ENVIRONMENTAL PHYSICS FOR ARCHITECTS

Evaluation of simulation tools for assessment of urban form based on physical performance

author: VIDMAR, Jernej; mentor: Prof. ROSET, Jaume
Faculty of Architecture, Ljubljana, Slovenia

ABSTRACT

The goal of this research is to find the most suitable computer simulation software for assessment of urban design performance from physical point of view. Although there are many physical simulation tools available today, there is no one which covers all the needs of urban design. After initial research of available software, we have chosen to assess three applications: ENVI-met, Project Vasari and IES VE-Pro. The assessment is composed from two parts: functionality assessment, which deals with the available features of the application and useability assessment, which deals with the user experience and friendliness. Since different aspects of assessed functionality and useability are not equally important, we have also included pondering mechanism in order to find the most suitable software for specific requirements. Complete assessment table is available online (http://tiny.cc/env_app_evaluation), so that the reader can modify ponder values so that it can find the application that suits his or her needs best.

The results of the assessment have shown that the most suitable application for our needs is ENVI-met (1017 points), with Project Vasari close behind (1001 points) and IES VE-Pro in the third place (917 points). From urban design perspective, there is still a lot of improvement space for each of the applications reviewed.

Keywords: urban design, urban climate, sustainability, computer simulation tools

1 Introduction

In the past few years a large set of building performance applications emerged. To date (August, 2012) U.S. Department of energy reports on 410 building software tools for evaluating energy efficiency, renewable energy, and sustainability in buildings[1]. Although this might imply there is an application for every need, this is not the case when we try to find an application which is suitable to assess performance of urban design geometry. The reason for this is twofold: on one hand we have a rich set of specialized analysis and simulation software, which deals with only one aspect of physical phenomena. On the other hand there are the tools, which are focused toward analysis of environmental performance for a single buildings.

Although there are many important factors involved when talking about holistic sustainable urban design (i.e. land use distribution, traffic networks, social equity, ...), we shall limit our investigation to the ones, which influence urban design performance directly in physical terms. Concluding from Robinson[2] we are most interested in factors of urban radiation exchange (radiation, irradiation), factors which impact the urban climate (winds, heat exchange, urban heat island / sensible and latent (influence of big green areas) heat) and factors which deal with the pedestrian comfort (air temperature, radiant temperature, relative humidity and local air velocity). In addition to that, we might also be interested in noise control (acoustic performance) of the development, since it might represent an important factor when the development is built along city arterial roads.

To the best of my knowledge, no single tool for complete evaluation of urban design

performance exist today. That is, there is no tool which provides analysis of both building and urban (district) scale at the same time. It is therefore the goal of this study to compare computer applications, which can help assess performance from physical point of view at urban scale.

2 Method

Although the main focus of this study is geared towards the need of urban designers and architects, it will not conclude with final ranking, as it is our main priority only to point out the strong and weak points of each of the selected applications. In order make objective judgment of applications, we will define set of indicators which shall help us estimate the advantages and disadvantages of each of the tools compared.

We will first establish the assessment criteria, which is divided in two categories. The first category is about pure functionality of the selected tools such as insolation, wind flow, etc., which we will call application features. The second assessment category consists of more subjective factors such as documentation, visual feedback etc. This will be referred to as useability features. The latter is of special importance as the tools vary significantly in this respect.

Application features and useability is followed by a quick introduction of the selected tools. In order to keep this paper short, we will assess only three tools with the greatest potential: ENVI-met (3.1)[3], Autodesk's Project Vasari (Beta 2)[4] and IES VE-Pro 2012 (6.4)[5]. Nevertheless, one can easily add another tool by assessing it and adding the rating in the final table to compare it against the selected applications.

ENVI-met model is designed for micro-climate and local air quality analyses. It is capable of solving complex three-dimensional flows, temperature and turbulence fields, relative humidity, long and short wave radiation, the dispersion of different gases and particulate matter typically traffic related. A special focus is on the simulation of surface-plant-air interaction in the urban environment[6].

Project Vasari is an easy-to-use, expressive design tool for creating building concepts. Vasari goes further, with integrated analysis for energy and carbon, providing design insight where the most important design decisions are made[7].

IES VE-Pro is a cutting-edge suite of building performance simulation tools. Used by leading sustainable design experts across the globe, it creates understanding of the performance impacts of different low-energy design strategies[8].

Once criteria and selected applications are briefly outlined, objective evaluation criteria for each of the features is defined, one by one, and an assessment for each of the applications in its respect is given and explained.

At the end of this paper, the selected applications will be rated in a spreadsheet together with the example on how to select the best tool for one's task by pondering this values.

3 Defining indicators – application features

As for the application features, there are three fields of physical factors that are of particular interest to urban designers, as they contribute to the lower energy use, better city climate and improved user comfort due to the form of the development. Although looking from four different perspectives (radiation exchange, urban climate, pedestrian comfort and noise control), there is some overlapping between these views (ie. both urban climate and pedestrian comfort are highly dependent on wind flows). This, in order to analyze urban development performance from physical point of view, can draw us to a conclusion that the software we are interested in should be able to analyze the following physical processes: radiation, irradiation, air exchange, heat exchange, evaporation and acoustics.

In addition to that, it should also be able to load climate data if the analysis depends on solar or wind influences. Building and ground materials, together with vegetation

can have a significant impact in physical performance of urban design. All of the should therefore also be included in features list. If different tools are to be used for complete simulation, it is also important to find the ones which are based on open standards, as only this can assure compatibility and interoperability between them.

Assessed application features list:

- incoming solar radiation analysis (insolation)
- irradiation analysis
- heat transfer (convection, conduction)
- air exchange (CFD)
- materials assignment
- water bodies
- humidity & evaporation
- vegetation (trees & green areas)
- acoustics
- data validation
- 3D modeling
- loading climate data
- open standards support
- application interoperability (coupling possibility)
- application programming interface

4 Defining indicators – application useability

Besides fulfilling the list of needed features, there is also another aspect of computer applications, which is not to be overlooked. It has to do with end-user experience and is therefore also of major importance. On one hand we have to consider the speed of calculations and possibility of extending via application programming interface (API) which can be assessed quite objectively, while on the other hand, there is a demand for steep learning curve & ease of use, need for good documentation (so we can drive the application to its limits) & community which can help us solve some problems if or when they emerge.

