Overview on Urban Climate and Microclimate Modeling Tools and Their Role to Achieve the Sustainable Development Goals

Matteo Trane, Matteo Giovanardi, Anja Pejovic, and Riccardo Pollo

Abstract The role of the fourth Industrial Revolution enabling technologies is pivotal if the paradigms of data-driven, performance-based, and optimized design have to become standard practice. Urban climate and microclimate models are increasingly likely to support the design for adaptation, resilience, and mitigation of the heat island in cities. In this context, the objective of this chapter is to emphasize the role of urban climate and microclimate modeling tools to achieve the Sustainable Development Goals at the local level. To this, firstly the authors screened the Agenda 2030 official Targets and Indicators and the European Handbook for Voluntary Local Reviews' indicators, highlighting how they deal with environmental quality, urban climate and microclimate issues. Interlinkages and possible trade-offs were identified among goals and targets, too. Secondly, a robust overview on the main software for climate modeling is provided. Tools were clustered, according to the domain of application, into scale, statistical, numerical, and dispersion/air quality models. Thus, the authors focused on numerical models, identified as proper tools for architects and planners to support urban and micro-urban scale design. A final matrix compares the most used numerical models at a glance, highlighting main features, fields of applications, environmental parameters simulated, and interoperability options.

Keywords Climate models · Computational fluid dynamics · Urban microclimate · Agenda 2030 · Sustainable development goals · ENVI-met

M. Trane (✉) · A. Pejovic · R. Pollo
Interuniversity Department of Regional and Urban Studies and Planning, Politecnico Di Torino, 10125 Turin, Italy
e-mail: matteo.trane@polito.it

A. Pejovic
e-mail: anja.pejovic@polito.it

R. Pollo
e-mail: riccardo.pollo@polito.it

M. Giovanardi
Department of Architecture and Design, Politecnico Di Torino, 10125 Turin, Italy
e-mail: matteo.giovanardi@polito.it

M. Barberio et al. (eds.), *Architecture and Design for Industry 4.0*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-3-031-36922-3_15

United Nations' Sustainable Development Goals 11. Make cities and human settlements inclusive, safe, resilient and sustainable · 13. Take urgent action to combat climate change and its impacts · 3. Ensure healthy lives and promote well-being for all at all ages

1 Introduction

Open public space is crucial when talking about quality of life within urban environments. It reflects the identity of a city in an aesthetic, ecological, and functional sense, thus providing environmental, social, economic, and health benefits and fostering the sense of community [58]. Moreover, redesigning the space between buildings has the great potential to both adapt cities and mitigate the causes of climate change, which, in turn, is the most promising strategy to cope with ongoing climate crises [11]. The role of open public space is also promising in attenuating the effects of the Urban Heat Island (UHI), as designing by combining strategies to cope with both climate change adaptation and mitigation has immediate effects on microclimate, thus quality of life and health [52]. Specifically, the role of greenification—i.e., the use of green infrastructure (green areas, roofs, and façades and vertical vegetation)—benefits the local climate conditions and has a direct impact on human thermal stress and mortality [29]. Indeed, heat waves accounted for 68% of natural hazard-related deaths in Europe in 1980–2017 and many climate models still project a global rise in climate hazards [59].

In such a scenario, the quality of public space is definitely a key element to convey sustainable development, and the Agenda 2030 put specific emphasis on access to safe open public space for all, good air quality, and environmental comfort. As a consequence, modeling the behavior of urban elements—both natural and artificial—is essential for decision and policy making, data-driven urban planning and climate projection-based scenario assessment. The rapid spread of enabling technologies, with the consequent increase in computing capabilities, redefines design practice in favor of computational approaches, which require interoperability, modeling, 'simulability' and connectivity [55] to finally boost the 'generative process' of an optimized design [14]. Specifically, the use of numerical models and tools may support domain experts (e.g., urban planners, architects, landscape designers, environmental engineers) and non-technical professionals (e.g., decision-makers, public and civic stakeholders) [29] in the early stage of a performance-based design process (*ex-ante*), thus allowing better monitoring of the effects of design and policies (*ex-post*). Nowadays, many software and solutions exist, enabling urban climate and microclimate simulations with different spatial resolution and grid size (from less than one meter to hundreds of kilometers) for different purposes (from urban streets to regional modeling).

In the perspective of an increasing full 4.0 awareness for architects and planners, i.e., shifting from a computer-based design to a computational one [3], the purpose of this chapter is to provide a detailed overview on the most used tools for urban climate and microclimate modeling, highlighting their role to ease the transition towards a sustainable development. Moreover, this chapter will focus on how these tools may support the achievement of the United Nations' Sustainable Development Goals (SDGs) at the local level. Indeed, it should be taken into consideration that 65% of SDG targets could not be achieved without a decisive commitment of cities towards the implementation of local sustainability agendas [40], possibly aligned with the UN Goals. In this context, computational design plays a crucial role in shaping cities' transition towards carbon neutrality, combining several dimensions: mitigating the UHI, reducing the resource consumption, promoting the user's comfort, and boosting the resilience to climate change. Indeed, planning for the adaptation claims for a combination of data and scenario assessment, that is, the results of knowledge exchange and contamination among disciplines, to eventually provide policy makers with consistent and sound 'environmental synthesis', grounding on predictive modeling and supported by research [4]. Thus, the role of the 4th Industrial Revolution enabling technologies towards the achievement of the SDGs is fundamental if the paradigms of data-driven, performance-based, and optimized design process must be universally pursued.

This paper is structured as it follows. After the introduction, Sect. 2 describes the methodology adopted. In Sect. 3, the authors map the recurrence of the urban climate and microclimate-related issues in the Agenda 2030, giving emphasis to possible interlinkages and trade-offs among them and their utility for progress measurement. In Sect. 4, the authors clustered urban climate and microclimate tools according to their features and scale of application. Section 5 specifically focuses on numerical models, providing an overview on the ones most frequently used and quoted by the literature. In Sect. 6, the results are discussed by a matrix summing up the main features of the software and providing some insights on how they may further support the Agenda 2030. Finally, in the Conclusions, the authors open up to the possibility of both integrating data from climate simulations into GIS environments and providing more and more local climate-specific boundary conditions, based on extensive sensor networks, time-series and climate projection data for future scenarios simulations and assessment.

2 Materials and Methods

The first objective of this chapter is to put into correlation climate analysis with the Agenda 2030 Sustainable Development Goals. Specifically, the authors highlight how models and tools for climate and microclimate simulation could assist to reach the SDGs (Sect. 3). To this, the authors screened the 17 goals, 179 targets and 239 indicators of the Agenda 2030. Correlations, both positive and negative, are made evident by means of several Sankey diagrams. First, it has been analyzed how Agenda 2030 deals with urban climate and microclimate issues, finding interlinkages with seven goals and eighteen targets. Second, the authors emphasized how urban climate and microclimate models may specifically help measuring progress towards some of the selected indicators, coming from both Agenda 2030 and the *European Handbook for Voluntary Local Reviews* (VLRs) [49]. Third, interlinkages and possible trade-offs both among the selected targets and between them and other Agenda 2030 targets are presented. To this, the European Commission's Joint Research Centre (JRC) *SDG Interlinkages* tool from the *KnowSDG Platform* was used [7]. This tool helps visualizing the cumulated interlinkages from a set of publications, to quickly see and understand for which interlinkages there is strong agreement in the literature. It should be noted that, at the time of finalizing the outputs and figures for this chapter (May 2022), the first edition of the *European Handbook* was available and a previous version of the tool, with less analyzed papers on the SDG interlinkages, was consulted.

