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Integrated Simulation-based Framework for Parametric Open Space Design with Focus on Sustainable Mobility and Climate Resilience

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1 ABSTRACT

Recent advances in the application of computational design show great potential in the holistic assessment of design scenarios. To tackle the challenges of climate change and urbanisation, we need intelligent planning methods to design sustainable urban development and resilient open spaces. Therefore, this paper presents an integrated simulation-based framework for parametric urban design with focus on sustainable mobility and climate resilience. Precisely, aspects from mobility, water management and microclimate are used for the evaluation of open space planning. The result is the framework including interfaces and the exemplary application to real-world scenarios in Aspern at Nelson Mandela Square.

Keywords: Performance-based design, Climate resilience, Sustainable mobility, Parametric design, Open space design

2 INTRODUCTION

2.1 Challenge

The microclimate and mobility patterns of a neighbourhood have a significant impact on the social and economic development within the city, as well as on the quality of life of the residents (Sharmin, Steemers 2020). The structure of public spaces, the built environment and blue-green urban spaces have a decisive influence on whether squares, streets and sidewalks are attractive areas to dwell and rest. Additionally, with the acceleration of the climate crisis, urban heat stress can have serious health repercussions for vulnerable demographic groups, such as the elderly, infants or individuals with pre-existing conditions. Likewise, water retention plays an increasingly crucial role, as urban growth leads to more sealed surfaces, while extreme precipitation is expected to intensify (Tabari 2020). The time for closer collaborations between landscape planners and the scientific community for truly resilient urban designs is now. Design, choice of materials and anticipated user behaviour are crucial factors in determining whether our urban fabric will stand the test of time. Municipalities and local governments are becoming increasingly aware of the importance of these factors in designing urban spaces. Within the city of Vienna, the aspects of microclimatic resilience and sustainability are rooted in municipal strategies (Vienna Municipal Department 2018) and has become institutionalised in the planning of selected urban development areas through the tool of the Quality Advisory Board ("Qualitätsbeirat") of the wohnfonds_wien.

Equally, a change in our mobility behaviour can contribute significantly to curbing greenhouse gas (GHG) emmissions, as passenger vehicles are responsible for approximately 70 percent of motorised transport emissions in industrialised nations (Tran et al 2021). Urban mobility modelling can plays a key role in facilitating the infrastructure required to attract urban dwellers in adapting more sustainable modes of transport (i.e. walking and cycling). In this regard, accessibility and possibilities to meet current and future mobility requirements need to be taken into account efficiently throughout the planning stages of public spaces and mobility hubs. Knowledge of this is not only of interest to municipalities and urban planners, but also to developers and business owners in their respective investments.

2.2 Background

This paper aims to establish the potential of cross-disciplinary framework from microclimate and active mobility simulations as planning support for open spaces. Located in a greenfield development 'Seestadt Aspern' in the Austrian capital city of Vienna, this case study depicts the strengths of a methodology comprised of simulation and parametric planning. The integration of urban analysis and optimisation into the planning process in practice is a major challenge, therefore tools and frameworks are needed to make different aspects of scenarios assessable.

In order to solve complex simulations for many variants, computational urban modelling was used to support the modelling, simulation and evaluation process (Koenig et. al 2019). In recent years, the use of computational urban modelling in architecture and urban planning has increased enormously (Fink 2018).

3 METHODOLOGY

The methodology is structured in three steps: the first step is the parametric modelling of buildings and vegetation (trees, green spaces, surfaces) within the given context and boundary conditions of the project site. The modelling of the urban design is done using the software environment Rhinoceros 3D and its native parametric plug-in Grasshopper. The second step of the methodology – the analyses - is split into three different topics: 1. Pedestrian Simulation, 2. Microclimate Simulation and 3. Urban Water Consultation. The microclimate simulations were conducted using the Rhinoceros 3D software alongside the Ladybug Tools plug-in to simulate the environmental impact of their designs. The pedestrian models were simulated using Simulate modelling software, developed by AIT. The methodology estimates the water retention potential of the area under investigation utilised the respective runoff coefficients of the anticipated surface materials. In close coordination with the partnering landscape architect, the surfaces and their characteristics were discussed to meet the client's expectations and the local resilience standards. The third step of the methodology concerns the evaluation of the results and translation into design decisions. Therefore, the results are therefore superimposed on the design across themes, further design scenarios are developed and used as a basis for decision-making for open space elements and the properties of surfaces.

