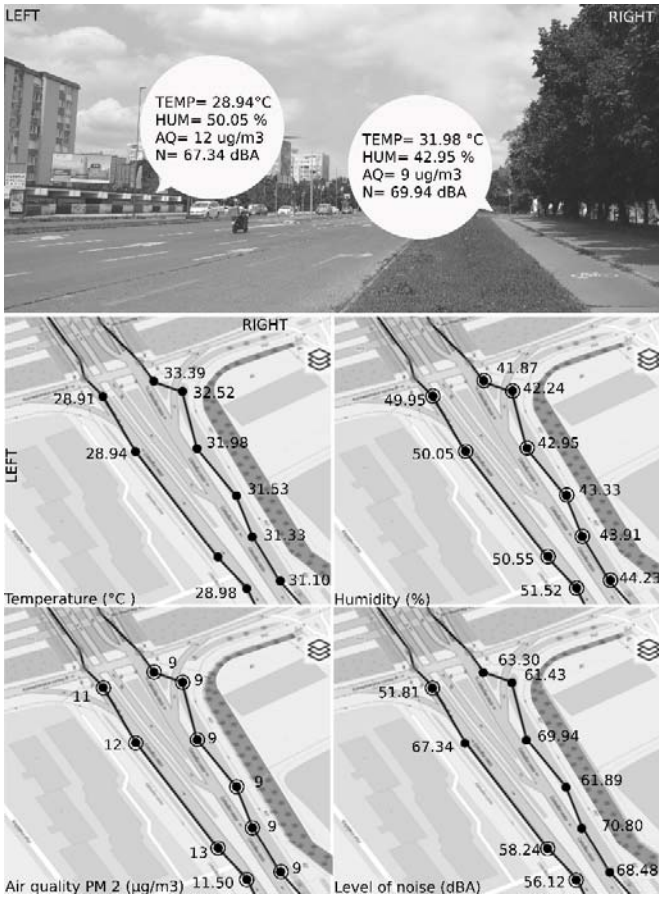

Fig. 3 Comparison of the environmental conditions on left and right cycling lane; Ljubljana, Monday, 19.7.2021 around 14.30

b. Environmental Conditions of Cycling Lane in the Historic City Centre and at the Outskirts of the City

The results indicate that the temperature in the historic part of the city is comfortable, varying between 22-24 °C, whereas, outside the historic part, one of the busiest cycling lanes, along heavy traffic road, varies between 25-28 °C (see Fig. 5). Pleasant temperature conditions in the historic part of the city could be correlated with dense urban tissue, where the buildings are offering more shade, and building and floor materials are usually more traditional, offering a cooling effect. The humidity parameter indicates that the cycling lane is all the way comfortable (varying between 46-51%) and does not offer any correlation in different spatial settings. Air quality as well does not offer any distinguish correlations. The level of noise is more comfortable in the historic part (around 60 dBA), which is corresponding to the fact that area is limited or closed for traffic, while the cycling lane along the heavy road is louder varying around 68 dBA.

