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Modelling Microclimates in the Smart City: a Campus Case Study on Natural Ventilation

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1 ABSTRACT

In recent years, modeling tools have been developed that allow quantifying and comparing the microclimatic impacts of different design options, e.g. modeling wind tunnel effects or surface heat.

Our research for open spaces as an essential part of smart cities investigates how landscape architecture designs, e.g. tree planting strategies, green roofs, etc. will interact with the microclimate and natural ventilation or air flow. Addressing open spaces is also an important connecting element across the various disciplines involved and will facilitate close interdisciplinary collaboration. Interdisciplinary collaboration could address the interrelation between outdoor spaces and indoor conditions, public stakeholder involvement, and the risks through extreme weather events. The expected results will inform sustainable landscape design solutions and increase resilience to climate change.

We started with a case study in modeling the micro-climate for the new campus masterplan of the University of Sheffield, currently developed by Feilden Clegg Bradley Studios, Grant Associates, & AECOM (2014). Peng & Elwan (2011) had already used ENVI-met to model the impact of climate change on building temperatures; Wong & Jusuf (2008) used GIS. After testing different software packages, we decided to use Autodesk Vasari in comparison, which is well integrated with other Autodesk products. First, past and current wind speeds were collected to calibrate the model. Applying our modelling approach provided figures on how the proposed masterplan design will change the local microclimate on campus and predicted effects on wind speeds on central parts of the campus.

The results show that street trees have a significant influence on the air flow and that improved street tree design can increase natural ventilation mitigating the UHI effect on campus. The model also showed some of the interactions between buildings and trees although the used software was rather limited with regard to different vegetation types. The presentation will conclude with suggestions for further research and for future software development to improve the accuracy of microclimate and air flow modeling in smart cities.

2 INTRODUCTION

Landscape architects have to be able to test design solutions against their climate performance. Without such an understanding of the urban micro-climate and how landscape elements will affect them, designers are at risk of creating urban landscapes, which will perform poorly or even have a negative impact on the micro-climate (Lenzholzer and Brown, 2013). Recent research has increasingly addressed the environmental modeling of design interventions and their impact on temperatures and air flow in open spaces. Gago et al. (2013) reviewed recent research of the Urban Heat Island (UHI) effect, i.e. the additional heat from solar radiation and urban activities contributing to increased inner-city temperatures, and various mitigation strategies such as green spaces with and without trees, albedo, ground surfaces and building types and materials. They also look into urban design and air flow as a factor and assume that a reduction in mean velocity will reinforce the UHI effect. While multiple authors studied the impact of building typologies on surface temperatures (e.g. Baumgart and Berger, 2015) and climate and comfort perimeters (Pedraza et al., 2013), Bruse and Fleer (1998) provided an early study of the impact of urban greening. At the time, they concluded that even small changes can effect local air flow and temperatures. More recently, Bowler et al. (2010) reviewed available evidence of the impact of greening interventions. Their meta-analysis showed that on average, a park was 0.94°C cooler in the day and that trees provided an additional cooling impact. However, they also concluded that future research is needed, i.e. investigating how different distributions and types of greening will impact the micro-climate. Evidence at the time did not allow any specific design recommendations of how to design urban greening to achieve specific mitigation effects.

Air flow in urban areas is linked to the relationship between buildings and open spaces. Furthermore, turbulences around buildings may have a negative impact on perceived comfort. On the other hand, gentle air flow can help mitigating UHI effects. In response to these questions, this study is looking at the micro-climate in general and air flow in particular on an university campus and how it may change as the result of proposed landscape changes, especially tree planting, in a masterplan. The benefits of trees in urban settings have been emphasized many times (cf. Tree and Design Action Group, 2012) but only recently, these benefits have been quantified and modeled in urban settings. Air flow models can further inform models of the distributions of pollutants or neighborhoud energy models.

Trees can be categorized in different ways with the basic distinction between deciduous and coniferous trees. More detailed classification factors are species, age, size, canopy height, condition and shape. Some commonly planted street trees for the UK are Acer platanoides, Acer pseudoplatanus, Betula pendula and Fraxinus excelsior. Gromke and Buck (2007) modeled street canyons with trees with varying crown diameter, crown permeability, trunk height and tree spacing. For small trees, only small changes could be measured. Trees of increasing size can ameliorate air-quality. In general, trees reduce wind speeds at crown-height and disrupt the air flow near the canopy. However, unlike buildings, trees are somewhat permeable and air flow can partially penetrate into the tree canopy. Wania et al. (2012) point out that the effect of trees on street ventilation in higher-density built-up areas is still not very well understood.

