WP2–BE and SLOD: SoA, risks and human behavior

T2.2 SoA on SLOD (heat wave and pollution) in BE and their effect on health and wellbeing of its users. Methods for data collection and analysis (on medium/long term datasets). Correlation betweenpollution and climate data (e.g. wind, rain, fog). Current mitigation solution analysis. Identification of BE features and users' (inappropriate) behaviors modifying SLOD effects/risk levels. Development ofindicators and relative weights for selected SLOD risk levels assessment

DELIVERABLE ID	D2.2.3
Deliverable Title	Impact of users' behavior and BE on SLOD risk levels report
Delivery month	M9
Revision	1.0
Main partner	UNIVPM
Additional partners	POLIMI
Authors of the contribution	Enrico Quagliarini (UNIVPM); Gabriele Bernardini (UNIVPM); Michele Lucesoli (UNIVPM).
Deliverable type	Report
Number of pages	22

Abstract

Slow-onset disasters such as air pollution and increasing temperature in our cities have currently acquired great relevance from the point of view of the research. Their causes have been investigated while researchers trying to understand what are the effects that have irreparably changed the natural environment in which we live. A further cause for concern, in which this study is focused, is the impact of these slow-onset disasters on the well-being of the population and on their health. For this reason, it is necessary immediately to provide risk and exposure-reducing measures on city dwellers. Novel simulation tools can be employed to support surveys and to solve these matters. Such tools are able to predict in detail their effects on populations and to test the effectiveness of proposed solutions. However, this deliverable has the purpose of understanding which factors related to human behaviour must be combined with the others and jointly provided as input to these simulation models. With this aim firstly, it is necessary to collect a complete state of the art concerning the impacts of SLODs on the behaviour, on the health, on the well-being, and on the habits of citizens. A categorization of the different issues encountered allows to process several aspects separately. Many key elements are collected. However, there is still no detailed classification of recurrent human behaviors, as differently done for SUODs events, where the mere observation of one of these events can provide much information on the response of individuals and the community.

Keywords

Human behaviours; SLODs impact; pedestrians' health; air pollution; increasing temperature; heatwaves.

Approvals

Role	**Name**	**Partner**

Coordinator / Task leader	Quagliarini Enrico	UNIVPM

Revision versions

Revision	Date	Short summary of modifications	Name	Partner
0.1	20.06.2020	Minor comments on Section 3.e and 3.2	Graziano Salvalai	POLIMI
			Juan Diego Blanco Cadena	POLIMI
1.0	30.06.2020	Solving of comments, proofreading, editing	Gabriele Bernardini	UNIVPM

Summary

1. Introduction

The study of human behaviors related to the Social Vulnerability issues (according to the Annex D2.2.5) and more focused on the observation of recurrent habits of different agent typologies (thus Individual vulnerability) in other types of sudden-onset disasters events (e.g.: earthquakes, floods, terrorist attacks) have revealed how it is possible to correlate them to the eventual presence of any factors related to the urban space configuration, or to events or critical conditions that may occur during a disaster (de Nazelle et al. 2009; Bernardini et al. 2016; Liang et al. 2020). These remarks, in such events, could permit to understand how to intervene on the BE structure and provisions to avoid all those human behaviors that lead to damages themselves and the others. Risk-mitigating interventions are aimed at improving the safety conditions of the surrounding environment. Hence, they must be rethought by starting from these detected data on human actions/reactions to ensure their efficiency and reliability (Zlateski et al. 2019). At the same time, it is thought that the appearance of slow-onset disasters may in some way have a similar impact on human behaviour to the one observed for other SUOD (according to D1.2.5 and D1.3.3). In particular, SLODs can affect human life in BE both for what regards immediate or short-term choices, which they can quickly assume/perform in their motion (e.g.: changing the side of the road on which they walk, looking for refreshment under a tree-lined path protecting from solar radiation (Langenheim et al. 2020)) and both for long-term choices that influence pedestrians habits (e.g.: starting to change travel modes, avoiding to take the shortest and busiest path by foot but preferring a longer street with a low rate of air pollution and perhaps crossing a green area of the city (Semenov et al. 2019)).

The main motivation that moves the entire work is to outline a first overall picture able to relate the effects of SLODs events with their generated impact on human beings. This impact has to be intended from one side as comprehensive of behavioral changing and BE users' habits, while on the other side it has to be evaluated as the sum of overall factors that affect the health and the well-being of inhabitants. The final aim is to understand what are the behavioral input parameters regarding the SLODs effects that must be integrated into the simulation models and risk evaluation metrics on the basis of future work packages. The importance of the simulations concerns the fact that they will allow considering all these aspects jointly in order to be able to evaluate different environmental conditions relative to the different types of the BE (Yang et al. 2018).

Topics dealt with in this work concern current arguments that have recently registered a significant increase in their attractiveness due to the relevant problems that air pollution and global warming have generated, especially in the built environment placed in the urban areas where are concentrated most of the human activities (according to the previous Deliverables D2.2.1 and D2.2.2). According to a critical overview of the state of the art on this issues (Forehead and Huynh 2018), the research activity on such topics can be divided into three main categories to lighten their size and to reduce the complexity of the different debated sub-themes.

- Firstly, we consider the impact that air pollution and the increasing heating can have directly on the behaviour and habits of pedestrians who live and move in cities. Hence, it is necessary to focus and comprehend which factors can influence these behaviors, for instance, the conditions of use of the Built Environment or the effects of these SLODs on the pedestrians' motion. Novel tools can emerge from the literature analysis to assess and quantify these factors also thanks to the precious support provided by technologies (Chen et al. 2020). An example is given by all the methodologies developed to understand the pedestrians' walking volume in relation to specific space and environmental conditions in the studied portion of the city (Omer and Kaplan 2017). Other studies focus on the determination of those elements of the BE that can cause an attractive or repulsive effect (Yıldız and

Çağdaş 2020) on pedestrians in relation to the occurrence of one of the considered SLODs. Possible tools or solutions for reducing the effects and the exposure to SLODs will be examined.

