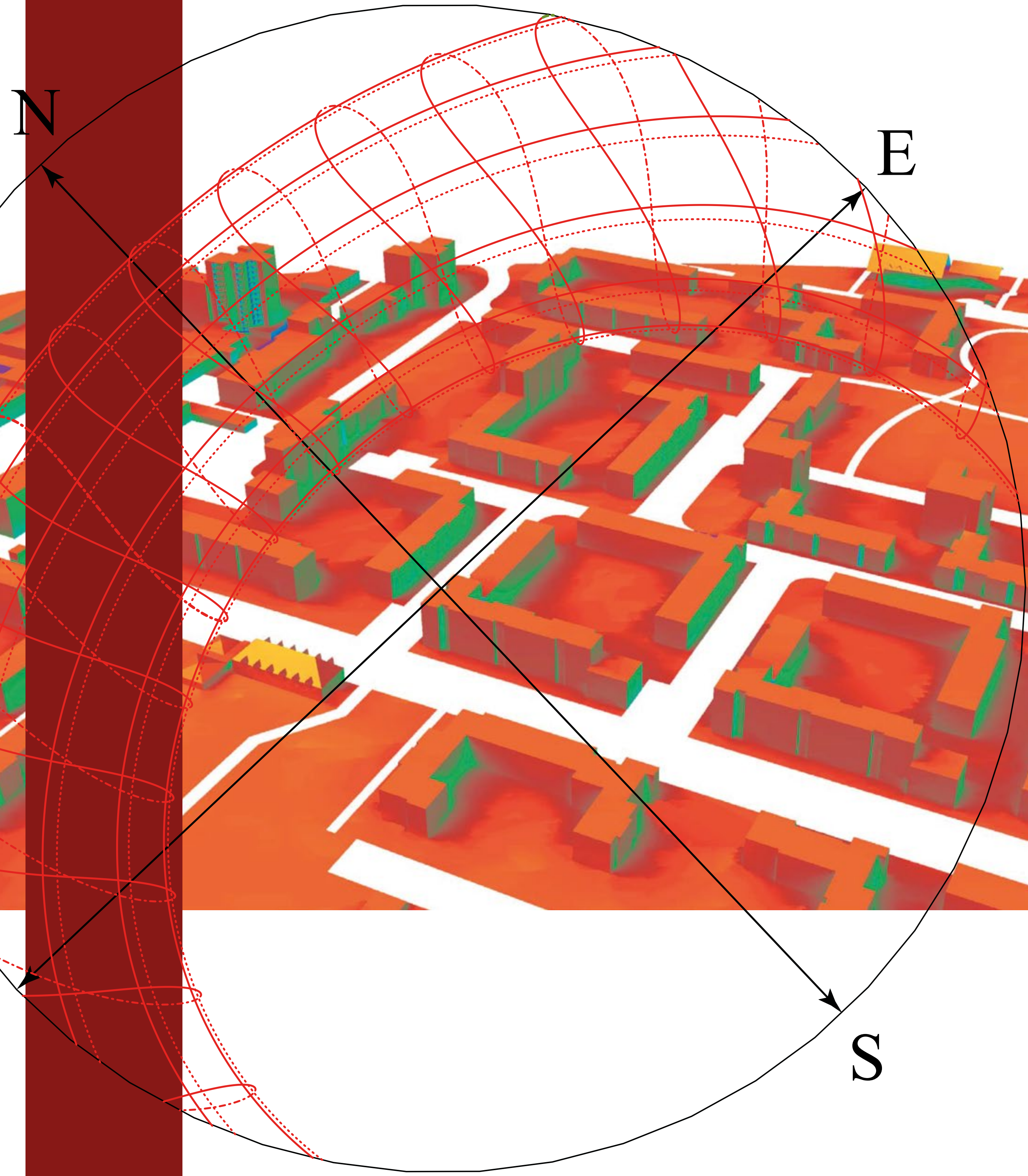

State-of-the-art of Education on Solar Energy in Urban Planning

Part II: Solar Irradiation Potential Tools in Education

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IEA SHC Task 51 Solar Energy in Urban Planning

Task 51/Report D1 Part 2

State-of-the-Art of Education on Solar Energy in Urban Planning

Part II: Solar Irradiation Potential Tools in Education

Editors:
Tanja Siems (University of Wuppertal)
Katharina Simon (University of Wuppertal)
Karsten Voss (University of Wuppertal)

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Authors (in alphabetical order)

Susanne Hendel
University of Wuppertal
Faculty of Architecture & Civil Engineering
Pauluskirchstraße 7
DE-42285 Wuppertal
GERMANY
s.hendel@uni-wuppertal.de

Carmel Margaret Lindkvist
Norwegian University of Science and Technology (NTNU)
Department of Architectural Design, History and Technology
NO-7491 Trondheim
NORWAY
carmel.lindkvist@ntnu.no

Gabriele Lobaccaro
Norwegian University of Science and Technology (NTNU)
Department of Architectural Design, History and Technology
NO-7491 Trondheim
NORWAY
gabriele.lobaccaro@ntnu.no

Marja Lundgren (contributor)
White Arkitekter AB
Östgötagatan 100
Box 4700
SE-116 92 Stockholm
SWEDEN
marja.lundgren@white.se

Romain Nouvel
Hochschule für Technik Stuttgart
zafh.net- Sustainable Energy Technology
Schellingstr. 24
DE- 70174 Stuttgart
GERMANY

Alexander Saurbier
University of Wuppertal
Fakulty of Architecture & Civil Engineering
Pauluskirchstraße 7
DE-42285 Wuppertal
GERMANY
saurbier@uni-wuppertal.de

Nava Shahin
Norwegian University of Science and Technology (NTNU)
Department of Architectural Design, History and Technology
NO-7491 Trondheim
NORWAY
nava.shahin@ntnu.no

Tanja Siems (editor)
University of Wuppertal
Institute for urban design and urban research
Pauluskirchstraße 7
DE-42285 Wuppertal
GERMANY
siems@uni-wuppertal.de

Katharina Simon (editor)
University of Wuppertal
Institute for urban design and urban research
Pauluskirchstraße 7
DE-42285 Wuppertal
GERMANY
ksimon@uni-wuppertal.de

Karsten Voss (editor)
University of Wuppertal
Faculty of Architecture & Civil Engineering
Pauluskirchstraße 7
DE-42285 Wuppertal
GERMANY
kvoss@uni-wuppertal.de

Tjado Voß
University of Wuppertal
Fakulty of Architecture & Civil Engineering
Pauluskirchstraße 7
DE-42285 Wuppertal
GERMANY
tvoss@uni-wuppertal.de

Maria Wall (OA)
Lund University
Energy and Building Design
P.O. Box 118
SE-221 00 Lund
SWEDEN
maria.wall@ebd.lth.se

IEA SHC Task 51 Introduction

Scope and Objectives

An increased use of solar energy is firmly acknowledged as a key ingredient for forging resilience and future proofing of our cities. This recognises the importance of the urban fabric being able to

- utilise passive solar gains and daylight
- reduce energy use in buildings and lighting outdoor environments,
- improve the inhabitants' comfort both inside and for outdoor urban areas.
- generate energy for more and more self-sustainable buildings, neighbourhoods and cities

Active solar energy systems integrated in the built environment will enable a supply of renewable energy, primarily for electricity and heat, but also for solar cooling, helping cities reach sustainable solutions.

The main objective of the IEA Solar Heating & Cooling Programme, Task 51 Solar Energy in Urban Planning project, is to provide support to urban planners, authorities and architects to achieve urban areas, and eventually whole cities, with architecturally integrated solar energy solutions (active and passive). The objective will contribute to urban planning by providing guidance for urban planners and policy makers on a large fraction of renewable energy supply. This includes approaches, methods and tools capable of assisting cities in developing a long term urban solar energy strategy. Heritage and aesthetic issues are carefully considered. Also, the goal is to prepare for and strengthen education at universities on solar energy in urban planning, by testing and developing teaching material for programmes in architecture, architectural engineering and/or urban planning. The material will serve a dual purpose by being inclusive for post graduate courses and continuing professional development (CPD).

The scope of the Task includes solar energy issues related to

1. New urban area development
2. Existing urban area development (a) fill-ins and densification, b) refurbishment)
3. Sensitive/protected landscapes (solar fields)

In all three above environments, both solar thermal and photovoltaics are taken into account. In addition, passive solar is considered in the urban environment (1 and 2). Passive solar includes passive solar heating, daylight access and outdoor thermal comfort.

Solar energy integration in existing and in new city districts are two different contexts with different opportunities and constraints. Furthermore, ground based active solar applications (PV and solar thermal) are interfacing with urban environments, creating solar landscapes that juxtaposition with the existing urban form with varying levels of aesthetic acceptance. In open landscapes, solar fields need to harmonize with the rural landscape and nature. Understanding the existing parameters under which planners operate and the challenges this presents is a key consideration of this Task.

Summary

In the framework of the “Solar Energy in Urban Planning” (IEA SHC Task 51) research project, experts concern themselves with the ways how the usage of solar energy can be better integrated into the urban planning context. For these efforts to be successful, questions about the status of solar potential analyses in the urban planning process and about tools that are necessary for early support in an urban planning process must be answered. The initial step was the evaluation of known software tools to evaluate solar radiation availability on the urban scale. Most tools work with 3D models that allow the generation of a model of existing urban structures. They act as planning aids, graphically depicting shadowed areas and solar radiation for areas or a district in the form of false-colour images.

This report compares on the one hand experiences in using the selected software tools in seminars at universities based on a design task example with experiences of international partners within the framework of IEA SHC Task 51. On the other hand, this report discusses the current development status of new research and teaching tools.

Apart from solar potential tools, other types of methods and tools have also been tested, developed and used within Task 51. Some are more suitable for professionals and some are appropriate to use in education. More information about such methods and tools can be found in the Task 51/Report B2 Approaches, Methods and Tools for Solar Energy in Urban Planning. For information about the use of methods and tools in practice, see the Task51/Report C1 Illustrative Prospective of Solar Energy in Urban Planning: Collection of International Case Studies.

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1. Introduction

Software tools are an important component of university training as it concerns the planning and use of active and passive solar energy. This report discusses the software tools as they were used by students in realistic case studies. On the basis of a generated evaluation sheet, the deficits and opportunities of the introduced tools are illuminated and evaluated. Complementing the experiences of the German seminar at the University of Wuppertal, the international research partners from the Norwegian University of Science and Technology in Trondheim also evaluated the tools applied in their seminar with the aid of a common questionnaire.

In order to show the further development in the field of solar tools for urban planning, a short overview is given from researchers' point of view. The analysis is completed by a more detailed and technical comparison of the results from the urban irradiation calculation with some selected tools.

1.1. Motivation

In both architecture and urban planning, software tools have long been used as aid for imparting a complex idea in 2D or 3D drawing. Each profession had an own tool for realising their projects. Given the multifaceted areas of responsibility with which planners are confronted now, the demands on scope of functions, operation, and effectiveness of such tools have risen dramatically. The working process is constituted due to interdisciplinary work. Tools are used to support representation and evaluation of alternative courses of action. That is the reason why researchers and software creators from around the world continuously are working on new solutions. Especially in the field of urban and energy planning the demands are high and vary between an easy to use interface and precise calculations. A general reflection of applied tools for energy planning is discussed in some publications, see chapter 8 “References“.

This report focuses especially on solar tools in the educational context. The extent to which they are up to this task at the level of planning districts and cities will be discussed and evaluated on the basis of example software tools.

1.2. Problem presentation

Important questions that must be answered prior to planning must be clearly anchored in the urban planning approach. In built-up or transformation of districts, the existing urban morphology is especially critical for new developments. Factors such as building density, building height, house typology, structure, roof typology and the type of residents are extremely significant. These factors affect both the perception of the urban space and the energy considerations of a district. The latter are different on an urban planning scale from such considerations at the level of a single building. Aspects such as energy networking of buildings, centralised (local heating networks) and decentralised (solar energy and heat systems) use of renewable energies, and the integration of CHP systems through cogeneration units are decisive for district-level concepts and should be evaluated at this level. A view of individual buildings that is too differentiated too early on can lead to an unintentional fragmentation of the entire concept during this phase.

In addition to energy-related questions, urban planning questions that actively involve the affected actors must be cleared up as early as possible in the planning process. To this end, the German partners from the University of Wuppertal's Faculty of Architecture and Civil Engineering previously completed research on urban planning processes in the analysed case studies, among them the EnEff:Stadt Ludwigsburg Grünbühl/ Sonnenberg[1] pilot project. The time-dependent evaluation of the individual planning steps and the leading

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[1] EnEff:Stadt Ludwigsburg Grünbühl/ Sonnenberg pilot project, see http://www.eneff-stadt.info/

actors allowed a comparative analysis of the analysed case studies despite their various planning conditions and goals. Important milestones in the planning process, among which was energy optimisation, were documented in a process chart. Problem presentations concerning which actors are affected and at which stage are essential for the further conduct of planning. In this context, it is the task of the planner to moderate the information exchange among various actors, such as city and residents, in order to bring the comprehensive planning together to form a coherent model.

2. Evaluation of tools for solar energy utilisation in urban planning at universities in Germany

Within the framework of the common Master course of the Urban Design (Prof. Siems) and Building Physics and Services (Prof. Voss) institutes in the winter semester of 2013/2014, the interplay of conceptual urban design and the development of an energy concept at the district level was analysed based on a built-up district. Students from both institutes participated in the course and in the tool evaluation.

A comparative analysis of existing pilot projects, such as those from EnEff:Stadt[2], reveals successful performances in the treatment of renewable energies. The analysis of realised case studies allows the planning processes and the applied tools to be better understood and the acquired knowledge to be adapted to new projects.

In this context, the main focus in the second phase was on selected simulation tools and on the problem of the extent to which they can support or improve the process of concept development at the urban and energy planning level. Because the urban planning process is a multifaceted and complex one that involves many actors, it is important to network the planning levels as early as possible in order to achieve sustainable concepts and new design strategies for districts and municipalities. In all this, powerful, visual communication of strategies and variants plays a significant role.[3]

The success factor is that effective urban planning and sensible approaches to energy cannot be developed separately from one another. On the contrary, the overlap between the two should be focused upon in order to generate an overarching concept and value added. Doing so appears to allow innovative and radical approaches for the development of ideas that are able to serve both the urban planning and the energy areas under a single guiding principle. By considering the visible structuring and the creative differentiation of façades in a district caused by systems for actively using solar energy, the visible orientation in the district besides generating energy can be improved.

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[2] http://www.eneff-stadt.info/

[3] Bott, Grassl, Anders: “Nachhaltige Stadtplanung”, 2013

2.1. Procedure and methodology

The selected test case was an existing 60-hectare district with 10,000 residents in the Rhineland that was built in the 1960s, see figure 1. The district remains in its original condition except for scattered measures to introduce green areas and offered high potential for our project with its largely three- and four-storey slab and block structures and relatively high proportion of green space. The size of the district – over 200 buildings – constituted a test of the power of the planning tools.