3.1 Step 1 – Parametric modelling

The use of parametric modelling allows many variants to be created under semi-automated processes. 2D CAD plans are used as a data basis, which are modelled in 3D within the software environment Rhinoceros 3D and Grasshopper with self-developed scripts. Buildings (height, land-use), vegetation (trees, green areas), benches, bus stops, entrances and public transport lines are created parametrically in three different variants within the framework conditions. The trees are modelled as simplified 3D shapes, differentiating between street trees and square trees in height and crown diameter to correspond to real conditions. Furthermore, the surface conditions of the ground surfaces are modelled differentially on layers to provide information for both stormwater management and the walkability of surfaces for pedestrians.

3.2 Step 2 – Simulations and Analyses

The analyses are further solved via additional plug-ins and other software environments. For this purpose, the data is prepared via interfaces from Grasshopper for the respective simulations and serve as a basis. In the following sub-chapters (Figure 1), the simulations for the individual topics are explained in more detail.

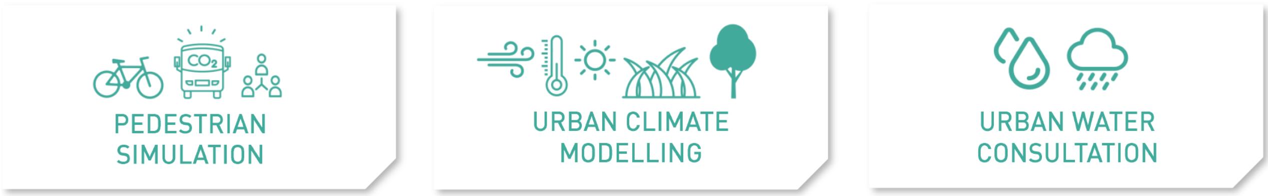

Fig. 1: Topic overview.

3.2.1 Pedestrian Simulation

For the analysis of the pedestrian flows at Nelson Mandela Square an agent-based simulation model (Simulate) was used to simulate the movements of all boarding and alighting public transportation passengers and of all persons crossing the square during five minutes of the morning peak hour. For this purpose, the entire transport infrastructure, including bicycle parking and all planning measures were taken into account. The data preparation for the interface between Rhinoceros 3D and Simulate is done in the parametric plug-in Grasshopper. Spatial elements with their properties (buildings, stops, PoI, (accessible) green spaces, benches, etc.) are modelled in 3D and exported as a .geojson file. A self-developed python parser translates the geometries, functional elements, start and end points into the input format of Simulate. The simulation in Simulate enables the integration of further information (i.e. number of pedestrians, public transport frequency) as well as the user group-specific definition of speeds and routes. All parametrically generated scenarios are analysed and a holistic overview for the planners and stakeholders generated.

3.2.2 Microclimate Simulation

To perform a microclimatic simulation of the design, the Ladybug tools from the Grasshopper plug-in are used. This allows the simulation of climate comfort based on the solar radition on open spaces to avoid unpleasant conditions for pedestrians. The evaluation and visualisation is also carried out in the Grasshopper software environment, which supports the creation of simulation maps in project-specific legend colours.

3.2.3 Urban Water Consultation

To assess the impact of pluvial events on the open spaces from green spaces and roofs over waterbound surfaces, site concrete and slab surfaces the local mean annual precipitation as well as the local design storm water events are used as a basis. The NaNu3 research project deals with the parametric planning of a sustainable utility roof by combining green roof, photovoltaics and grey water treatment. Based on this project, the local framework conditions and the building parameters are used to evaluate the planning along the indicators. There are synergies between the two projects, both in the subject matter and in the parametric approach of the evaluation.