Assessed useability features:

- calculation speed
- visual environment & feedback
- UI simplicity & intuitiveness
- ease of use & learning curve
- software documentation
- supported operating systems
- community & technical support
- license, cost & development activity

5 Assessment of application features

Application features are limited to those, which have direct effect on urban climate and energy demand.

Some of the popular features (such as building energy demand estimation) are excluded, since they are too dependent on other factors such as HVAC or materials used and should therefore be calculated for each building separately.

General range of functionality marks spans from 0 to 10, where 0 means the functionality is not implemented at all and 10 that the functionality is fully implemented. Individual marks are defined and explained at each of the functionality descriptions.

5.1 Incoming solar radiation (insolation)

Insolation is a measure of solar radiation energy received on a given surface area and recorded during a given time[9].

In respect to urban design, insolation can have both positive and negative impact, mostly depending on location. While it might desirable in colder climate it represents a problem in hot and humid regions. It therefore needs to be accounted for when analyzing different urban patterns in different climate zones.

Insolation can be divided in two parts: direct sun radiation and diffuse sky radiation. Both can also be affected by the cloud coverage. We therefore set the following marks: if the application can not calculate direct solar radiation nor sky radiation it will get 0 points. If it can calculate only one of them it will get the

mark 4. If it can calculate both, sun and sky radiation, but it can not account for clouds it will receive a mark 7. Mark 9 will be given to the applications which can calculate both, sun and sky radiation together with the accounting of clouds. Additional point will be given to the applications which can show the results visually (images).

ENVI-met: 5 points
ENVI-met uses both shortwave direct and shortwave diffuse radiation components. Clouds can also be included. However, the results of radiation are calculated only for the ground plane, but not for the vertical walls, which somewhat limits its usefulness.

Project Vasari: 5 points
Current version of Vasari can only calculate direct sun radiation. The results can be exported to .csv files or displayed directly in 3D model.

IES VE-Pro: 7 points
Using SunCast module VE-Pro can calculate direct sun and diffuse sky radiation, but the cloud coverage option is not available. Radiation is calculated for walls, windows and roofs, but not for outside ground.

5.2 Irradiation analysis

Another important radiation process, which affects the urban environment is the irradiation (reflected radiation) of the buildings and floor surfaces. In contrast to solar radiation, where we talk about directly received radiation on a given surface, we speak of irradiation when calculating the radiation which is bounced of given surface.

Calculation of irradiation is more complex and time consuming when compared to solar radiation due to the radiation transfer mechanism since application needs to reflect irradiation rays between buildings several times. The more times the rays are reflected, the more accurate the calculation is.

If the application can not calculate irradiation it will get 0 points. If it can calculate the irradiation, it will receive 5 points. If it can also account for materials (see also section 6.5) when calculating irradiation, it should get 10 points.

ENVI-met: 3 points
When running simulation, ENVI-met takes into account reflected radiation from the building volumes, but not the floors.

Project Vasari: 0 points
Vasari can not calculate reflected radiation.

IES VE-Pro: 0 points
VE-Pro can not calculate reflected radiation.

5.3 Air exchange / wind (CFD)

Wind flows play an important role when assessing the user comfort at pedestrian level. On the other hand, wind also helps to disperse different air pollutants in the city. In addition to that, the winds contribute also to the building statics due to the drag.

It is therefore important to include airflow calculation when assessing outdoor comfort and air quality at urban scale. If the application has no possibility to calculate air movement, it will get 0 points. If it can evaluate basic airflow movement to asses wind speeds it should receive 5 points. If we are able to add pollutant sources, and it can calculate the dispersion it will be rewarded with 7 points. An additional point should be given to the applications which can load and take into account wind rose information, so it is easier to assess airflow movements at different geographic locations.

Another 2 additional points should be given to the applications, which can present the results of CFD with graphic representation of 3D model (either with vectors or by “heatmaps” at different height levels).

ENVI-met: 8 points
ENVI-met is able to calculate wind flows and pollutant dispersion. Loading of wind rose is not available. Graphic representation is available using only 2D images.

Project Vasari: 8 points
Vasari can calculate wind flows, but is not able to account for pollutants. Loading of wind rose is possible and the results can be displayed in actual 3D model.

IES VE-Pro: 9 points
VE-Pro can calculate wind flows; it can account for humidity, CO2 and CO dispersion but only when calculating internal spaces. Loading of wind rose is possible and the results can be displayed in 3D model.

5.4 Materials assignment

Material properties have a significant effect on heat transfer calculations. Thermal conductivity is one of the most important factors when calculating building energy demand. Another important aspect is the concept of thermal mass, which describes how the mass of the building provides "inertia" against temperature fluctuations[10].

Built surfaces are composed of a high percentage of non-reflective and water-resistant construction materials. As consequence, they tend to absorb a significant proportion of the incident radiation, which is released as heat[11]. This is the main cause of the urban heat island (UHI) effect. Since most of the UHI impacts are negative[12], it usually needs to be avoided. In order to estimate UHI effect of different urban design proposals, it is important to assign materials to built structures.

If the application does not enable assigning materials to the built structures, it will receive 0 points. If the application supports assigning of different predefined materials, it will receive 7 points. If user can define its own material, the application should receive 10 points.

ENVI-met: 5 points
In ENVI-met there is no option to define actual building materials. However, there are a few properties, that can be assigned to the buildings: inside temperature, heat transmission and albedo of wall and roof. All buildings in the model share the same properties.

Project Vasari: 7 points
Vasari provides powerful material management system. User can define several groups of physical and appearance properties. It also provide a library of predefined materials. Yet Vasari Beta 2 does not seem to use all this information in its calculations.