In the second part of this chapter (Sects. 4 and 5) a robust overview on the software available for urban climate and microclimate modeling is provided. First, by screening the scientific literature, the authors clustered them into scale, statistical, numerical and dispersion and air quality models (based on [15] and according to the scale of applications (meso- and micro-scale). Second, by screening manuals, websites, and literature providing information on the main commercial solutions available, the analysis focused on numerical models only, identified as the main tools for architects and urban planners to assess the effects of local-scale design options. Third, in the Discussions (Sect. 6) a matrix offers a complete figure to compare the most used numerical models, highlighting their main features, scale of applications, and environmental parameters that can be simulated.

3 Urban Microclimate in Light of the Agenda 2030

3.1 An Overview: Urban Microclimate, SDGs, Targets

The 17 Sustainable Development Goals (SDGs) were adopted by the United Nations in September 2015 as part of the 2030 Agenda for Sustainable Development [57]. They replaced the previous Millenium Development Goals by defining a path towards sustainability fitting to all countries. The concept of genuine quality of life for all, to be ensured in respect of the planetary boundaries [50], stays behind the Agenda 2030's vision. Although not legally binding, SDGs have been setting up a normative framework by which cities, as major actors towards climate neutrality, may boost sustainability. However, many challenges remain in fully localizing the SDGs, mostly due to lacking data, the need to establish local priorities in light of policy regulations and a complex framework of highly interlinked targets, and capacity building [54].

Although the term "microclimate" is not explicitly mentioned within Agenda 2030, at deeper look connections among the topic and the SDGs exist and are strong. As recalled by [58], the potential of quality public spaces to contribute to sustainability involve five SDGs (3, 5, 8, 11, 13) and eight targets (3.4, 3.6, 3.9, 5.2, 8.8, 11.7, 13.1, 13.2). In a broader perspective, the authors argue that efforts towards

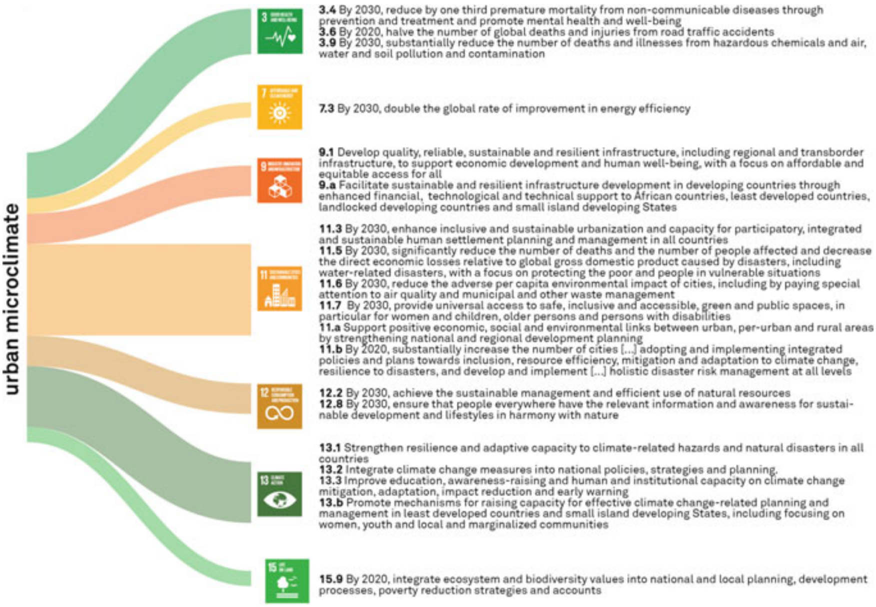

Fig. 1 Interlinkages between mitigating Urban Heat Island and SDG targets

urban microclimate mitigation by public space redesigning may imply benefits in achieving SDG 7.3 ("By 2030, double the global rate of improvement in energy efficiency"), as lowering outdoor temperatures turns into reducing energy demand for buildings [44]. Besides, it may still have positive effects on SDG 9.1, 9.a, 11.3, 11.5, 11.6, 11.a, 11.b, 12.2, 12.8, 13.3, 13.b, 15.9 (Fig. 1).

3.2 Urban Microclimate: Models and Tools for SDGs' Indicators

In the context of the Agenda 2030, climate and microclimate modeling tools may assist to measure progress towards the achievement of SDGs, fulfill the lack of intra-urban scala data by simulating, and analyze the effects of policies and design *ex-ante* and *ex-post* [53]. Specifically, among the target interlinkages identified, climate models may provide a strong support to indicators 3.9.1 ("Mortality rate attributed to household and ambient air pollution") and 11.6.2 ("Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)"), when it comes to models able to assess air pollution concentration. However, major contribution of climate modeling approaches is linked to SDG 13 indicators, which can benefit the employment of modeling approaches when it comes to assess national policies facing disaster risk mitigation, local strategies for disaster risk reduction strategies, adoption of national adaptation plans, and the communication of risks arising from climate hazards (respectively, indicators 13.1.2, 13.1.3, 13.2.1, 13.3.1). Finally climate models are still central in contributing to the measure of target 11.7.1 ("Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities"), 11.a.1 ("Number of countries that have national urban policies or regional development plans that (a) respond to population dynamics, (b) ensure balanced territorial development; and (c) increase local fiscal space") and both 11.b.1 and 11.b.2 ("Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030", "Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies") (Fig. 2).

SDG localization is highly challenging: scholars, practitioners, policy makers and practitioners are committed in measuring progress at urban and local level by framing and implementing indicators needing high data granularity. The *European Handbook for SDG Voluntary Local Reviews* (VLRs) [49] provides a "fundamental instrument to monitor progress and sustain the transformative and inclusive action of local actors towards the achievement of the Sustainable Development Goals" in the specific European Union (EU) context. The structure of the *Handbook* (first edition—2020) is lighter than the 2030 Agenda framework and tailored to the EU cities needs: it comes with 72 indicators, each of which is related to one or more SDGs targets. The use of climate models may provide effective support in assessing indicators 49 and 53 (if a pollution concentration module is embedded in the software), 48, 58, 61 (Fig. 2).