3.3 Step 3 – Evaluation

The evaluation of the design scenarios is based on the simulation results and carried out in discussions with the thematic experts. Strengths and weaknesses of designs can be better understood, and the fact-based simulation basis can ensure a performance comparison between variants.

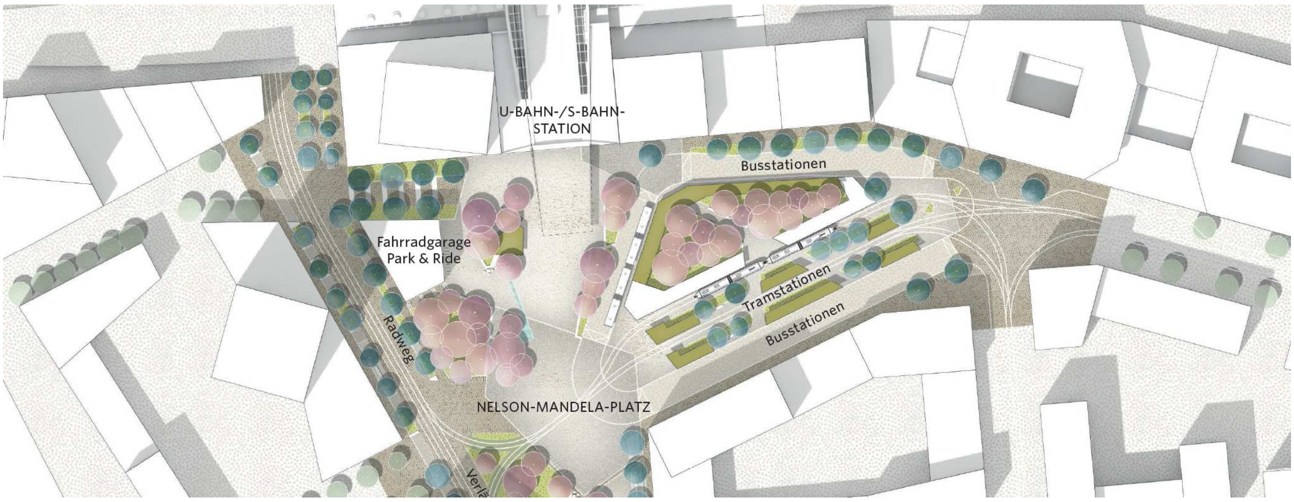

Fig. 2: Top view scenario 03 – Nelson Mandela Square, Aspern (© Lindle+Bukor)

4 CASE STUDY

4.1 Description Aspern Use Case

The presented framework was applied for the assessment of the landscape plan of Nelson Mandela Square in Vienna (see Figure 2). This public square has access to metro, bus and tram stops and is located in the north of a planned high traffic shopping street in the Aspern urban development area. This entails high demands on the multimodal mobility hub and on the quality of the square. The parameters for this use case are based on the objectives from the developers and on the weather boundary conditions of this location. The population, visitor frequencies of the shopping street and capacity of public transport were assumed for the case study based on GFA (gross floor area) of the buildings and reference mobility values from Vienna. The tasks identified were the parametric modelling of the landscape plan, the translation into a simulation model and the assessment based on the issues of microclimatic open space comfort, pedestrian flows and water management. The buildings from a master plan for the development area in the north are generated from the contour lines with height allocation. Space-defining elements such as the canopy in the metro access area and stops were reproduced in detail to achieve accurate results. In interactive workshops, three scenarios differentiated by land-use, density, green areas and trees were developed and evaluated. The development of the scenarios includes the change in building heights and land-use as well as vegetation and green spaces at Nelson Mandela Square (see Table 1). These variations have an impact on pedestrian behaviour (origin, destination, frequency), solar radiation and urban water management. The synergies and impacts of the planning decisions were examined on the basis of the three scenarios.