3 CASE STUDY: THE UNIVERSITY OF SHEFFIELD MASTERPLAN

The University of Sheffield Masterplan provides an ideal case study because it allows the comparison of current and proposed future landscape designs in a coherent urban space. Campuses have been used as case studies for micro-climate modeling before, e.g. by Lenzholzer and Brown (2013) or Wong and Jusuf (2008). Peng and Elwan (2011) examined the Sheffield university campus in terms of resilience to future climate change predictions – allowing for a comparison with the methods and results of this study. They first used Autodesk Ecotect building simulations and then ENVI-met to contextualize the results of the building simulations at campus scale using weather data from 2010 to predicted data until 2050. Their results were modeled air temperatures. They concluded that further field measurements are required to validate the potential correlations between urban neighborhood scale micro-climate simulations and the individual building simulations.

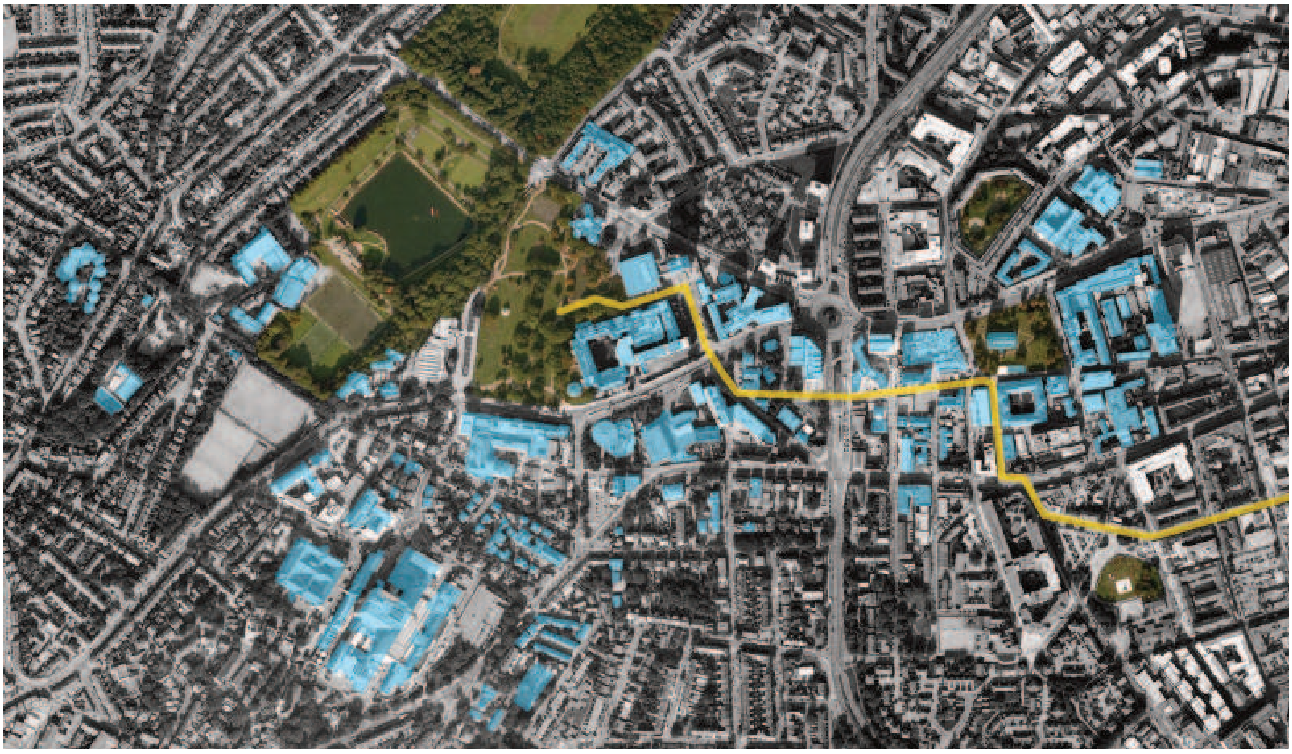

Fig. 1: The University of Sheffield draft masterplan 2014 (Feilden Clegg Bradley Studios, Grant Associates, & AECOM, 2014: 32).