- The second macro topic on which the research focuses concerns the impact that these slow-onset events can have directly on the well-being and health of the inhabitants (de Nazelle et al. 2009). Nowadays, simulation models can be valid tools to understand the probable expansion of the SLODs and certainly to improve and accelerate the comprehension of the pedestrians' exposure. Those surveys overpass the infield measurements through weather stations of the current conditions through the prediction of their trend thanks to rigorous computational models (Akopov et al. 2019). Inquiring about the impacts on human health and well-being means also to understand what the different forms of risk perception and discomfort and what are the sensations experienced by users especially in function of the user's typology (i.e.: age, gender, and past diseases). All these factors contribute to delineate an overall picture that helps to understand both the risk entity and the impact on health. Moreover, exists particular conditions that can occur in relation to particular urban stressors that afflict the well-being of citizens, these can also be also objectively assessed through the definition of Key Performance Indicators (Yang et al. 2020). Finally, also for the impact on the inhabitants' health, researches have already been undertaken to determine possible solutions or alternatives to reduce exposure also thanks to methodologies that re-design and mitigate the influence that the use of specific building components can have (e.g.: materials with certain characteristics (Falasca et al. 2019)) or urban furnishings (which generate, for example, shading such as tree-lined paths (Borrego et al. 2012)).
- The last categorization serves to direct the attention no longer on the behaviour or health of the single individual but on the whole community as a whole, reminding that there are two levels of investigation, precisely one micro, and one macro scale; This second aims to describe an overall situation that support the monitoring to detect possible risky conditions (Forehead and Huynh 2018). However, the analysis models and the implemented solutions regard the made considerations above starting from a smaller and more detailed scale.

A large number of studies investigates such topics, especially in the last decade, when these kinds of problems have revealed a strong attractiveness not only for researchers but also from national and international organizations that have developed and supported precise policies. Nevertheless, no specific studies are already been conducted specifically on SLODs effects influence on human behaviours (in relation to similar works of D1.2.5 and D1.3.3) and no classification of different recurring behaviour or a specific reaction is observed from real-world data. However,

In view of defining a common framework for behavioural-related effects of SLODs, this work organization will follow the structure of these three topics, by outlining the related literature-review based results in specific sections and merging them into a unique behavioural-modelling oriented perspective.

In particular, it is worthy of notice that the focus of the work concerns SLODs impacts on human behaviours performed in the BE and related risk perception, by considering the individuals (women and men) living, working and visiting the BE according to previous literature bases (Yang et al. 2018). Special attention is also clearly paid for outdoor environments, i.e. Open Spaces in the BE, as previously remarked in the general perspective of D1.1.2. Hence, the present report frequently talks about pedestrians, indeed people along streets and sidewalks are mainly exposed to SLODs effects. Considered SLODs are connected with air pollution, especially related to the emissions caused by transportation systems and traffics (compare to D2.2.5). At the same time, heat waves and urban heat island are considered as well and assumed how extremely risky for citizens health and wellbeing.

2. Materials and methods

The work organizes the literature review according to the key topics evidenced in Section 1: impacts of SLODs on human behaviours, on the inhabitants' health and their exposure and finally from a general point of view on the impact of entire communities. The literature-review-oriented research is carried out in June 2020 (limiting to: Original Article, Conference Paper, Review in English language) adopting as search database Scopus[1]. Then, in order to search on Scopus database, four keyword combinations are employed to direct the research on such specific topic by avoiding all the large amount of works limited to SLODs analysis and completely detached by the "human factors" (out of topics), thus focusing the research on a specific aspects of literature researches.

The first keywords combination (Boolean operator AND) on time-dependent air pollution impacts involves the following keywords "pollution", "exposure", "during", "the", "time", "pedestrian" setting out 100 publications. 25 of these are selected after the rapid screening of the title, abstract and keywords, 14 are the interesting paper selected to be considered in the present review. The second keywords combination explore papers related to agent-based simulation models employed for air pollution assessment through the keywords "agent", "based", "modeling", "simulation", "human", "behaviours", "pollution" setting out 14 publications. 3 of these are selected after the rapid screening of the title, abstract and keywords, 1 is resulted valid to be assumed in this review. Keeping the investigation on air pollution the third keywords combination ("pedestrian", "behaviour", "analysis", "pollution") reveals 25 found elements, 6 of this are chosen through the reading of the title, keywords and abstract and 4 are fully read and deeply analysed. Finally, the last keyword combination is totally centred on increasing heat and temperature effects on pedestrians after that the keywords "heatwaves" and "heat island" related to "pedestrian" and "behaviour" have produced insignificant results. Hence, the simpler combination "pedestrian" AND "behaviour" AND "temperature" allows to obtain 90 documents, 15 passes the first screening and 10 are employed in the present review work. Resuming obtained papers from the described methodology, 24 works are collected from Scopus, then other 30 are added coming from collected literature for both previous work activities (mainly those related to T2.2) and for past research experience on such themes. A totally of 54 articles are investigated and exposed in the results section by dividing them into specific and restricted themes. Three different classifications of SLODs impact on human beings are adopted for a preliminary discussions subdivision according to what is introduced in Section 1.

3. Results

Research papers and previous works collected from literature according to the methodological section are deeply analyzed to develop and discuss the classification proposed in Table 1. The distribution in three different types of impact allows to distinguish other subthemes from a user-centered perspective by keeping jointly the two main SLODs sources (increasing temperature and air pollution) and their risk influencing factors according to the D2.2.5. Understanding how such SLODs can influence the human behaviours and users' routine is aimed to set up behavioural input parameters in future work programs simulations.

Studies resumed in Table 1 show the effects of adverse conditions to the livability of our cities that lead citizens to adopt different choices on micro-scale variable, over time and seasons and in relation to environmental modification. Urban stressors (e.g.: heatwaves, extreme precipitation, sudden changing

[1] Scopus database: https://www.scopus.com/home.uri?zone=header&origin= (last access: 15/07/2020)

temperature, air pollution) have also a sensible impact on the health of inhabitants (Yang et al. 2018), considering both the wellbeing of young students walking to school in a polluted environment both to elders exposed to the hottest hours in urban canyons. Additionally, a macro-scale perspective of SLOD impacts is considered, systems and methodologies to esteem SLOD severity are collected. Strategies to reduce inhabitants' exposure, should be based on those data and be advanced in a short time as possible at the urban scale level.

In the following, the three topics are discussed in detail, in reference with the identification codes (IDs) in Table 1.