IES VE-Pro: 10 points
VE-Pro includes a library of predefined materials, which can be extended if needed. Material definitions carry all of the information needed for energy analysis (conductivity, solar absorbance, specific heat capacity, etc.).

5.5 Water bodies & evaporation

Water bodies form urban cooling islands (UCI) to mitigate the UHI effects[13]. It is thus important to consider cooling effect of lakes and rivers at urban scale.

The cooling effects of water bodies mainly depend on how radiant energy is partitioned into sensible and latent heat fluxes. The high ambient temperature in dense built-up areas may increase the water temperature as well as the temperature gradient between water bodies and surrounding landscapes. Water bodies can absorb more sensible heat compared with rural areas on the one hand and cool ambient temperature by high latent heat of evaporation on the other hand. Given the same total area of water bodies, more small water bodies can offer more beneficial effects[13].

If the application can not take into account water bodies it will be given no points. If it is able to calculate the cooling effect of water bodies on its surrounding it will be rewarded with 8 points. If it is able to differentiate between lakes and rivers (different temperatures), it will get 10 points.

ENVI-met: 8 points
ENVI-met is able to calculate the effect of still water on its surrounding.

Project Vasari: 0 points
Water material exists in Project Vasari, but it is currently limited to the visualization purposes.

IES VE-Pro: 7 points
VE-Pro can not calculate the amount of evaporation and its effect on cooling (or heating) the surrounding. However, there exists a workaround[14], to include the effects of water bodies in calculation.

5.6 Humidity

Humans are sensitive to humid air because the human body uses evaporative cooling as the primary mechanism to regulate temperature[15]. For humans relative humidity (RH) below 25% feels uncomfortable dry, while RH above 60% feels uncomfortable wet[16]. Our organism therefore requires the RH to be in the range 25 – 60% in order to for us to feel comfortable. As assessed in this paper, we see humidity mostly as a parameter of user comfort; it's effect on air temperature is considered to be part of evaporation (6.6).

If the application can not calculate humidity it will receive no point, while it will be rewarded with 8 points if it can be calculated. If it can distinguish the source of humidity (water bodies or vegetation), it will be rewarded with 10 points.

ENVI-met: 10 points
ENVI-met needs the information about relative humidity as a part of initialization data. Besides taking into account water bodies, it integrates the humidity of soil. Humidity changes can be observed by using receptors at specified palces.

Project Vasari: 2 points
Vasari can present relative humidity data for specific locations, but it can not incorporate it in its calculations.

IES VE-Pro: 3 points
VE-Pro needs information on external relative humidity. However, being more building oriented it only calculates humidity levels for internal spaces. Using IES repot, one can receive extensive location data, including humidity.

5.7 Vegetation (trees & green areas)

Vegetation has a similar effect on urban environment as water bodies. It is the second part of evapotranspiration process which cools down the city. In addition to evapotranspiration, trees also provide shade in summer, which can diminish air temperature of its surrounding significantly.

If there is a library of predefined plants, that can be used in simulation, the application will receive 6 points. If we can add our own plants, it will receive 10. If plants are not included in calculations, the application will receive no points.

ENVI-met: 10 points
ENVI-met uses detailed plant descriptions in its calculations (plant type, stomata resistance, crown density, etc). Green areas can be defined as soil with specific characteristics. There are 27 plants provided with the installation of ENVI-met.

Project Vasari: 2 points
Vasari provides very rudimentary vegetation analysis, as it is only possible to analyze its effects on shadowing and winds. There is no tree library included, but the trees can be imported from Revit.

IES VE-Pro: 3 points
A tree library for Radiance is included in VE-Pro. Since MicroFlo uses different kind of objects, they need to be prepared separately for wind analysis. Thus only part shading and wind effects of vegetation can be simulated in VE-Pro.

5.8 Evapotranspiration

Evapotranspiration (ET) is the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere and thus represents an important part of the water cycle[17]. Lack of evapotranspiration can lead to creation of UHI in urban areas[18]. While this might not be a problem in colder climate, it can have significant impact on cities in hot climate zones.

If the application can calculate the amount of water released by evaporation and transpiration, it will be rewarded with 10 points. If not, it will receive 0.

ENVI-met: 0 points
Envi-met can not calculate evapotranspiration.

Project Vasari: 0 points
Vasari can not calculate evapotranspiration.

IES VE-Pro: 0 points
IES VE-Pro can not calculate evapotranspiration.

5.9 Acoustics

Sound is one of the five senses which influence human behavior the most. From urban design perspective, we are most interested in its negative side – noise pollution, as it can have negative influence on human health. Poor urban design may give rise to noise pollution, since e.g. side-by-side industrial and residential buildings can result in noise pollution in the residential areas[19].

Correct placement of the buildings can mitigate the noise pollution in the first place. By simulating the noise levels further, we can decide if other mitigation strategies[20] are needed in order to reduce the noise.

If the application has the ability to simulate acoustic waves, it will be rewarded with 7 points. Since most of the noise comes from traffic (car, train, airplane), the application will receive 10 points if the noise source can be moved around in space and time. The application will receive no points if it can not simulate acoustics at all.

ENVI-met: 0 points
ENVI-met is not able simulate acoustics.

Project Vasari: 0 points
Project Vasari is not able simulate acoustics.

IES VE-Pro: points
IES VE-Pro is not able simulate acoustics.

5.10 Albedo

Albedo represents the diffuse reflectivity or reflecting power of a surface. It is defined as the ratio of reflected radiation from the surface to incident radiation upon it[21]. As such, low albedo implies higher surface temperatures since the larger amounts of energy are absorbed. As surfaces throughout an entire community or city become hotter, overall ambient air temperature increases[22] which might represent the major contribution to creation of UHI effect.

If the application can not account for albedo effect it will receive no points. If albedo can be calculated it will receive 10 points.