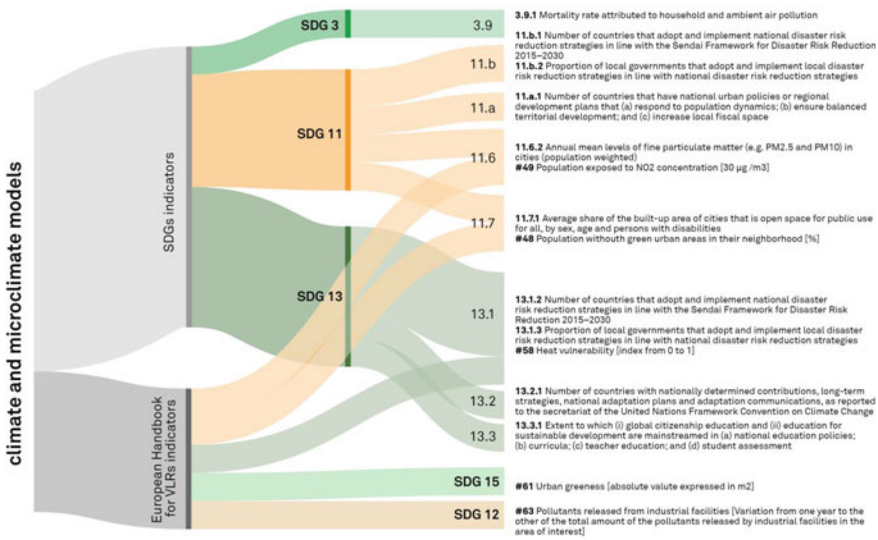

Fig. 2 Climate and microclimate models in support of SDGs indicators measurement

3.3 Mapping SDG Interlinkages and Trade-Offs

The analysis of the potential contribution of climate and microclimate models in achieving the SDGs confirmed that major benefits could be registered in progressing SDG 11 and 13. However, boosting sustainable development in all dimensions (social, economic, environment) implies a systemic approach, assessing interlinkages and possible trade-offs among targets to eventually minimize them [54]. Indeed, according to scholars the general lack of progress in effectively reaching the SDGs [19] is also due to poor understanding and addressing of interactions between goals and targets. As stated by [9], "the challenge lies in identifying and countering inherent conflicts (trade-offs), while harnessing and building on potential synergies (co-benefits) between the 169 targets", to finally unveil the "invisible" nature of Agenda 2030, i.e., enhancing interlinkages among targets to achieve them faster and with minimized drawbacks.

Coming back to highlighted targets, according to the *Interlinkages Visualization tool* (version: May 2022) 11.6, 11.7, and 11.a manifest eight positive interlinkages; among them, strong support to target 3.9, 13.2 and 12 could be provided (Fig. 3). No trade-offs are detected among SDG 11 selected targets and other targets. Moreover, fifty-two positive interactions exist among targets 13.1, 13.2, 13.3 and other targets. Target 13.1 is one with the greatest number of interlinkages (twenty-six), especially with SDG 9 and 11. On the contrary, target 13.2 is the one with major possible trade-offs, especially with goal 14 ("Life below water"). However, no trade-offs are detected among SDG 13 targets and the ones related to urban climate and microclimate (from other SDGs). To conclude, although trade-offs exist and SDG 13 implementation should be managed "with care", no specific drawbacks exist among the selected targets, implying that the targets to which climate modeling may provide support could be achieved independently and eventually providing benefits to other Agenda 2030 targets.

4 Climate Analysis Models: An Overview

4.1 Clustering Climate Models

Scale models. Scale models have mainly been used for the simulation of urban flow, turbulence and dispersion phenomena in wind tunnels and water flumes or outdoors over type-arrays of building-like obstacles. They have been using a range of experimental facilities, maquettes and techniques for measurement of urban canyons that have deeply contributed to the understanding of the urban atmosphere [15]. The development of Computational Fluid Dynamics (CFD) models was also possible thanks to high resolution datasets produced in laboratories. Scale studies were able to demonstrate that small-scale features such as roof shape or tree placement can significantly impact street canyon ventilation rates (Kastner-Klein and Plat 1999).

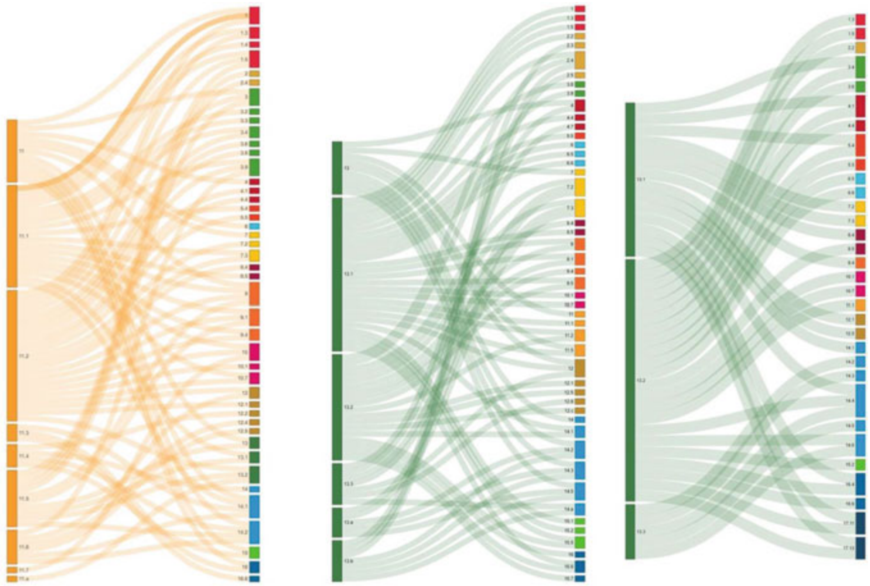

Fig. 3 In orange, the interlinkages among SDG 11 targets and the Agenda 2030. In green, interlinkages (left) and trade-offs (right) among SDG 13 targets and the Agenda 2030 (*Source* JRC's Know SDG Platform—Interlinkages visualization, https://knowsdgs.jrc.ec.europa.eu/)

Only a few studies used city-scale models, demonstrating that building height has a strong influence on the Urban Canopy Layer (UCL) [15]. One of the limitations of scale models is the size, because of the typical size of wind tunnels allowing only a small range of model scales to be evaluated.

Statistical models. Statistical models estimate the effects of cities on climate. Among their main advantages, they usually produce realistic results, require low computational features and input parameters. The disadvantages of certain statistical models imply long observation periods, lack of physical basis and data from many different locations [15]. Their main field of application is the study of the UHI and most of them are simple linear (multiple) regressions of temperature differences between the center of the city and the surrounding area (ΔT), where temperature is calculated as function of several meteorological variables (e.g., wind speed, rural lapse rate, etc.) [22]. More advanced statistical models use spectral analysis, eigenvectors or neural networks to predict risks related to UHI [46]. Statistical relations have been also used for assessing the normalized evolution of UHI, allowing fast forecasts of city temperatures and helping predict future climate conditions [15].

Numerical models. Numerical models allow 3D simulation of urban thermal environments to assess the interactions among (vertical and horizontal) surfaces, solar radiation and wind. They mostly deal with the governing equations of the flow (e.g. Navier–Stokes equations). The use of numerical tools is becoming practice at meso- and local scale to assess multiple design alternatives, informing urban planners, decision makers and designers [29]. They are able to provide information about any evaluated parameter in all points of the computational domain and conduct comparative analysis based on different scenarios [6]. Numerical methods are used to predict impacts of different microclimates and design options on the urban environment. The most used numerical simulation approaches are Energy Balance Model (EBM) and CFD [51].

Dispersion and air quality models. Dispersion and air quality models are used for evaluation of air quality and prediction of environmental phenomena that could finally affect people's health. These applications vary from evaluation of long-term health effects to short-term emergency response [15]. The complexity of the models depends on the computational speed and storage capacity. CFD models are widely used for urban dispersion simulation today. However, all models should include a meteorological model or parameterization scheme to examine urban phenomena such as wind slowing, turbulence increase, the vertical profile of meteorological variables in the UCL etc. Ideally, the models should also evaluate changes in meteorological conditions between different urban districts [15].