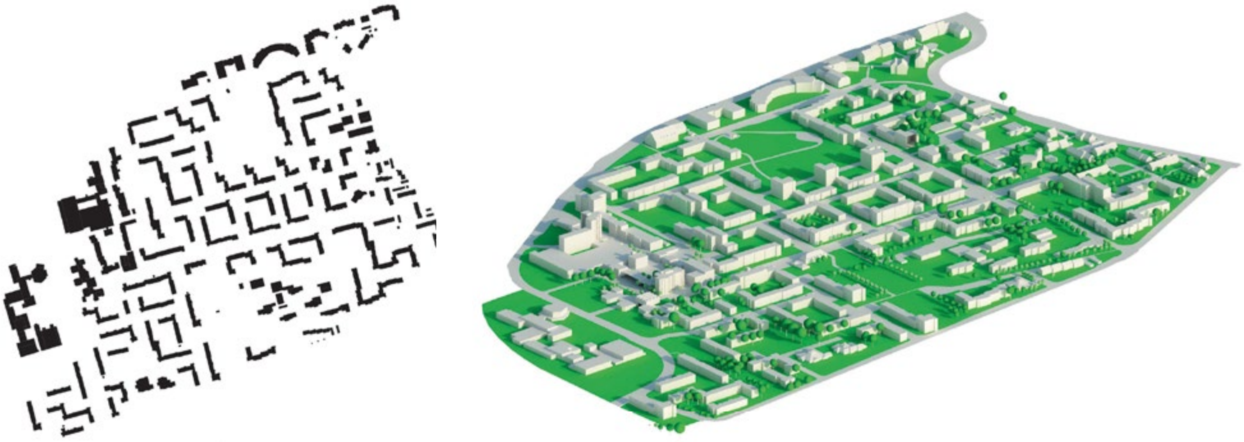
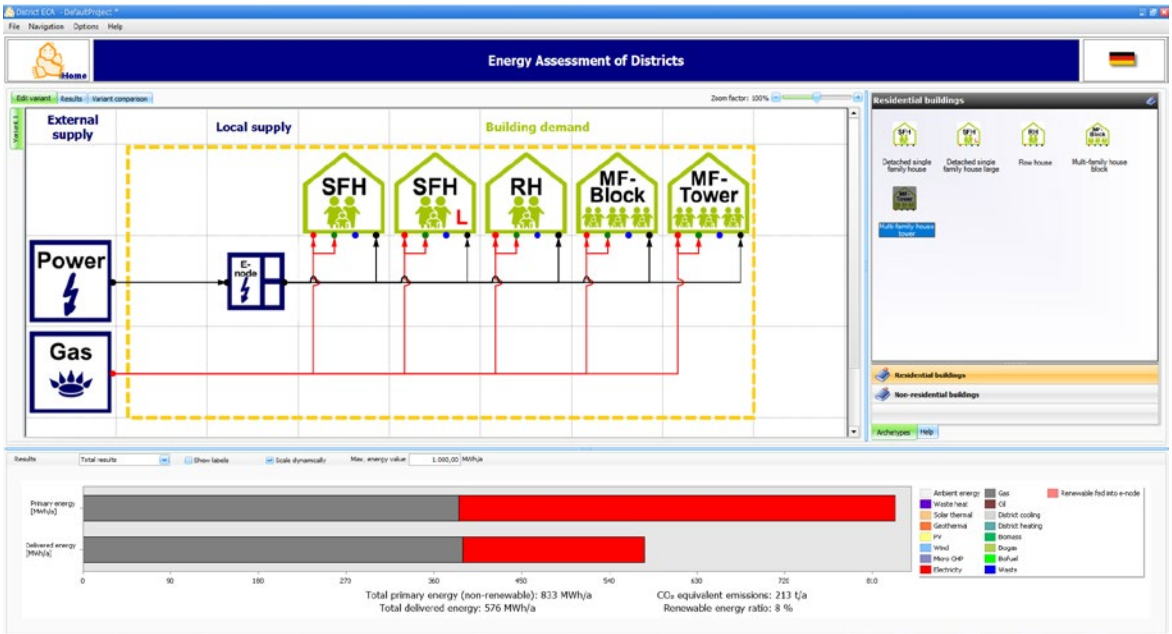


Fig. 1: Figure-ground-plan and perspective of the 60-hectare district (without scale)

The first step was an assessment of the condition of energy generation with the help of the "District Energy Concept Adviser"[4], which differentiates based on area among the usage typologies in the district. This is done in connection with its integrated typological database and the DIN V 18599 calculating algorithms, a relatively quick, if rough, evaluation of the status quo, see the screenshot of the user interface in figure 2.



Results: Total results ☐ Show labels ☑ Scale dynamically Max. energy value 1.000,00 MWh/a

Total primary energy (non-renewable): 833 MWh/a
Total delivered energy: 576 MWh/a
CO_2 equivalent emissions: 213 t/a
Renewable energy ratio: 8 %

Fig. 2: Screenshot District Energy Concept Adviser (DECA)

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[4] Developer: Fraunhofer Institute for Building Physics, Stuttgart, developed in the context of the IEA ECBCS Annex 51 "Energy-Efficient Communities: Case Studies and Strategic Guidance for Urban Decision-Makers" research project.
Reference: http://www.district-eca.de/index.php?lang=de

In the framework of a holistic district analysis, the urban planning strengths and weaknesses were identified in order to highlight the initial options in this area. Using the analyses, students developed ideas and concepts for both urban planning and energy problem presentations. For more information about the District Energy Concept Adviser see Task 51 Report/ D2.

The second step was an analysis of the district's solar potential with explicitly "solar" tools. In addition to the analysis, the evaluation of the tools themselves was the focus. It was performed by students using the software. Hard factors such as procurement costs, required operating systems, and basic functions such as the correct or logical calculation results in the area of solar radiation using parameter studies, soft factors such as user-friendliness, help functions, and the like were tested. The evaluation was oriented on the research field described above and also took into consideration aspects of networking and support of urban and energy concept planning (CAD interfaces, etc.).

2.2. Solar tools

The selected tools for the evaluation were:
- ArchiWizard[5],
- DIVA (plug-in for Rhino and Grasshopper)[6],
- OpenStudio (plug-in for SketchUp)[7],
- Autodesk Ecotect[8].

Tools were selected by availability and with a clear focus on the urban scale. The evaluation covers the status of development in 2014. Progress might have been achieved since that time in specific cases.

The existing district was modelled within the tools. This task was performed, depending on the tool in question, by importing a 3D model, either from a CAD program or independently, into the software. The advantages of the district chosen were the flat landscape, the absence of distant shadow-casting objects (mountains, etc.) and the homogeneous flat roofs. This means that no evaluations about the handling of such features were made in the current phase. This basic task drew attention to significant differences in the operation of the tools, namely the allowed number of objects or the grid size for the radiation analysis.

Parametric studies were completed parallel to the actual model data entry. They were performed by means of simplified building geometry and allowed conclusions to be drawn about the calculation procedure and simplifications the tools used. Furthermore, many factors were discovered during concept-related work with the tools. For instance, areas such as material library, representation of shadow-casting objects at small or large distances, precise depiction of surface materials, export capabilities of results were evaluated during work with the tools.

In general, critical observation and examination of all the results or insights provided by the calculations is decisive. This examination clearly shows that simulation tools, in whatever respect, are merely tools; they can support planning, but can in no way conduct it independently. The implication is that the sensible use of a given tool requires a certain degree of technical knowledge.

From a physical point of view, there are fundamental differences among the calculation methods used by

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[5] http://www.archiwizard.fr

[6] http://diva4rhino.com

[7] https://openstudio.nrel.gov

[8] www.autodesk.de/ecotect-analysis

the various tools, and they have significant effects on the simulations' calculation times. An important issue here is the handling of light or of solar radiation, see chapter 6. Without describing the calculation methods in detail, it is comprehensible that the more precise the simulation with regard to diffuse radiation shading or the reflective characteristics of surfaces, the longer the calculation time required. Complex models may limit the scale of a district to be handled. Longer calculation times may also be expected to produce more precise results. However, the user must be aware of the goal of the simulation in question in order to specify an appropriate degree of precision. In the early phases of an urban planning project, a high degree of precision is generally not required. However, it is expedient for the same tool to be able to achieve more precise results in later planning phases.

Another important point in tool evaluation is the capability of extracting insights for urban planning concept work from the models and communicating those insights in images. In this context, the ability to perform annual or very precise shadow studies or generate solar position diagrams plays an important role.

2.2.1. Explanation of the graphic evaluation

Below, the various evaluation points for the graphically prepared evaluation for each individual tool are explained. The original evaluation format is presented in appendix 1.

- installation/download/forum
  The installation process, download availability, and forum activity are evaluated here.

- required level of expertise
  This point rates the degree of technical knowledge required for proper use of the software tool. 100% indicates a very high level of necessary technical knowledge.

- user friendliness/editing/workflow
  This evaluation point evaluates the user-friendliness (of inputs and outputs), the editability at all levels of the simulation model, and the work process that arises from these two points.

- model precision
  The precision of the simulation model is the focus of this evaluation point. The level of detail in the simulation model plays an especially important role here.

- import/export
  This evaluation point describes the flexibility of the evaluated tools with respect to import and export (such as the CAD import of pre-generated building geometries) of foreign files and the export capabilities for the calculation results.

- software stability
  As the name indicates, this evaluation point rates the stability of software operation. Crashes during simulations or incorrect depictions during input are critical here.

- coupling to urban design process/urban energy planning
  This evaluation point determines the utility for the urban planning design process and the related energy planning at the urban level.

- simulation scale
  This point indicates the size of the possible simulation scales of the given model. It is determined by the number of possible buildings in the simulation model.

2.2.2. ArchiWizard

Table 1: Software Profile ArchiWizard

Developer:	RayCreatis	Calculation	
Year of Creation:	2012	Calculation engine:	RayBooster, ZUB Helena
Last update:	-	Shading model:	direct & diffuse shading model
Licence Price:	2000€ one-time payment		
Language:	English, German, French	Thermal Model:	multi zone
OS:	Windows & Mac	Inside daylighting:	yes
Structure:	plug-in	Outside daylighting:	yes
Target Group:	engineers, architects		
Input & Editor		Export	
Input weather files:	integrated weather files	Format Export:	jpeg
Formal import:	import by CAD plugin	Graphical Output:	falsecolour images, diagrams
Terrain input or import:	import by CAD plugin	Parameter study:	not integrated
Urban middle obstructions:	object library		
Sun protection:	object library		
Reflection / absorption:	factors for reflections		
Libraries (Materials etc.):			

One of ArchiWizard's strengths is its intuitive user interface (see figure 3), which allows users who are unfamiliar with the software to get started easily. Its real-time result depiction and CAD import capability also deserve credit. Its compatibility with many CAD programs allows ArchiWizard to offer a high degree of flexibility in geometry inputs.

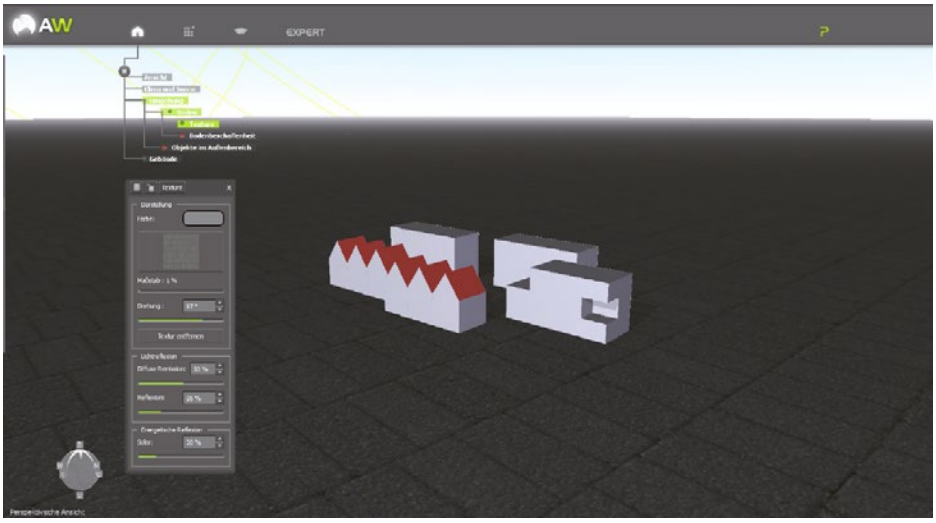


Fig. 3: Example for generating a 3D model in ArchiWizard (Source: Screenshot)

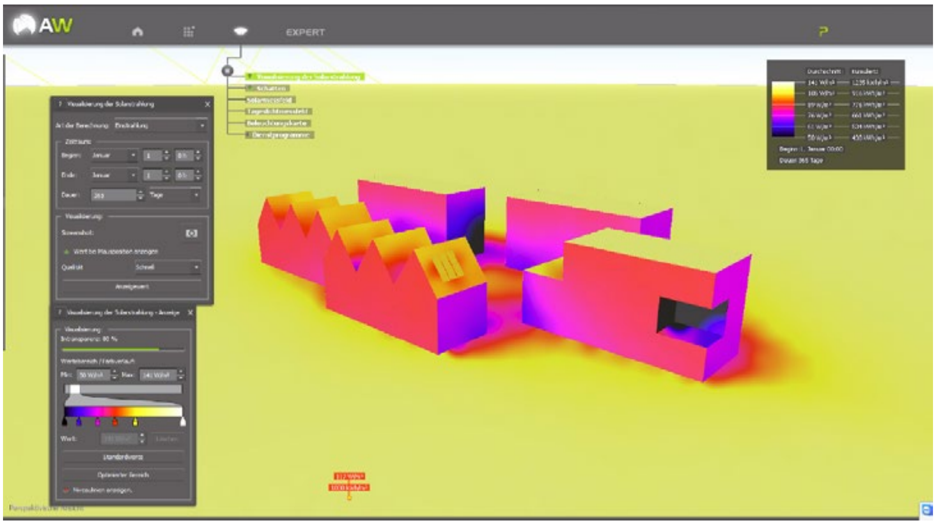


Fig. 4: Example for outcome as false-colour solar radiation (Source: Screenshot)

Figure 4 shows a false-colour image describing the solar radiation for a group of buildings.

ArchiWizard's weaknesses are primarily at the level of language. The translation from French to German and English was not uniformly successful at the time of testing, which leads to technically incorrect terms and user uncertainty. ArchiWizard's calculations are limited; at the time of this evaluation, only the integrated weather data sets could be used. The parametric studies revealed that surface reflection was not taken into account in the solar calculations. The software costs of € 2000 is high compared to the other tools analysed. A graphical comparison of some aspects is shown in figure 5.