This study follows up from there focusing particularly on air flow and the implications of the proposed campus masterplan (see Figure 1) by Feilden Clegg Bradley Studios, Grant Associates and AECOM (2014). Within the wider campus area, we selected the open space between the Arts Tower and the library (named "Information Commons IC") building (see the annotations in Figure 1) and the proposed redesign of this area. Figure 2 is a map of the existing tree planting on campus, tree species and their approximate height were recorded in a linked table. Dominant species are Acer platanoides (13 trees, 8m), Platanus x hispanica

(16 trees, 10-12m) and Tilia x europaea (18 trees, 4-10m). In comparison, Figure 3 shows the proposed tree planting according to the masterplan.

Fig. 2: Trees on campus under current conditions (base map: OS MasterMap Topography Layer, Coverage: The University of Sheffield, Updated Jan 2014, Ordnance Survey, GB. Using: EDINA Digimap Ordnance Survey Service, http://edina.ac.uk/digimap, downloaded: June 2014)

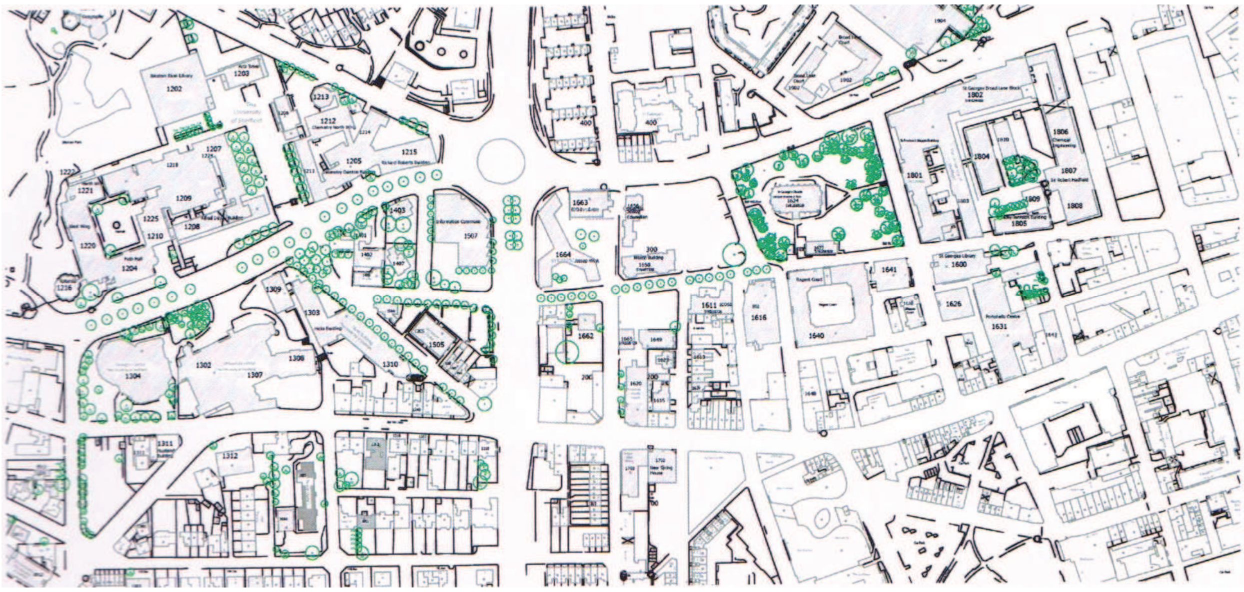

Fig. 3: Trees on campus according to the proposed masterplan (base map: OS MasterMap Topography Layer, Coverage: The University of Sheffield, Updated Jan 2014, Ordnance Survey, GB. Using: EDINA Digimap Ordnance Survey Service, http://edina.ac.uk/digimap, downloaded: June 2014)

Peng and Elwan (2011) further recommend the use of "3D virtual neighborhood modeling" to more effectively communicate environmental modeling approaches. Trimble Sketchup was used to model the case study area in 3D (Fig. 4).