Table 1. SLODs effects on users' behaviours: impacts classification and related subthemes analysed in results subsections. IDs associated to columns and rows allow to identify subthemes in the text below (Section 3.1, 3.2 and 3.3)

	Impact on users' behaviours outdoors	Impact on the health/wellbeing of the users	Impact of overall community behaviours
IDs	**A**	**B**	**C**
1	Model of behaviours in outdoor affected by the effective surrounding conditions (Yıldız and Çağdaş 2020) as well as of use of BE (Omer and Kaplan 2017)	Simulating the routines of the users and their exposure to the environmental stressors (Yang et al. 2018)	General systems for the urban organism (including dynamics in the population) to estimate the overall pollution levels and planning the town (Forehead and Huynh 2018)
2	Experimental analysis of movement-affecting factors in BE (Liang et al. 2020) and understanding the walking volume as input to the specific exposure conditions (Kang 2018)	Assess the users' perception about the local microclimate conditions of the passage urban area to provide strategies for the mitigation (movement of people by survey; perception by survey and matrix) (Piselli et al. 2018)	
3	Understanding the space uses by data on the net (Qiu et al. 2019; Chen et al. 2020; Happle et al. 2020)(Langenheim et al. 2020)[2], or even by using surveys (see WP1 activities), by including data on the transportation (e.g. pedestrians VS bicycle (Lee and Sener 2020))	Estimating the overall livability of urban areas, from a general approach (Martínez-Bravo et al. 2019)	
4	Attractiveness of the urban areas/paths (also regardless of SLOD-related factors) (Semenov et al. 2019)	Considering the impact of transportation systems (Yang et al. 2020); Specialization in relation to particular stressors, e.g. CO (Luo et al. 2018; Polednik and Piotrowicz 2020), by including perceptual dimensions of the surrounding disturbing conditions (e.g. not only pollution/heat waves but also noise (Lu et al. 2020)	
5		Proposing microscale KPIs (Yang et al. 2020), also related to general "walkability" issues (AlKheder and AlRukaibi 2020), (Mascio et al. 2020) and attractiveness of the urban areas/paths (also regardless of SLOD-related factors) (Semenov et al. 2019); Human feels (Kim et al. 2020) in view of feedback of choices from the end users	

[2] http://www.pedcatch.com/ to assess the walking distance radius in the BE, by a pedestrian (last access: 22/6/2020)

6		Proposing solutions to pollution/increasing temperature mitigation via simulation-based models (Akopov et al. 2019)
7		Thermal comfort issues (Erell et al. 2014; Djekic et al. 2018; Falasca et al. 2019), including time-dependent effects (Krüger et al. 2017) and in heatwaves (Lam et al. 2018); specific issues on illumination/shadows also in relation to different kind of pedestrians (White et al. 2017)
8		Effects of other weather quantities on specific user-related accidents (Zhai et al. 2019)
9		Effects in critical conditions (implying evacuation) (Salze et al. 2014)
10	Defining alternatives on motion-exposure coupled effects (Davies and Whyatt 2014; Melnikov et al. 2017; Luo et al. 2018), or design strategies to increase the pedestrian behaviours (Langenheim et al. 2020)	

3.1. The impact on users' behaviours outdoors

A1. As remarked ahead (Section 1), computational models can help us to simulate user behaviors where agents represent users as a collection of autonomous decision-making entities. Such studies can investigate how the users are involved in urban space, and to analyze the relationship between urban space components and the users' behaviours to be able to develop a model for user motion simulation. However, models necessitate of behavioural data collection with observation studies and environmental analysis. The work proposed by (Yıldız and Çağdaş 2020) evaluates three factors typologies influencing human behaviours and motion in the BE. Firstly, the research is focused on *physical factors* including ground floor usage, movement sources, quality of pedestrian ways. Secondly, the *environmental factors* comprise topography and weather conditions such as temperature, rain, landscape etc. In fact, studies on urban warming show that temperature change affects the flow of users depending on the season. While the sun has a negative impact in summer, it can be considered a positive stimulus in winter. The wind has a positive refreshing effect in the summer but a negative effect in the winter. Finally, the *human factor* evidence that the user movement is influenced by the presence of other people in the environment (attraction and repulsion forces) depending on the density of pedestrians and the desired movement speed, people tend to keep a certain distance from other users (Yıldız and Çağdaş 2020).

The study of (Melnikov et al. 2020) focuses on the urban heat as an urban stressor grown in the last decade due to the phenomena of climate change and urban heat island, which involves a high risk to human health and wellbeing. Heat problems in BE lead to influence peoples' choices in their motion. Pedestrians tend to adapt their walking speed to minimize environmental stimulation, due for instance, by heat condition. The research proposed by (Melnikov et al. 2020) investigates the effect of walking speed on heat stress. The heat-stress-optimal walking speed is reached by estimating its values for a wide range of air temperatures with the use of computational modelling of metabolic heat production and body thermal regulation. However, in hot urban environments, the increased walking speed would imply that people are producing extra heat amplifying their heat stress. From the same point of view, another paper (Liang et al. 2020) aims to catch how the weather and climate conditions affect pedestrian walking speed. Through the use of computer vision

technology (Figure 1), they trace pedestrians motions and speeds across a square understanding their choices in relation to weather parameters (e.g.: air temperature, relative humidity, wind speed) and BE conditions (i.e.: the presence of snow on the ground, the height of buildings in the surrounding that constitutes shading and protection from winds).