4.2 Spatial Scale of Analysis

Tools for climate and microclimate analysis are usually clusterable according to the scale of application and resolution, too. In this perspective, urban climate-related phenomena were classified as meso-, local, and micro-scale [41], while [29] identified two main domains for climate tools application: macroscale and microscale models. Meso-scale represents a region or city, local scale corresponds to a neighborhood or district area, while micro-scale varies from 10 to 102 m and includes street canyons or single buildings [12].

Meso-scale models. Tools for climate analysis on meso-scale focus on the entire city rather than street-level phenomena [29]. The size of the model is usually a few tens of kilometers, with the grid of up to 10 or 20 km on a city scale or up to 100 or 200 km on a regional scale. The spatial resolution is usually 100 or 200 m [29]. Since 1970s, many organizations developed their own models: mentioning a few, National Center for Atmospheric Research (NCAR) and Pennsylvania State University developed their 5th Generation Meso-scale Model (MM5), Colorado State University developed the Colorado State University Meso-scale Model (CSUMM) and later the Regional Atmospheric Modelling System (RAMS). The research on meso-scale climate is mostly done by remotely sensed data and satellite images to derive Land Surface Temperature (LST), which is used for modeling UHI [29, 29], supported by meteorological data coming from urban stations [56]. Other mesoscale studies use numerical models, such as Weather Research and Forecasting model (WRF) [12], designed for "numerical weather prediction systems for both atmospheric research and operational forecasting needs to analyze impact of climate phenomena on the city" [29].

Micro-scale models. Research on microclimate at intra-urban level is mostly done by Urban Canopy Models (UCM) or CFD models [60]. CFD simulations for neighborhood scale models are mostly based on area range of 200 m to 2 km and they are commonly used for assessing the impacts of mitigation measures on the thermal environment of local-scale urban area, the relationship between the form and layout of buildings or blocks and the local urban thermal environment [35], the layout and planning of ventilation corridors and its impact on the thermal environment and the relationship between the thermal environment and human thermal comfort indices [5]. At this scale, "the measurements and analyses are usually the most suitable to estimate local impacts and benefits in terms of human thermal comfort at the pedestrian level and the impacts of the different planning scenarios" [29]. Mathematical modeling and simulations are mainly coupled with field measurements in order to evaluate the effects of the urban environment on the microclimate and thermal comfort [12]. UCMs are mainly used for examining the energy budget of an urban canopy layer and the airflow derives from the energy budget equations, unlike CFD models [34]. Both types can assess the impact of various parameters such as building orientation, street aspect ratio, surface materials, vegetation, pedestrian comfort and urban ventilation. However, they both have certain weaknesses. CFD models have limited domain size due to immense computational cost, while UCMs have less detailed presentation of airflow around the buildings [34].

5 Focus on Numerical Models: A Comparison

5.1 Energy Balance Models (EBMs)

As recalled by Toparlar et al. [51] numerical models can be further clustered into EBMs and CFDs. EBMs are based on the law of energy conservation and have been used extensively in the past. They take into account energy exchanges between surfaces and ambient air in the UCL and can be used to predict the ambient temperatures and surface temperatures of buildings, pavements and streets [47]. Although they are quick to run and provide accurate results, their major drawback is the absence of air velocity [18]. Indeed, they "separate temperature and velocity fields, such that the assumptions used do not always accurately represent the interaction of velocity and temperature in reality" [47]. According to Imran et al. [18], UCMs are derived from energy balance equations "for a control volume such as two adjacent buildings". Surface and control volumes interact with each other like electric nodes, which results in the matrix of humidity and temperatures. UCMs can be the single-layer canopy model or multi-layer canopy. The difference is that the latter takes into account vertical distribution of the canopy features instead of the average building height [18], providing more detailed analysis but needing more computational resources [60]. The great limitation of the EBMs is the absence of a wind flow field, which causes incomplete representation of atmospheric phenomena. They are not able to determine the latent and sensible fluxes due to the lack of flow pattern information [18].

5.2 Computational Fluid Dynamics Models

Compared to EBMs, CFDs have numerous advantages. The main one is that it can assess a wide range of issues "comprising air speed and movement, air quality and pollution diffusion, wind comfort and thermal comfort as well as the effects of relative humidity and vegetation on indoor and outdoor spaces", as well as being readily available and analyzing complex environments [47]. As such, CFD is the most used numerical simulation method at microscale. CFD models include a variety of numerical models from Reynolds-averaged Navier–Stokes, through Large Eddy Simulation (LES) to Direct Numerical Simulation (DNS) [15]. They consider all principal fluid equations in urban areas simultaneously, solving the equations of temperatures, momentum and conservation of mass [18]. CFD simulations can be used to study urban microclimate, user thermal comfort, and pollutant dispersion at both meso- and micro-scale. At micro-scale CFD simulations are conducted with a resolution from less than one meter up to 100 m. Still they are able to represent more realistic information compared to the EBM [18]. However, CFD models have certain limitations. They have high computational requirements due to their complexity and the wide range of environmental parameters and indexes to be assessed (especially for meso-scale models). High resolution representation of the urban geometry is required, along with the knowledge of the boundary conditions and relevant parameters [51]. Furthermore, CFDs may require expertise in governing equations for output interpretation, while "different scales of turbulence in an urban environment require separate modeling and simplified simulation, which may result in inaccurate outcomes" [47].

5.3 Most Used Tools

ENVI-met. ENVI-met is a CFD 3D microclimate modeling software based on the fundamental laws of fluid dynamics and thermodynamics [48]. It was designed by Professor M. Bruse in 1994 and has been under constant development and scientific expansion ever since. The software uses an urban weather generator to predict the meteorological parameters based on which the most probable weather conditions are recreated [2]. It reconstructs the microclimate dynamics of the urban environment through the interaction between climate variables, vegetation, surfaces and built environment [10]. ENVI-met simulates the atmosphere processes such as air flow, air temperature, humidity, turbulence, radiation fluxes and calculates the indexes and factors of comfort in the urban area—such as Physiological Equivalent Temperature (PET), Predicted Mean Vote (PMV), Universal Thermal Comfort Index (UTCI) and many others [53]. ENVI-met has been used widely in the microclimate research, urban design and thermal comfort studies due to its ability to recreate microclimatic conditions within the UCL [1, 23, 39]. The application of the software has been validated through numerous studies under different climate conditions. ENVI-met also includes plant physiology and soil science. Indeed, the software takes into account transpiration, evaporation and sensible heat flux from vegetation and air, as well as physical parameters of the plants, water and heat exchange from soil and plant water uptake [43]. The software is grid-based and has high temporal and spatial resolution, allowing accurate microclimate analysis up to a street level. The horizontal resolution typically ranges from 1 to 10 m and it is therefore suitable for intra-urban scale assessment. By the latest version, ENVI-met v5.0, Python was integrated into the system, to facilitate the management and visualization of output results via the DataStudio module. Some other new features (such as the Indexed VieW Sphere and the renovated Albero module for vegetation modeling) are meant to make simulations even more accurate on sun radiation and greenery effects. Due to holistic approach and complexity of the calculations, ENVI-met has certain limitations, mostly regarding the computation time with high space resolution and wide simulation domains, and the high temporal resolution of meteorological data needed (30-min timesteps for full forcing mode).