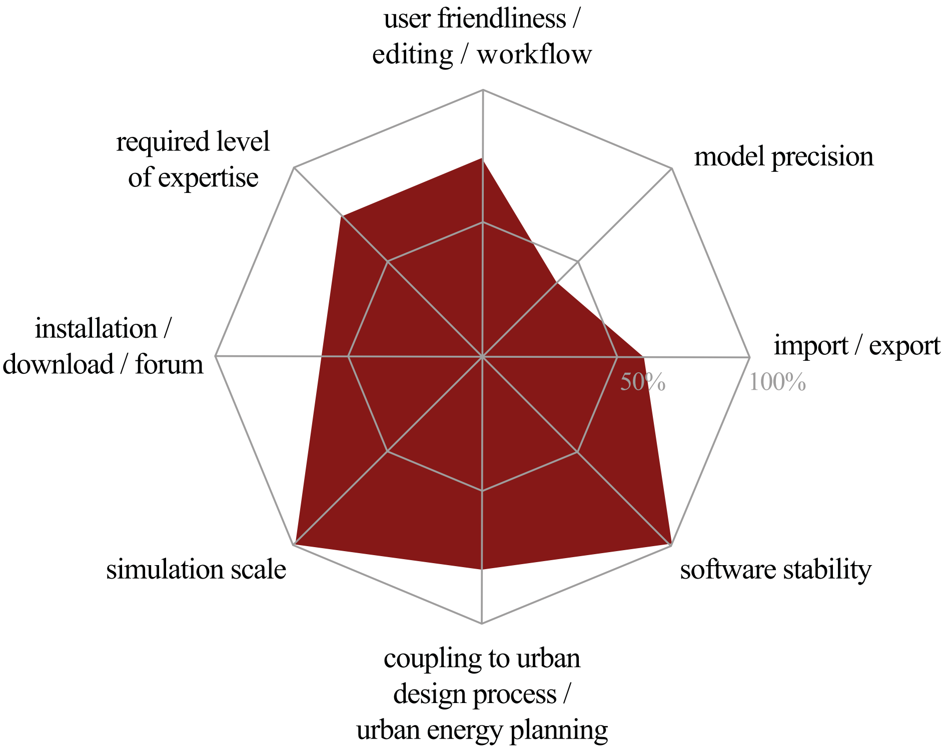


Fig. 5: Evaluation of ArchiWizard (Source: BUW, A. Saurbier)

2.2.3. DIVA (plug-in for Rhino and Grasshopper)

Table 2: Software Profile DIVA for Rhino

Developer:	Solemma
Year of Creation:	2011
Last update:	2012
Licence Price:	free Trial, 470 USD+ 995€ for Rhino itself
Language:	English
OS:	Windows
Structure:	plug-in
Target Group:	architects
Input & Editor	
Input weather files:	epw
Formal import:	modelling in Rhino / GH
Terrain input or import:	modelling in Rhino / GH
Urban middle obstructions:	modelling in Rhino / GH
Sun protection:	modelling in Rhino / GH
Reflection / absorption:	RGB reflectance, specularity, roughness & transmissivity definable
Libraries (Materials etc.):	defaults, but possible to customise / add

Calculation	
Calculation engine:	Daysim / Radiance, EnergyPlus
Shading model:	direct & diffuse shading model, surface and reflection properties taken into account
Thermal Model:	thermal analysis, only single-zone-spaces
Inside daylighting:	yes
Outside daylighting:	yes
Export	
Format Export:	image and numerical export (from project folder)
Graphical Output:	visualised within Rhino / via Radiance false colour tool
Parameter study:	not integrated

Diva as a plug-in for Rhino and Grasshopper was the most convincing tool evaluated. Its good user-friendliness, facilitated by a visual user interface, helps the user get started easily and learn the software quickly. Short simulation times allow quick insights into the results.

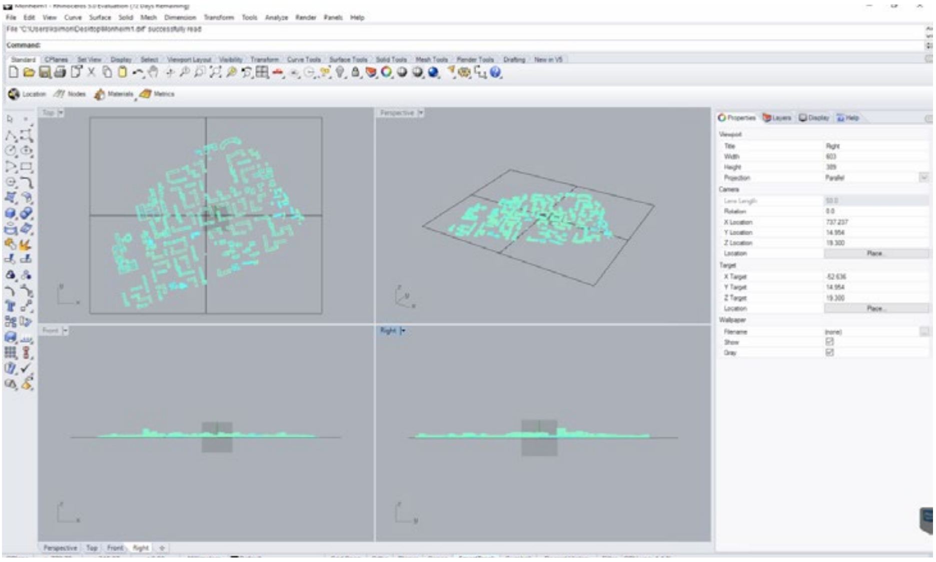


Fig. 6: Example of generating a 3D model in Rhino3D, Source: Screenshots

Depending on the purpose of the simulation, the requirements for building the 3D model differ e.g. concerning degree of detail and material properties. For the simulation of solar radiation into an urban district in which a scale of 1:1000 is used for planning, for example, a "block model" that represents the cubature including the roof areas and inclinations of individual buildings is sufficient, see figure 6. For more detailed planning (such as 1:200), the buildings must be modelled in a more differentiated manner so that window areas, balconies, dormers, etc. can be taken into account. In this phase, the materials of the individual components are important for the simulation because at this small scale, the calculated reflection is depicted using false-colour imaging, see figure 7. The more precise level of detail for the constructed model extends calculation time. It should be mentioned that thermal simulation is only available as a single-zone model. However, this is entirely sufficient for the urban planning scale.

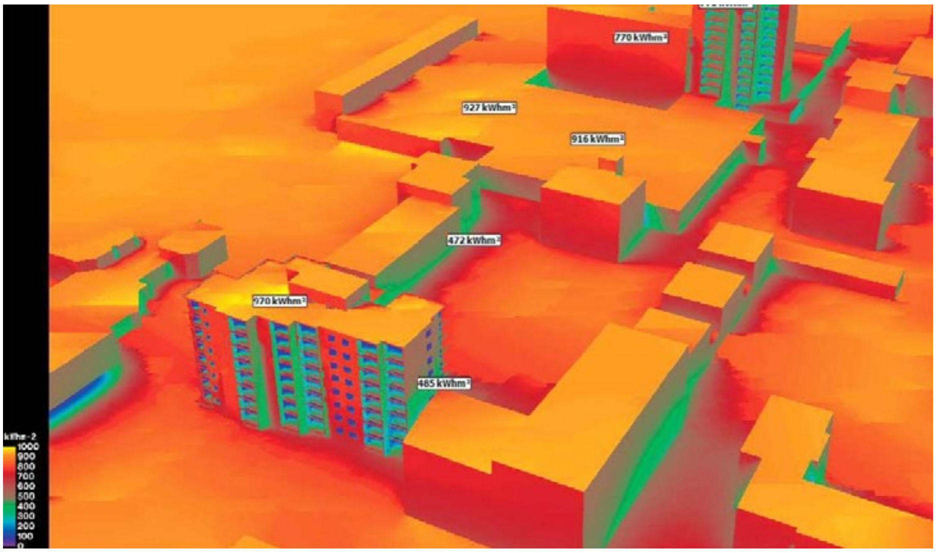


Fig. 7: Example of outcome as false-colour solar radiation; Source: Screenshots

The plausible calculation results in conjunction with the user-friendly program interface and the direct link to Rhino and Grasshopper gives Diva very high development potential. During the work, it became clear that there are occasional compatibility problems (version and language) between Rhino and Diva. A graphical comparison of some aspects is shown in figure 8.

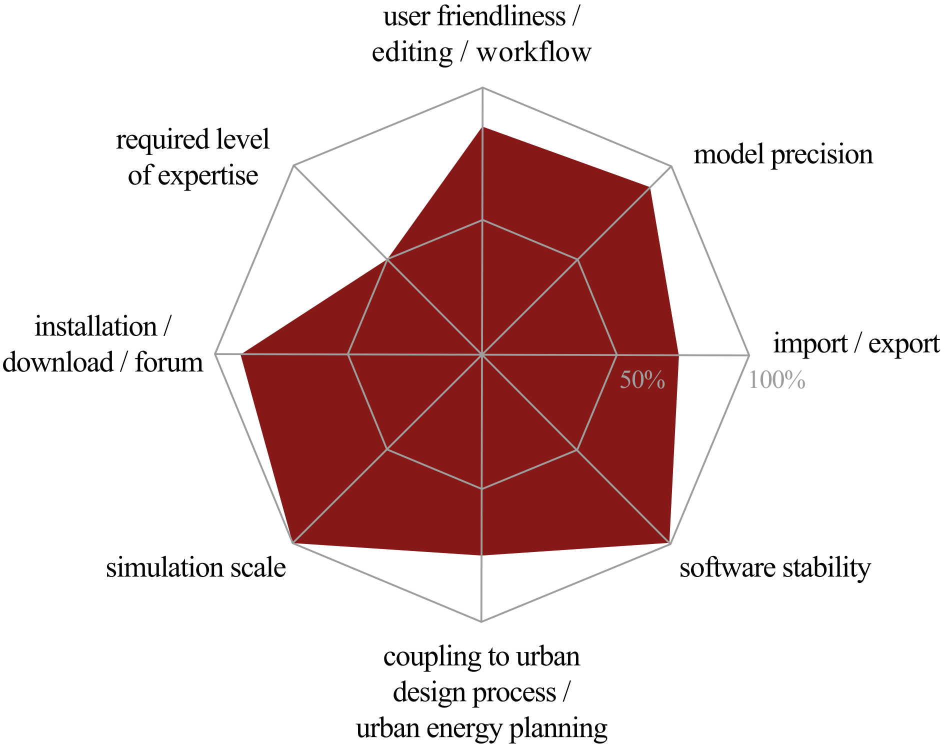


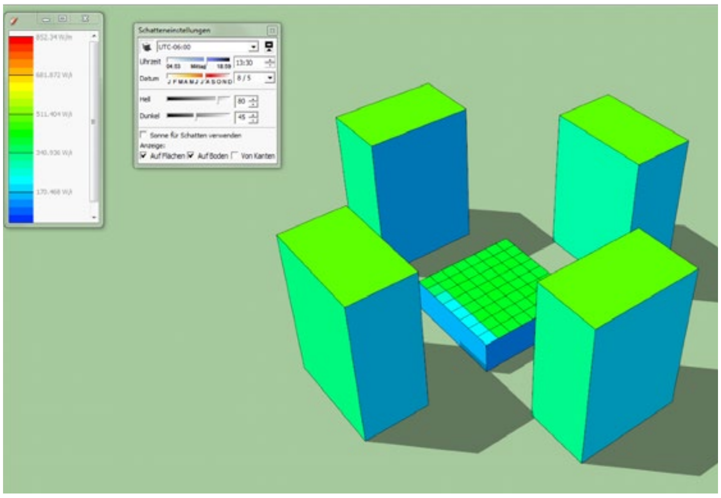
Fig. 8: Evaluation of DIVA (Source: BUW, A. Saurbier)

2.2.4. OpenStudio (plug-in for SketchUp)

Table 3: Software Profile Open Studio

Developer:	NREL	**Calculation**	
Year of Creation:	2010	Calculation engine:	EnergyPlus
Last update:	01/2014	Shading model:	direct and diffuse shading model surface properties are taken into account
Licence Price:	free		
Language:	English		
OS:	Windows	Thermal Model:	multi zone
Structure:	plug-in	Inside daylighting:	yes
Target Group:	engineers, developer	Outside daylighting:	no
Input & Editor		**Export**	
Input weather files:	epw	Format Export:	csv, sql, eso
Formal import:	dwg, dxf, jpeg, pdf	Graphical Output:	no - only real time result viewing
Terrain input or import:	no - static monthly values for ground reflection	Parameter study:	ParametricAnalysisTool
Urban middle obstructions:	shading objects possible, but no library		
Sun protection:	shading objects possible, but no library		
Reflection / absorption:	material dependent / individually definable factors for absorption		
Libraries (Materials etc.):	default ASHRAE, editable		

The OpenStudio plug-in's strengths are clearly in the simple, quick model generation in SketchUp. Following successful calculation, it is also possible to display and analyse results in the 3D model in SketchUp in real time, see figure 9. During the evaluation, it became clear that the simulation scale is very heavily dependent on the available computing power. A model with 25 building objects can be calculated in an hour with a modern laptop without any problem.



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☐ Sonne für Schatten verwenden

☑ Auf Flächen ☑ Auf Boden ☐ Von Kanten

Fig. 9: Interface OpenStudio - Solar radiation in real-time as false-colour image (Source: Screenshot)

An opaque user interface means that getting started with this software requires a high degree of technical knowledge. The plug-in adds a new toolbar to SketchUp; this allows the user to generate analysis groups with buildings for later simulation. The work process is simple due to the simplicity of modelling in SketchUp, but not clear for a first-time user. This means that the user first has to inquire in the forums about how the plug-in's functions work in order to arrive at a successful simulation. The impression of the high level of necessary technical knowledge is exacerbated by the necessity of processing the simulation file in the IDF editor before each simulation. The IDF editor is the EnergyPlus software's basic input interface and is exclusively text-based. Various graphical plug-ins are available to facilitate the geometry input, one of which is OpenStudio for SketchUp. This interface with the IDF editor or the EnergyPlus software can lead to a high level of flexibility if the user generates scripts himself, but this requires complementary programming knowledge. The EnergyPlus software was developed on behalf of the U.S. Department of Energy[9] and is freely available. It offers complex thermal simulation capability in the areas of heating, cooling, ventilation, and water heating. It has no graphical input interface and writes results as text files. The detailed programme structure is shown in figure 10.

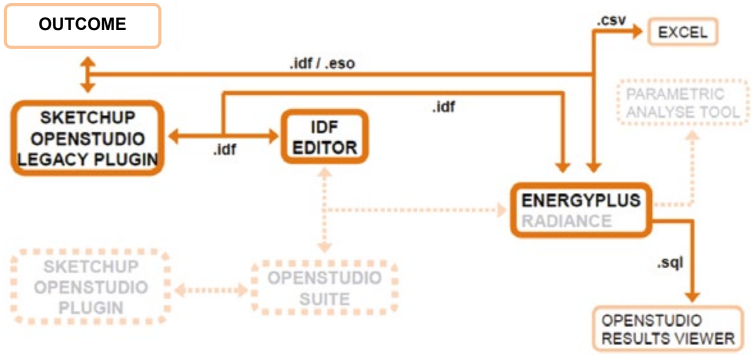

Fig. 10: Programme structure (Source: BUW, A. Saurbier)

In addition to the high degree of necessary expert knowledge, the software's instability became obvious during the evaluation. The simulation file can be irreparably damaged during simulation, and the complex editing in the IDF editor can easily result in input errors and thus to implausible and incorrect calculation results. A graphical comparison of some aspects is shown in figure 11.