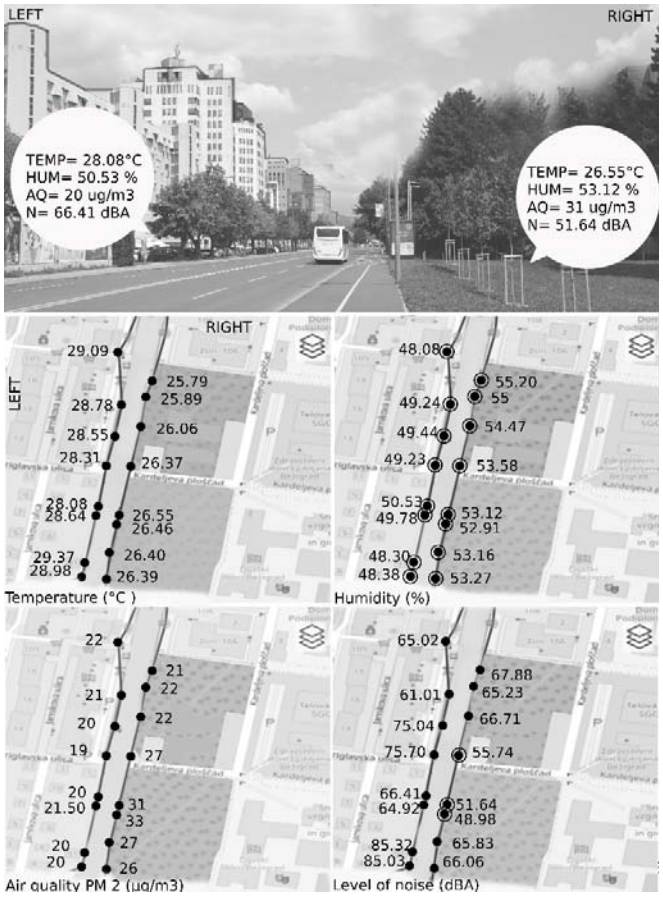

Fig. 4 Comparison of the environmental conditions on left and right cycling lane; Ljubljana, Wednesday, 21.7.2021 around 12.50

Fig. 6 is referring to data gathering performed in the urban area characterized by low-density private housing. The cycling lane is passing through open green spaces accompanied by agricultural land, where lower temperature (around 24 °C) is correlated with a green seminatural setting. In a residential area with sealed surfaces the temperature is still comfortable, yet 1 °C higher. Humidity is more comfortable in residential areas (around 74%), while in green and agricultural land is considered uncomfortable (around 80%). Air quality does not offer any correlations since it randomly varies between 9-14 µg/m^3. The level of noise throughout the whole path is comfortable, which corresponds with the fact that the cycling path along the green setting is closed to traffic, and the area with private housing is mostly intended for local traffic.

B. The Potential of the Tool for the Interpretation of Environmental Conditions in Terms of Human Comfort

The preliminary results suggest that the spatial resolution of data is precise enough to represent changeable environmental conditions cyclers might experience within a few meters. Data gathering was performed using a bicycle, driving with the approximately 18 km/h, where the device took measurements every 5-second interval. In that sense, the device took measurements every 25 m. Considering that environmental conditions can vary between 10 m and 100 m [2], with the usage of the ICT tool, it is possible to produce data detailed enough, yet to obtain even more detailed data, driving speed must be reduced. Continuing with the temporal resolution the tool enabled gathering in any time section during one day. Considering that microclimate conditions change within 24 h [2], and that commute cycler travels at least two times per day, results suggest that 5-s resolution could enable identifying environmental conditions cyclers experience when commuting. With the tool we were able to simultaneously gather most of the human comfort parameters, where data are presented through different human comfort zones, indicating how comfortable the space is. The implications of these findings are seen within urban planning for identifying environmental challenges, referring to high temperature, air quality, humidity, and level of noise. Continuing to the map-making characteristics, enabling to link environmental conditions with a spatial setting, the results suggest that the platform enables graphical and easy steps to perform environmental assessment analysis.

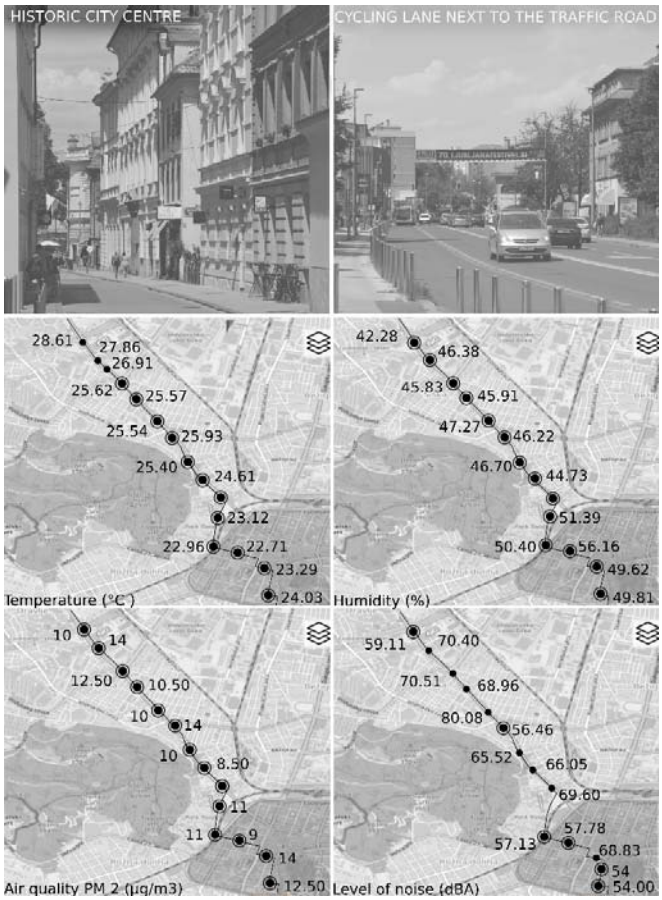

Fig. 5 Environmental conditions of cycling lane passing the historic part of the city and continuing on the one of the busiest cycling lane along heavy traffic road, Thursday, 2.9.2021 around 13.00

