

CFD Comparison Project for Wind Simulation in Landscape Architecture

Joshua Brook-Lawson, Sophie Holz²

¹Technische Universität Berlin, Berlin/Germany · joshua.brook-lawson@tu-berlin.de

²Technische Universität Berlin, Berlin/Germany

Abstract: While computational fluid dynamics (CFD) software for wind simulation offer exciting new possibilities for landscape architects, beginners are often overwhelmed by the diversity of available software, the complexity of CFD programs and a lack of user friendliness. In order to facilitate a start in climatic simulation, the aim of the paper is to compare different CFD software to simulate wind direction and wind speed in urban open space. The paper summarizes the results in a table to give greater clarity on the advantages and disadvantages of different software in order to facilitate decision-making on which program to use.

Keywords: CFD software, wind simulation, microclimate, landscape architecture, open source

1 Introduction and Aim of Paper

With the upcoming and growing possibilities of simulating climate conditions, and with growing pressure due to climate change, more and more landscape architects are interested in opening up the field of climate simulation for landscape architectural projects. While CFD software offer exciting new possibilities for landscape architects (LAUE 2019), beginners often face huge challenges. The two main challenges are:

- 1) Choosing a CFD software: Today a large variety of CFD simulation software exist. To date, there is not a single software which dominates the market and would therefore be the obvious choice. Depending on the scale of the landscape architectural project, personal computing knowledge and available computer system, every software has its advantages and disadvantages. Beginners are mostly overwhelmed by the sheer amount of available options and are hence unable to decide which software to use.
- 2) Complexity and user friendliness: As CFD software is built upon complex physics equations (for example the Navier Stokes equation) and then written and compiled into a programming language (e. g. C++, Java, Python), CFD programs are highly complex and require the user to have a good level of both physics and computer science in order to be used effectively. Due to the relative newness of CFD programs, graphical user interfaces (GUIs) are still greatly under development and are often not user friendly.

The aim of the paper is to compare different CFD software to simulate wind direction and wind speed in an open urban environment, in order to facilitate a start in microclimate simulation. The authors are landscape architects who have been working with the introduced software for research and teaching. The software will be compared by means of six criteria: geometrical accuracy, simulation of vegetation, user friendliness, post-processing possibilities, cost, software and hardware requirements. The compared software (Butterfly, Blue CFD, Simgscale and ENVI-met) have been chosen because they represent a variety of alternative workflows that suits the needs of landscape architects. They are either open source or at least offer a free light version.

2 CFD Software

Computational fluid dynamics software (CFD) is used in engineering industries to calculate the forces exerted by incompressible and compressible fluids such as gas and liquids on solid and porous media. In this paper the following programs will be compared:

- 1) Butterfly is part of the Ladybug Tools LLC co-founded by Mostapha Sadeghipour Roudsari and Chris Mackey. The environmental analysis tools suit engages architects, landscape architects and urban planners with microclimate simulation. Through the Grasshopper (GH) GUI for Rhino 6, the user can load specific plugins to analyze the environmental performance of their design. The Ladybug Tools is an open source project which relies on the contribution and community of users to update and generate new plugins.
- 2) Blue CFD-Core-2017 is a Windows distribution of the open source CFD software OpenFOAM. It is a scriptable software with no graphical user interface (GUI). The user must understand bashrc commands to run the software using a terminal window. The software is programmed in C++ and requires the user to have a reasonable knowledge of C++ in order to edit the script files (SEGERSSON 2017). An OpenFoam case consists of 3 separate directories; '0', 'constant' and 'system' that define the; meteorological conditions, meshing and simulation parameters.
- 3) SimScale is a cloud based computer aided engineering (CAE) software, which offers several simulation types, such as CFD, finite element analyses and thermal analyses (SIMSCALE-1 2018). The software uses open source codes, including OpenFOAM for CFD simulation (SIMSCALE-1 2019). SimScale works with a web interface and cloud computing in order to minimize hardware requirements.
- 4) ENVI-met is a holistic, three-dimensional microclimate modelling system, based on the principles of fluid dynamics and thermodynamics. It is specialized in the simulation of urban outdoor microclimate and includes all the important elements of the urban settings (such as buildings, vegetation, surfaces, topography) and microclimatic elements, plus their interaction with each other. (ENVI-MET-1 2019)

3 Software Comparison – Case Study

3.1 Site, Climate Input Parameters and Used Hardware

The Savignyplatz in Berlin has been chosen as site for the case study as it represents Berlin's typical block buildings. The radial streets, leading to the main square, are a good example to study how wind speed and wind direction changes due to the direction of the street.