ENVI-met: 8 points
Roof and wall albedo are a part of ENVI-met model specification. However, all buildings in the model share the same albedo value. Soil and water shortwave albedo is calculated inside the application using the soil wetness and sun elevation angle.

Project Vasari: 0 points
Although Vasari has an option to define material reflectivity of a material, it is only used for rendering purposes.

IES VE-Pro: 0 points
VE-Pro does not have the ability to use albedo in its calculations.

5.11 Analysis accuracy

When using computer software to gather the data it is important to know if and how accurate the data really is. The only way to check/control if the results from simulation engines are correct is to compare the calculated results to real-world measurements. Although desirable, the results may not match the measurements 100% due to simplifications in both, algorithms and urban geometry. What is more important is that the simulation behaves in a similar manner as a real-world. This way one can get the sense of how one change of geometry or input parameter will be reflected in the end result. Will the change improve or decrease the performance? This way we can find out the optimal value even if the end result is not identical to the measurement.

Since taking real-world measurements relies on using expensive equipment, which is not at our disposal, we will will rely on whitepapers, which confirm or deny the validity of simulation results.

If the results from simulation engine have not been validated against real-world data and/or the mathematical models behind it are not revealed, the application will receive no points. It will, of course, also receive no points if the results are tested but not correct. If the application has been tested, but the mathematical models behind it are not revealed, the application will

receive 8 points. The application will receive 10 points if it has been evaluated and validated positively againsy real measurements and the calculations behind it are disclosed.

ENVI-met: 10 points
ENVI-met has been evaluated and validated numerous times[23,24,25]. Although there are some deviations between the numerical simulations and actual measurements, the difference is not significant. Also, the model architecture is disclosed.

Project Vasari: 8 points
The Autodesk Green Building Studio web service (used by Vasari) simulation results were evaluated under ANSI/ASHRAE Standard 140-2004, Standard Method of Test for the Evaluation of Building[26]. Wind analysis is done using Falcon solver, which proved to provide correct results[27]. However, the calculations behind the software are not documented.

IES VE-Pro: 8 points
Air temperature and relative humidity calculations proved to be within 10-20% difference when compared to real world measurement[28]. VE-Pro has also been validated using several standards: ASHRAE 140: 2001, 2004, 2007 / BEST TEST / CIBSE TM33 / European Union EN13791: July 2000 / EPACT Qualified and methodologies: Methodologies: UK National Calculation methodology (NCM) / ASHRAE 55 calculation procedure / ASHRAE 90.1 Appendix G PRM calculation procedure / ASHRAE 62.1 calculation procedure / ISO 7730 calculation procedure[29]. However, the calculations behind the software are not documented.

5.12 3D modeling

Although we are mainly focused on assessment of simulation options, it is handy to be able to modify 3d geometry directly in simulation software. If this is not possible we need to find a 3d modeling application, which can export the geometry to the required format. Since switching back and forth between two applications can be time consuming and error prone, it is important to take this aspect into consideration.

If we can not use any 3d editing features directly in the software, it will receive no points. If the basic set of tools, such as drawing faces, extrusion, etc., is provided, the application will receive 7 points. If also advanced tools are offered, i.e. parametric shapes the application will be rewarded with 10 points.

Can we model the urban environment directly in the UI or should the 3d model be created in some other software?

ENVI-met: 7 points
ENVI-met supports a basic 3D modeling which is adequate for urban design analysis. However, a drawing interface is quite unusual – it is a regular 2D grid, on which the volumes (buildings or trees) are placed by specifying their heights and clicking on chosen grid cells, thus creating floor plan.

Project Vasari: 10 points
Vasari incorporates advanced 3D modeling tools, including the option to create parametric objects, which can be easily modified.

IES VE-Pro: 8 points
VE-Pro offers a basic 3D modeling support, together with the set of tools to modify (copy, mirror, ….) an measure already created geometry.

5.13 Climate data loading

In order to calculate the performance of urban geometry at different locations, we need to have access to the data at those locations. The data can usually be provided by services such as meteonorm[30], which collects the parameters such as monthly means of global radiation, temperature, humidity, precipitation, days with precipitation, wind speed and direction, sunshine duration.

The application will be rewarded with 2 points for each of the requested parameters. If the data can be downloaded from internet, it will receive bonus points at useability section (7.4). The parameters in question are:

1. air temperature

2. air humidity
3. wind direction
4. wind speed
5. solar radiation

ENVI-met: 10 points
We are able to define all requested parameters (and many more!) within ENVI-met. The main drawback is that there is no option to load the data automatically, based on location specified.

Project Vasari: 8 points
With the exception of air humidity, all of the requested parameters can be loaded automatically and used for simulation. Note: when reviewing the output of the analysis, there is a chart that shows the annual range of relative humidity.

IES VE-Pro: 10 points
VE-Pro can make use of all requested parameters when running simulation.

5.14 Open format support

An important aspect when dealing with the (simulation) data is the type of file, which is used for storing it. An open file format[31] is a published specification for storing digital data, usually maintained by a standards organization, which can therefore be used and implemented by anyone. If the application uses open standards to store the data, we can easily access and extract the data from it. On the contrast, closed formats are owned and controlled by a private person or organization and intended to give the license holder exclusive control of the technology to the (current or future) exclusion of others[32].

If closed formats are used to store original data, the application will receive no points. If open, but proprietary format is used, the application will be given 8 points and if open and free file format is used the application will be awarded with 10 points. If application can export the data it will receive the same amount of points.

ENVI-met: 10 points
ENVI-met simulation data is stored in binary files due to file size reasons, but it can be extracted to readable ASCII file using included Xtract tool.

Project Vasari: 8 points
Vasari can save detailed solar analysis data in readable .csv files, which can be easily examined using spreadsheet software. Results of wind analysis can only be viewed as a bitmap images.

IES VE-Pro: 2 points
Wind data is stored in closed binary format, but there seems to be a workaround[33] to get ASCII data by dumping current data while simulation is run. Similarly, shading and solar insolation analysis seems to be written in binary format only, with no export options.