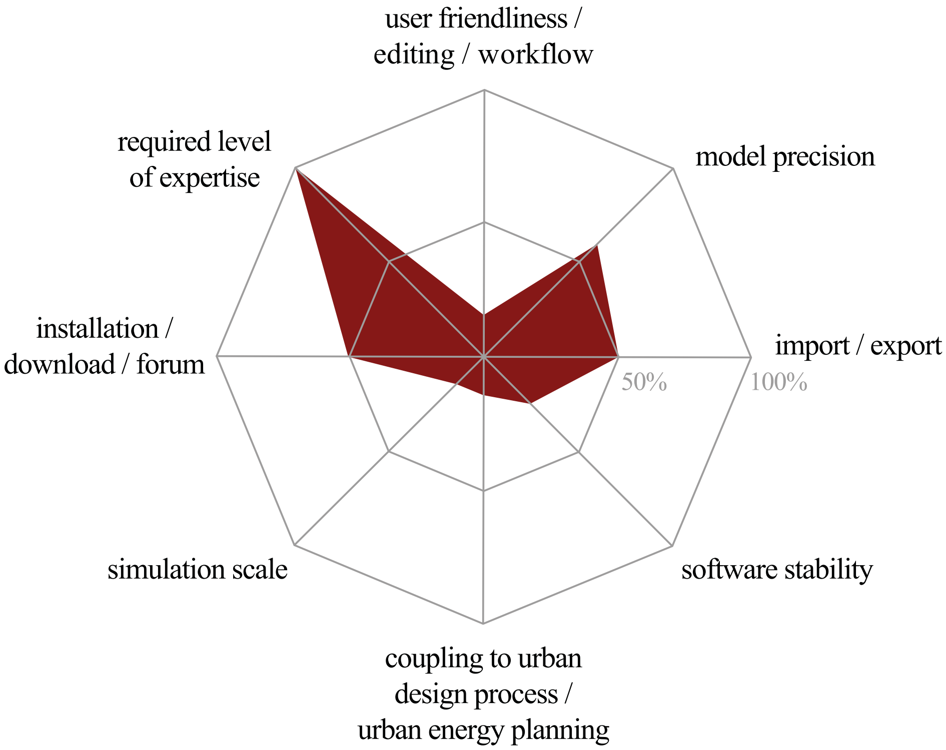

Fig. 11: Evaluation of OpenStudio (Source: BUW, A. Saurbier)

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[9] See http://apps1.eere.energy.gov/buildings/energyplus/ and http://www.energy.gov/

2.2.5. Autodesk Ecotect

Table 4: Software Profile Autodesk Ecotect

Developer:	Andrew March	Language:	English
Year of Creation:	2008	OS:	Windows
Last update:	2011	Structure:	standalone
Licence Price:	free for students	Target Group:	architects, urban planners
Input & Editor		**Export**	
Input weather files:	integrated & epw	Format Export:	image files
Formal import:	dwg, dxf & many more	Graphical Output:	diagrams, 3D views
Terrain input or import:	yes, but formal import	Parameter study:	not integrated
Urban middle obstructions:	yes, but formal import		
Sun protection:	yes, but formal import		
Reflection / absorption:	material dependent / individually definable factors for reflection		
Libraries (Materials etc.):	material library, editable		
Calculation			
Calculation engine:	CIBSE, Radiance		
Shading model:	direct & diffuse shading model		
Thermal Model:	multi zone		
Inside daylighting:	yes		
Outside daylighting:	yes		

The first impression made by Autodesk Ecotect is a positive one. The user interface's graphical similarity to other Autodesk products makes it easy to get started with this software and guarantees the user an overview of the available functions. Different simulations can be run, e.g. solar radiation or shading calculation, see figure 12 and figure 13.

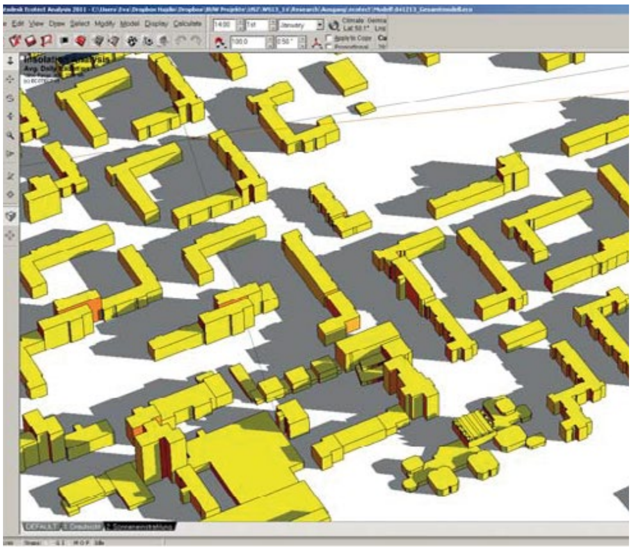

Fig. 12: Autodesk Ecotect interface (Source: Screenshot)

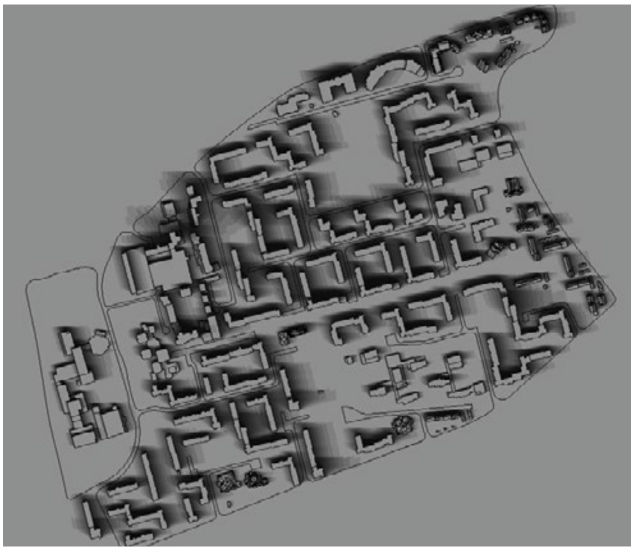

Fig. 13: Autodesk Ecotect shading calculation for the 21st of September (Source: Screenshot)

However, a deeper evaluation of the calculation results reveals significant weaknesses. It was observed that definable reflection factors and the associated surface reflection of various materials were not taken into account in the calculations. The results of the Autodesk Ecotect solar potential analysis are qualitatively plausible, but at the quantitative (absolute) level, the calculation results are obviously incorrect. An evaluation of the results for the selected location (Wuppertal) showed that the calculated radiation was consistently too high and occasionally exceeded the maximum available solar radiation at that location. This discovery calls the entire simulation and the effort involved in it into question. Given a very long simulation period of up to six hours that is constantly susceptible to unpredictable crashes, the effort does not seem practicable.

This criticism should be qualified by the fact that Autodesk Ecotect was released in 2008 and has not been further developed since an update in 2011. Updating this software with current levels of knowledge would make it significantly more usable. On the positive side, the software allows the generation of solar position diagrams and shadow studies, and thus an urban planning analysis of public areas and spaces in addition to the energy applications. A graphical comparison of some aspects is shown in figure 14.

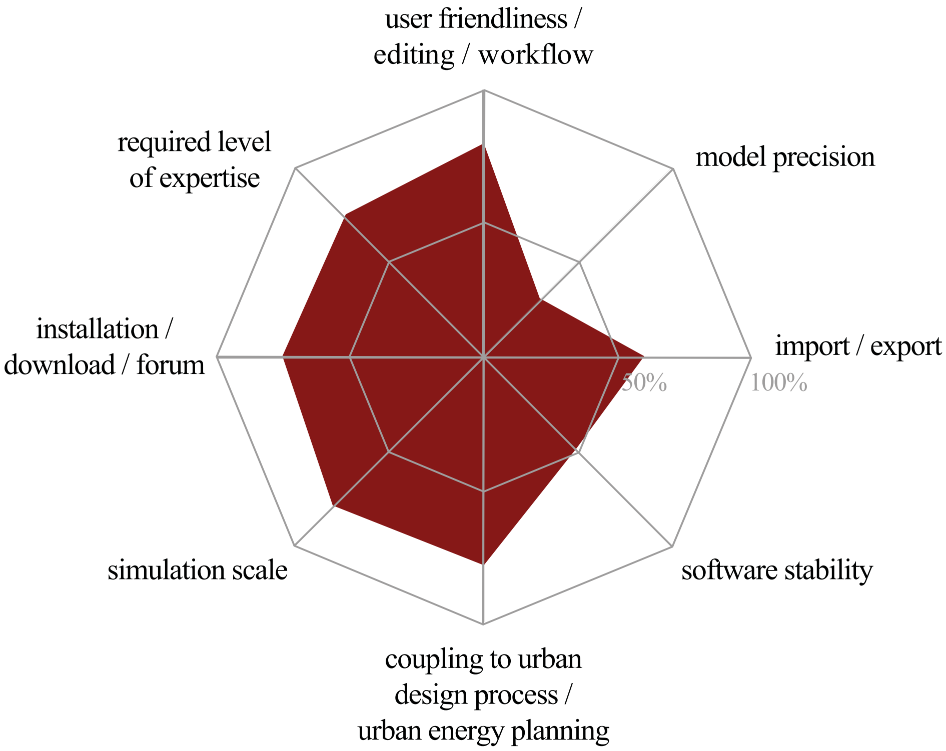

Fig. 14: Evaluation of Autodesk Ecotect (Source: BUW, A. Saurbier)

2.3. Interim conclusion of the German partners

The differences among the analysed software tools are large, both in functional scope and operation, see figuare 15. Only “Diva for Rhino3D” gets high marks for ease of use and precise calculation results. Its short initiation period for new users, its high computing power, and its visual results in the form of false-colour imaging makes this tool eminently suitable for use in training and continuing education. Number-based output of the calculation results for further use in other software tools and a version for the Mac OS would be welcome.

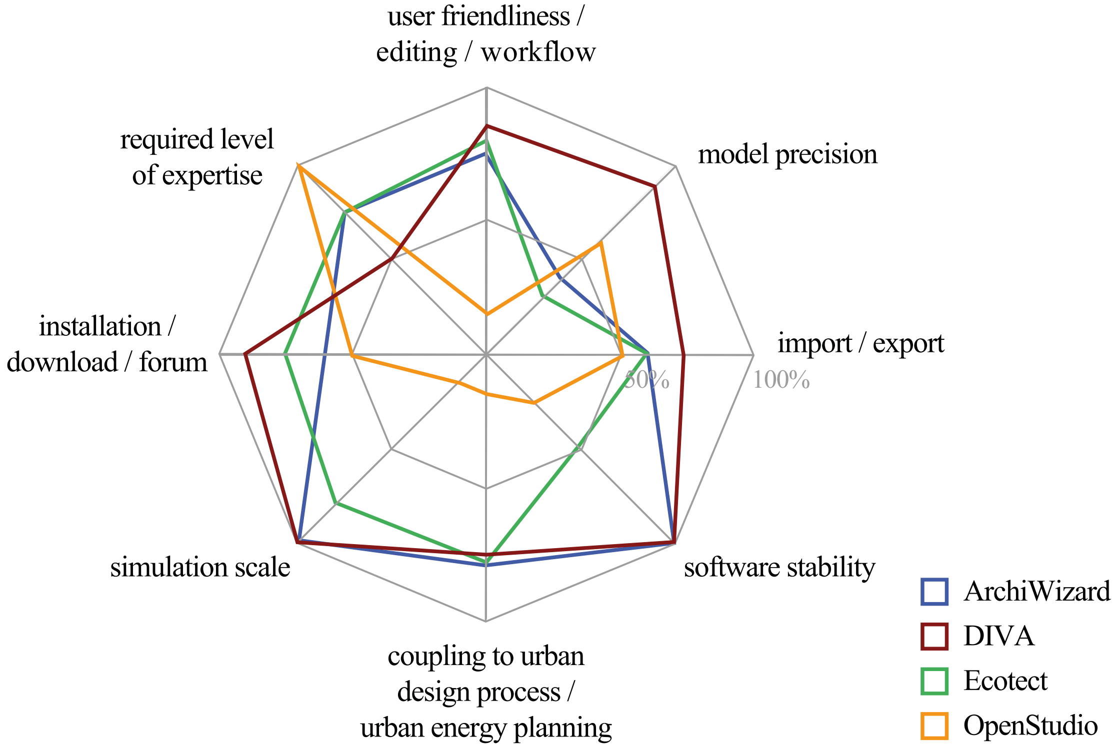

Fig. 15: Evaluation – Summary of the Tools (Source: BUW, A. Saurbier)

For students’ design work at universities “Diva for Rhino3D” seems to be a good solution for simulating solar potentials. This depends on the fact that Rhino3D is a common 3D modelling software at various universities. The well-known interface is the reason why “Diva for Rhino3D” seems to be more user-friendly and self-explaining than other tools.

For use as a decision aid for practising planners, especially urban planners, all tools display significant deficits. Although some urban planners are working for instance with “Diva for Rhino3D”, they does not necessarily use plug-ins like “Diva for Rhino3D”. Some architects or planners in practice use these tools only by working in transdisciplinary collaboration. Another reason is definitely the lack of interfaces to tools commonly used in urban planning, such as geographic information systems, hampers practical use. Geographic information systems are a preferred tool of urban planners, because they allow a digital compilation of space-related data in the form of a geometrical representation, sometimes in 3D, and linked to numerical databases. The gap between GI systems and solar tools could be bridged with a new three-dimensional layer in the form of precise building representation using false-colour imaging for roof and façade areas and numerical radiation values that is input into the commonly used GI systems.

However, if urban planners began to use the software tools examined here, they could definitely garner insights into open space design provided by shadow studies and into the general handling of daylight in the design process.

3. Evaluation of tools for solar energy utilisation in urban planning at universities in Norway

The University of Science and Technology (NTNU) in Trondheim is actually working in a field of solar energy in urban areas analysing different cases studies in Norway. In particular these research activities are focused on how the simulation tools could be used for preventing urban and design failures in term of solar accessibility, solar potential and rights of light.

The study conducted on a Trondheim case[10] demonstrated that solar potential analyses in the early design phases needs to be part of the planning process in order to avoid some future problems caused by overshadowing effects due to newly developed nearby buildings and insufficient urban regulations such as right of daylight. The work presents a case study of an office building with a façade integrated PV system located in Trondheim. Once the building was complete, the PV system was subject to significant overshadowing created by two nearby buildings within the urban surrounding. The conducted study demonstrated how to optimise, applying a multi-level simulation approach, the solar energy potential of the building in order to propose improved alternatives to the current system.

In the first level the maximum solar potential on the building envelope in an unobstructed scenario has been calculated. The second level examined the shading effect on the building in its urban context. The analyses of these levels were performed by using *DIVA for Rhino* and they allowed localising the areas of the building envelope with the highest solar potential. In the third level, the energy output of different solar technologies (solar thermal and PV) were evaluated by *PVsyst* and *Polysun*. The results demonstrate that the solar potential analysis in the early stage is a necessary and important practice for choosing the most performing system.

Regarding the education activities, the Department of Architecture and Technology at NTNU will offer two courses in the Master of Science in Sustainable Architecture[11] .

In the course of *Climate and built forms* (first semester), the students learn to analyse local site and climate and their consequences on built form. Particular attention is dedicated to the daylight, solar access and shading principles; ventilation; wind and precipitation; climate-adapted design of outdoor-indoor areas.