4 METHODOLOGY

Computational Fluid Dynamics (CFD) are software programs for wind analysis in open space environment (Moya, 2015). One of these programs is Autodesk Vasari (http://autodeskvasari.com), which is based on Autodesk Ecotect (Pedraza et al., 2013). Since the campus data is also managed in Autodesk products (Autodesk AutoCAD) and because the Vasari Wind Tunnel Tool provides two different air flow simulations, a quick 2D analysis based on 2D slices and a more accurate 3D analysis, we decided using Vasari for this study. Moya (2015) compare Autodesk Vasari with ODS-Studio and ANSYS CFX. If even more detail is needed, Moya comes to the conclusion that the latter two provide better resolution and other advantages, but at the cost of usability. A short cost-benefit discussion will be included in the conclusions. Another well-established modeling software is ENVI-met (http://envi-met.com), which was used by Ng et al. (2012), Wania et al. (2012), Peng and Elwan (2011) and Wong and Jusuf (2008), and has just been released as version 4.

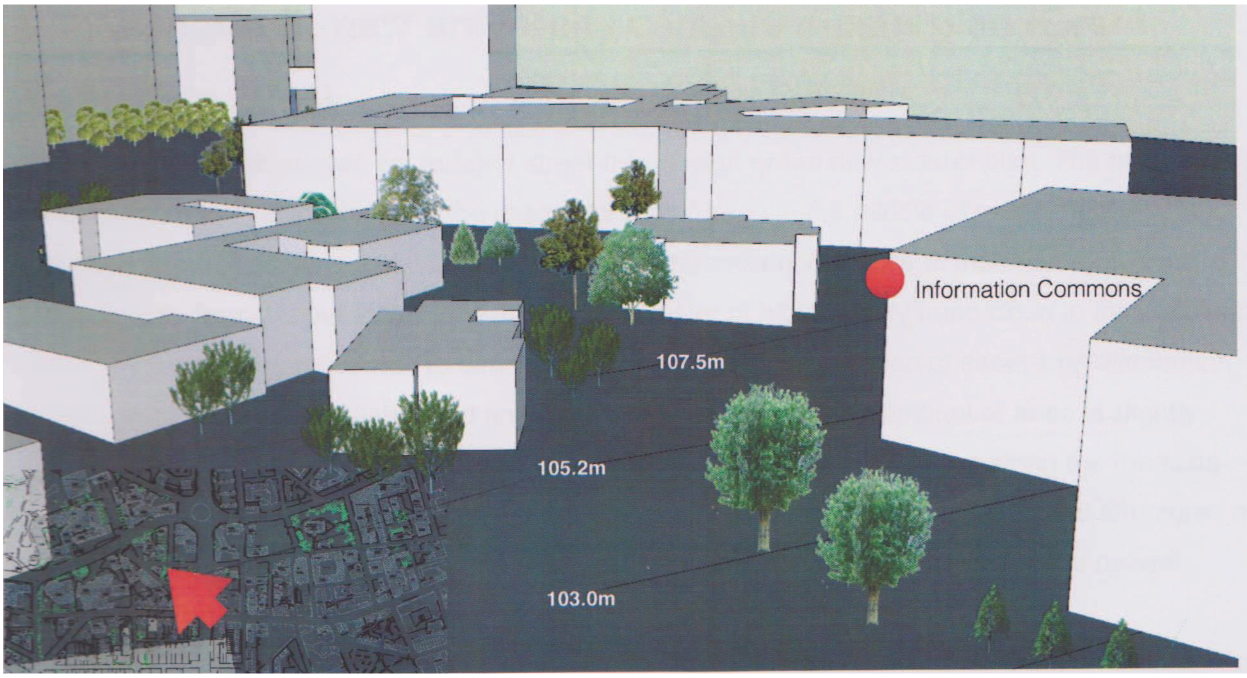

Fig. 4: 3D Visualisation of tree planting in Trimble Sketchup.

Main source for past weather data for the calibration of the model were Met Office averages based on the website http://sheffieldweather.co.uk/. In addition, wind speeds were measured throughout the study with a hand-held wind meter (Fig. 5).

Last not least, species and condition of existing trees were identified in a tree survey. Figure 2 and the underlying data were complemented based on the results from the tree survey.