5.15 Application interoperability

Since no application provides all the functionality needed for a research, it is important to be able to transfer the data from one application to another. E.g we gather the simulation data using application in question, yet we need to move that data to some spreadsheet software in order to create graphs. This can be achieved 2 ways: by exporting data from the first application in a file format that can be read by the second application or by creating a direct link between both applications. The latter method is preferred, since we can usually update the data on the fly.

If the application does not export any data to widely adopted formats, it will receive no points. If the data can be exported for use in other software, it will be given 5 points. If the application can be directly linked to another application (either with built-in functionality or by using plug-ins), it will be awarded with 10 points.

ENVI-met: 6 points
ENVI-met exports 2,5D model only as .wmf image, which is not really usable to transfer 3D models. Though there is no option to export simulation data, it can be extracted to text file. According to several authors[34,35,36], coupling with other software can be achieved to some extent. However, the coupling is not automatic and great amount of knowledge is needed to connect ENVI-met directly to other applications.

Project Vasari: 7 points
Being also a powerful 3D modeling tool, Vasari is able to export the model to various external formats (.gbXML, .dwg, .dxf, .dwf). Simulation results can be exported to .csv files and thus connected to other applications.

IES VE-Pro: 6 points
VE-Pro can be directly connected to several other applications (Vectorworks, SketchUp, Revit) using the provided plug-ins. This enables seamless workflow, since the user can modify the model in eg. Sketchup and it gets updated accordingly in VE-Pro. VE-Pro can also import .gbXML files. However, this seems to be only one direction link as there are no export options to use the data from VE-Pro in other applications.

5.16 Application programming interface (API)

An application programming interface (API) is a specification intended to be used as an interface by software components to communicate with each other[37]. This way one can extend the application with the features that are not provided by the software itself. It provides the option to write exporters, connectors to other applications or even add some simulation ability, etc.

If the application has no API, it will be given no points. If API is proprietary and specific to the application, it will be given 8 points. If application uses API and the libraries of some programming language (eg. C++ or Python), it will be rewarded with 10 points.

ENVI-met: 0 points
ENVI-met does not provide any API.

Project Vasari: 10 points
Being Revit-based, Project Vasari shares its API as a separate application. It can be programmed with any .NET compliant language including Visual Basic.NET, C#, and C++/CLI.

IES VE-Pro: 0 points
VE-Pro does not provide any API.

6 Assessment of application useability

Assessment of useability evaluates if the application in question is efficient and effective to use. This way we can evaluate if it satisfies the needs of end-users in terms of user experience.

In order to asses useability, we need to define measurable useability goals that the system must achieve[38]. They represent objective criteria against which the results of the usability evaluation are compared to assess the usability of the application[39].

Some of the goals are defined in a qualitative way (ie. Ease of use) while other in quantitative (ie. Calculation speed), as they can be compared directly. Descriptive assessment of qualitative goals is turned into quantitative goals to support an objective quantifiable assessment[38].

General range of useability marks spans from 1 to 10, where 1 means that the goal is not achieved at all and 10 that the goal is achieved according to all expectations. Individual methods for scoring are defined and explained at each of the useability descriptions.

6.1 Calculation speed / completion time

A computer simulation is a computer program that attempts to simulate an abstract model of a particular system[40]. In order to simulate natural phenomena, such as solar radiation or winds, computers solve very complex equations which can take anywhere from a few minutes to several days. The speed at which the application is able to calculate the result is therefore one of the main concerns when dealing with physical analysis of urban environment.

The speed of calculation mostly depends on two factors: scale and resolution of the model and the computer used to calculate the result.

Exact comparison of calculation speed performance between different application is beyond the scope of this paper, as too many factors need to be taken into account. Nevertheless, we will try to obtain

simplified result, which will give us some sense of the speed the applications are able to carry out calculations.

As there is no single kind of analysis, which can be carried out with each of the applications using exactly the same settings, we will focus our observation on two aspects: how quick can the application simulate one of its basic analysis (eg. solar radiation) and how it behaves when the size of the development increases. For this 2 models have been created in each of the applications, one representing 3x3 buildings and the other 5x5 buildings. All building blocks are 10x10x10 meters with 5 meters of space in-between them. Specific settings are written in the ranking section. Average time of 3 runs (appendix A) was then used to compare the results to other applications as different operating system processes can influence the end result. The computer used to run the simulations was based on Intel Core i5-2540M CPU (2.6 GHz) with 8gb RAM and running on Windows 7 Professional 64 bit.

The mark for calculation speed is based on 3 observations: 4 points will be given to the application which seems to produce the results in minimum time, 3 to the second one and 2 to the slowest application. 3 points will be rewarded to the applications where calculation time rises linearly. If time rises exponential, an application will receive 0 points. Another 3 points will be given to the application, which can use multiple CPU cores for calculations. If only one core can be used, it will receive 1 point.

ENVI-met: 6 points
- analysis performed: complete
- resolution: 1m
- simulation interval: 3 hours
- time step: 10 sec
- result 3x3 grid: 1 hr 4 min 16 sec
- result 5x5 grid: 3 hr 4 min 49 sec

ENVI-met's complex architecture requires the calculation of all the parameters, even if it is set to save only some of them as they influence one another. This makes it the slower in comparison to other two applications, when observing the calculation of single parameter. Another drawback is that it calculates in 10 second interval and is therefore practical unusable for long simulation intervals, such as 1 year.

ENVI-met uses only one core of CPU. When more complex models are introduced, the calculation time seems to increase only linearly.

Project Vasari: 10 points
- analysis performed: solar
- resolution: Highest
- simulation interval: 1 year
- time step: 1 hr
- result 3x3 grid: 0 hr 0 min 13 sec
- result 5x5 grid: 0 hr 0 min 45 sec

Vasari seems to be the quickest application by far. It is also important to note that Vasari is the only application among the three, which is capable of using multi-core CPU technology, which significantly increases its calculation speed. When increasing the model size, calculation time increases only linearly.