The contents of the *Integrated Energy Design* course (third semester) are mostly related to energy systems and services and their integration in architecture. During the semester, the students develop a conscious approach in treated solar energy challenges related to the renovation of existing buildings and cultural heritage. In addition, the students learn how to use design and evaluation tools in integrated design methodology for developing and verifying their architectural and technological solutions critically and iteratively.

In these courses, NTNU had a range of practicing professionals with municipal experts, designers and architects that give lectures, guide students in developing the design project along the semester during the studio class.

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[10] Good CS., Lobaccaro G., Hårklau S., Optimization of solar energy potential for buildings in urban areas – a Norwegian case study, Energy Procedia, Volume 58, 2014, Pages 166-171)

[11] Reference of the course: https://www.ntnu.edu/studies/mssusarc

3.1. Evaluation of existing taught tools

The evaluation of the existing tools was estimated from a questionnaire invented by the University of Wuppertal. In this part of evaluation, students were asked to rate the software in five different aspects in which the form of the questionnaire was organised: software general information, input and editing, calculation, modelling output and summary, see appendix 1.

This form was submitted to 12 students attending the cycle of study in Master of Science in Sustainable Architecture at NTNU. After completing the course of *Climate and built forms* (AAR4532 and AAR4832) and *Integrated Energy Design* (AAR4926), the students have filled out the form in order to evaluate their grade of satisfaction (from 0% to 100%) in using two tools, *Ecotect Autodesk Analysis* taught in the *Climate and built form* course (1st semester), and *DIVA for Rhino* and *DIVA for Grasshopper* taught in *Integrated Energy Design* course (3rd semester).

3.1.1. Results of the evaluation

Only two out of 12 interviewed students had experience of working with both the software (Fig. 18). The students were supposed to rate the specific software from 0% to 100% of satisfaction grade for each specific section.

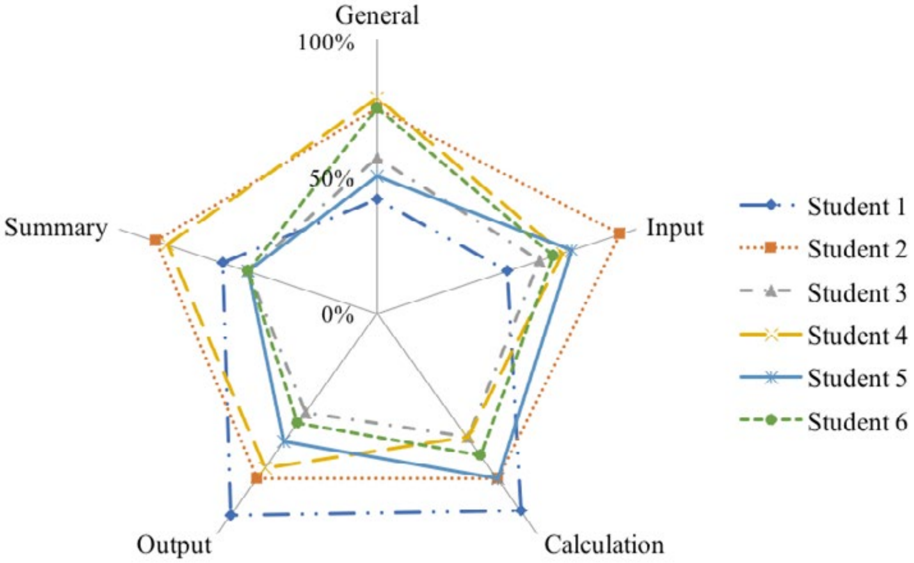

Fig. 16: Result of survey for DIVA for Rhino

According to the survey, different opinions were observed using DIVA for Rhino: half of the students rated this software generally in or above the average level (Fig. 16).

In particular, the student 3, 5, and 6 considered the software as fairly user-friendly, easy to extract different formats from original file, different range of input and materials and easy to use and understand the software. The Student 1, 2 and 4 rated DIVA for Rhino rather (around 50% of satisfaction) compatible and stable in the categories mentioned in above. Based on the overall results from the questionnaire, DIVA for Rhino could be considered user-friendly, stable and easy to operate with in a very average range.

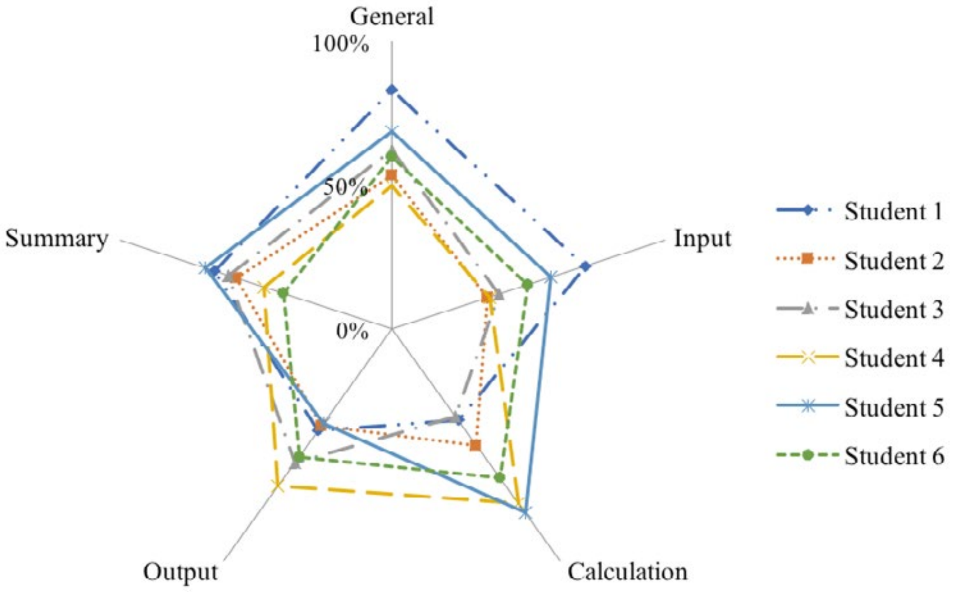

Fig. 17: Result of survey for ECOTECT

Regarding to the evaluation of Autodesk Ecotect Analysis, students had more homogeneous opinion about this software and considered it overall user-friendly, stable, easy to input data, model, simulate and analyse. Results from their responses are illustrated in figure 17.

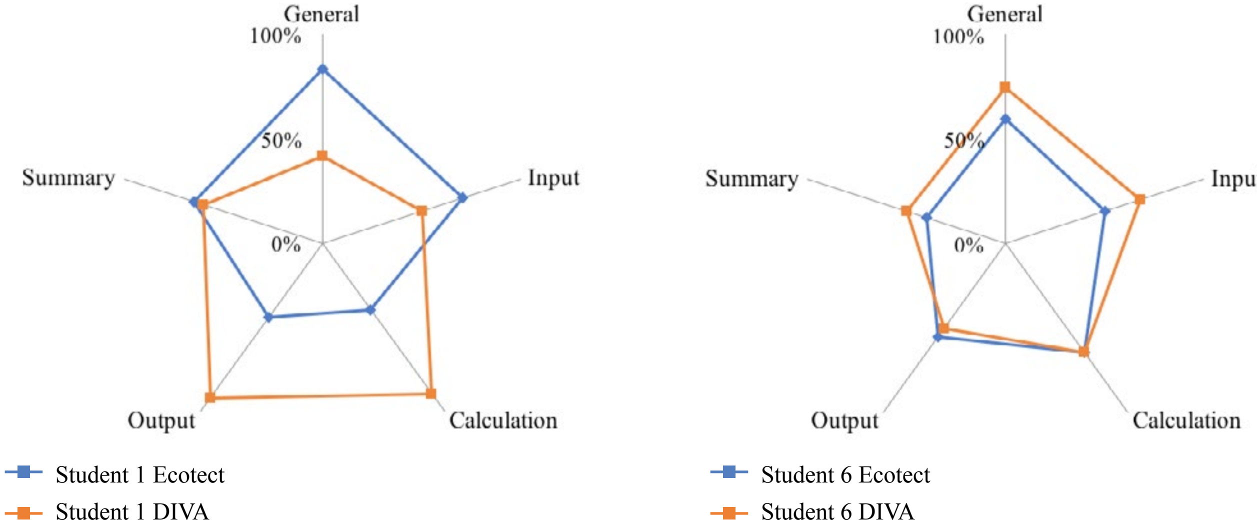

Fig. 18a and Fig. 18b: Comparing ECOTECT and Diva - Student 1 and Student 6

Figure 18a and Figure 18b are showing the responses from the two students who used both the software. As it is presented in the charts these two operators have very different impression from the software. Student 6 considered both the software in almost same level while Student 1 rated them with a very different scale. However, both students have a similar total opinion for Autodesk Ecotect Analysis while Student 6 has different total result for DIVA for Rhino compared to Student 1 (Fig. 18b).

As it is illustrated in Figure 16 and 17, students had more homogenous opinion towards Autodesk Ecotect Analysis than DIVA for Rhino when comparing the software according all defined categories in the questionaire. However, DIVA for Rhino has slightly higher satisfaction than Autodesk Ecotect Analysis according the interviewed students (Fig. 19).

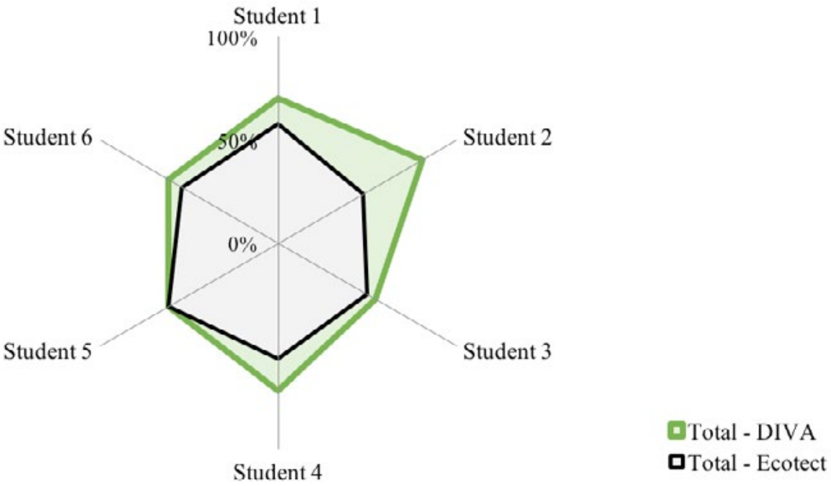

Fig. 19: Ranking Autodesk Ecotect Analysis and DIVA for Rhino according to the master students participating in the survey

The form will be submitted to other students of MSc in Sustainable Architecture during the next cycle of study at NTNU in order to get more feedback from the students and their experience in using analysis tools.

4. New teaching tool developments: Solar Potential Analysis

Table 5: Software Profile Solar Potential Analysis

Developer:	KIT Karlsruhe	**Calculation**	
Year of Creation:	2008 - 2017	Calculation engine:	internal engine (future integration of WUFI & Radiance)
Last update:	development		
Licence Price:	free	Shading model:	shading over a day (hourly) and as a sum of shading
Language:	English, German		
OS:	web-based	Thermal Model:	still not possible
Structure:	standalone	Inside daylighting:	still not possible
Target Group:	education	Outside daylighting:	Radiation based on a simplified internal engine for a very fast calculation (the period of time is selectable)
Input & Editor			
Input weather files:	epw		
Formal import:	pdf and image files		
Terrain input or import:	still not possible	**Export**	
Urban middle obstructions:	still not possible	Format Export:	image files, csv
Sun protection:	still not possible	Graphical Output:	radiation and shading maps
Reflection / absorption:	still not possible	Parameter study:	not integrated
Libraries (Materials etc.):	not yet		

As a part of the framework project “Lernnetz Bauphysik” (Building Physics Learning Network) the Solar Potential Analysis – EnOB-Lernnetz has been developed as an independent tool for urban-based solar potential analyses. The Solar Potential Analysis is distinguished from the previously addressed tools by being non-commercial with the education sector as the main target group.

The project is based on the idea of enabling a simple application of simulations for teaching purposes with a minimum of software requirements. The tool is suitable for basic urban planning teaching and for supporting solar potential analyses for planning tasks at the district level.

The tool was first tested in a student seminar in 2013, but was not working properly back then. Mayor changes were necessary, one of which was to run it as a local Java applet instead of as a Java browser Plugin. Good experiences with the new approach have been made in the context of compact courses, such as summer academies. Exemplary is EnEff:Stadt’s interdisciplinary “Cities in Transformation” Summer School, which was held in Berlin in 2016, see Task 51 Report/ D2.

Advantageous are the low system requirements, the platform-independent work and the ability to quickly achieve conceptual findings based on the calculations.

The urban-based solar potential analysis combines simulation tools for calculating solar hours shading and solar irradiation in a Java-based and platform-independent application. Unlike solar registers, which exclusively display solar irradiation totals for roof surfaces of existing buildings, the vertical and inclined surfaces are also taken into account in the Solar Potential Analysis system and included in the calculations. The simulations are therefore suitable for investigating structural changes in existing urban districts or parameter studies with new-build schemes. The Solar Potential Analysis functions are currently limited to urban-based solar potential analyses on flat sites without horizon shading or influences by trees.

The calculation tool uses a central CAD model and accesses a common database that provides the additional data required for the calculations. The CAD model is generated in 3D via a Project Editor, as part of the tool. The 3D Editor is using predefined elements. Predefined elements are buildings with different footprints (rectangular, L- shaped, comb-shaped, free-form) and roof shape (saddle roof, flat roof, hip roof, pent roof), which can be inserted in different heights, numbers of levels and sizes.

The simulations are location-based and refer to an online weather database from the US Department of Energy at https://energyplus.net/weather. Internet connection is needed to import the weather data. The standard weather dataset in offline mode is Mannheim, Germany.

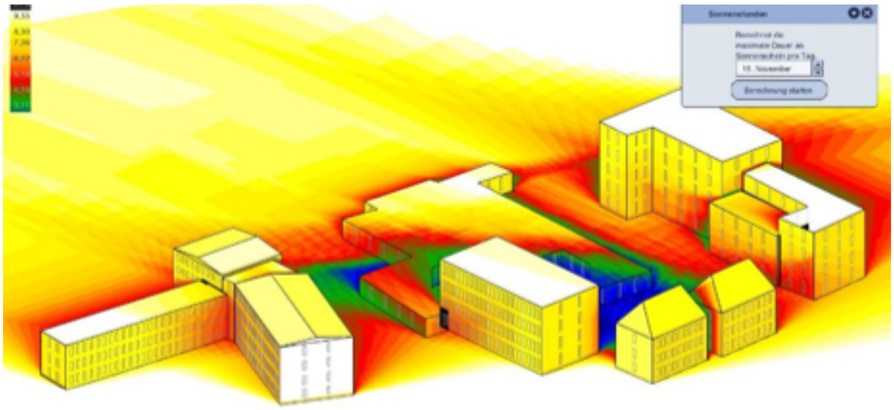

Fig. 20: False-colour picture, Calculation result of daily solar hours presented in an exportable false-colour picture.