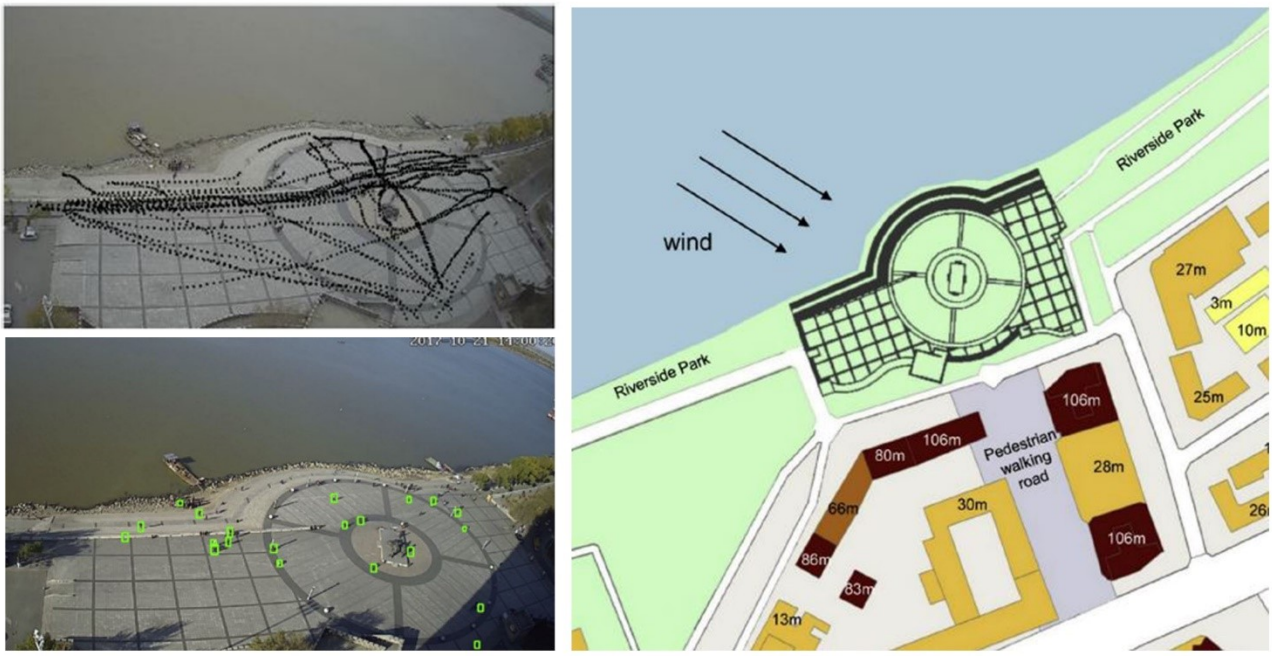

Figure 1. Tracing pedestrians motion and speeds in urban outdoor environments understanding possible correlation to whether parameters (image from (Liang et al. 2020)*).*

Weather and its parameters such as air temperature, sunlight and precipitation have also specific influence not only in human motion within an outdoor urban environment but also on the pedestrians' walking volume. The study of (de Montigny et al. 2012) tries to delineate a Poisson regression among weather parameters and the related walking volume by dethatching it from video analysis from Web cameras pointed in specific locations of the BE. It is necessary to highlight how this discussion is not limited to SLOD related to increasing temperatures but other studies are aimed to comprehend how environmental condition related to air pollution influence human behaviours as well, specifically studying how citizens spent their leisure time. (Choi et al. 2019) confirm that over certain exposure (i.e.: individual presence under certain condition for an extended period of time according to *exposure* concept in the Annex D2.2.5) to particulate matter conditions pedestrians tend to avoid open spaces and outdoor activities, refuging them into indoor public buildings such as commercial spaces, which have free entrance.

A2. In the literature exist experimental models that indicate the probability of choice of the way to move (by feet or with private vehicles) according to (Briggs et al. 2008). They are based on experimental studies conducted to evaluate individual exposure to air pollution especially to PM10 and PM2.5. Monitoring different routes in London, demonstrate how those people who chose to cover certain paths walking rather than driving their car are excessively exposed to pollution, and that the additional travel time involved in walking increases sensibly pedestrian's exposure to particulate matters. Policies that push to leave at home the own car could have a negative effect on pedestrian's wellbeing. Hence, separate routes (between pedestrians and vehicle traffic) should be planned. Determining the distribution of pedestrian volume in the

street networks could be an interesting data to bring in input to the prediction models exhibiting difficulties specifically in some context and taking into account of the combined effect of street network structures and land-use patterns (Omer and Kaplan 2017). Walking volume can be reasonably related to density, diversity of land use, and design including safety and amenity, and destination accessibility and distance to transit according to (Kang 2018). These factors affect walkers' behaviours. Moreover, this study suggests how the street configuration has to be centered on the spatial accessibility for pedestrians and combined with the centrality to pedestrian environments, such issues could affect pedestrian mobility. Specific exposure conditions to pollutant could influence the walking volume as well. The study of (Chung et al. 2019) investigates the relationship between particulate matter (PM10) and pedestrian volumes in streets empirically. The regression results suggest that PM10 concentration determines people's intention to walk and affects the volume of street-level pedestrians

A3. Occupants presence in space and time is a major source of uncertainty in the urban environment. However, some researches are focused on detecting inhabitant presence by gathering location-based services data to create context-specific, data-driven occupancy schedules by using a web mapping service (Happle et al. 2020). Novel technologies can help research activities collecting data on pedestrian trips frequency and duration, through the use of locative digital data. GPS data from a broadly available activity tracking mobile phone application is recorded tracking correlation among weather and temperature conditions (Vanky et al. 2017). Pedestrian volume is an important indicator of urban walkability to comprehend the influence on pedestrians behaviours of air pollution and increasing temperature. Hence, information on pedestrian volumes of different streets is indispensable for creating healthy, pedestrian-oriented cities. The work proposed by (Chen et al. 2020) takes advantages from Street View images with machine learning techniques to detect people presence along outdoor BE by providing a wide geographic approach through web image acquisition. To comprehend people motion in whatever BE the work proposed by (Langenheim et al. 2020) takes advantages from an online tools http://www.pedcatch.com/ (last access: 22/6/2020) able to simulate the walking distance radius of pedestrians by setting different parameter such as the motion speed and walking time.

A4. An innovative navigation algorithm is proposed by (Semenov et al. 2019) where they create a and design a mobile application specific for pedestrians based on attractiveness of urban environment elements. Indeed, pedestrians in their walks should be protected to the exposure to high-level noise, to air pollution, safer paths should be provided suggesting the more illuminated and the ones in the proximity of a green area by preferring shading paths and avoiding the hottest urban canyons. Nowadays, mobile applications allow us to travel towards a destination by car suggesting us only the shortest path, at most they show us the traffic conditions. No research activities have developed before ad hoc applications for pedestrians' travels in the BE. In the reported case, the paths choice can be affected by many key aspects rather than the possibility to minimize distances.

3.2. The impact on the health/wellbeing of the users

B1. Nowadays a large part of papers inquiring about the outdoor thermal comfort and the air quality in the BE are limited to recording thermal indices and pollution or to interviewing people in limited areas (Zhang et al. 2020). Other papers start to introduce the human presence by taking into account the impact of SLOD on individuals' health and wellbeing. However, the pedestrian exposure (according to the Annex D2.2.5 definition) is frequently considered in relation to the performed activities related to transport in the BE (e.g.:

walking and cycling) (Zavala-Reyes et al. 2019). Few studies deeply analyse further aspects related to human behaviors associated to the social vulnerability in their simulation models. The simulation indeed is considered as the new frontiers to jointly combine individual's vulnerability and their presence in the BE towards which designers and city planners should move. Strategies and design solution (e.g.: planting roadside trees) to mitigate the pedestrians exposure and vulnerability, and to improve human health and comfort conditions are proposed and verified for instance through computational fluid dynamics models (Borrego et al. 2012; Amorim et al. 2013). Understanding the air pollution situation in a wider urban area rather than the pedestrians' thermal perception could be accelerated and improved by the development of simulations models.