4.2 Simulaton Set-up

4.2.1 Pedestrian Simulation

Simulations of pedestrian flows in the whole area were used to study the mobility aspects of the layout. For this purpose, an approach was implemented which uses social forces to describe the movements of the pedestrians and their interactions (Helbing et al 2009) with each other and with obstructing infrastructure elements. In general, pedestrians choose the shortest path to get from their starting point to their destination. By positioning attraction points along their path, it is possible to adjust their routes and and generate higher frequency on more attractive routes. Five minutes during the morning peak period were used as basis for estimating the passenger numbers. This resulted in a total of 1.310 persons, including 650 from and to the metro, 200 to and from the trams, 100 to and from the busses and 360 others, who passed through the area without using any form of public transport. Additionally, depending on the scenario, between 105 and 140 pedestrians walked through the area, starting at the building exits. These numbers are determined by the type of use of the buildings (e.g. office or residental building) and their GFA. As a consequence, pedestrian's mobility patterns are strongly linked to the building development of the area.

	Scenario 1	Scenario 2	Scenario 3
Planning KPIs	Total GFA: 187.623m² GFA commercial: 15.763m² GFA office: 41.025m² GFA residential: 130.835m² Residents: 2.617 Employees: 1.476 Density: 2,5 Average number of floors: 6,8	Total GFA: 129.948m² GFA commercial: 8.721m² GFA office: 67.831m² GFA residential: 129.948m² Residents: 2.599 Employees: 1.945 Density: 2,8 Average number of floors: 6,6	Total GFA: 203.896m² GFA commercial: 30.790m² GFA office: 75.062m² GFA residential: 98.044m² Residents: 1.961 Employees: 2.756 Density: 2,7 Average number of floors: 7,1
Pedestrian simulation	The pedestrian simulation reveals two areas of concern. 1) Many paths are crossing the bus lane in front of the bus stops. This prevents the buses from arriving and departing smoothly. 2) pedestrians are crossing the tram tracks right in front of the station. Since they are approaching the waiting vehicles from behind right this may lead to dangerous situations when a tram starts to leave the station.	The layout changes in this scenario do not solve the problems concerning the pedestrian flows described in scenario 1.	The redesign in this scenario significantly defuses the analyzed problem areas. The paths crossing the bus lanes are concentrated in a corridor between two bus stops and less pedestrians are crossing the tram tracks in front of the station. Furthermore, they are now approaching the waiting vehicles from the front which makes it much easier for the drivers to avoid collisions.
Microclimate Simulation	Number of trees: 98 Share of green: 11% % of >5Wh areas: 26,5% % of <2kWh areas: 20,7% Average solar radiation: 3,63 kWh/day Total solar radiation: 42.546kWh	Number of trees: 153 Share of green: 22% % of >5kWh areas: 25,6% % of <2kWh areas: 23,3% Average solar radiation: 3,51 kWh/day Total solar radiation: 41.173kWh	Number of trees: 140 Share of green: 18% % of >5kWh areas: 25,7 % of <2kWh areas: 21,7 Average solar radiation: 3,56 kWh/day Total solar radiation: 41.795kWh
Urban Water Consultation	Amount of water to be discharged (m^3 per area) 73 % of mean annual precipitation or design precipitation	Amount of water to be discharged (m^3 per area) 66 % of mean annual precipitation or of design precipitation	Amount of water to be discharged (m^3 per area) 69 % of mean annual precipitation or design precipitation

Table 1: KPI overview of the 3 scenarios developed.

4.2.2 Microclimate Simulation

Weather data of a meterological reference year for Vienna between 2004 and 2018 from an online data base was used as the basis for the simulations. The analysis period was set on 21st of June, a very hot summer day, and is intended to generate insights into the heat development at the site. The grid size for the simulation was set at 2 metre resolution for the entire area.