SOLENE Microclimat. SOLENE-microclimat is a simulation tool for modeling at neighborhood scale. It consists of a thermo-radiative model, a CFD model and a thermal building model [17]. SOLENE was developed in the 1990s by CRENAU, *Laboratoire de l'école d'architecture de Nantes*. It was first developed for simulating natural light both outdoors and indoors, taking into account direct solar radiation, diffused sky luminous radiation and inter-reflections [33]. New sub-modules were added as the tool continued to evolve, which allowed it to take into account radiative transfers, conduction and storage in walls and soils, airflow and convective exchanges, evapotranspiration from natural surfaces, energy balance for a building in the simulated area [38]. SOLENE-microclimat is a result of coupling two tools—Code-Saturne which is a CFD open-source code developed by EDF and SOLENE [24]. Code-Saturne allows for calculation of wind speed and airflow distribution within the model. When coupled with SOLENE, a thermo-radiative model, it is able to calculate energy and moisture transportation, based on which it can determine physical characteristics of air and its interaction with urban surfaces [17]. The tool enables parameterization and representation of vegetation, natural soil, green walls and roofs, street humidification, but it is difficult to achieve it on a high level, since it requires a very detailed input and parameters such as leaf area index, water availability and soil/building characteristics [8]. The vegetation layer included in the model takes into account energy transfer by evapotranspiration, radiation and convection [37]. SOLENE-microclimat is able to simulate solar radiation and its impacts on urban surfaces, air flow and its effect, impacts of vegetation and water bodies as well as buildings' energy demand for the whole 3D modeled urban environment [17]. As the outcome of the simulation, outdoor air temperature, humidity, wind velocity and surface temperatures are calculated along with comfort indexes (MRT, PET, UTCI). The advantages of using SOLENE-microclimat are the possibility of representing the whole urban environment [36] and its capability of detail describing, consideration of thermal behavior of buildings, taking into account energy and humidity transfers through green devices and the ability to analyze different greenery types on building energy consumption [42]. The main weaknesses of the tool are the need for coupling with a CFD model for a full assessment and the complexity in terms of program use [8]. There is no user manual, so the guidance is mostly provided by the researchers and engineers already working with it [17] or annual meeting for collective formation [8]. Some modules of SOLENE-microclimat have been validated, such as radiative module, soil, green wall and building. However, due to a wide range of parameters concerning various physical phenomena on different locations, the model has not been validated as a whole [8].

UMEP & SOLWEIG. UMEP (Urban Multi-scale Environmental Predictor) is an integrated tool for urban climatology and climate sensitive planning applications [25] developed in Sweden and Great Britain, written as a plug-in to QGIS which makes it easier to use in integrated urban assessments. UMEP analyses can be performed on various scales, from street canyon to city-scale. It is comprised of four main models: the SOLWEIG model (SOlar and LongWave Environmental Irradiance Geometry model), the SUEWS model (Surface Urban Energy and Water Balance Scheme), the BLUEWS model (Boundary Layer Urban Energy Water Scheme), and the LUCY model (Large scale Urban Consumption of energY model) [20]. UMEP enables users to input atmospheric and surface data from different sources, adapt measured meteorological data for the urban environment, use reanalysis or climate prediction data and compare different climate scenarios and parameters. One of the advantages of UMEP is the ability to analyze different scenarios and problems related to climate-sensitive urban design can be addressed within one tool, on various scales [20]. It is also able to integrate relevant processes and use common data across a range of applications. UMEP tools can provide export data for more complex systems and software. Data from more complex models can be imported into UMEP as well [25]. SOLWEIG is a tool for simulation of spatial variation of 3D radiation flux and Mean Radiant Temperature (MRT) in complex urban environments. The tool uses a digital elevation model of buildings and plants for construction of complex urban structures, which results in relatively high accuracy of the simulation [25]. The model requires geographical information, urban geometry, direct, diffuse and global short-wave radiation, air temperature and relative humidity [28]. The tool works best in clear weather conditions, because it does not consider the cloud amount for diffuse radiation calculation, which results in calculation error. It takes into account combined effects of ground, wall and vegetation on reflected radiation. SOLWEIG focuses on radiation scenarios and therefore calculates MRT as the main comfort indicator [8], but PET and UTCI can be calculated as well [27]. MRT is calculated by modeling shortwave and longwave radiation in six directions and angular factors. It also requires continuous maps of sky view factors to determine MRT [26]. The advantage of using SOLWEIG on a neighborhood scale is GIS representation of buildings and other important modeling elements. One of the limitations of SOLWEIG is that it requires spatial datasets that could be difficult to obtain or integrate [8]. SOLWEIG has been widely evaluated and applied at various urban locations [25]. UMEP, as well as SOLWEIG, is a plug-in to

QGIS, allowing the creation of urban climate maps. UMEP is a free tool that encourages users to participate in their development by submitting comments, reporting issues, getting updates and sharing with other users. UMEP and SOLWEIG also provide detailed manuals and training material [20].

RAYMAN. Rayman is a largely validated [8] micro-scale model developed by Professor A. Matzarakis at the University of Freiburg, Germany, in 2007 [28]. It is used for calculation of radiation fluxes in simple and complex environments [30, 31], with the aim of calculating various thermal indices in order to evaluate the thermal conditions of different climates and regions (Matzarakis et al. 2017). RayMan is able to simulate different thermal indices: PMV, PET, UTCI, Standard Effective Temperature (SET), Perceived Temperature (PT) and MRT [32]. The model requires certain input data regarding air temperature, humidity, wind speed, short and longwave radiation fluxes and activity and clothing data for calculating PET [20]. Aside from the thermal index simulation, the software is capable of calculating and graphically presenting the sun paths for each day of the year, as well as sunshine duration and shadows caused by the surrounding obstacles [30]. All the calculations in RayMan are performed for one point in space and are time-dependent. The software considers only the thermal effects of buildings and vegetation [8]. It takes into account both simple and complex environments with their radiation properties, albedo and emissivity. It is able to calculate radiation fluxes due to the possibility of various input parameters and forms such as topography input, environmental morphology input, free-hand drawing and fish-eye photographic input. The software also calculates the Sky View Factor (SVF) in different ways, based on fish-eye images, free drawing of the horizon limitation, topographic raster or obstacle [30]. The main advantages of RayMan are low computational requirements and clear structure allowing the non-experts in human-biometeorology to use it [31]. The software is able to simulate the microclimate in different urban environments accurately, due to the precise calculation of radiation effects of the complex surface structure [16]. The preparation of input data can be time-consuming [8], but the main limitation regards the absence of the wind model.