The impact of air pollution on the community become a popular topic in different research fields because of the highly affected individuals' health. But the major problem is that air pollution is not only a matter of the field concentration but also of where and how long individuals may inhale the pollutant in relation to their habits and space uses. The paper proposed by (de Nazelle et al. 2009) demonstrates that to evaluate the effective impact of air pollution on users' health, simulation models have to consider necessarily the human behaviours. In their operational model, they recognize from a holistic perspective four key aspects (Figure 2). On the background the BE is characterized by a specific air pollution situation, then the researcher activity is focused to the analysis of the users' behaviour and of all those aspects that can influence it (e.g.: the Built Environment intrinsic features). Finally, the simulation outcomes show the inhalant dose of pollutants obtained by the previous complete analysis that quantify individuals' exposure, this task could be employed by supporting the next B4 inquiring the impact of transportation systems in relation to the released substances causing air pollution.

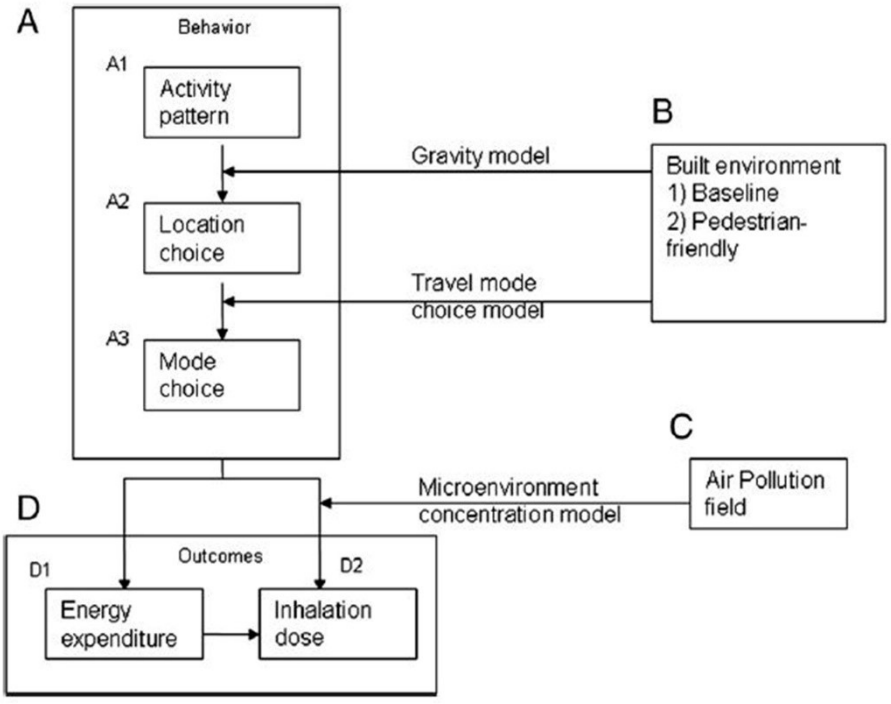

Figure 2. Operational model for the analysis of competing risks associated with the air pollution within the built environment according to (de Nazelle et al. 2009).

The paper of (Melnikov et al. 2017) provide an agent-based modelling approach to simulate the influence of increasing temperature on users and how people develop an adaptive behaviour in the urban environment. This work differently from others tries to consider the "human component" in a microclimate urban simulation system. Two types of emerging behaviours as consequence of a thermal discomfort are defined in this study: the reactive and the proactive. The first known as steering behaviour, regulates to the movement in space, complying with a set of rules, such as the path to follow, collision avoidance, cohesion, alignment. While the proactive level is responsible for planning and motivating of travel choices. The agent-based model is the engine of the simulation, the user's adaptive behaviour has to be defined to describe and perform human interaction with the BE in thermal stress conditions. Three adaptive behaviour typologies are delineated. The *speed adaption model*, able to define the influence of all factors that affect the speed motion (e.g.: crowd density, surface slope, gender, age). The *reactive thermal attraction model* is performed by pedestrians who sense the temperature gradient through their skin receptors due for example by winds or drafts or air conditioning. Finally, the *proactive vision-motivated route planning model* that can motivate pedestrians to deviate from a straight pathway towards a cooler area: obstacles, crowdedness embodies negative aspects while sun/shade, greenery area or even commercial shops could attract pedestrians and influence their travel choices.

Other works encompass the agent-based model to assess human exposure to environmental stressors simulating agents individually and continuously using a novel approach based on an analysis of the daily routines of individuals (Yang et al. 2018). An innovative framework employs a specific map made by three main layers to represent the BE features with buildings, streets, shops, green areas on the first layer (lower layer in Figure 3). On a second layer, spatial data of the changing concentration patterns of the environmental stress factors (central layer in Figure 3). Finally, on the upper layer of Figure 3 are merged the agents with initial attributes act daily to work, rest, entertain, shop, by following certain paths. This ABM framework is implemented in the Netlogo platform to activate the simulation process.

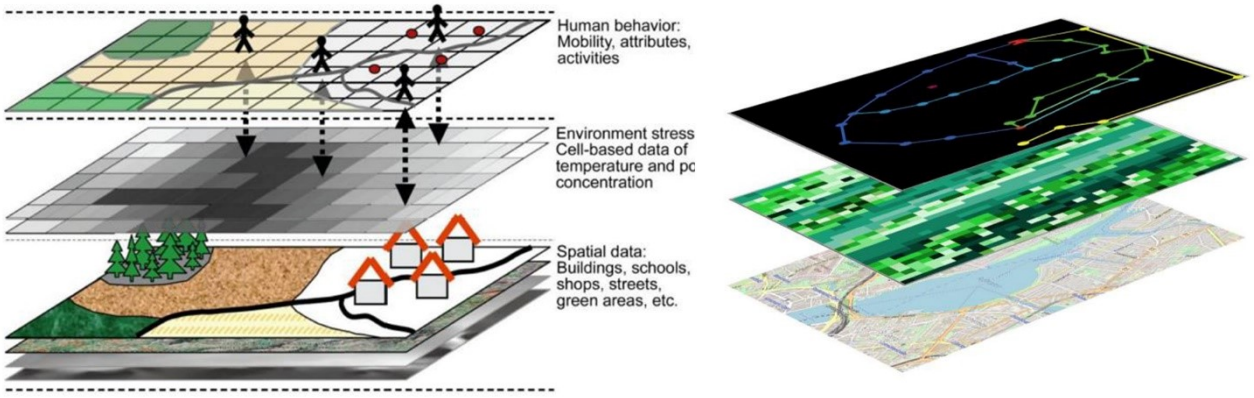

Figure 3. Illustration of the different layers involved in the agent-based model framework of (Yang et al. 2018)

B2. The direct evaluation (i.e.: interviews) of users' perception about the local microclimate conditions of an urban area can be considered as a consolidated way adopted by researchers to collect data on SLOD impacts. Some papers are aimed to investigate the perspective of travelling citizens about local microclimate conditions in a transportation hub (Liu et al. 2015). The study of (Piselli et al. 2018) a survey was submitted

to pedestrians while crossing the area to understand their actual perception of visual-thermal-acoustic conditions characterizing the outdoor environment, with varying weather and personal characteristics. Another work (Zeng and Dong 2015) develops a questionnaire subdivided in the following way. The first section dealt with personal factors such as age and gender, activity level, clothing, residence, visit reason and frequency, and time spent in the street. The second section asked respondents to evaluate their sensations of air temperature, air humidity, and the comfort level of the outdoor environment. Collected data are then compared and correlated with the in-situ weather factors measurements.