The following climatic input parameter have been set: wind speed: 5m/s; wind direction: west wind; air temperature: 7 degrees Celsius (averaged climate data March 2019). All Data from Deutscher Wetterdienst (DEUTSCHER WETTERDIENST 2019).

For all four simulations the same computer has been used with the following specifications. CPU: 2.90GHz Intel Core i9-8950HK (hexa-core, 12MB cache, up to 4.8GHz); Intel UHD Graphics 630; RAM: 32.0 GB DDR4 SDRAM;

Mesh refinements: Cell size for blockMesh (blueCFD, Butterfly, SimScale) has been set to $10\text{ m} \times 10\text{ m} \times 10\text{ m}$ for the snappyHexMesh, refinements up to 1.25 m. Grid resolution for ENVI-met has been set to $3\text{ m} \times 3\text{ m} \times 3\text{ m}$.

3.2 Simulation Ladybug Tools LLC – Butterfly, 0.0.05

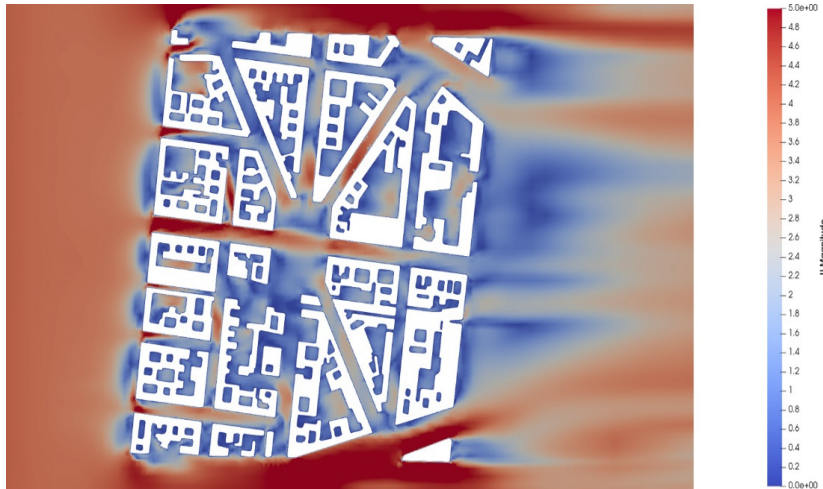


Fig. 1: Butterfly simulation result, visualized in ParaView, cutting plane 1.5 meter

1) Geometrical accuracy: grid size, orthogonal grid or free form possible

Grid size is not limited by the software. This can be defined by the blockMesh and snappyHexMesh function to a high level of accuracy using refinement parameters in the Butterfly script (LADYBUG TOOLS-1 2017).

2) Simulation of vegetation

Currently Butterfly does not have the capability to simulate trees and vegetation.

3) User friendliness for landscape architects and workflow

Online documentation: Butterfly provides extensive online documentation, which can be found on their homepage: <https://www.ladybug.tools/butterfly.html>. However, as it is open source contribution, there is no proprietary regulation of documentation, which can lead to misunderstanding. A tutorial explaining the workflow can be found at the following link: <https://youtu.be/0auA5exoL9M>.

Installation: Butterfly can be downloaded from Food4Rhino:

<https://www.food4rhino.com/app/ladybug-tools>. The installation process is fairly complex, however detailed documentation is specified here:

<https://github.com/ladybug-tools/butterfly/wiki>.