4.2.3 Urban Water Consultation

For the analyses the local mean annual precipitation as well as the local design storm water event were accessed via eHYD for the grid point 2791 (mean precipitation 563 mm) and two nearest modelled grid points 2765 'Stadlau' (near the intersection of Hans-Steger-Gasse and Aribogasse) and 2766 'Eastern Seestadt' (near the intersection of Niklas-Eslarn-Straße and Hänischgasse) repectively. Since the planning area is located in the mid-point between the two grid points, the mean value for local design storm of 48.1 mm for 60 minutes with a return period of 50 year was assumed for further calculation.

4.3 Results

4.3.1 Pedestrian Simulation

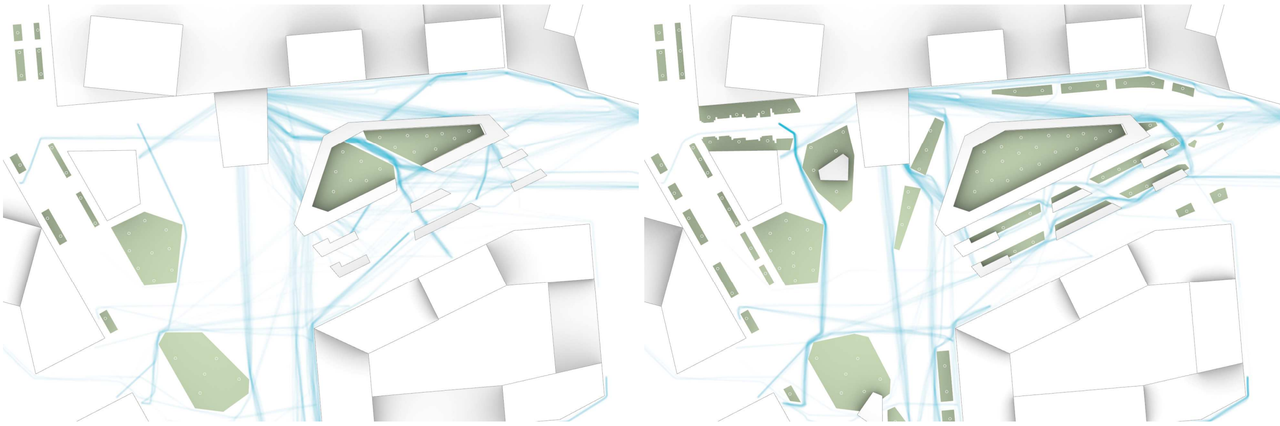

Fig. 3: Pedestrian simulation paths results - scenario 1 left, scenario 2 right

The results of the pedestrian flow simulations (see Figure 3) were visualized by marking the course of the most used paths and indicating the spots of high densities by orange or red colors (see Figure 4). Both the diagonal connections and the crossability, as well as the sufficient dimensions of the walkable areas, ensure smooth movements of the pedestrians (green). Increased person densities are expected only in the area in front of the entrance to the metro station (orange-red).