Ladybug ecosystem. Ladybug Tools is a group of four environmental plug-ins that are built on top of several simulation engines. It is written in Python, which can be plugged into any geometry engine if the geometry library is translated. It is an open-source interface which unites open source simulation engines. It is connected to the 3D modeling software, which allows the geometry creation, simulation and visualization to be performed within one interface. The tool is mainly known as a Grasshopper plug-in. However, it can be connected to other 3D modeling software, such as Dynamo or Blender. Ladybug Tools consist of: Ladybug, Honeybee, Butterfly and Dragonfly. Ladybug tools are able to assess the thermal conditions and integrate it into the design flow, which makes it a comprehensive instrument for architects and urban planners. They are used for simulating climatic conditions on various scales, from canyon to city scale [32]. Ladybug's components are modular, which makes it capable of evaluating different parameters over various stages of design. Ladybug imports EnergyPlus Weather files (*.epw) which provide weather and location data. Integration with Grasshopper's parametric tools allows for immediate simulation of environmental parameters along with the change in design. This gives designers the possibility to explore the direct relationship between environmental data and the generation of the design [45]. Honeybee performs the analysis of daylight through Radiance, energy models using OpenStudio and envelope heat flow with Therm. Ladybug and Honeybee are capable of simulating the envelope interaction with both indoor and outdoor. They calculate heating and cooling demand with EnergyPlus while evaluating outdoor MRT [13]. Butterfly creates and runs CFD simulations using OpenFOAM, which is capable of running several simulations and turbulence models. Butterfly exports geometry to OpenFOAM and runs different types of airflow design, including simulations of urban wind patterns, indoor buoyancy-driven simulations, thermal comfort, ventilation effectiveness and more. Dragonfly is able to model and estimate large-scale climate phenomena such as UHI, climate change and influence of local climate factors. It is connected to Urban Weather Generator (UWG) and CitySim as well as several datasets which contain publicly available weather data and thermal satellite image datasets. With UWG, Dragonfly is able to estimate hourly air temperature and relative humidity in the UCL [13].

6 Discussion

As for the links between urban climate and microclimate issues and the Agenda 2030, the majority of positive interrelations occurs with targets of SDG 11 (six interlinkages), followed by SDG 13 (four), SDG 3 (three), SDG 9 and SDG 12 (two), finally SDG 7 and SDG 15 (one) (Fig. 2). Shifting to targets and indicators, SDG 11, 3 and 9 may specifically benefit from urban climate modeling. Moreover, the indicators addressing (mostly indirectly) urban climate and microclimate issues are fifteen, coming from Agenda 2030 (ten) and the *European Handbook* (five). However, the authors argue that more robust and direct support can be provided to the indicators by the *European Handbook* (specifically to #58 on "Heat Vulnerability"), which are more urban scale tailored with respect to the ones coming from Agenda 2030 but in turn support the achievement of prioritized targets. Besides, we still argue that no indicator within the *European Handbook* supports the measure of people's exposure to Particulate Matter (PM 2.5–10), although it is considered among the main risk factors for cardiovascular, respiratory, and carcinogenic diseases. Major attention to this issue is put by Agenda 2030 (11.6.2), but the annual mean level of exposure may provide no specific insights on site-specific urban level of exposure, which may significantly vary over a city, thus not providing specific support for design.

A wide range of software for urban climate and microclimate modeling to support the achievement of Agenda 2030 exist. According to the main findings, the most used and cited within the scientific literature are presented in Fig. 4, providing a direct comparison among them. Typology, application scale, environmental parameters that can be analyzed, indices simulated, and accessibility are shown for each software. From a general overview two main aspects clearly emerge: first, all the tools analyzed allows simulations at the micro-scale while only a few of them can be used for local and meso-scale; secondly, only about the half of them (e.g., ENVI-met, RayMan, Ladybug tools, Ansys Fluent) offer a wide range of environmental parameters and thermal comfort indices that can be simulated. For instance, air pollution simulation can be carried out by ENVI-met, Ladybug, Ansys Fluent and OpenFoam. The price affordability is another key factor in choosing software. Although most software developed and provided by academia are free, the most used for advanced analysis require an annual license subscription, while free licenses may come with large constraints. Among software analyzed and for design scenario assessment for local adaptation purposes, it is worth mentioning ENVI-met and Ladybug as the two most promising software for microclimate assessment at intra-urban level, considering the wide range of environmental parameters and indexes assessable, great number of papers validating their use, accuracy of the calculation, field scalability, implementability of functions, interoperability with GIS, CAD, Rhino or SketchUp for modeling, and most user-friendly visualization tools and interfaces.

	Type of model		Model scale			Simulated variables						Simulated thermal comfort index							Simulating air pollution	Native module for modelling	Free Accessibility
	EBM	CFD	Meso	Local	Micro	T_a	T_s	W_s	W_d	Q	Other	PMV	PET	UTCI	SET	PT	MRT	Other			
TEB (Town Energy Balance)	●		●	●	●	●	●	●		●	●			●							●
UWG	●		●	●	●		●				●			●							●
ENVI_MET		●		●	●	●	●	●	●	●	●	●	●	●	●		●		●	●	only with very limited features
RayMan	●				●	●	●			●		●	●	●	●	●	●			●	●
SOLWEIG	●			●	●		●			●			●	●			●				●
UMEP	●		●	●	●		●			●			●	●			●				●
Solene-Microclimat		●		●	●	●	●	●	●	●			●	●			●				●
Ladybug Ecosystem			●	●	●	●	●	●	●	●	●	●	●	●			●				open tools for pay per use software
ANSYS FLUENT		●		●	●		●	●	●		●	●	●	●	●		●		●	●	
TownScope	●				●					●								●			
OpenFOAM®		●	●	●	●			●	●			●							●		●
SkyHelios	●				●			●	●	●			●	●		●	●			●	●

Fig. 4 A comparison among the most used numerical software. Abbreviations: EBM (Energy Balance Model), CFD (Computational Fluid Dynamics), Ta (Air Temperature), Ts (Surface Temperature), Ws (Wind speed), Wd (Wind direction), Q (long and shortwave radiation), PMV (Predicted Mean Vote), PET (Physiological Equivalent Temperature), UTCI (Universal Thermal Climate Index), SET (Standard Effective Temperature), PT (Perceived Temperature), MRT (Mean Radiant Temperature)

7 Conclusions

The development of a full awareness by architects, urban planners, designers and policy makers on Industry 4.0 potential to drive cities in transition towards carbon neutrality is central in supporting environmentally sound policies. Parallelly, the paradigm of enabling technologies may allow for greater quality of life, in a context—the urban one—within which people's health is threatened by several structural stress conditions, to finally "leave no one behind". This chapter highlighted the specific role of urban climate and microclimate modeling tools with respect to open space redesign, as a means to accomplish climate adaptation and mitigation of the UHI effects within cities, the main "theater" of sustainability-related challenges. As mentioned, climate modeling can be a practical tool for measuring and achieving several indicators of the Agenda 2030 SDGs, especially 11, 13 and 3 when on-field measurable data is scarce or not available. To successfully implement the SDGs, interlinkages and trade-offs evaluation should be central. Climate models for simulating and minimizing the effect of projects on the urban thermal comfort and resource consumption may help to achieve multiple targets, but other targets may benefit from the usage of these tools.