Direct and diffuse radiation is taken into account in the calculations as well as ground reflection (set constant to 20%). An example of a calculation result is shown in figure 20. However, only the shading from direct radiation is taken into account for simplification purposes. The reflections from building surfaces are ignored. The solar irradiation on inclined, various oriented surfaces is calculated using the same algorithm deployed by the Therakles thermal simulation tool at:
https://projektinfos.energiewendebauen.de/fileadmin/user_upload/therakles_2_handbuch.pdf

The origin for the Solar Potential Analysis system comes from a research initiative funded by the German Federal Ministry of Education and Research's "Multimedia-Based Learning Network Building Physics" (2001 and 2004). The core work stems from Karlsruher Institute of Technology (KIT) and was developed as part of a doctorate project (Arne Abromeit). Project partners at the time were the departments for building physics at Darmstadt, Karlsruhe, Kassel, Stuttgart and Weimar universities as well as at Biberach University of Applied Sciences. The project's main objective was to provide example building physics and calculation methods on the Internet in order to be able to use the new possibilities of this medium in teaching. Since 2007, the work within the EnOB research initiative has been funded within various projects. The "Solar energy use in the urban context" project (2015-2017) completed and stabilised the Project Editor as well as the calculation module for the urban-based analyses.

Projector editors for individual buildings and rooms as well as calculation modules for the indoor environment and lighting of interior spaces have been created but are not yet available for the application.

The current project package is free of charge and can be downloaded under the following link:
http://solarpotential-fbta.ieb.kit.edu

The user interface can be activated and used in both German and English.

5. New research tool developments

Besides the commercial solar tools, few urban energy simulation platforms have been developed by international research institutes and mainly during the last decades. They enable expert urban analysis going much beyond a solar potential study, integrating a multitude of other studies like long-wave irradiance simulation, computational fluid dynamics (CFD) simulation, outdoor comfort, urban energy infrastructure sizing etc. in order to design and optimise sustainable energy and urban planning strategies.

These urban energy simulation platforms require a higher expertise level from their users. Ease-to-use and user-friendliness are not priorities of these software developments. However, some of these tools are coming slowly to the market, either commercialised by spin-off companies of the research institutes (kaemco for the software CitySim[12]), or made available as freeware (Software UMI[13] from MIT). These simulation platforms designed for integrated urban studies could represent the future of the existing commercialised solar tools. Therefore, in this section we introduce some of these innovative and powerful urban simulation platforms, detailing their main features and their development framework.

5.1. Solene

Development story and aims
The development of the software Solene is a long story which started in 1980 in the research center of the Architecture School of Nantes (CERMA). Since, Solene has been continuously developed in the framework of a dozen of research projects and applied to numerous urban planning projects (new districts as Confluence of Lyon, Ile de Nantes etc.).
Solene aims originally at architects and urban planners in the design of new districts, by simulating the influences of urban planning decisions on the energy demand and thermal comfort.

Features and functionalities
The actual Solene-microclimate model[14] allows for the integrated consideration of:

- radiant transfers, including long-wave radiation;
- thermal conduction and storage in walls and soils;
- airflow and convective exchanges;
- evapotranspiration from natural surfaces like vegetation and water ponds or humidification systems;
- building energy balance (i.e. energy demand or indoor temperature).

These features are made possible through the coupling of a thermal building model, a radiation model and the CFD model of Code-Saturne, at the different scales of the district.

The thermal building model of Solene is based on a multi-zone building nodal network model, allowing for the calculation of the hourly heating and cooling demands as well as the simulation of the wall and roof temperatures considering also the outside long-wave radiation exchanges. This building model also calculates the Mean Radiant Temperature (MRT) and the resulting indoor thermal comfort indicators: The Predicted Mean Vote (ISO 7730), the Physiological Equivalent Temperature and the Universal Thermal Climate Index.

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[12] Robinson, D., Haldi, F., Kaempf, J. et al. (2009). CitySim: Comprehensive Micro-simulation of resource flows for sustainable urban planing.

[13] Reinhart, C.F., Dogan, T., Jakubiec, J.A., Rahka, T., Sanf, A. (2013). UMI – An urban simulation environment for building energy use, daylighting and walkability. In: Proceedings of Building Simulation Conference 2013.

[14] Musy, M., Malys, L., Morille, B., Inard, C. (2015). The use of SOLENE-microclimat model to assess adaptation strategies at the district scale. In Urban Climate 2015.

The short-wave and long-wave radiation exchanges are simulated based on a radiosity calculation with diffuse reflection.

State of development, validation and perspectives

Concretely, SOLENE is a package of 200 executables which can be called with external scripts. It integrates functions to import geometrical and semantic input files like the GMSH formats (geoSHP, msh, stl), GIS typical file formats (Shape File and database file), Salomé, ArchiCAD and appli web (JSON). A 3D visualisation in 3D VTU (freeware Paraview) is also integrated. These features make it possible to calculate customised values related to numerous aspects of the urban microclimate (fluid dynamics, humidity transport, albedo calculation, radiation exchanges, thermal comfort).

An integration of these executable and scripts into the interface of Google SketchUp is on-going. Besides the user-friendliness improvement, this development will also allow for the modification of 3D geometry during the integrated process.

The validation of the diverse models of SOLENE is an on-going process. Its thermo-radiative models as well as the green wall model have already been validated by means of comparison with measurement data in a district of Nantes. The coupling of thermo-radiative and CFD models still requires to be validated.

5.2. CitySim

Development story and aims

The Software CitySim is the inheritor of the SUNTool (Sustainable Urban Neighbourhood Modelling Tool) developed in the framework of the eponym European project from 2004. Its development was realised over the last decade at the Ecole Polytechnique Fédérale de Lausanne (EPFL). The CitySim software has improved modelling capabilities that allow for the simulation of thousands of buildings (towards the city scale) in a reasonable computing time frame. Since 2013, the research on the software is continued at EPFL while the installation, maintenance, documentation and training services are ensured by the EPFL spin-off company kaemco (www.kaemco.ch).

The software is aiming at providing a decision support for urban energy planners and stakeholders to minimise the net use of non-renewable energy sources as well as the associated emissions of greenhouse gases at scales from a small neighborhood to an entire city.

Features and functionalities

The software CitySim is composed of CitySim Designer, a Graphical User Interface (GUI) set-up to facilitate the 3D geometrical and thermo-physical description of buildings as well as the visualisation of simulation results, and CitySim Solver, an Integrated Solver (IS) for simulating the energy fluxes of the model.

CitySim Designer allows for the parameterisation and modification of:

- the placement, shape and orientation of the buildings that can be imported in DXF format
- the attribution of the physical and occupational characteristics of the buildings (such as glazing ratio, glazing type and insulation thickness)
- the solar protections and natural ventilation of the buildings
- the physical characteristics of photovoltaic panels

It relies on a default database of construction, schedule and systems libraries in order to quickly parameterise a new district model with default data at the masterplan stage.

CitySim Solver (a command line executable) includes a series of algorithms allowing for the simulation at hourly time step of:

- shortwave radiation on the surfaces of the scene such as facades and roofs, based on the Simplified Radiosity Algorithm (see figure 21)
- indoor and outdoor illuminances of buildings
- heating and cooling demands, based on a resistance-capacitance network model
- surface temperatures of buildings and grounds (including the long-wave radiation exchanges, see figure 22)
- final and primary energy fluxes required and produced by the cogeneration heat and power, boiler, heat pump and solar systems (thermal and PV)

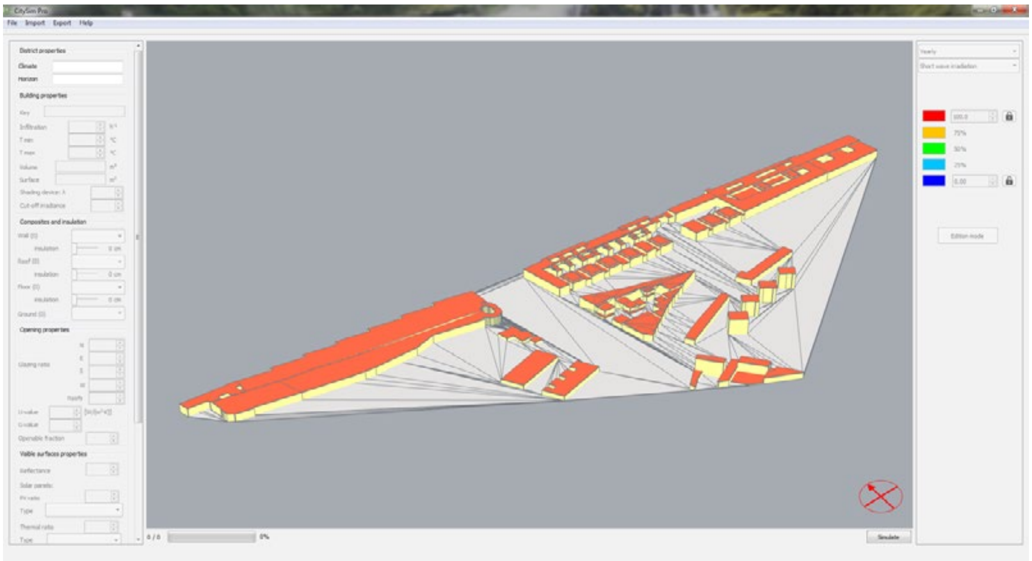

Fig. 21: Screenshot CitySim Pro – Building characteristics attribution on a case study in Paris

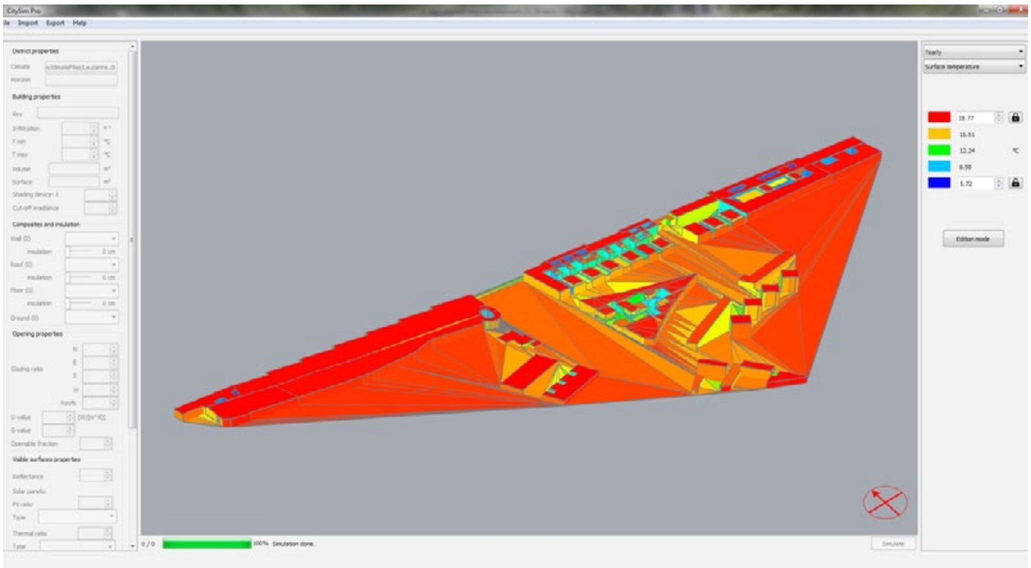

Fig. 22: Screenshot CitySim Pro – Simulation results of the average annual surface temperature of a case study in Paris

State of development, validation and perspectives

In order to improve the functionality and usability of the graphical user interface, CitySim Designer is progressively abandoned in favor of a new interface named CitySim Pro. For the latter, a group of alpha-users which comprises undergraduate and graduate students, as well as urban planners and building energy simulation experts, was set-up in Europe and abroad, their feedback contributing to the software improvement. CitySim Pro will remain free for academic purposes.

The actual features of CitySim Pro comprise:

- the import of 3D geometrical files (AutoCAD 2000 DXF)
- the attribution of the physical and occupational characteristics of the buildings (such as glazing ratio, glazing type and insulation thickness)
- the attribution of physical characteristics of photovoltaic panels
- the export of the geometry in different 3D formats (DXF, CityGML, STL)
- the export of the simulation results in tab-separated variable format (TSV)

CitySim Pro embeds the latest Solver developments realised at EPFL and will be continuously updated with new features. The short (less than one year) development perspectives of CitySim include:

- the import and export of CityGML with Energy ADE files
- the development of an evapotranspiration model for the ground
- the quantification of the outdoor human comfort at the city scale, by the Mean Radiant Temperature, the Index Of Thermal Stress and the COMFA* model
- the modelling of trees and their impact on pedestrians' comfort
- the co-simulation with EnergyPlus as Functional Mockup Unit (FMU)

Middle term (less than two years) development perspectives include:

- the coupling with a wind model, able to locally quantify the wind speed and direction in the built environment

Field surveys within residential and non-residential buildings, as well as World-class building energy analysis software such as ESP-r[15], were used to validate the novel models and algorithms implemented in CitySim. Results obtained by the software CitySim were further validated with on-site monitoring[16] as well as with the standard BESTEST procedure[17].

5.3. SimStadt

Development story and aims

The urban energy simulation platform SimStadt is commonly developed by the departments Energy and Geo-informatics of the University of Applied Sciences Stuttgart, in the framework of an eponym project since 2012 (www.simstadt.eu).

This platform aims at supporting urban planners and city managers with defining and coordinating low-carbon energy strategies for their cities, with a variety of multi-scale energy analyses. It shall also allow scientists developing and testing new simulation algorithms and exploring the potential of new data sources.

SimStadt design is marked by two particular features: 1- it is based on the open 3D city model CityGML and, 2- its workflow-driven structure is highly modular and extensible. These particularities allow a potentially

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[15] J. Kämpf and D. Robinson. A simplified thermal model to support analysis of urban resource flows. in Energy & Buildings, vol. 39, num. 4, p. 445-453, 2007

[16] Coccolo, S., Kaempf, J., Scartezzini, J.-L. 2015. The EPFL campus in Lausanne: new energy strategies for 2050. 6th international Building Physics Conference

[17] Walter, E., Kaempf, J. 2015. A verification of CitySim results using the BESTEST and monitored consumption values. 2nd IBSA-Italy Conference.

unlimited variety of urban analysis, benefiting from the big geo data possibilities.

Based on the open city model CityGML[18] is an Open-Geospatial-Consortium (OGC) Standard for 3D city model, open and multi-domain (land use, buildings, transport etc.). Providing a basis for 3D geospatial visualisation, analysis, simulation and exploration tools, it is used for modelling an ever-growing number of cities (e.g. Berlin, Lyon), regions and even countries (Germany). A considerable asset is its flexible object modelling in 4 different Levels of Details (LoDs), enabling the virtual city model to adapt to local building parameter availability and application requirements. The present release of SimStadt deals with the Level of Details LoD1 and LoD2, consideration of LoD3 is under way, see figure 23.