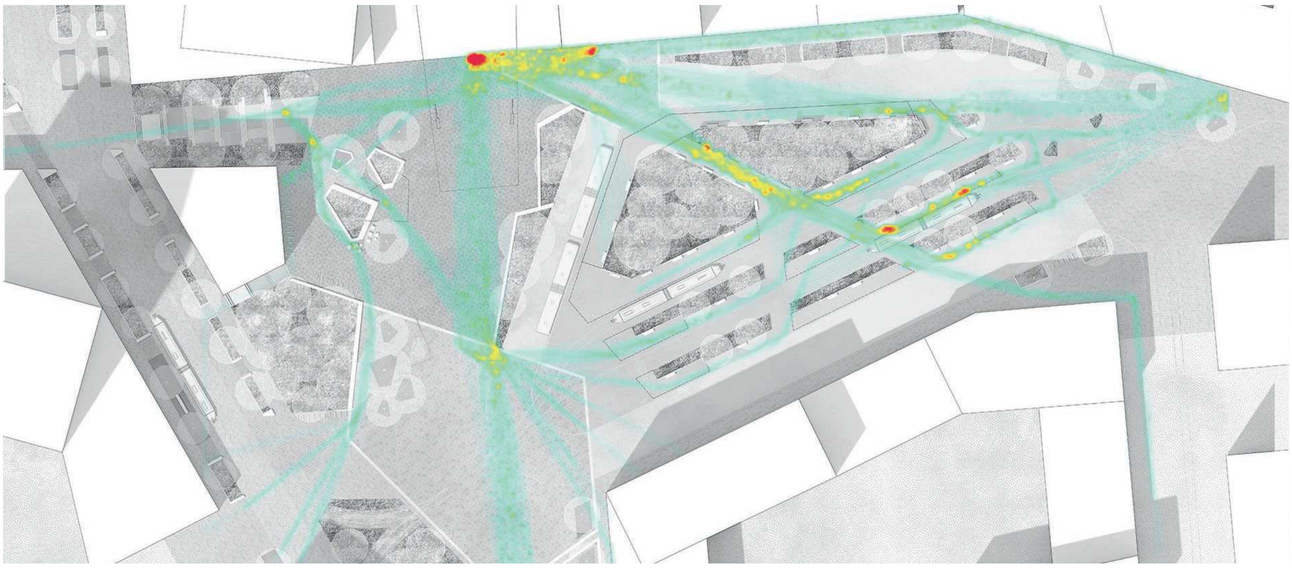

Fig. 4: Pedestrian simulation density results (© AIT, Lindle+Bukor)

4.3.2 Microclimate Simulation

The results on the solar radiation simulation show the effect of shading of vegetation, building configuration and bus stops. The optimised position of the trees reduces the percentage of places with high solar radiation to avoid overheating in summer. The mean radiation temperature - the perceived temperature by human - is strongly influenced by solar radiation. Especially in the waiting areas of the bus stops, the vegetation and canopies have a shading effect, which is characterised by the blue areas (see Figure 5). The red areas receive a high amount of solar radiation, these indicate a strong heat development on hot summer days. In addition to solar radiation, the surface properties of the square and the surrounding buildings also have a significant influence on the microclimate. The results of the three scenarios reflect the different building heights and tree placements. Scenario 2 achieves the best performance with 25.6% of the areas above 5kWh and 153 trees despite having the highest density in the area.

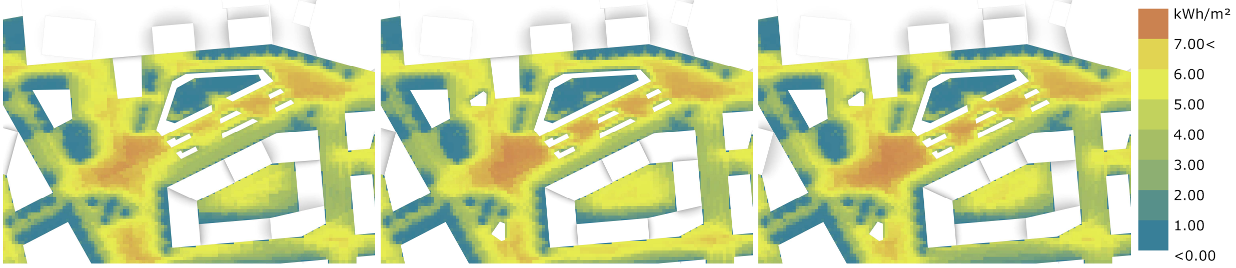

Fig. 5: Solar radiation results – scenario 1 left, scenario 2 middle, scenario 3 right.

4.3.3 Urban Water Consultation

The results in Table 2 show that at most 73% of the precipitation (scenario 1) must be discharged, with the majority originating from the more (heavily) sealed surfaces (97%) – site concrete and slabbed surfaces. Consequently, the integration of infiltration-capable surfaces and targeted planning of green spaces was discussed together with the landscape planners.