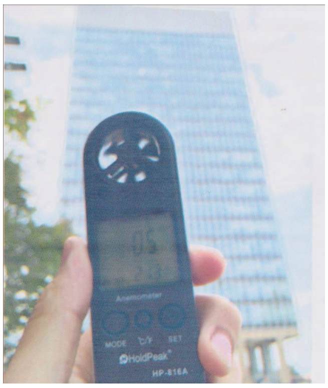

Fig. 5: Wind meter

5 RESULTS

For the results from the Vasari wind tunnel model, shown in Fig. 6, the prevalent wind direction was set as south-west to north-east. Based on a classification of our wind speed measurements and historic wind speed data, three different wind speeds were used to calibrate the model: a low wind speed of 0.98 m/s, a medium mean wind speed of 2.7 m/s, and the maximum wind speed of 23 m/s. It must be noted that Vasari only allowed the distinction of two different types of trees: broadleaf and coniferous. Another limitation is that topography is only considered in the wind tunnel simulation if provided as a mass object. The wind tunnel simulation will not consider a topographical surface as you would normally import from CAD software.

First, we ran the Vasari wind tunnel 2D analysis for existing and proposed street tree designs for the three wind speeds (Fig. 6). The comparison of current and proposed design indicate a general increase of air flow, especially during high wind speeds. However, it is difficult to draw any more detailed conclusions from the 2D analysis and the 3D analysis was run next.

The 3D analysis succeeded in providing much more detail: For the existing conditions, the highest wind speeds are modeled for the surrounding of the Arts Tower (Fig. 7). According to the Vasari model, the proposed design will mitigate this critical “hotspot” while providing a more even air flow on the wider campus area. In this respect, the masterplan is likely to improve air flow on campus.

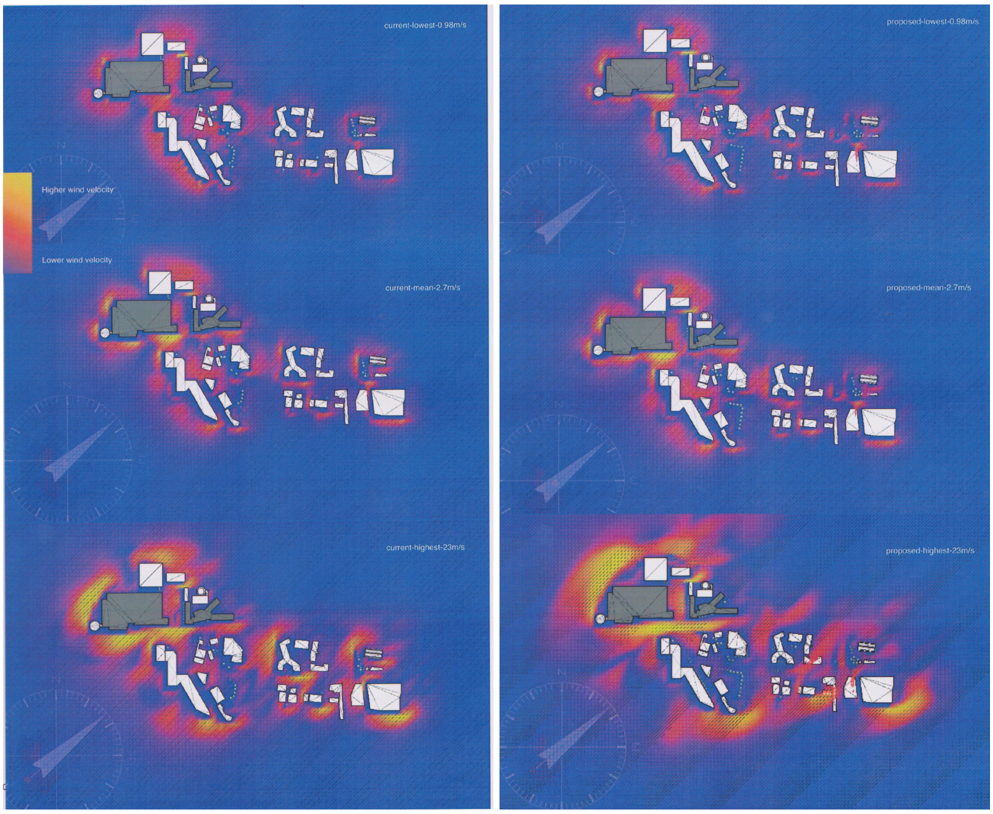

Fig. 6: 2D Vasari Wind Tunnel simulations under current conditions (left) and future conditions (right) for three different wind speeds.