Intuitive GUI: The user should have some previous experience using Grasshopper (GH) for Rhino 6 in order to use the software effectively. The Butterfly GUI is used through Grasshopper. This makes understanding an OpenFOAM case far more intuitive.

Generation of geometry: All geometry for Butterfly is made in Rhino 6. There is also the option to create the geometry in another 3D software and import into Rhino 6 (over 30

different file formats available) however this may cause complications due reading different file types. All geometry must consist of only manifold closed poly surfaces defined in Grasshopper as either 'Breps', 'Srf' or 'Mesh'. Other geometry logic may be rejected by the butterfly geometry input.

4) Inbuilt post processor

Butterfly results visualization tool utilizes Ladybug to display wind vectors that represent; wind speed, direction and pressure. The vectors appear in the adjacent Rhino 6 window to Grasshopper. These results are updated live as the simulation runs. This is a major advantage over other CFD software as the user can decide early in the simulation if the result is without error and provides early forecasting of a result. However, the visualization is limited by a restriction of points that can be visualized at any one time. This is limiting for large scale simulations as we encountered. Residual values for pressure, velocity and turbulence are also visualized in an adjacent graph.

5) Costs and simulation details

Purchase price: Butterfly and Ladybug Tools LLC is free and open source, distributed under the GPL v3+ license (LADYBUG TOOLS-2 2017). However, it requires Rhino 6, a proprietary software that the user must purchase in order to use the software. Rhino 6 provides a 90-day free trial which enables the user to learn the basics.

Time of simulating, total case size, computer requirements: please see table 1.

3.3 Simulation blueCFD-Core, 2017-2

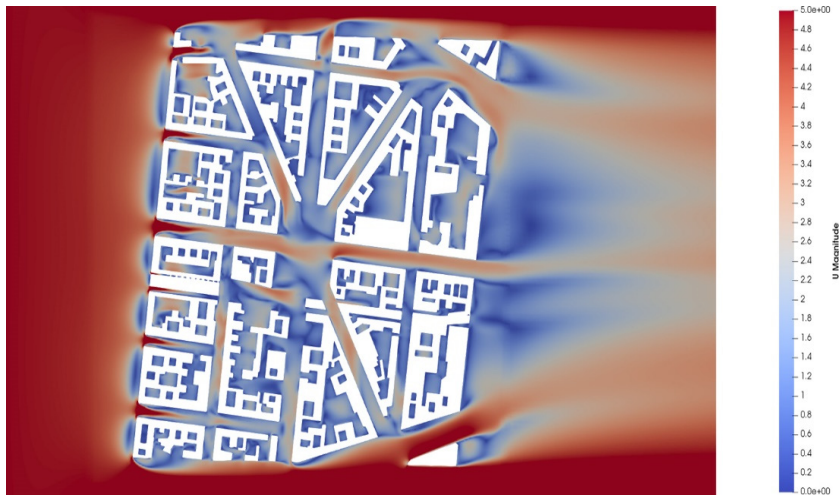


Fig. 2: Blue CFD simulation results, visualized in ParaView, cutting plane at 1.5 meter

1) Geometrical accuracy: grid size, orthogonal grid or free form possible

Grid size is not limited by the software. This can be defined by the blockMesh and snappyHexMesh function to a high level of accuracy using refinement parameters. These parameters are edited in script files in the 'system' directory – 'blockMeshDict' and 'snappyHexMeshDict' (ENGYS 2012).

2) **Simulation of vegetation**

Porous media like trees can be simulated by using porous media (SEGERSSON 2017). However, in this simulation, trees have not been included, as it extends the goal of this paper.

3) **User friendliness for landscape architects and workflow**

Online documentation: blueCFD-Core provides succinct online documentation, which can be found here: <http://bluecfd.github.io/Core/UserGuide/>. blueCFD-Core also shares its documentation with the OpenFOAM community as the tutorials and documentation are almost identical. OpenFOAM documentation can be found here: <https://www.openfoam.com/documentation/>. A further online tutorial that explains the case setup workflow can be found here: <https://youtu.be/LCjYMtcFB2k>.