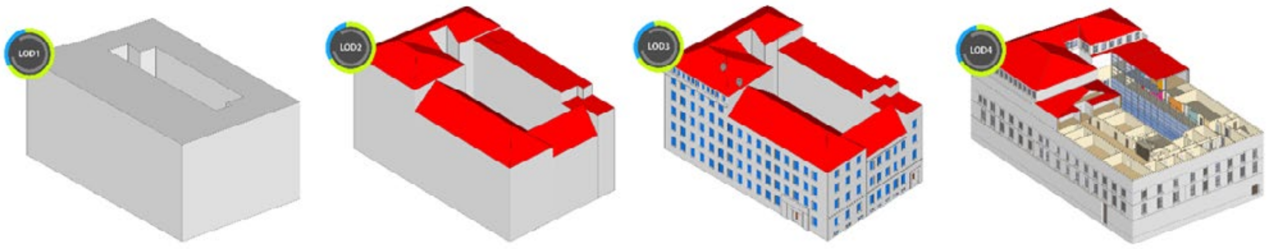

Fig. 23: The four Levels of Detail of CityGML applied to the Building 2 of the HfT Stuttgart.

Presently, the CityGML data model (version 2.0) does not contain any energy-related objects and attributes among its semantics. To solve this issue, an application domain extension (ADE) for CityGML, called Energy ADE, has been designed and implemented with other European partner institutes[19]. This extension enables the modelling of building thermal zones and boundary surfaces, construction and material properties, occupancy conditions of zone area, energy systems and consumptions. Having the energy-related data integrated into the city models eases the processing of this data through SimStadt.

Workflows and functionalities

Programmed in Java 8, SimStadt is structured in modular workflows. They basically consist of chains of modular processing steps (so-called workflow steps) that create, transform and consume specific data objects step by step. While dealing with large-scale models based on different data sources, the risk of errors and incoherent results are generally very high. A Graphical User Interface (GUI) enables to navigate in the different workflows and workflow steps, allowing for the analysis of the intermediary results at each step of the workflow, through charts, tables or maps and soon 3D navigation. The GUI also enables the user to modify the hypotheses and parameters of workflow steps and create scenarios accordingly.

At the redaction date of this report, the SimStadt Platform integrates the workflows solar and photovoltaic potential analysis, heating demand, primary energy and CO_2 emission calculations, district heating network sizing and refurbishment scenarios. Due to its modular structure, SimStadt may be extended with new workflow steps and workflows corresponding to new urban energy analyses, provided that the required data are available in the 3D city model or processed previously by other workflow steps.

Plug-ins interfacing with third-party simulation softwares may be programmed inside a workflow step, enabling to provide rich pre-processed geo data input to expert simulation softwares. For instance, based on the geo-localised heat demand and loads calculated in SimStadt, an optimised network layout is automatically

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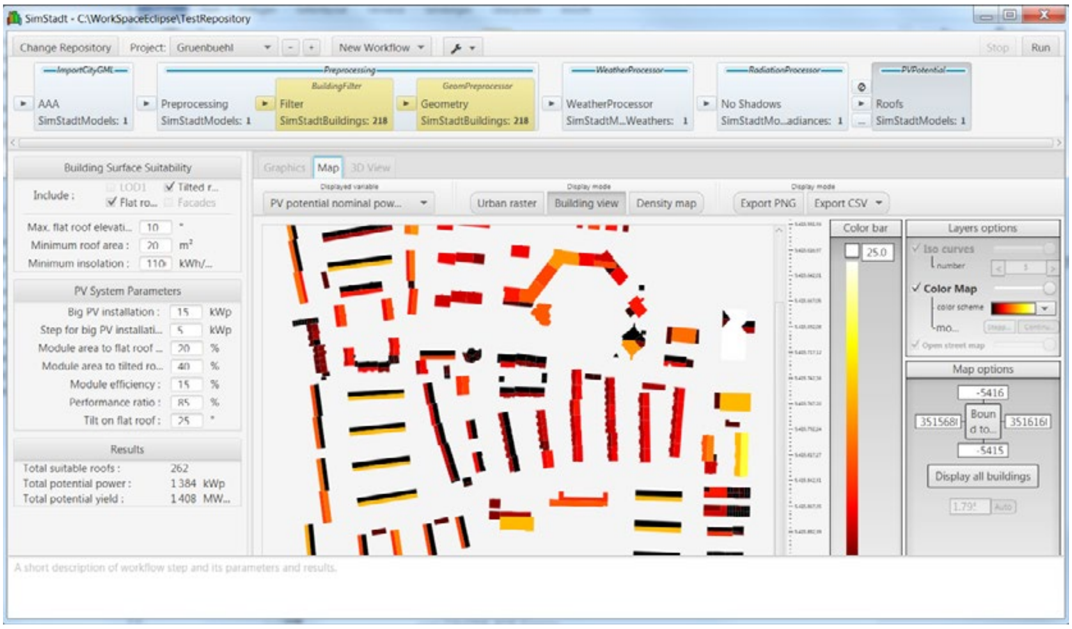
[18] Groeger, G., Kolbe, T.H., Nagel, C., Häfele, K.H (2012). OGC City Geography Markup Language (CityGML) En-coding Standard. OpenGIS® Encoding Standard, Version: 2.0.0, OGC 12-019, 2012-04-04

[19] R. Nouvel; J-M. Bahu; R. Kaden; J. Kaempf; P. Cipriano; M. Lauster; K.H. Haefele; E. Munoz; O. Tournaire; E. Casper (2015). Development oft he CityGML Application Domain Extension Energy for urban energy simulation. In: Proceedings of conference Building Simulation 2015, Hyderabad.

generated by means of graph algorithms, and its pipe sizes and heat losses calculated by the utility network calculation software Stanet.


SimStadt - C:\WorkSpaceEclipse\TestRepository

Project: Gruenbuehl

Building Surface Suitability
Include : ☐ LOD1 ☑ Tilted r... ☑ Flat ro... ☐ Facades
Max. flat roof elevati... 10 °
Minimum roof area : 20 m²
Minimum insolation : 110 kWh/...

PV System Parameters
Big PV installation : 15 kWp
Step for big PV installati... 5 kWp
Module area to flat roof ... 20 %
Module area to tilted ro... 40 %
Module efficiency : 15 %
Performance ratio : 85 %
Tilt on flat roof : 25 °

Results
Total suitable roofs : 262
Total potential power : 1 384 kWp
Total potential yield : 1 408 MW...

A short description of workflow step and its parameters and results.

Fig. 24: Screenshot SimStadt – Solar potentials in Ludwigsburg-Grünbühl

The functionalities of SimStadt which directly relates with the aim of the IEA SHC Task 51 are the weather and radiation processing. Urban energy analyses such as the heating demand or solar potential analysis (see figure 24) require local weather data, at hourly or monthly basis (e.g. ambient temperature, relative humidity, horizontal global and diffuse radiation). They are imported in the workflow step WeatherProcessor from different online/software databases (PVGIS, Insel) or weather data files (Meteonorm), selected by the user, and if required pre-processed. The workflow step RadiationProcessor allows for the computation of the incoming short-wave radiation on each building boundary surface. For this purpose, the user may select different radiation distribution models, depending on its precision requirements and allowed computational time:

- A radiation/orientation mapping, based on the Hay sky model. It considers each building as an insulated object without interaction with its surrounding. This model may be preferably used in urban areas with low-density.
- A ray-casting algorithm, coupled with the Hay sky model. Programmed to benefit from the full computational power of GPU, it considers the obstruction of surrounding urban objects, but not the mutual reflections (instead, an urban albedo is considered).
- The Cumulative Sky Model Algorithm[20], coupled with the Perez sky model. It considers both shadowing and reflexion effects of surrounding urban objects.

For the calculation of the heating demand, the thermal building model is based on the monthly energy balance, standardised in the DIN V 18599.

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[20] Robinson, D., Stone, A. (2005). A simplified radiosity algorithm for general urban radiation exchange. In: Building Serv. Eng. Res. Technol. 26,4 (2005) pp. 271/284

State of development, validation and perspectives

The SimStadt platform is still at the state of prototype (beta version 0.3 in August 2015). Several developments are planned before the end of the SimStadt project (March 2016), like the implementation of a 3D viewer in the Java GUI or the integration of a dynamic building simulation algorithm. Other interesting developments, like the consideration of CityGML LoD3 and LoD4 or the integration of further urban energy aspects (long-wave irradiance exchange, urban heat island effect), could be the purpose of further research projects.

Recently, the University of Applied Sciences Stuttgart applied and validated the SimStadt models on case studies. A comparison between calculated heating demands and available energy consumption measurements in the district Ludwigsburg-Grünbühl showed some deviations between 2% and 31%, depending on the input data quality and availability[21]. SimStadt has been also applied at larger scale in the project "Integriertes Klimaschutzkonzept Landkreis Ludwigsburg" where an Energy action plan was conducted for the whole administrative district of Ludwigsburg (34 municipalities for a total population over half a million inhabitants). Based on the available 3D city models (CityGML, Level of Details 1 and 2), different workflows of SimStadt have been used and combined to assess

- the actual heating demand and the related CO_2 emissions per building,
- predict energy savings potential following different refurbishment scenarios,
- identify the solar energy potential, the related photovoltaic electricity generated and the electrical consumption coverage.

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[21] R. Nouvel, M. Zirak, H. Dastageeri, V. Coors and U. Eicker (2014). Urban Energy Analysis based on 3D city model for national scale applications. In: Proceedings BauSim 2014, Aachen.

6. Comparison of solar radiation calculations

The solar potentials for roof and façade areas and open spaces in inner cities may be very precisely determined with the help of digital 3D urban models. Computer-aided simulations offer a more detailed consideration of the occurrence of shadows by day and season than analysis on the base of 'flat' city maps do.

With this in mind the above-mentioned simulation tools CitySim Pro in the version dated 25 April 2017, Diva for Rhino 4.0.2.17 and Solar Potential Analysis 0.20 were tested and compared on carrying out solar potential analyses using an actual urban model. The investigations focused primarily on usage and suitability for simulations at an urban scale. The simulation results are subsequently compared and subjected to critical evaluation.

6.1. The test scene

The 'Berliner Viertel in Monheim' ('Berliner District') in Germany was chosen as the focus of the investigations[22], see figures 25 and 26. This district was selected due to the fact that planning materials and a 3D model of the entire urban area (62 ha, approximately 90 complexes) were available from previous student projects. It was established during the course of the investigations, that the existing 3D model was too imprecise for comparison on the basis of comparative simulations with the Solar Potential Analysis model, that was newly generated from land-registry plans. Therefore it was necessary to create a new model. Tests with the students' urban model had shown that Solar Potential Analysis in particular and, in some aspects, also Diva experienced difficulties in simulating large-scale scenarios and therefore it was decided that the new model should only map a central section with 20 buildings. It must be noted here that the comparatively moderate number of buildings already produced 51 areas of different orientations and different exposures to the sun[23].

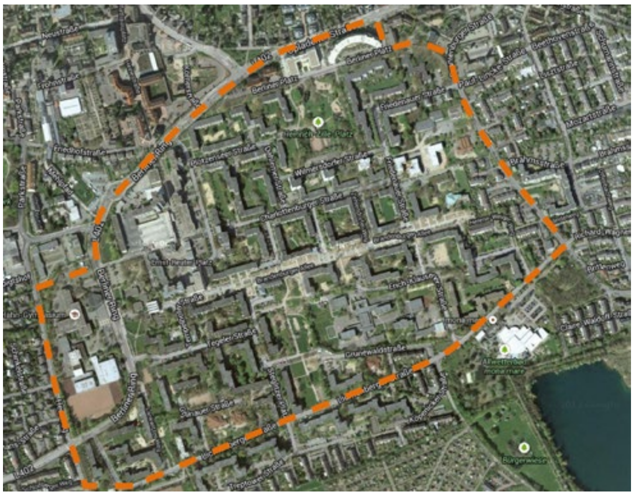

Fig. 25: Aerial view of the Berliner Viertel in Monheim. (Image: GoogleEarth)

Fig. 26: Oblique view from the south-east of the central section of Monheim. (Image: GoogleEarth)

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[22] Information on the "Berliner Viertel" at Monheim can be found here: https://monheim.de/stadtleben-aktuelles/stadtprofil/monheim-lexikon/berliner-viertel/

[23] A variance of at least 2 % in the surface-specific solar irradiation was used as the criterion.

6.2. The simulation model

The town of Monheim is located on a bend in the River Rhine, approximately in the middle between Düsseldorf and Cologne. The surrounding area of the Cologne Lowland is flat, therefor the casting of horizontal shadows does not need to be considered.
The DOE weather data records[24] for Düsseldorf, which is located around 10 kilometres away, were used for all simulations as they offered a good match for the local weather.

The investigation was carried out entirely without the representation of trees due to the fact that Solar Potential Analysis is not able to map trees and that the consideration of trees resulted in extremely long computation times in the other programs. The 3D model of the district and the section with 20 buildings that was used to compare the simulation programs are shown in figures 27 and 28.

Ground reflections are always calculated in CitySim and Solar Potential Analysis with an albedo of 0.2. As users are not able to edit this setting a ground-reflectance of 20 % was set in Diva too.

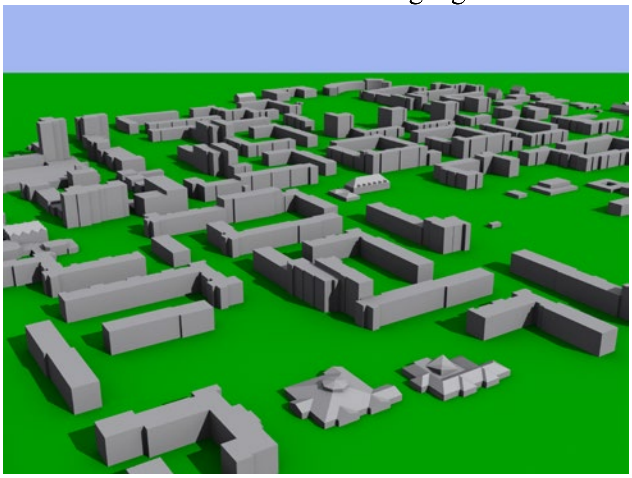

Fig. 27: 3D model of the entire “Berliner Viertel” in Monheim with 90 building blocks and 62 hectares of ground. (Image: Wuppertal University)

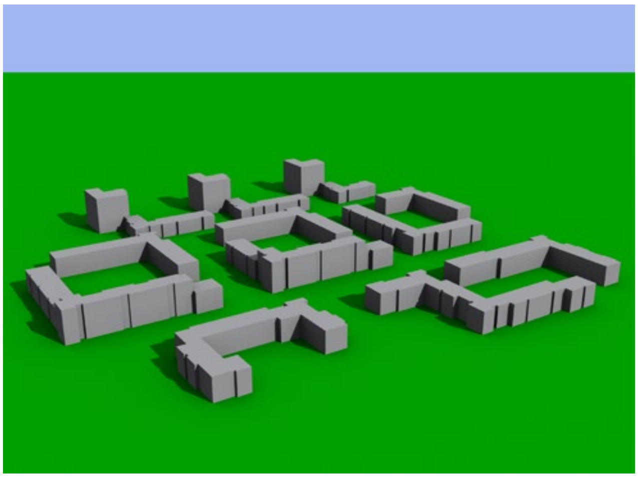

Fig. 28: The section with 20 buildings that was used to compare the simulation programs. (Image: Wuppertal University)

6.3. Creation or import of the simulation model

The specific features and limitations that have an effect on the creation respectively import of the simulation model in the individual tools are presented below.