B3. City liveability can be conceptualized as a city's ability to provide adequate conditions for citizens to thrive and have a good quality of life. A fundamental indicator of liveability for a city is the pollution level. Specific research has been undertaken to explores how pollution influences the three pillars of urban sustainability (economic, social, and environmental) (Martínez-Bravo et al. 2019). Several papers inquiring the inhabitant's exposure to pollution traffic-related from a general point of view or in relation to predefined urban areas (Zhou and Levy 2008). Case studies from industrialized areas (Bereitschaft 2015) and from developing countries (Dewi et al. 2019) are examined demonstrating how particulate matter is dangerous for human health, not only for those who live in that places but also for who goes to work (Bae and Sinha 2016). Even though such topics on health are discussed from an engineering point of view, it is easy to understand how exposure to pollutants can cause different consequences on people who have registered an already compromised respiratory clinical picture. A study compares the impact of pollutant exposure to a sample of healthy persons against the effects on others affected by Chronic Obstructive Pulmonary Disease (Manigrasso et al. 2017).

B4. Vehicle emissions are identified as a major source of air pollution in metropolitan areas according to (de Nazelle et al. 2017). The impact of urban street configurations on pollutant dispersion has been investigated specifically concerning the air quality in urban canyons and along roadsides. However, there are few investigations in the literature to study the impact of the change of vehicles alimentation for private and public transport fleets (Rakowska et al. 2014). Thus, is possible to operate directly on traffic management, firstly already exists research groups that centred their studies on traffic-related emission calculation through agent-based traffic prediction model, microclimate simulations, and human thermal comfort assessment. In addition, such work evaluates the effects of five alternative urban design strategies on traffic pollution and pedestrian level microclimate (Yang et al. 2020). Further researches are specialized in specific traffic related stressors. For instance (Polednik and Piotrowicz 2020) and (Luo et al. 2018) evaluate the CO emission in relation to external influencing factors and in different moments of the day, during the working day and the weekend and in the different seasons of the year by studying the specific issue of such time-dependent pollutants. Surveys with questionnaires on a case study site allow researchers to evaluate different effects of another factor deal with the vehicle traffic that seriously disturb the walking pedestrian in an urban area, the traffic noise (Lu et al. 2020).

B5. Independently from SLOD disasters, further factors are evaluated from studies focused on the assessment of safety levels for pedestrians (Mascio et al. 2020). Paths walkability can be affected by maintenance problems of pathways, the poor installation of adequate equipment, and substandard execution of the sidewalks. Such factors are singularly evaluated and considered in a whole evaluation system. A similar evaluation centred on pedestrians pathways (Yang et al. 2020) concerns the use of key performance indicators (KPIs) to objectively measure the level of users' thermal comfort. Here, agent-based model results of simulating traffic and related emission are deeply assessed in order to provide a holistic

picture of a study area situation. KPI's assessment concerns the mesoscale traffic-related air pollution, the pedestrian-level air pollutant concentration, wind, and thermal environment, and the human thermal comfort. Ultimately, a comparison of the KPIs of different scenarios can be used to rapidly support redesign and decision-making. Other works focusing on paths walkability acquiring information from open spaces configuration to understand eventual attractive elements (Semenov et al. 2019) (e.g.: green areas and water bodies) and repulsive ones (AlKheder and AlRukaibi 2020) (e.g.: the presence of parking access/exits along sidewalks, scarce illumination) proposing design solution and elements generating a more walkability-friendly environment with green areas, creating underground parking, improve illumination and specific path to pedestrians and bicycles etc. Path walkability can be also influenced by the perceptions and human feels that concern the objectives of a research field aimed to comprehend if a visible disorder in the BE or an adverse condition for pedestrians can cause physical discomfort and/or emotional distress through the detection of physiological responses to such stimuli. Different discomfort situations in the BE have evaluated that affect walkability, decreasing the perception of safety in the urban space, and compromising residents' well-being. Results reveal the existence of continuous and changing interaction between citizens and the urban environment able to detect the eventual presence of a significant impact on users' physical and mental health (Kim et al. 2020).

B6. Urban greenery such as trees can be considered as a strategy to reduce effectively the reduce air pollution in a natural and eco-friendly way. However, how to spatially locate and arrange threes plantations is a challenging task that researchers aim to solve through simulation model support. An agent-based model of air pollution dynamics to support the optimal trees allocation is developed by (Akopov et al. 2019). While a computational fluid dynamics model is employed by (Manickathan et al. 2018) to model the effects of a transpirative cooling generated by the vegetation presence in a city against heat islands. The study shows that, at low wind speeds, pedestrians would only perceive a local benefit of transpirative cooling. However, at higher wind speeds, vegetation extracts overall more heat from the urban environment. In each case, the trees shading provisions improve the users' thermal comfort.

B7. The main factors that influence the individual thermal comfort sensation are weather parameters of course, but also personal and psychological factors. Within the weather factors, air temperature and wind speed are the most important according to (Pantavou et al. 2013). Weather parameters depends on the considered season, and so thermal comfort issues are strictly time/season-dependent. Additionally, the variation of thermal perception through the season is confirmed by the study of (Krüger et al. 2017). From results is demonstrated that women tend to be more sensitive to weather variation. The study proposed by (Jin et al. 2020) affirms that the more influent elements that affect thermal comfort in outdoor spaces are the gender but also the issues related to the wellbeing and human health (frequently associate to the agent age) that influence people choices exposed to such discomforts according to A1 section. This study through field survey and questioner evaluates several aspects. Results show that regarding thermal preference, in the same thermal environment, females were more likely to prefer higher temperatures, while males were more likely to prefer lower wind speeds. When both genders are exposed to the same solar irradiation intensity, females perceive stronger sunshine, regardless of the solar radiation level. Female regulate thermal comfort with more difficult rather than male, Therefore, females wear thicker clothes in the cold season. In line with the previously cited work, females are more exposed to weather variation and they prefer to keep indoors or move from sunshine to shade and vice versa. A sensible influence of clothing in human thermal comfort perception is also evidenced by the study of (Lam et al. 2018) that evaluate their effect on extreme increasing

temperature conditions. The age has to be considered as further aspect that affects the differences in human exposure. The young and elder categories of people register a higher exposure to heatwaves, solar radiation (White et al. 2017) and pollutant inhalation (Qiu et al. 2019) rather than adults.