IES VE-Pro: 4 points
- analysis performed: solar
- resolution: 1m
- simulation interval: 1 year
- time step: 1 hr
- result 3x3 grid: 0 hr 6 min 28 sec
- result 5x5 grid: 1 hr 4 min 09 sec

VE-Pro seems to take the second place when evaluating solely the time to calculate the result of one parameter. However, the main concern, due to exponential growth of time needed to perform calculation when increasing model size makes it questionable when considered for use on mid-size urban development. It also doesn't take the advantage of multi-core CPU technology.

6.2 Visual environment & feedback

Although the models used in physical simulations are numerical, the working with the data can be greatly facilitated by using some kind of visual environment to represent the data. This can be achieved by using several approaches: graphical user interface, interactive 3d window and using graphs or different kind of images to present the simulation results in a way, that

is easily understood by different users.

The visual environment and feedback is of special importance to us since we are primarily a visual beings.

The application will be awarded with specified points if it fulfills the following criteria:

- interactive 3D model – 4 points
- results presented in graphs and tables – 4 points
- results presented using images – 2 point

All points will be summed in the end to calculate the final mark.

ENVI-met: 6 points
There is no interactive 3D model visualization in ENVI-met. Graphs and images can be created using LEONARDO module.

Project Vasari: 10 points
Vasari is a highly visual tool, with its interactive 3D model being among its core functions. Some of the simulation results (eg, wind flow or insolation) can be presented directly in 3D model. Tables and graphs are also available.

IES VE-Pro: 8 points
VE-Pro includes interactive 3D model which is somewhat limited. It is used only as a visualization tool to display results, but one can not model development directly inside it. Graphs and tables to show the results of simulations are also available.

6.3 User interface simplicity & intuitiveness

User interface (UI) refers to the graphical, textual and auditory information the program presents to the user, and the control sequences (such as keystrokes with the computer keyboard, movements of the computer mouse, and selections with the touchscreen) the user employs to control the program[41]. According to Berin Loritsch, good UI needs to be clear, concise, familiar, responsive, consistent, attractive, efficient and forgiving[42].

Assessing the UI is subjective by nature, and assessment differs from user to user. In order to get more objective result, a group of users is needed. However, objective assessment of UI is a task, which is beyond the limits of this research. The marks given here will be based on my personal assessment; nevertheless, they can be changed by the reader of this paper if needed.

The user interface simplicity and intuitiveness assessment will look at how the following requirements are fulfilled:

- is UI simple to use or do we need to deal with configuration files in order to set up the analysis?
- is UI structured logically, is everything at appropriate place?
- does the workflow follow the logic of urban design process?
- is UI consistent, can controls be found easily?

ENVI-met: 3 points
User interface of ENVI-met is not very intuitive, as it is distributed among 5 main windows: Eddi, Configuration editor, ENVI-met default config, Leonardo and Extract. Each part needs to be run separately, which is not very concise. Most of the simulation data needs to be specified by modifying text based configuration files which is unfamiliar to average PC user. The application is not adapted to urban design needs as it is solely a simulation tool and it expects that the urban design solution is already known. Apart from working with several windows, the available controls are found easily.

Project Vasari: 8 points
User interface of Vasari is intuitive and easy to use. Modeling 3D environment is superb, all the tools needed are easily found. Although it is not specialized urban design tool, it enables quick and intuitive placing of objects. Setting up analysis does not require much knowledge and is straightforward. Results are presented in easy to understand manner.

IES VE-Pro: 5 points
VE-Pro combines several application modules within one user interface. Being

primarily a tool for building energy demand evaluation, it is not best suited for urban design needs as it provides too many options which are not relevant (indoor climate, HVAC simulation, lighting simulation, etc.).

6.4 Ease of use & learning curve

Usability and ease of use are key software attributes, making it possible to complete tasks efficiently and effectively[43]. Easy-to-use software tool does not require that the user possess a great deal of specialized knowledge nor training to produce the end product[44]. Similarly as in previous section, the ease of use and learning curve can be objectively estimated by summarizing multiple user surveys and the assessment in this paper is more subjective, based on author's experience.

When rating the ease of use and learning curve of application, the following the following objectives will be taken in consideration:

- is installation procedure easy?
- how much does the user need to know about the actual physical processes that are being simulated?
- how long does it take to get the first results from the application?
- can we learn to use the application fast or does it take a lot of time?
- can we load the climate data from internet?
- are the simulations run separately or together?

ENVI-met: 3 points
ENVI-met is easy to install, but large amount of knowledge is needed to run the simulations. To get the first results, user has to study the application in depth. Climate data can not be dowloaded from internet. One simulation takes into account all parameters.

Project Vasari: 8 points
Project Vasari is self-executable package which needs no installation. Usage is pretty straightforward and user does not need to know a lot about all the parameters included in calculations. First results can be obtained quickly. Climate data is downloaded from internet once site location is specified. Simulations are run separately.

IES VE-Pro: 5 points
VE-Pro installation procedure is a two-step process. First the library is installed, which is followed with the installation of the application itself. User only needs to have some basic knowledge. To get the first results, user has to study the application in depth. A large library of weather data comes with VE-Pro. In addition to that, it is also able to download the data from the US Department of Energy's website[45]. Different simulations need to be run in different modules.

6.5 Software documentation

Software documentation explains how the software operates and/or how to use it[46]. According to Blue Mango Learning Systems[47], the documentation should follow the Goldilocks principle[48], which states that documentation should give the user just enough information to accomplish their task and nothing more. In addition to the documentation itself, we are also interested into tools which help us get up-and-running with the software, ie. text based or video tutorials which usually show how to use the software using a case study.

Since there is no reference score for the assessment of software documentation, it will be rated using norm-referenced test[49], i.e. the documentation will be compared against each other based on examination of the following criteria:

- does the documentation provide the right amount of information to start using the tool right away?
- are there any tutorials available?
- does the documentation provide information on what methods are used to calculate the result?