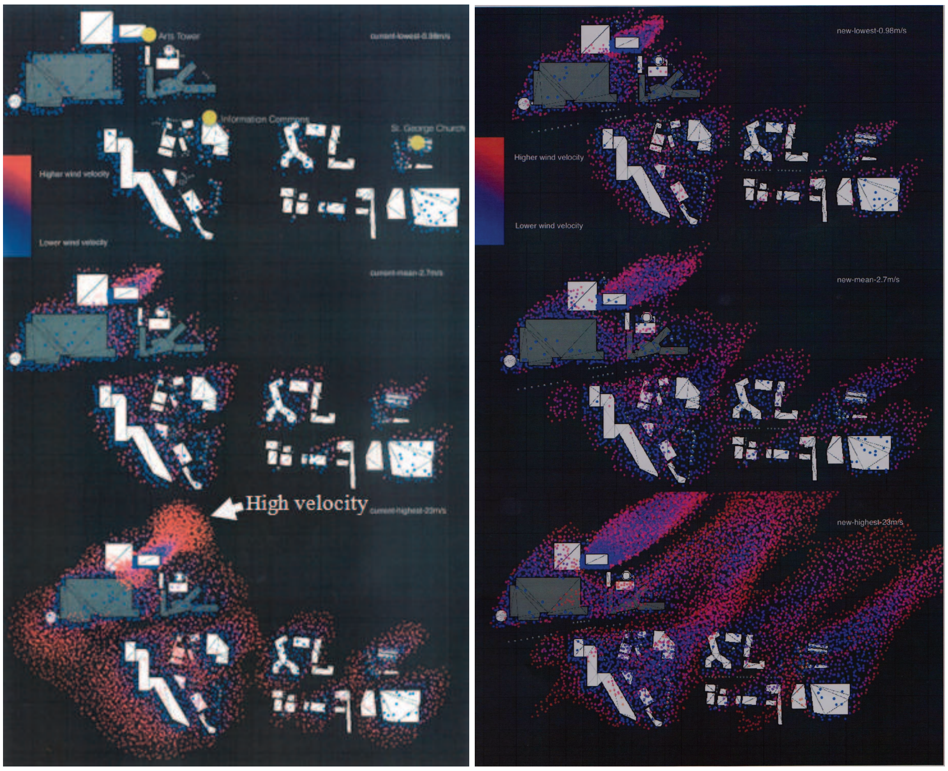

Fig. 7: 3D Vasari Wind Tunnel simulations under current conditions (left) and future conditions (right) for three different wind speeds.

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6 CONCLUSIONS

The 2D Analysis provided a quick and easy to read but rather coarse model of air flow. Comparing current and future conditions, there are hardly any obvious changes and it is difficult to locate more specific phenomena. In contrast, the 3D Analysis of the existing conditions revealed extreme wind velocities around the Arts Tower (see the annotation in Fig. 7). Anecdotal evidence matches the model result: When the Arts Tower was built, a shallow pond had been constructed next to it. The pond had to be removed because the strong wind would shower bypassers with water from the pool. Even today, the main entrance has occasionally been closed during very windy weather conditions due to safety concerns. Comparing current and future conditions in the 3D Analysis, the model results for the proposed design show an increased but more evenly distributed air flow campus-wide. In conclusion, the 3D Wind Tunnel Analysis in Autodesk Vasari provided a quick and sufficiently accurate way of modeling the impact of a campus masterplan in this case study.

However, the case study also revealed the main limitations of Autodesk Vasari, namely difficulties integrating terrain surfaces and the limited choice of tree species (broadleaf and coniferous). Other vegetation such as bushes or climbers are not available at all. Comparing the results to Peng and Elwan (2011), ENVI-met provides much more options in customizing vegetation objects. Furthermore, ENVI-met allows integrating the air flow model into a wider model of the microclimate. However, the higher usability comes at the cost of a steeper learning curve although this might change with version 4 of ENVI-met. Moya (2015) also compared Vasari with ODS-studio and ANSYS CFX. According to Moya, ODS-studio can be used for a more detailed visualisation of wind interaction with windbreak screens and as validation method for Vasari's results. Only if the results between them are significantly different, Moya recommends incorporating a third wind analysis program like ANSYS CFX to verify results. However, its use requires a more complete knowledge and possibly consultation from an expert. These conclusions must be considered by architects if they want to incorporate these tools for design exploration, in the early stage of the design process, with a dynamic feedback level. (Moya 2015)

For future research, it is recommended to customize more types of plants and more plant species for both Vasari and ENVI-met. Since the latter is open source, it would be easier for researchers to set up a plant library in ENVI-met. Then, landscape architects could systematically test different configurations in terms of their performance in terms of air flow and microclimate. For examples, please see Pedraza et al. (2013) for their work on urban buildign blocks and Cho (1996), who started such a typology in his PhD thesis. If CFD programs are then integrated with the Building Information Model (BIM) workflow, all stakeholders in the construction process could not only share and but also test their design changes.