Although still mostly requiring a high degree of specialization, numerical modeling in the field of micro-urban climatology is crucial when it comes to *ex-ante* assessment of several design options, affecting the user comfort, the UHI mitigation and, thus, the climate adaptation scenarios. Indeed, the authors highly recommend the use of such tools for enhancing the role of architecture and urban planning in supporting climate-proof urban landscapes design, as well as to consider possible trade-offs when implementing a project by embracing the SDG framework. Besides, further recommendations may regard the production and use of more and more site-specific and temporal fine-grain input meteorological boundary conditions to rely on accurate climate and pollutant distribution simulation [53]. Finally, enhancing the interoperability of these tools with GIS may constitute a tremendous opportunity to perform complex multivariate analysis, by which to turn climatic data into georeferenced climate maps to be coupled with other type of information (e.g., population density, pattern of land use and coverage, epidemiological data etc.). Indeed, boosting an evidence-based approach in the technological environmental design at urban and micro-urban scale needs updated and robust datasets, accessible to the stakeholders. Turning data on microclimate into georeferenced information may definitely constitute the next field of research for intra-urban scale modeling and simulation. Indeed, the role of open data on urban climate and microclimate, as proper GIS databases derived by advanced simulations, may support a system of shared information policy makers and domain experts may rely on, towards performance-based design as a praxis. In this perspective, performing climate simulations based on projection of temperature rise could contribute to the assessment of climate change impacts in the near future too, strengthening the role of performative design as a sound means to face current and future environmental emergencies and achieve the SDGs.

Acknowledgements This chapter is part of the work developed by the Research Unit of Politecnico di Torino as partner of the National Research Project PRIN TECH-START (*key enabling TECHnologies and Smart environmenT in the Age of gReen economy, convergent innovations in the open space/building system for climaTe mitigation*). This chapter is the result of a joint research by the Authors, who are equally responsible for it.

Author contributions: Conceptualization, M.T. (Matteo Trane), R.P. (Riccardo Pollo); investigation coordination: M.T., M.G. (Matteo Giovanardi), R.P.; methodology: M.T., A.P. (Anja Pejovic); literature selection and review process, M.T., A.P. (Anja Pejovic); writing—original draft, M.T., A.P.; writing—review and editing, M.T., M.G., R.P. All authors have read and agreed to the published version of the manuscript.

References

1. Ali-Toudert, F., Mayer, H.: Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons. Sol. Energy **81**, 742–754 (2007)
2. Bande, L., Afshari, A., Al Masri, D., Jha, M., Norford, L., Tsoupos, A., Marpu, P., Pasha, Y., Armstrong, P.: Validation of UWG and Envi-Met Models in an Abu Dhabi District, Based on Site Measurements. Sustainability 11 (2019)
3. Barberio, M., Colella, M.: Architettura 4.0. Fondamenti ed esperienze di ricerca progettuale. Maggioli Editore, Santarcangelo di Romagna, Italy (2020)
4. Battisti, A.: Il progetto come volontà e rappresentazione: dai big data all'apprendimento collettivo. In: Perriccioli, M., Rigillo, M., Russo Ermolli, S. Tucci, F. (eds.), Design in the Digital Age. Technology Nature Culture, pp. 335–339. Maggioli Editore, Santarcangelo di Romagna, Italy (2020).
5. Blocken, B.: Computational fluid dynamics for urban physics: importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations. Build. Environ. **91**, 219–245 (2015)
6. Blocken, B., Janssen, W.D., van Hooff., T.: CFD Simulation for Pedestrian Wind Comfort and Wind Safety in Urban Areas: General Decision Framework and Case Study for the Eindhoven University Campus. Environmental Modeling & Software 30, 15–34 (2012)
7. Borchardt S., Barbero-Vignola G., Buscaglia D., Maroni M., Marelli L.: A Sustainable Recovery for the EU: A text mining approach to map the EU Recovery Plan to the Sustainable Development Goals. EUR 30452 EN, Publications Office of the EuropeanUnion, Luxembourg, (2020)
8. Bouzouidja, R., Cannavo, P., Bodénan, P., Gulyás, A., Kiss, M., Kovács, A., Béchet, B., et al.: How to evaluate nature-based solutions performance for microclimate, water and soil management issues – available tools and methods from Nature4Cities European Project Results. Ecol. Ind. **125**, 107556 (2021)
9. Breu, T., Bergoo, M., Ebneter, L., Pham-Truffert, M., Bieri, S., Messerli, P., Ott, C., Bader, C.: Where to begin? Defining national strategies for implementing the 2030 Agenda: the case of Switzerland. Sustain. Sci. **16**, 183–201 (2021)
10. Bruse, M., Fleer, H.: Simulating surface–plant–air interactions inside urban environments with a three-dimensional numerical model. Environ. Model. Softw. **13**, 373–384 (1998)
11. Denton, F., Wilbanks, T.J., Abeysinghe, A.C., Burton, I., Gao, Q., Lemos, M.C., Masui, T., O'Brien, K.L., Warner, K.L.: Climate-resilient pathways: adaptation, mitigation, and sustainable development. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1101–1131 (2014)

12. Elbondira, T.A., Tokimatsu, K., Asawa, T., Ibrahim, M.G.: Impact of neighborhood spatial characteristics on the microclimate in a hot arid climate – a field based study. Sustain. Cities Soc. 75 (2021)
13. Evola, G., Costanzo, V., Magrì, C., Margani, G., Marletta, L., Naboni, E.: A Novel Comprehensive workflow for modeling outdoor thermal comfort and energy demand in urban canyons: results and critical issues. Energy Build. 216 (2020)
14. Figliola, A.: Envision the construction sector in 2050. Technol. Innov. Vert. TECHNE **17**, 213–221 (2019)
15. Grimmond, C.S.B., Roth, M., Oke, T.R., Au, Y.C., Best, M., Betts, R., Carmichael, G., et al.: Climate and more sustainable cities: climate information for improved planning and management of cities (producers/capabilities perspective). Procedia Environ. Sci. **1**, 247–274 (2010)
16. Gulyás, A., Unger, J., Matzarakis, A.: Assessment of the microclimatic and human comfort conditions in a complex urban environment: modelling and measurements. Build. Environ. **41**(12), 1713–1722 (2006)
17. Imbert, C., Bhattacharjee, S., Tencar, J.: Simulation of urban microclimate with SOLENE-Microclimat—an outdoor comfort case study. In: Proceedings of the Symposium on Simulation for Architecture and Urban Design. Delft (2018)
18. Imran, H.M., Shammas, M.S., Rahman, A., Jacobs, S.J., Ng, A.W.M., Muthukumaran, S.: Causes, modeling and mitigation of urban heat island: a review. Earth Sci. **10**(6), 244–264 (2021)
19. Independent Group of Scientists appointed by the Secretary-General: Global Sustainable development report 2019: the future is now-science for achieving sustainable development. United Nations, New York (2019)
20. Jänicke, B., Milošević, D., Manavvi, S.: Review of user-friendly models to improve the urban micro-climate. Atmosphere 12 (2021)
21. Kastner-Klein, P., Plate, E.J.: Wind-tunnel study of concentration fields in street canyons. Atmos. Environ. **33**, 3973–3979 (1999)
22. Kim, Y.H., Baik, J.J.: Maximum urban heat island intensity in Seoul. J. Appl. Meteorol. **41**(6), 651–659 (2002)
23. Krüger, E.L., Minella, F.O., Rasia, F.: Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil. Build. Environ. **46**(3), 621–634 (2011)
24. Lauzet, N., Rodler, A., Musy, M., Azam, M.H., Guernouti, s., Mauree, D., Colinart, T.: How building energy models take the local climate into account in an urban context – a review. Renew. Sustain. Energy Rev. 116 (2019)
25. Lindberg, F., Grimmond, C.S.B., Gabey, A., Huang, B., Kent, C.W., Sun, T., Theeuwes, N.E., et al.: Urban multi-scale environmental predictor (UMEP): an integrated tool for city-based climate services. Environ. Model. Softw. **99**, 70–87 (2018)
26. Lindberg, F., Grimmond, C.S.B., Gabey, A., Jarvi, L., Kent, C.W., Krave, N., Sun, T., Wallenberg, N., Ward, H.C.: Urban multi-scale environmental predictor (UMEP) manual. University of Reading UK, University of Gothenburg Sweden, SIMS China (2019)
27. Lindberg, F., Holmer, B., Thorsson, S.: Solweig 1.0—modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings. Int. J. Biometeorol. 52 (7), 697–713 (2008)
28. Liu, D., Hu, S., Liu, J.: Contrasting the performance capabilities of urban radiation field between three microclimate simulation tools. Build. Environ. 175 (2020)
29. Lobaccaro, G., De Ridder, K., Acero, J.A., Hooyberghs, H., Lauwaet, D., Maiheu, B., Sharma, R., Govehovitch, B.: Applications of models and tools for mesoscale and microscale thermal analysis in mid-latitude climate regions—a review. Sustainability **13**(22), 12385 (2021)
30. Matzarakis, A., Rutz, F., Mayer, H.: Modelling radiation fluxes in simple and complex environments—application of the RayMan model. Int. J. Biometeorol. **51**(4), 323–334 (2007)
31. Matzarakis, A., Rutz, F., Mayer, H.: Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. Int. J. Biometeorol. **54**(2), 131–139 (2010)