B8. Specific weather conditions could lead to another kind of risk for pedestrians in the BE completely different from the discussed SLODs but quite related since their effects are correlated. Many studies have attempted to identify factors contributing to crashes and pedestrian accidents. While, a specific study (Zhai et al. 2019) proves relation between a high frequency of pedestrians accident and particular meteorological conditions. Results individuate the high temperature and the presence of rain as weather conditions reason for accidents. For instance, driver's inattention and reckless crossing are more frequent in hot weather conditions.

B9. The literature review evidences that just one study considers a critical condition where an accident generate in few second a large leakage of pollutant agent toxic for inhabitants. In an emergency condition that affects an entire urban area, the reactions of citizens could be different. The main objective of (Salze et al. 2014) is to understand human behaviours in such sudden onset disaster typologies related to an unsustainable air pollution situation. Through an agent-based model, they explore the relationship between the global survival rate and the individual behaviour of agents, detecting possible emergent patterns, measuring the impacts of the spatial configuration on the global survival rate.

A-B 10. Firstly, it has to be specified that IDs A10 and B10 can be jointly discussed. Indeed, whatever are the adopted strategies to mitigate SLODs impacts they influence both behavioral and healthy issues. The wellbeing and human health improvement can be reached only as a consequence of an alternative behaviour from the previous aimed to follows the support of the provided risk-mitigating solutions.

Individual exposure to air pollution depends not only upon pollution concentrations in the surrounding environment, but also on the volume of air inhaled, which is determined by an individual's physiology and activity level and by the time that individuals spent in polluted places (B1 issues can be support such analysis). Through the use of network analysis in a GIS environment is possible to identify common pedestrian routes between multiple origins and destinations within the urban centre (Davies and Whyatt 2014). Another work develops a method for esteem the inhaled mass of fine particles (PM2.5) by pedestrians and able to consider such data into the safer walking route calculations (Luo et al. 2018). The calculated route with the low air pollution inhalation was compared against the traditional shortest paths. Results demonstrate that traditional pedestrian trips are less longer than healthy walking ones, but they show significant benefits on human health. In the future, the possibility to follow a low air pollution route should be provided to pedestrians through a mobile application and integrating data in real-time so as it is nowadays for traffic and weather information. Alternatives solutions to reduce citizen exposure to SLODs are proposed in several studies. Against particular matter inhalation due to increasing vehicle traffic in the large Asiatic metropolis a series of pathways on footbridges are studied that permit to avoid the more trafficked intersections at the road level (Pan et al. 2018). From the point of view of increasing temperature and heatwaves (as a consequence of the first) registered in urban canyons, specific studies are conducted on building materials able to mitigate the heat island effects. The study of (Alchapar et al. 2014) is focused on the thermal behaviour of materials used in enveloping urban surfaces trying to decrease the solar infrared radiation absorption both for pedestrian pavements tiles and both vertical claddings. Results confirm that an appropriate selection of materials that compose the urban envelopes contribute to reducing the negative

effects of the heat island. The same purpose is the base of other studies that deeply analyse solutions involving the high-albedo of materials (Erell et al. 2014; Falasca et al. 2019). Different paving materials used for the pedestrian zone are tested in (Djekic et al. 2018) buildings material and urban components features are evaluated as well such as the type of material, colour, roughness and shading of an area, as influencing factors of the heating up of pedestrian surfaces. A more sustainable solution against high rise temperature in cities is to constitute a shading pathway to protect pedestrian motion from solar rays through trees planting interventions. The paper presented by (Langenheim et al. 2020) describes a new performance-based tree-scape design approach to optimize shaded walking routes based directly on detected pedestrians' mobility. The potential of this approach is demonstrated by the targeted strategy to plant trees on predefined routes, for instance planting trees across lanes in proximity to schools and other facilities to citizens provide the co-benefits of improved thermal comfort and reduced solar and ultra-violet exposure of inhabitants (Figure 4). Architects and city planners to test their concepts and to design smarter and more liveable cities can be also supported by researches aimed to simulate people's thermal perception along their activities in public spaces rather than exposure to pollutants.