Since urban planning is still very much map-related, the greatest asset of this tool is also the ability to identify correlations between environmental conditions and different spatial settings. Even though those are just the preliminary results, the applicable value is seen in urban analyses to prioritize spatial interventions or monitor the existing

sustainable solutions to ensure their environmental benefits over time.

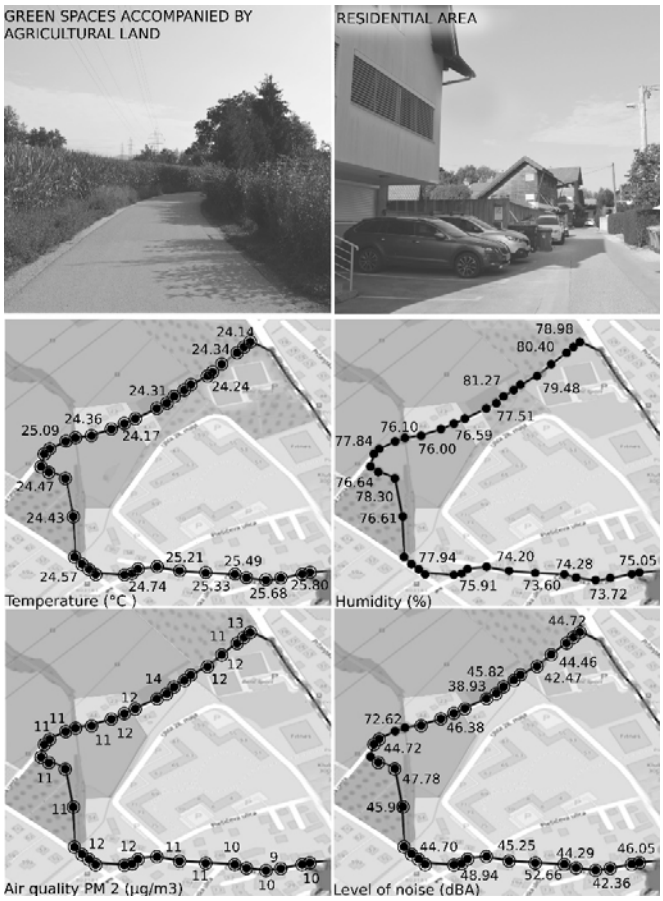

Fig. 6 Comparison of the environmental conditions on cycling path crossing urban environment characterized with private housing and open green spaces accompanied with agricultural land; Ljubljana, Thursday, 2.9.2021 around 12.00

V. Conclusion

This paper is based on the premise that by influencing the physical environment and environmental conditions, we can support cycling behavior. In that sense, the paper emphasizes that microclimate consideration should be a necessary consideration in urban planning when designing cycling lanes to support active mobility. The paper explores the potential of ICT detailed data for overcoming that gap. Even though new technologies for environmental data gathering are arising, such tools need to be understood in terms of their data applicability within urban planning. In that sense, the aim of this research was to explore the potential of one particular ICT tool for better consideration of human comfort in urban planning. Findings indicate that ICT enabled data gathering with a precise temporal and spatial resolution, indicating variability of microclimatic conditions on different cycling lanes. Findings also identify that with the tool it is possible to interpret most of the human comfort parameters, which can help urban planners to assess cycling lanes in terms of environmental conditions referring to temperature, air quality, humidity, and level of sound. Another important finding is that the tool and its data have the potential for identifying correlations between environmental conditions and different spatial settings, which can help to prioritize spatial interventions or monitor the existing sustainable solutions to ensure their environmental benefits over time. The study as well provides some preliminary results suggesting that pleasant environmental conditions are correlated with natural elements (row of trees, open green areas, cluster of trees) as well as built elements (height and orientation of buildings, suitable building materials). In that sense the paper also contributes to the awareness that apart from natural elements there are also built elements that can provide environmental benefits. This is especially relevant in urban areas where because of the space constraints and rational usage of space it is necessary to combine living and non-living elements which can support or enable natural processes.

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