32. Mauree, D., Naboni, E., Coccolo, S., Perera, A.T.D., Nik, V.M., Scartezzini, J.L.: A review of assessment methods for the urban environment and its energy sustainability to guarantee climate adaptation of future cities. Renew. Sustain. Energy Rev. **112**, 733–746 (2019)
33. Miguet, F., Groleau, D.: A daylight simulation tool for urban and architectural spaces . application to transmitted direct and diffuse light through glazing. Build. Environ. 37(8–9), 833–43 (2002)
34. Mirzaei, P.A.: Recent challenges in modeling of urban heat island. Sustain. Cities Soc. **19**, 200–206 (2015)
35. Montazeri, H., Blocken, B., Derome, D., Carmeliet, J., Hensen, J.L.M.: CFD analysis of forced convective heat transfer coefficients at windward building facades: influence of building geometry. J. Wind Eng. Ind. Aerodyn. **146**, 102–116 (2015)
36. Morille, B., Lauzet, N., Musy, M.: Solene-microclimate: a tool to evaluate envelopes efficiency on energy consumption at district scale. Energy Procedia **78**, 1165–1170 (2015)
37. Musy, M., Malys, L., Inard, C.: assessment of direct and indirect impacts of vegetation on building comfort: a comparative study of lawns, green walls and green roofs. Procedia Environ. Sci. **38**, 603–610 (2017)
38. Musy, M., Malys, L., Morille, B., Inard, C.: The use of solene-microclimat model to assess adaptation strategies at the district scale. Urban Climate **14**, 213–223 (2015)
39. Ng, E., Chen, L., Wang, Y., Yuan, C.: A study on the cooling effects of greening in a high-density city: an experience from Hong Kong. Build. Environ. **47**, 256–271 (2012)
40. OECD: A Territorial Approach to the Sustainable Development Goals: Synthesis report. OECD Publishing, Paris, OECD Urban Policy Reviews (2020)
41. Oke, T.R.: Towards better scientific communication in urban climate. Theoret. Appl. Climatol. **84**(1–3), 179–190 (2006)
42. Parsaee, M., Joybari, M.M., Mirzaei, P.A., Haghighat, F.: Urban heat island, urban climate maps and urban development policies and action plans. Environ. Technol. Innov. 14 (2019)
43. Petri, A. C., Wilson, B., Koeser, A.: Planning the urban forest: adding microclimate simulation to the planner's toolkit. Land Use Policy 88 (2019)
44. Pollo, R., Elisa B., Giulia S., Bono, R.: Designing the healthy city: an interdisciplinary approach. Sustain. Mediterr. Constr. 11 (2019)
45. Roudsari, M.S., Pak, M., Smith, A., Gill, G.: Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design. In: Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, 3128–35. Chambery (2013)
46. Santamouris, M., Mihalakakou, G., Papanikolaou, N., Asimakopoulos, D.N.: A neural network approach for modeling the heat island phenomenon in urban areas during the summer period. Geophys. Res. Lett. **26**(3), 337–340 (1999)
47. Setaih, K., Hamza, N., Mohammed, M.A., Dudek, S., Townshend, T.: CFD modeling as a tool for assessing outdoor thermal comfort conditions in urban settings in hot arid climates. J. Inf. Technol. Constr. (ITCon) 19 (2014).
48. Sharmin, T., Steemers, K., Matzarakis, A.: Microclimatic modelling in assessing the impact of urban geometry on urban thermal environment. Sustain. Cities Soc. **34**, 293–308 (2017)
49. Siragusa, A., Vizcaino, P., Proietti, P., Lavalle, C.: European Handbook for SDG Voluntary Local Reviews. In: EUR 30067 EN, Publications Office of the European Union, Luxembourg (2020)
50. Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., et al.: Planetary boundaries: Guiding human development on a changing planet. Science **347**, 736 (2015)
51. Toparlar, Y., Blocken, B., Maiheu, B., van Heijst, G.J.F.: A review on the CFD analysis of urban microclimate. Renew. Sustain. Energy Rev. **80**, 1613–1640 (2017)
52. Trane, M., Giovanardi, M., Pollo, R., Martoccia, C.: Microclimate design for micro-urban design. A case study in Granada, Spain. Sustain. Mediterr. Constr. 14, 149–55 (2021)
53. Trane, M., Ricciardi, G., Scalas, M., Ellena, M.: From CFD to GIS: a methodology to implement urban microclimate georeferenced databases. TECHNE Journal of Technology for Architecture and Environment **25**, 124–133(2023)

54. Trane, M., Marelli, L., Siragusa, A., Pollo, R., Lombardi, P.: Progress by Research to Achieve the Sustainable Development Goals in the EU: A Systematic Literature Review. Sustainability **15**(9), 7055 (2023)
55. Tucci, F.: Requirements, approaches, visions in the prospects for development of technological design. In: Lauria, M., Mussinelli, E., and Tucci, F. (eds.), Producing Project. Maggioli Editore, Sant'Arcangelo di Romagna, Italy (2020)
56. United Nations, Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). United Nations, New York (2019)
57. United Nations: Transforming our world: The 2030 agenda for sustainable development. Resolution Adopted by the General Assembly A/RES/70/1
58. Vukmirovic, M., Gavrilovic, S., Stojanovic, D.: The improvement of the comfort of public spaces as a local initiative in coping with climate change. Sustainability **11**(23), 6546 (2019)
59. Woetzel, J., Pinner, D., Samandari, H., et al.: Climate risk and response. Physical hazards and socioeconomic impacts. McKinsey Global Institute (2020)
60. Wong, N.H., He, Y., Nguyen, N.S., Raghavan, S.V., Martin, M., Hii, D.J., Yu, Z., Deng, J.: An integrated multiscale urban microclimate model for the urban thermal environment. Urban Climate **35**, 100730 (2021)