Installation: A download file is provided on their website:

<http://bluecfd.github.io/Core/Downloads/>

A video is provided that explains the installation steps:

<http://bluecfd.github.io/Core/UserGuide/>

Intuitive GUI: It is a scriptable software with no graphical user interface (GUI). The user must understand bashrc and basic C++ knowledge (SEGERSSON 2017) in order to edit this script files and run the software using a terminal window. This makes for a steep learning curve for users with no previous bashrc and C++ knowledge. The intuitive nature of the software is subject to the user's previous experience.

Generating of geometry: BlueCFD-Core has no built in 3D modelling capabilities the user must generate the geometries in a separate CAD software. This geometry must only include manifold closed poly surfaces.

Import file formats: BlueCFD-Core supports the following file types: stl – Stereolithography ASCII; stlb – Stereolithography binary; obj – Wavefront object; vtk – Legacy Visualisation Toolkit (VTK); ftr – OpenFOAM triangulated format; ac, smesh, tri and dx.

4) **Inbuilt post processor**

BlueCFD-Core has no inbuilt post processor; however, the results can be visualized in an additional software called ParaView.

Export file formats: for other visualization software: BlueCFD-Core 2017-2 includes ParaView 5.4.1 for Windows 64-bit. The user must either add the touch “\${PWD##*/}.foam” command to the ‘Allrun’ batch file or type the command directly into the terminal once the simulation has finished. This will produce a .FOAM file that can be opened by ParaView 5.4.1. There is also the option to post process using VTK.

5) **Costs and simulation details**

Purchase cost: BlueCFD-Core is free and open source, distributed under the GPL v3+ license.

Required time of simulating, total case size, software and hardware requirements: please see table 1.

3.4 **Simulation SimScale, Online Version February 2020**

1) **Geometrical accuracy: grid size, orthogonal grid or free form possible**

Grid size is not limited by the software, also free forms are possible. Accuracy and detail of the mesh are therefore only limited by time and core hours.

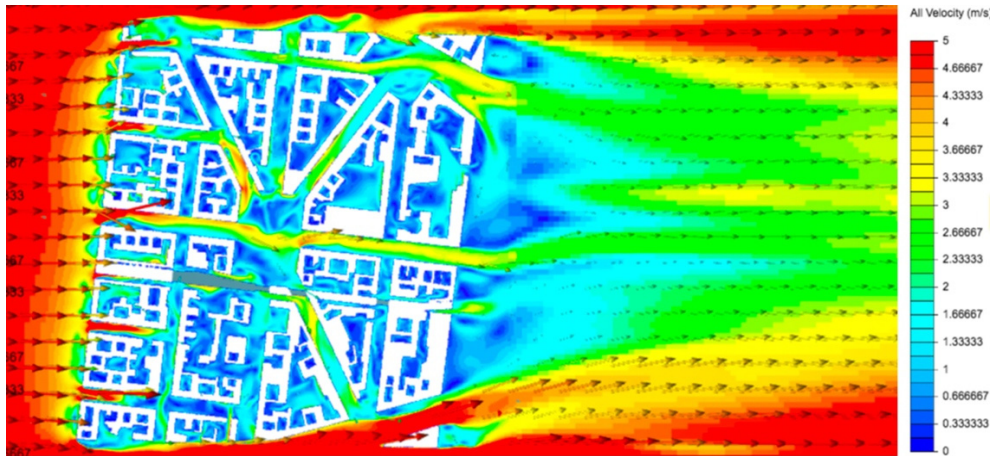


Fig. 3: SimScale simulation results, visualized with inbuilt post-postprocessor, cutting plane at 1.5 meter

2) Simulation of vegetation

Porous media like trees can be simulated by using Advanced concepts > Porous media (RETSAM 2019). However, in this simulation, trees have not been included, as it extends the goal of this paper. Setting up of trees should be addressed in a different single paper as for its complexity.