	Scenario	**m²**	**Runoff coefficients (Range)**	**Applied runoff coefficient**	**Mean annual precipitation (m³)**	**Amount of water to be discharged (m³)** Mean annual precipitation	**Design precipitation (m³)**	**Amount of water to be discharged (in m³)** Design precipitation
Total Area	1	20.325			11.443	8.359	550	402
	2					7.597		365
	3					7.839		377
Green space (flat)	1	2.276	0-0,1	0,10	1.281	128	62	6
	2	4.411			2.483	248	119	12
	3	3.557			2.003	200	96	10
Site concrete, sealed surface	1	9.317	0,9-1	1,00	5.245	5.245	252	252
	2	9.030			5.084	5.084	245	245
	3	8.854			4.985	4.985	240	240
Slabbed surfaces of all squares and sidewalk, Water-bound surface	1	7.844	0,5-0,75 (depending on joint closure)	0,65	4.416	2.871	212	138
	2	5.810			3.271	2.126	157	102
	3	6.888			3.878	2.521	187	121
Green roofs (6-12 cm substrate; e.g. tram/bus stop roofs)	1	888	0,13-0,33	0,23	500	115	24	6
	2	1.074			605	139	29	7
	3	1.026			578	133	28	6

Table 2: Pluvial impact assessment of the planned open spaces and estimated water to be discharged for the man annual precipitation (563 mm) and the local design storm water event (48,1 mm for 60 minutes with a return period of 50 years). Runoff coefficient is based on DIN 1986 [2016], DWA-M 153 (2007), ÖNORM B 2506 (2013).

The result of this framework is a visual respresentation of the simulation output and KPI-based evaluation to support multi-stakeholder discussions and the decision-making process. Based on the integrated analysis using all three components, the planning variants were compared, and individual aspects of the designs optimised (i.e. tree locations). The evolution from the heavily sealed, low-density scenario 1 to the intensively greened scenario 2 was further optimised after evaluating the performance indicators to scenario 3. In addition, the problems of pedestrian flows arising in scenarios 1 and 2 were solved, and good performance was achieved in urban water management and microclimatic considerations, while at the same time achieving the necessary building density in the area. Furthermore, recommendations for action for the spatial elements of open space planning (benches, bus stops, etc.) can be derived and can be integrated in the further process.

5 CONCLUSION

The application to a real planning task has refined the key performance indicators (KPIs) and optimised them for practical applicability. The evaluation and analysis of the simulations served to optimise the open space planning scenarios. The height of buildings, land-use mix, position of trees and shading elements, the bus stop roofs and the design of seating elements were adjusted based on the analysis results. The bus stop design could also be optimised in the placement of columns and walls based on the results of the pedestrian simulation.

In addition, the methodology developed can be applied to all open space planning, but also to the optimisation of urban squares. With the same structured data basis, the tasks can be solved for different locations, and the framework conditions (weather data) can be used for any locations in Austria to generate findings on the performance of open space scenarios. A potential further development of the methodology can go into the parts of the individual simulations, as well as into the broader scope and integrate further analyses.

Moving forward, the methodology and its associated findings can be utilised by a number of actors and experts in the field of urban planning. For actors in the private sector, visibility, accessibility and duration of stay can have a significant impact on their interaction with customers and pedestrian traffic to individual locations. For example, restaurants and cafés in urban heat islands will have a harder time attracting customers than competitors in comfortable areas. As the use of retail space is considered in early planning stages of developments, our findings embody an important variable in these planning stages.

On a societal level, the data may be used to climate-proof urban spaces that are being exposed to higher average temperatures throughout the warmer seasons. Heat-related health implications are on the rise (Matthews et al 2017), especially for vulnerable groups such as the elderly and infants. To promote safe and sustainable mobility for all in society, the findings and methodology should be taken into consideration in the planning phases for new and redevelopments alike.

6 ACKNOWLEDGEMENT

The Aspern use-case was developed in cooperation with the landscape planners Lindle+Bukor from Vienna.

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