ENVI-met: 7 points
ENVI-met online manual is consistent and provides the right amount of information to

use the software. Search function is missing and users would benefit if a quick introduction tutorial was added.

Project Vasari: 10 points
Vasari has the best documentation among the three tested applications. Application is well documented with integrated search function. Documentation is also supported by video tutorials showing how to use the tool.

IES VE-Pro: 6 points
VE-Pro documentation is consistent and very detailed, however I have missed some simple tutorials to get up-and-running quickly. Another drawback is that help system is based on separate .pdf files, one for each module. This makes it hard to find answer for basic questions.

6.6 Supported operating systems & hardware requirements

An operating system (OS) is a collection of software that manages computer hardware resources and provides common services for computer programs[50]. Although there are significant differences between them, we are not interested in which one is better, but rather if the assessed applications can run on them. It's up to the reader to decide which platform she or he will use.

We will check if the application in question can be run on three most widespread operating systems for desktop computers today: Microsoft Windows(69,2%), Mac OS X(7%) and Linux (1,6%)[51]. Although the Linux has a relatively small market share, it is worth to note that it is the only one among the three that widely used to run supercomputers, which are by far most appropriate to run simulations. But unfortunately, they are not available to ordinary users. On the other hand there is a fast growing market for mobile devices and tablet computers, with Android and iOS as most widespread operating systems. However, these will not be taken into account as the hardware specifications (CPU, GPU speed) can not compare to desktop computers.

Application will be awarded with 3 points if it can run on Microsoft Windows, 3 for Mac OS X and 3 for Linux.

ENVI-met: 4 points
ENVI-met is available only for Windows operating system. Hardware requirements are not high (min. 1Gb RAM, 4Gb RAM recommended) with regard to today's computer capabilities.

Project Vasari: 4 points
Project Vasari is available only for Windows operating system. Project Vasari can be run on common PC's. However, in order to perform wind analysis the system has to be equiped with Open GL graphics card.

IES VE-Pro: 4 points
IES VE-Pro is available only for Windows operating system. Hardware requirements can be fulfilled by common PC's (min. 2Gb RAM, OpenGL-compliant graphics card, 1152 x 864 screen resolution).

6.7 Community & technical support

In addition to the software documentation, a strong, vibrant community and efficient technical support represent an important means of providing assistance to end-users. This is of special importance when learning to use the software.

To rate the community and technical support, the number of community members, an (official) forum activity (if it exists) and the availability of technical support will be compared against each other.

The application with the best community will be rewarded with 6 points, down to 3 points for the application with weak community. If there is no community (forums, etc.) around the software, it will receive 1 point. An additional 4 points will be given to each application where the technical support is available.

ENVI-met: 7 points
ENVI-met has a solid base of users, a lot of which are active on its online forum. However the activity on the forum is somewhat limited with only a few posts per week. The forum also represents the technical support, as the users get their answers answered directly by the ENVI-met creators.

Project Vasari: 7 points

Project Vasari's community is strong, but due to its limited number of users only a post or two are posted on its forum each day. However, since the application is the youngest among the three and the application is still in beta phase, the community is not

IES VE-Pro: 10 points
Virtual Environment is supported by a vivid community, with several posts on its forum each day. There is also commercial technical support available for users with appropriate license.

6.8 License, cost & active development

The last, but not least, we are interested in the license and cost of the reviewed applications. The most important question to answer regarding the license is if the application is open source or proprietary software. In contrast to closed software, open source licenses enable everyone to use and modify the software. This way, one can learn how the application works internally and extend it to suit her or his needs better. On the contrary, proprietary software usually hides the actual algorithms which run the software in order to protect developer's interests and know-how.

In addition to the license itself, we are also interested if the applications are still being in active development. This way we can compensate for the drawbacks of payable software, since funding can have a great impact on software development.

Both components will be added together to calculate the result of this section.

5 points shall be given to the open source applications. Proprietary, but free applications will be given 3 points. Closed applications which traditionally follow the pay per-seat model will be given 1 points.

If the application is under active development (last update not older than 6 months), it will be rewarded with 5 points. If the last update of the application is more than 1 year old, it will receive 3 points. 1 point will be given to the applications, which were last updated 2 years ago or more.

ENVI-met: 6 points
ENVI-met is released as an open source application and therefore available free of charge. Although it is still in development, the last public release (v3.1) dates back to October 2010. This is most probably due to the fact that authors are working on ENVI-met v4 for at least from 2009[52], which has not yet been released for public and is available only to limited number of users.

Project Vasari: 8 points
Althouh closed source, Project Vasari is available free of charge as a Beta version. It is under active development and the last version (Beta 2) was released in November 2012.

IES VE-Pro: 7 points
IES VE-Pro is commercial product with a 30 day trial period. The price depends on the selected modules, e.g. yearly license of VE-Pro + GLD Premier Financial bundle costs $4,400 per seat[53]. However, VE-Ware, a product based on VE-Pro is available free of charge. IES VE-Pro is under active development, with the last update available in March 2013[54].

7 Comparison table & pondering example

Comparison table (appendix B) sums up the results from both, application features and useability. In addition to that, comparison table also features pondering, so that the final results can be adapted to suit specific needs. This way a reader who eg. searches the most user friendly application easily finds the most appropriate application just by raising the ponder values (weights) of certain useability features. For this reason the interactive table, same as in appendix B, is also available online at http://tiny.cc/env_app_evaluation. When changing the ponder values, please note that they are supposed to be in-between 0 and 10 points.

The final results of application evaluation are presented numerically in absolute and relative value. Absolute value shows how well the application scored against a total possible value (perfect application). Relative value shows how well the application performed against the other

two. The results are further divided in two categories, as they are calculated for both, raw and pondered values. Raw values represent the pure, unbiased result whereas the pondered values shows the weighted result that can be changed according to specific needs.