3) User friendliness for landscape architects and workflow

Online documentation: SimScale provides an extended online documentation, including the full workflow, which can be found here: <https://www.SimScale.com/learning/>. The heart of the documentation is ‘SimScale documentation’ (<https://www.SimScale.com/docs/>), where detailed information regarding the SimScale platform is given. It is supplemented by tutorials, workshops and webinars, a blog, the forum and SimScale academy.

Installation: Installation is not necessary, as SimScale is a cloud-based program. Registration is necessary to start using the program.

Intuitive GUI: SimScale’s simulation platform is clearly structured. Main elements are the navigation tree with pop up setting panels on the left-hand side and the viewer. The navigation tree includes all settings that are required for the chosen analysis type and can simply be followed from top to bottom. The viewer contains the whole project, this is the original geometry, the mesh, and additional geometry primitives.

Generating of geometry: SimScale does not offer the option to draw complex geometry. An additional CAD program is needed to create and prepare geometry. The most important requirements for the base CAD model are: First, the model needs to be watertight (SIMSCALE-2 2019). Second, as complicated geometries can heavily enlarge meshing and simulation time, it is advised to check, which grade of detail is necessary for the wind simulating and when appropriate simplify the geometry (SIMSCALE-3 2019).

Import file formats: SimScale currently supports ten file types, for example: 3DM, Autodesk Inventor, STEP, BREP, STL. For a full list see here:

<https://www.simscale.com/docs/cad-preparation/>.

Other: If invalid geometry is uploaded to SimScale, CAD faults are highlighted and a description about the fault plus potential ways to fix are given (SIMSCALE-4 2019). This is extremely useful, as the fixing of faulty geometry can take up much time.

4) Inbuilt post-processor and export options for external post-processor

SimScale offers a basic inbuilt post processor, which enables the possibility to set cutting planes, isosurfaces, isovolumes, animation and particle traces, to name a few. There are some options to customize the representation, such as setting min and max value for the visualized range of wind speed or different preset color schemes.

Simulation results can be easily downloaded via a download button. The packed archive includes a .FOAM file, which can be imported for post processing in ParaView.

5) Cost and simulation details

Purchase cost: SimScale offers two free plans: The community plan is for students, open source, and hobby projects (SIMSCALE-5 2019). All projects must be public projects. The community plan offers limited simulation features, for example, incompressible fluid flow analyses based on OpenFOAM are included, incompressible fluid flow analyses working with the LBM solver is currently not. The plan is restricted to a limit of 16 cloud computing cores. Core hours are restricted to 3000 and will not be renewed once there are used (JOUSEFM 2019). The second free plan is the academic plan. Qualified students, researchers, and educators are enabled to apply for it. The academic plan works similar to the professional plan and offers 3000 core hours per year plus private projects (SIMSCALE-6 2019).

Required time of simulating, total case size, software and hardware requirements: please see table 1.

3.5 ENVI-met, Version 4.4.3

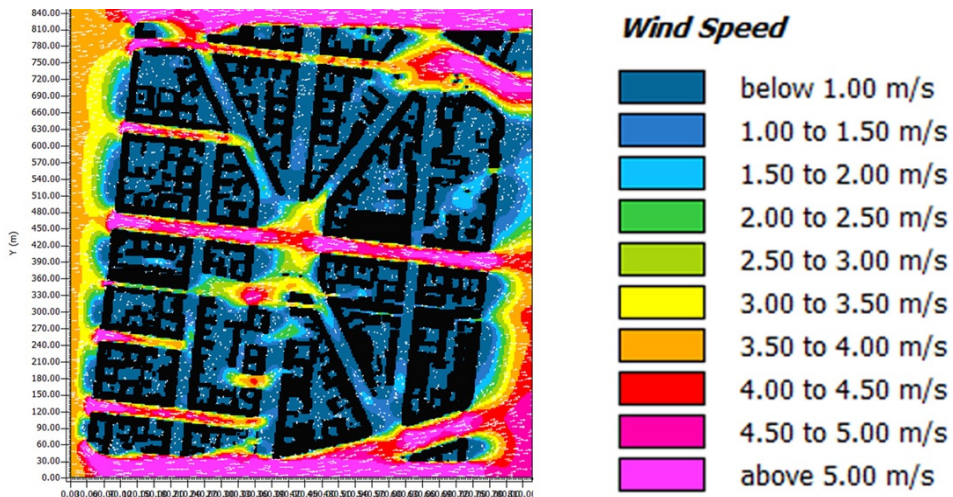


Fig. 4: ENVI-met simulation results, visualized in inbuilt post-processor Leonardo, cutting plane at 1.5 meter