7 REFERENCES

BAUMGART, C., & BERGER, C. (2015). Analysis of 2D/3D Urban Density Indices in Context of Land Surface Temperature Caroline Baumgart, Christian Berger. In C. B. M. Schrenk, V.V. Popovich, P. Zeile, P. Elisei (Ed.), CORP 2015 (Vol. 2, pp. 729–734). Ghent, Belgium.

BOWLER, D. E., BUYUNG-ALI, L., KNIGHT, T. M., & PULLIN, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. Landscape and Urban Planning, 97(3), 147–155. http://doi.org/doi: DOI: 10.1016/j.landurbplan.2010.05.006

BRUSE, M., & FLEER, H. (1998). Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. Environmental Modelling & Software, 13, 373–384.

CHO, J.-S. (1996). Urban microclimate modification through the use of vegetation. PhD thesis at the Department of Landscape, The University of Sheffield.

FEILDEN CLEGG BRADLEY STUDIOS, GRANT ASSOCIATES, & AECOM. (2014). The university of sheffield masterplan 2014.

GAGO, E. J., ROLDAN, J., PACHECO-TORRES, R., & ORDONEZ, J. (2013). The city and urban heat islands: A review of strategies to mitigate adverse effects. Renewable and Sustainable Energy Reviews, 25, 749–758. http://doi.org/10.1016/j.rser.2013.05.057

GROMKE, C., & RUCK, B. (2007). Influence of trees on the dispersion of pollutants in an urban street canyon-Experimental investigation of the flow and concentration field. Atmospheric Environment, 41(16), 3287–3302. http://doi.org/10.1016/j.atmosenv.2006.12.043

LENZHOLZER, S., & BROWN, R. D. (2013). Climate-responsive landscape architecture design education. Journal of Cleaner Production, 61, 89–99. http://doi.org/10.1016/j.jclepro.2012.12.038

MOYA, R. (2015). Empirical evaluation of three wind analysis tools for concept design of an urban wind shelter. Emerging Experience in Past, Present and Future of Digital Architecture, Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), 313–322.

NG, E., CHEN, L., WANG, Y., & YUAN, C. (2012). A study on the cooling effects of greening in a high-density city: An experience from Hong Kong. Building and Environment, 47(1), 256–271. http://doi.org/10.1016/j.buildenv.2011.07.014

PEDRAZA, E. T., KUNZE, A., ROCCASALVA, G., & SCHMITT, G. (2013). Best Practices for Urban Densification: A decision-making support process using microclimate analysis methods and parametric models for optimizing urban climate comfort. In eCAADe 2013: Computation and Performance–Proceedings of the 31st International Conference on Education and research in Computer Aided Architectural Design in Europe, Delft, The Netherlands, September 18-20, 2013. Faculty of Architecture, Delft University of Technology; eCAADe (Education and research in Computer Aided Architectural Design in Europe). 41–50.

PENG, C., & ELWAN, A. F. (2011). How Hot Can the University Campus Get in 2050 ? Environmental Simulation of Climate Chang Scenarios at an Urban Neighborhood Scale. Sheffield.

TREES & DESIGN ACTION GROUP (2012). Trees in the Townscape: A Guide for Decision Makers. London. Retrieved from https://landscapeiskingston.wordpress.com/2015/02/17/trees-in-the-townscape-a-guide-for-decision-makers/?goback=.gde_38616_member_5973498833861120002

WANIA, A., BRUSE, M., BLOND, N., & WEBER, C. (2012). Analysing the influence of different street vegetation on traffic-induced particle dispersion using microscale simulations. Journal of Environmental Management, 94(1), 91–101. http://doi.org/10.1016/j.jenvman.2011.06.036

WONG, N., & JUSUF, S. (2008). GIS-based greenery evaluation on campus master plan. Landscape and Urban Planning, 84(2), 166–182. http://doi.org/10.1016/j.landurbplan.2007.07.005

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