Although the results are based on author's subjective opinion, we may conclude that the best application is ENVI-met, which collected 142 raw points (from 240 possible) or 1017 pondered points (from 1590 possible). It is closely followed by Project Vasari which collected 140 raw points or 1001 pondered points (only 1,5% lower score). A bit more behind is IES VE-Pro, which scored 122 raw and 917 pondered points.

8 Conclusion

This paper shows that a.) there is still plenty of room to make a more complete tool for assessment of urban form from environmental point of view, b.) there is no clear winner among the three tested applications c.) no one application covers all the needs to analyze urban design.

For the moment, it seems that the most appropriate workflow would be to quickly analyze the urban form using solar analysis function by Project Vasari. The reason behind it is that Vasari combines the best tools for quick 3d modeling and extremely fast solar simulation, which is one of the key factors that influence environmental conscious urban design the most. This makes it superb in early stages of design process, when several urban design alternatives should be tested. The drawback of Vasari is that its analysis capabilities are somewhat limited. Therefore it can not perform more detailed environmental simulation, where ENVI-met steps in. Although a bit archaic in terms of user interface and flexibility it offers the most detailed analysis, and it therefore seems to be the most suitable for simulating real-world cases. For cases when more elaborate results are needed, ENVI-met is suggested.

ENVI-met would benefit the most with improved user interface. Additionally, it is crucial to implement solar radiation analysis for walls and roofs. Adding some more functionality, such as API, and tutorials on how to use it would make it near perfect. We hope to see this improvements in ENVI-met 4.0.

Project Vasari shines in terms of user experience. It lacks some important features from urban design perspective, but the ones which are implemented are implemented really well. By adding some more functionality, geared towards urban design, such as albedo calculation or irradiation, humidity and evapotranspiration analysis and it could outrun ENVI-met.

IES VE-Pro was created to analyze the performance of single buildings and it shows. If this was the case, it would win hands down among the three applications in question. However, when assessed from urban design requirements, it lags behind the other two applications, as both, functionality and useability are missing some important features.

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Appendix A - calculation benchmarks

EVALUATION OF ENVIRONMENTAL SIMULATION TOOLS						
CALCULATION BENCHMARKS						
Application	**ENVI-met**		**Project Vasari**		**IES VE-Pro**	
Model size	3x3	5x5	3x3	5x5	3x3	5x5
1st run	1:05:56	3:00:02	0:00:13	0:00:45	0:06:15	1:04:09
2nd run	1:07:06	3:12:12	0:00:12	0:00:44	0:06:11	1:06:48
3rd run	0:59:46	3:02:12	0:00:13	0:00:46	0:06:57	1:01:30
Average	**1:04:16**	**3:04:49**	**0:00:13**	**0:00:45**	**0:06:28**	**1:04:09**

Appendix A - evaluation table

EVALUATION OF ENVIRONMENTAL SIMULATION TOOLS					
EVALUATION TABLE					
ID	**APPLICATION FEATURES**	**PONDER**	**ENVI-met**	**Project Vasari**	**IES VE-Pro**
5,1	Incoming solar radiation	10	5 -> *50*	5 -> *50*	7 -> *70*
5,2	Irradiation analysis	6	3 -> *18*	0 -> *0*	0 -> *0*
5,3	Air exhange / wind (CFD)	10	8 -> *80*	8 -> *80*	9 -> *90*
5,4	Materials assignment	8	5 -> *40*	7 -> *56*	10 -> *80*
5,5	Water bodies & evaporation	8	8 -> *64*	0 -> *0*	7 -> *56*
5,6	Humidity	6	10 -> *60*	2 -> *12*	3 -> *18*
5,7	Vegetation	6	10 -> *60*	2 -> *12*	3 -> *18*
5,8	Evapotranspiration	3	0 -> *0*	0 -> *0*	0 -> *0*
5,9	Acoustics	3	0 -> *0*	0 -> *0*	0 -> *0*
5,1	Albedo	6	8 -> *48*	0 -> *0*	0 -> *0*
5,11	Analysis accuracy	8	10 -> *80*	8 -> *64*	8 -> *64*
5,12	3D modeling	8	7 -> *56*	10 -> *80*	8 -> *64*
5,13	Climate data loading	10	10 -> *100*	8 -> *80*	10 -> *100*
5,14	Open format support	6	10 -> *60*	8 -> *48*	2 -> *12*
5,15	Application interoperability	4	6 -> *24*	7 -> *28*	6 -> *24*
5,16	Application programming interface	6	0 -> *0*	10 -> *60*	0 -> *0*
FEATURES SUM			**63% 69%**	**47% 53%**	**46% 55%**
ID	**APPLICATION USEABILITY**	**PONDER**	**ENVI-met**	**Project Vasari**	**IES VE-Pro**
6,1	Calculation speed	7	6 -> *42*	10 -> *70*	4 -> *28*
6,2	Visual environment & feedback	8	6 -> *48*	10 -> *80*	8 -> *64*
6,3	UI simplicity & intuitivness	6	3 -> *18*	8 -> *48*	5 -> *30*
6,4	Ease of use & learning curve	6	3 -> *18*	8 -> *48*	5 -> *30*
6,5	Software documentation	8	7 -> *56*	10 -> *80*	6 -> *48*
6,6	Supported operating systems	4	4 -> *16*	4 -> *16*	4 -> *16*
6,7	Community & technical support	7	7 -> *49*	7 -> *49*	10 -> *70*
6,8	License, cost & development activity	5	6 -> *30*	8 -> *40*	7 -> *35*
USEABILITY SUM			**53% 54%**	**81% 85%**	**61% 63%**

RAW VALUE	142	140	122
PONDERED VALUE	**1017**	**1001**	**917**
FINAL RANK	**1**	**2**	**3**
ABSOLUTE RAW VALUE	59,17 %	58,33 %	50,83 %
RELATIVE RAW VALUE	100,00 %	98,59 %	85,92 %
ABSOLUTE PONDERED VALUE	63,96 %	62,96 %	57,67 %
RELATIVE PONDERED VALUE	100,00 %	98,43 %	90,17 %