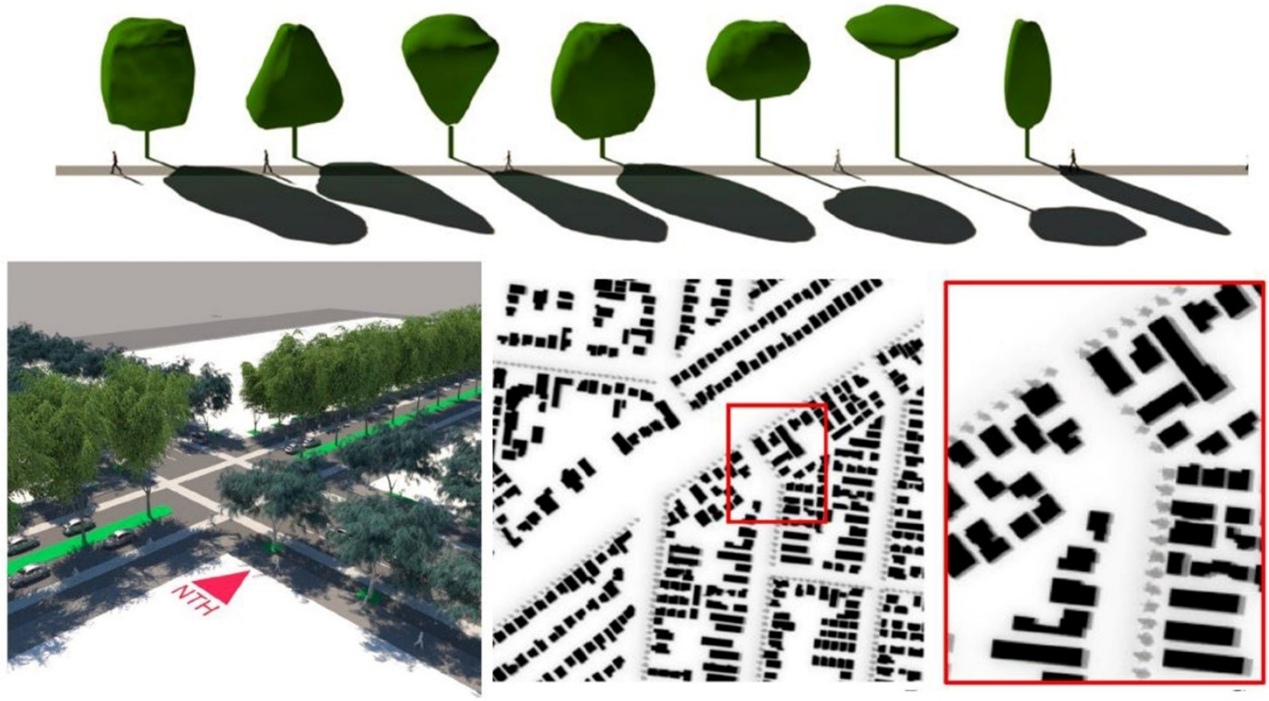

Figure 4 The optimal trees placement model in the BE is presented above according to (Langenheim et al. 2020) *with the aim to create shading routes for pedestrians the visual impact of tree-scape design is showed as well.*

3.3. The impact of overall community behaviours

C1. Atmospheric pollution traffic-related and the increment of global warming contribute to affect negatively life condition of the BE inhabitants. Human exposure from a macro scale (i.e.: city-level) perspective to such SLODs is one of the major sources of worries for researchers that try to develop ad hoc assessment methodologies for those parts of cities where people live, commute and work. Reducing exposure requires information about the distribution and the nature of emissions. In accordance with the

aforementioned and discussed papers spatially and temporally detailed data are required because both the main weather parameters both the emissions vary significantly with time of day with local changes in wind, and with the seasons relative to the traffic composition and flow. Novel technologies provide more powerful computers able to process simulation models that accept highly detailed inputs. Similar literature works are collected in the detailed review (Forehead and Huynh 2018). They explicate how such complex models can integrate into a simulation model the SLODs' impacts to the overall communities encompassing human behaviours (e.g.: attractive and repulsive forces and their motion in the urban space) and SLODs' impacts (e.g.: pollutants emissions, heatwaves and heat island effects and solar radiation distribution) on of all the individuals, their vehicles and on the road network.

4. Discussion

In the view of the review traced above and according to the D2.2.5 (especially for the discussions in Section 2.1, 2.2, 2.3 and 2.4) where the risk matrix for SLODs is delineated, it is possible to advance an idea about how the citizens interact whit the BE in discomfort condition due to increasing temperature and air pollution. From literary review and from the experimental observations of previous deliverable (D2.2.4) it emerges that pedestrians prefer:

- shaded urban canyons in summer conditions, either by trees or the self-shading from the buildings;
- low traffic level street corridors;
- areas with greater greenery or water bodies coverage;
- canyons were the wind-flow is favored in summer;
- surfaces with low surface temperature in summer and the opposite during winter.

These favorable BE configurations against SLODs embody an attractive factor especially for those categories of people with frail health, elders, or youngsters constituting for them a source of wellbeing. Table 2, for different combinations of SLODs events, resumes a qualitative description of probable behaviours performed by the BE users. Agents in urban areas tend to deviate their routes making choices in relation to what the surrounding offers to them, they are attracted by green areas, shaded paths and water bodies, they move and take a break inside public or shopping buildings with cooler air temperatures. Such choices have an influence also in relation to the preferred transportation system (public rather than private). If the delineated probable behaviours are performed by the majority of people moving in the BE, they inevitably lead to criticalities that have to be considered (e.g.: an overcrowded conditions in the preferred paths, the large use of private automobiles with the consequent increase of particulate matter emissions). The third column of Table 2 summarizes such critical situations that could be useful for future scenarios definition. Finally, in the last column, the IDs of the previous topics' subdivision are related to each event-behaviours-criticalities row. This traced correlation with the previously discussed topics could be considered not only as a bibliography to justify such behavioural outcomes but also as a source of inspiration for possible solutions or for citizens exposure reduction strategies.

SLOD scenario	Users' probable behaviors	BE criticalities	Related IDs
Warm – Non polluted	People will tend to move towards more shaded pathway/corridors/areas. Perhaps, they will prefer to be near green and water bodies; and often access conditioned services (e.g. shops, restaurants) which provide cooler air temperatures. Moreover, lighter and lower surface temperatures superficies will be preferred.	Crowded outdoor areas or streets. In particular, secondary streets, green corridors, water features, urban forests. In addition, larger use of automobiles.	A1, A4, B1,B2, B5, B6, B7, A-B10

Warm – Polluted	Same considerations of the previous scenarios prevail. In addition, people will tend to move through and closer to less crowded pathways/corridors/areas. Moreover, they will avoid trafficked street corridors when possible.	Crowded outdoor and indoor areas or streets. In particular, secondary streets. In addition, larger use of automobiles and mid-traffic levels in every street type are expected.	A1, A2, A3, B3, B4, A-B10
Mild/Cold – Polluted *Mild/Cold – Non polluted*	In this case, people will tend to move through and closer to less shaded areas (i.e. sunny) and, even if polluted, crowded pathways/corridors/areas are preferred. Moreover, trafficked street corridors represent a source of heat, becoming more attractive. In addition, people are most probably indoors and transferring in automobiles.	Less crowded outdoors, people tend to be indoors. Higher automobile use, favoring traffic and pollution production.	A1, A2, A3, B3, B4, A-B10

Table 2: Probable users' behaviours in SLODs scenarios and their implications on the BE.

5. Conclusion

The work is aimed at determining the effects of SLODs on human behaviour and habits and on the other hand on the health and well-being of the urban inhabitants. Considering the previous deliverables (D1.2.5 and D1.2.3) on the same arguments but in relation to sudden-onset disasters, it is wondered if it was possible to reveal recurring behaviors from real-world observation for SLODs. Obviously, the different temporal conditions do not always permit to record or collect such evidence. Therefore, a bibliographic approach is then adopted, tracing a report with the same structure of review work. The states of the art on these issues are developed and debated by dividing the collected papers into three categories related to impact typologies; Firstly, the impacts on pedestrians' behaviour influencing their motion in the urban space are considered. The effects of SLODs on citizens' health and well-being are then examined. Finally, tools and methodologies able to understand the risk and exposure levels of entire communities on a larger scale are reported.

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