1) Geometrical accuracy: grid size, orthogonal grid or free form possible

With ENVI-met, geometries need to be converted to a rectangular grid model, before running a simulation. Free forms are not possible. Minimum resolution of the grid is 0.5 meter (ENVI-MET-1 2019). As simulation time significantly increases with the number of cells, a 2-3-meter grid resolution is often used for a simulation of this size, to cut simulation time. The rectangular grid model results in a huge simplification of the original landscape design.

2) Simulating of vegetation

ENVI-met offers a wide range of different materials, both vegetative and hard material, which can easily be applied and customized. For landscape architects this is a big advantage, as the influence of different green material (trees, façade greening, roof greening) can be simulated.

3) User friendliness for landscape architects and workflow

Online documentation: ENVI-met provides a precise online documentation, including a full workflow, which can be found here: <https://www.envi-met.com/learning-support/>. The documentation consists of tutorials, case studies, a forum and a technical documentation page of ENVI-met. The tutorials are easy to follow and give a very good introduction to the software. For a deeper understanding of the software, the technical documentation is helpful.

Installation: ENVI-met is easy to install. No special knowledge is needed.

Intuitive GUI: ENVI-met is not an intuitive software, but it is necessary to learn about the structure and tools by watching the relevant tutorials.

Generating of geometry, import file formats: In ENVI-met spaces ENVI-met models can be built from scratch. As this is a rather time-consuming process, ENVI-met introduced Monde, a vector-based editor to import existing data from ESRI Shapefiles or OpenStreetMap data (BRUSE 2017). Using the Grasshopper/Dragonfly workflow (NUNZIO-1 2019), one can auto generate an ENVI-met model based on a Rhino 6 file.

4) Inbuilt post processor and export options for external post-processor

ENVI-met offers an inbuilt post processor, Leonardo, with the option to generate 2D and basic 3D visualizations of the simulation. In 2D and 3D mode, cutting planes can be set with the option to follow topography or to cut flat. Inter alia, vectors, particles, contour layers can be switched on and off. There are options to customize the representation, such as setting min and max value for visualized range or editing colors.

Alternatively, ENVI-met results can be read and visualized with ParaView. Therefore ENVI-met provides the 'Convert EDX to NetCFD' file converter. Also, they can be post-processed via a Grasshopper ladybug plug in (NUNZIO-2 2019).

5) Costs and simulation details

Purchase cost: ENVI-met offers a free plan – ENVI-met light – which comes with restrictions: The domain size is limited to a maximum of 50×50 cells, output and analysis options are reduced and parallel computing is not supported. For students (only graduate and PhD projects) there is a price reduced student license (ENVI-MET-2 2019).

Required time of simulating, total case size, software and hardware requirements: please see table 1.

4 Discussion

The summarized results of the comparison study (see table 1) show with high clarity advantages and disadvantages of the four different CFD software. SimScale convinces with high user friendliness due to a nearly intuitive workflow, provided by a well-structured GUI and no special hardware requirements. For beginners it is probably the easiest software to start with, at the same time it offers complex simulation settings for advanced users. A limiting factor is that the software is not free, however for students and researcher it offers free plans. ENVI-met can be recommended to everybody, who wants to simulate holistic microclimate (not only wind) on a long run. Specialized inter alia in calculating the effect of green infrastructure, it offers great opportunities for landscape architects. Amongst the largest constraints are the rectangular grid model and the high cost due to the need of very powerful hardware, large storage facilities and the very limited free plan. In contrast, BlueCFD and Butterfly are open source, which provides a high incentive especially for beginners, who may want to start a simulation without investing too much finance. In order to change meteorological settings like wind speed/ direction in blueCFD-Core, a basic understanding of C++ is required (SEGERSSON 2017). In order to add functions to the existing script, advanced knowledge of C++ is necessary, which most landscape architects do not have. For landscape architects with a basic understanding of Grasshopper, Butterfly is a good free option. Still, there are some functions (like mesh generation) which we could not fully control in the current script due to limited 'meshQualityControls' input parameters (GITHUB 2017).

Table 1: Summary of the analyzed criteria of comparison

Criteria of Comparison	Butterfly	blueCFD-Core	SimScale	ENVI-met
Geometrical Accuracy	Defined by the blockMesh and snappyHexMesh function to a high level.	Defined by the blockMesh and snappyHexMesh function to a high level.	includes free forms, grid size is not limited by software	rectangular grid, min. dimension 0.5 meter
Simulation of Vegetation	Limited to simulating solid objects only. No option for trees as porous media.	Option for trees as porous media. However complex.	trees can be simulated as porous media (expert knowledge necessary)	Trees and material can easily be set
Online Documentation	Wide community based online documentation	Short and precise online documentation	Comprehensive online documentation and active forum	Comprehensive online documentation
Installation	Complex. Many steps.	Simple and well documented.	not necessary – cloud software	easy
GUI	GUI included. Knowledge of GH needed	No GUI. Knowledge of C++/ bashrc needed	GUI included. Very well structured, almost intuitive	GUI included. Well structured, not intuitive

Criteria of Comparison	Butterfly	blueCFD-Core	SimScale	ENVI-met
Generating of Geometry	Geometry generated with Rhino 6.	Geometry generated with additional CAD software	Geometry generated with additional CAD software	Auto generated via monde and Rhino 6 / GH; generated manually ENVImet spaces
Import File Formats	Supports over 30 files types including: DWG,DXF, OBJ, STL,3DS	STL, STLb, OBJ, VTK, AC, SMESH, TRI AND DX	Supports many file types, inter alia: Rhino 6, Autodesk Inventor, STEP, STL	ESRI Shapefiles, OpenStreetMap; Rhino 6 files via Grasshopper workflow
Inbuilt Post-Processor	Yes, although limited by case size.	No	yes	yes
Export Options for External Post-Processor	.FOAM (para-view), VTK	.FOAM (Para-View), VTK	.FOAM (Para-View)	.NC (ParaView), GH / Ladybug
Purchase Cost	Butterfly (GH) Free, Rhino 6 90-day free trial.	Free / initial cost for hardware.	slightly restricted free plan available	highly restricted free plan available
Meshing and Simulating Time	Mesh: 18 min Sim: 124 min	Mesh: 9 min Sim: 127 min	Mesh: 27 min Sim.: 200 min	Mesh: 25 min Sim.: 1820 min
Total Case Size	1.49 GB	1.07 GB	620 MB	9.65 GB
Operation system	Windows 7 to 10.	Windows 7 to 10.	Windows, MAC, Linux, Chrome, OS,	Windows
Hardware Requirements	64-bit version of Windows.	64-bit version of Windows.	any computer with internet connection	CPU: 6 or 8 core, Intel i5-8400 – Ryzen 5 1600X RAM: 16 GB internet connection ENVI-MET-3. (2019)

5 Conclusion and Outlook

The comparison of four CFD software shows strong differences between software for wind simulation. So far, there is not a single market leading software, but one needs to choose a software according to pre-knowledge and project-based goals. All the more important are comparison studies of different CFD software, which clearly state the advantages and disadvantages. This paper also functions as a snapshot of the current state of simulation software in a rapidly developing industry.

There is a need for further paper which addresses post-processing methodologies, focusing especially on the interface of 3D CAD and simulation software in order to produce complex 3D graphics. There is also scope for a paper which addresses the simulation of vegetation in different CFD software. This would be of great value in the practice of landscape architecture.

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