CitySim Pro

CitySim does not offer an option for creating or editing geometries (it is also not possible to flip surface orientations). Therefore the models must be created entirely in a 3D modelling program and then imported.
The formats AutoCAD2000-DXF, CityGML 2.0 and Stereolithography STL (only individual objects) are available for importing geometries. It must be noted that it is only possible to import “3DFaces” and “Polylines” when the DXF format is used. This requires either a corresponding method when creating geometries in AutoCAD or the appropriate export filters in other 3D programs. The Blender OpenSource 3D program ships with such an export filter, for instance; a corresponding export add-on for SketchUp is supplied with CitySim Pro.

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[24] The weather data by the US Department of Energy are available at: https://energyplus.net/weather

Because CitySim displays the results on a face-wise basis, large surfaces and surfaces that are partially in shadow should be divided into smaller surfaces, i.e. discretised.

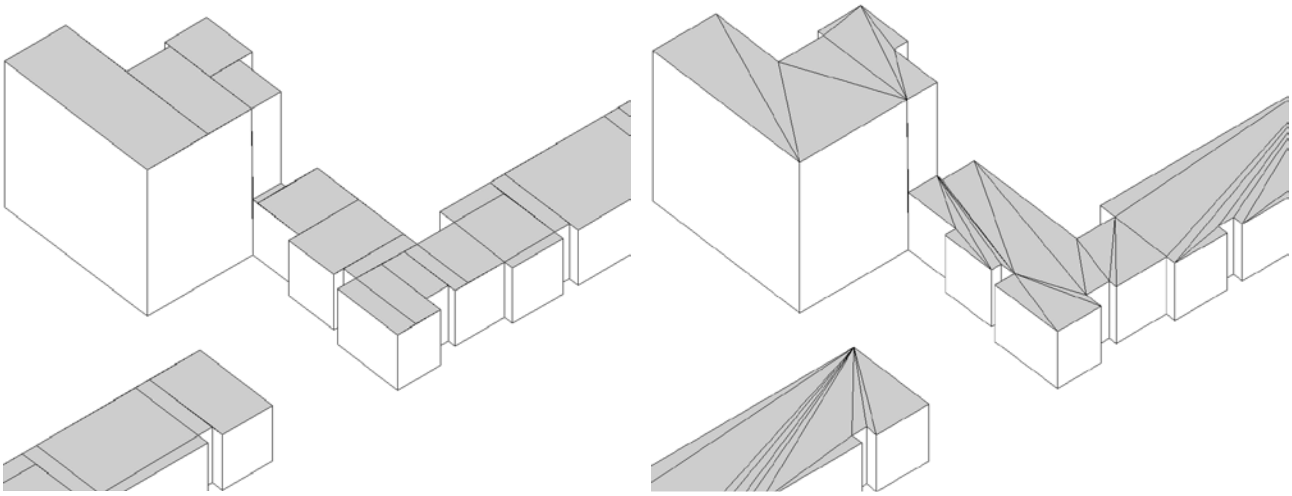


Fig. 29: Rectangular (left) and triangulated (right) roof surfaces. Triangulation requires the calculation and evaluation of a considerably greater number of surfaces. (Image: Wuppertal University)

As far as possible, the objects should be composed of rectangular surfaces. Surfaces with polygonal edges are triangulated during export[25], which produces a larger number of surface sections, see figure 29. As the number of areas increases, both the resource requirements for the simulation computation as well as the effort for evaluating the results are increasing strongly.

Weather data is only imported in the CLI format, which is a CitySim specific ASCII format. Corresponding files may be generated easily in MeteoNorm. TRNSYS was used here to convert the DOE weather data for Düsseldorf from the epw to cli format.

Diva for Rhino

Diva is used as an add-on for Rhino. The geometries are generated or imported independently of Diva in the Rhinoceros 5.0 3D modelling software. This means that very sophisticated modelling options and many import filters (including 3ds, dwg/dxf, obj, skp) are available. When generating the objects, it has to be taken into account, that surface models are required for grid-based simulations, whereby it is possible to subsequently convert volume models into surface models. Surfaces with the same surface properties must be merged into specific layers because Diva assigns materials by layers. It must also be noted that Diva only works with Rhino‘s English interface. Weather data can only be imported in the .epw format.

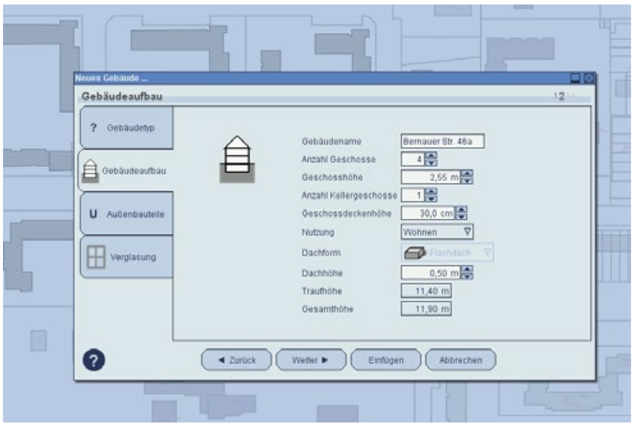
Solar Potential Analysis

In contrast to the surface-oriented method that CitySim and Diva use, Solar Potential Analysis works on a floor-by-floor basis. First, the building floor plan is also drawn here, or traced from a land-registry plan. Once the lines for the exterior walls have been closed off, a wizard appears and queries the parameters for the floors, wall structures and window data (see figure 30). The model editor uses this information to generate a building that can be detailed floor by floor if necessary (e.g. by inserting partitions, windows etc., cf. figure 31). An

---

[25] “3D Faces” may possess a maximum of four corners in AutoCAD 2000.

import of geometries from other 3D programs is not provided. This is because the original intention was to use a common editor (with educational extensions, such as databases and glossaries) with different computing tools.



Gebäudename: Bernauer Str. 46a
Anzahl Geschosse: 4
Geschosshöhe: 2,55 m
Anzahl Kellergeschosse: 1
Geschossdeckenhöhe: 30,0 cm
Nutzung: Wohnen
Dachform: Flachdach
Dachhöhe: 0,50 m
Traufhöhe: 11,40 m
Gesamthöhe: 11,90 m

Fig. 30: Wizard for setting the parameters for buildings.
(Image: Wuppertal University)

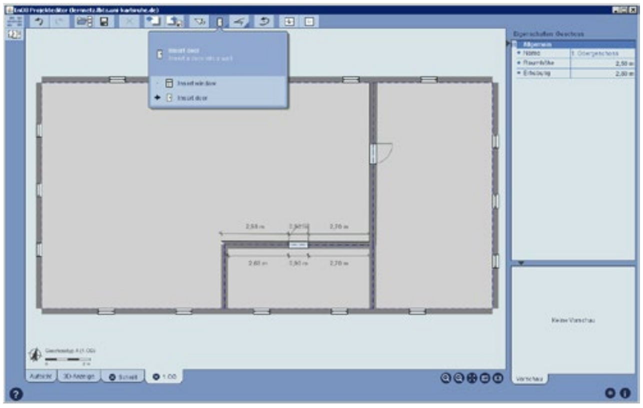


Fig. 31: Details of a storey as an example.
(Image: Wuppertal University)

Buildings with varying heights turned out to be problematic in Solar Potential Analysis. Such building geometries must be drawn as separate adjacent buildings. There is no way to convert the interfaces between the buildings into the inner walls. Due to the mutual shading of the directly adjoining building walls, too low solar irradiation values are always predicted for such external wall surfaces (cf. Fig. 38).

Weather data are loaded from an Internet database with DOE weather data. Because an import of locally stored weather data files currently is not possible, an internet connection is required.

Table 6: List of operational requirements and import options

	CitySim Pro	Diva for Rhino	Solar Potential Analysis
Operating requirements	None	Rhino (with English interface)	Installed Java runtime environment, Internet connection
Geometry editor	No	Rhino	Yes
Geometry import formats	DXF (only 3DFaces) CityGML 2.0 STL (single models)	3dm, 3ds, dwg/dxf, lwo, obj, skp, vrml and others	No
Weather data import formats	CLI	EPW	Internet database with DOE data
Storage format	XML file	Rhino file (.3dm)	Database, which contains all the user's models

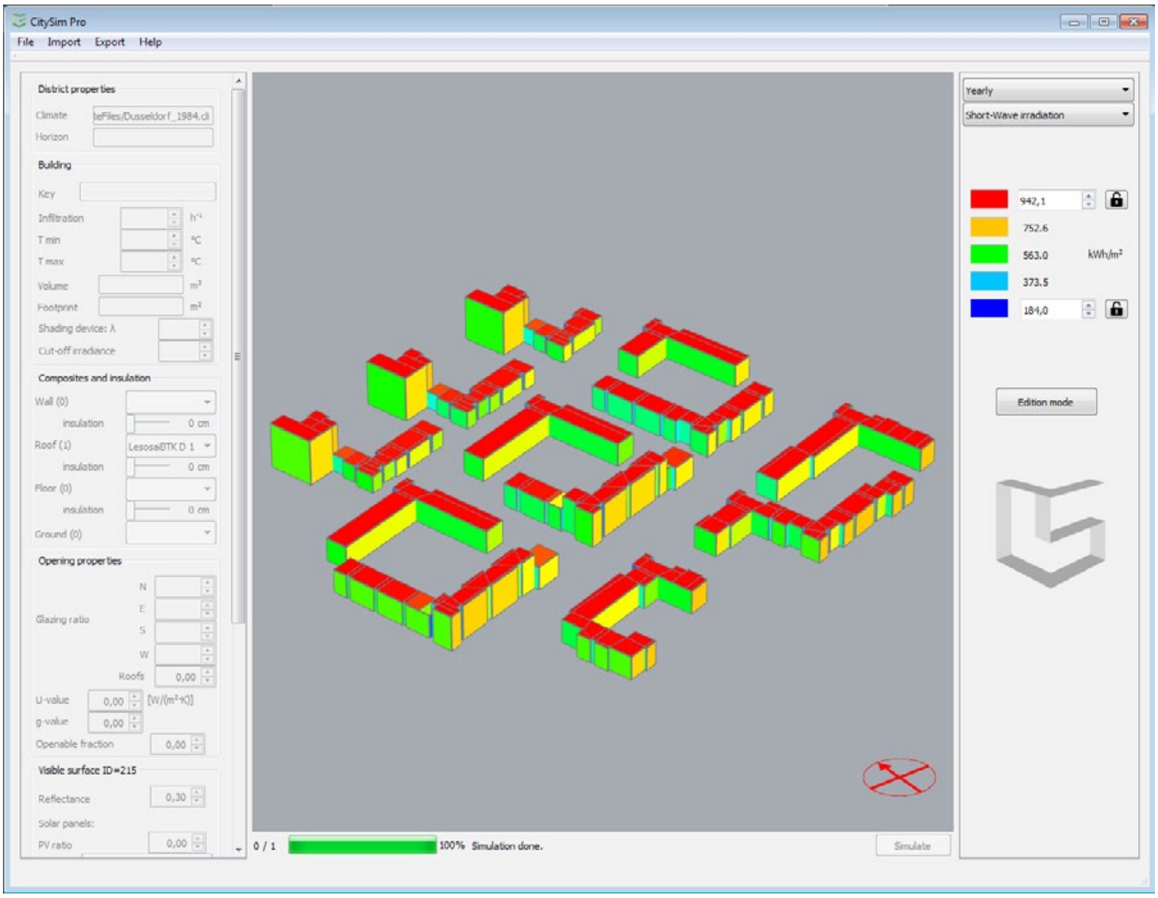
6.4. Simulation model set-up

The parameterisation of the simulation models and the computation times for the separate tools are discussed below; the discussion is concluded with a summary of the details in a table. For the test simulations, a reflectance of 30 % was assigned to the façade surfaces in CitySim and Diva. The assignment of reflectance values is not possible in Solar Potential Analysis because it does not compute the radiation exchanged between façade surfaces.All programs used an albedo of 0.2 to calculate ground reflections. The computing times were measured on a workstation with two Intel Xeon 5160 processors (with four 3 GHz cores in total) and eight gigabytes of RAM.

CitySim Pro

Starting a simulation calculation only requires the import of a building geometry and specification of a weather data file[26]. The specification of a horizon file[27] is optional. It is possible to assign individual properties for reflectance, U value, window areas, photovoltaic and solar-thermal surfaces to the façade and roof surfaces. If these properties are not modified, default values are used for the simulation. This allows initial results to be achieved very quickly.

When the simulation calculation is started, a computational grid is generated internally[28]. The grid-point spacing is generated as follows: The scene is enclosed with a shell and its diameter is divided into 8,192 segments. The length of the segments corresponds to the spacing between calculation points. This produces a grid spacing of approximately five centimetres for the small city model (with 20 buildings) and approximately 15 centimetres for the large one (with 90 building blocks). At least one calculation point is assigned to all surfaces so that even surfaces with edge lengths shorter than the grid spacing will be considered. The size of the model does not affect the computation times because the grid resolution is scene-based. The computational accuracy, however, decreases with an increasing model size. It is not possible for users to adapt the computational grid. The existence of many small surfaces (e.g. as a result of the triangulation of polygonal surfaces or the modelling of trees) may significantly increase the computation times and increase the amount of RAM required.



Climate: teFiles/Dusseldorf_1984.cli
Horizon:
Wall (0)
insulation 0 cm
Roof (1) LesosaiBTK D 1
insulation 0 cm
Floor (0)
insulation 0 cm
Ground (0)
Roofs 0,00
U-value 0,00 [W/(m²·K)]
g-value 0,00
Openable fraction 0,00
Reflectance 0,30
PV ratio 0,00
Yearly
Short-Wave irradiation
🟥 942,1
🟧 752.6
🟩 563.0 kWh/m²
🟦 373.5
🟦 184,0
0 / 1 100% Simulation done.

Fig. 32: Graphic presentation of the simulation results in CitySim Pro. (Image: Wuppertal University)

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[26] The geo position is taken from the weather data file. The user can not enter a different location.

[27] The horizon file describes the horizon line around the simulation model so that shadows, e.g. from mountains, can be taken into account during the simulation. For this, the respective elevation angle in relation to the horizon is assigned to the perimeter, starting in the north, using a variable increment of around 10° (depending on the type of terrain).

[28] The computational grid is not displayed in the graphical user interface.

The “CitySim Solver”[29], developed at the École Polytechnique Fédérale de Lausanne, is integrated as the computing kernel.

The simulation calculations always compute a whole year in hourly increments. The calculation time for the model used here, consisting of 20 buildings with a total of 645 surfaces, is about two minutes. For comparison: The job for the entire “Berliner Viertel” possessing 80 building blocks and 129,000 surfaces takes around 100 hours.

After completion of the simulation calculation, hourly, daily, monthly and yearly totals or average values for short-wave solar radiation, long-wave radiation exchange, surface temperatures as well as photovoltaic and solar thermal production can be graphically displayed (cf. Fig. 32).

The scale division for the result presentation is however very coarse with only five gradations. Since the graphical interface does not permit to display numeric results for individual surfaces, the export to an ASCII file with subsequent analysis by spreadsheet is highly recommended.

Diva for Rhino

Diva creates a separate icon bar in Rhino. Surface properties are assigned by layer to the geometry after the weather data has been selected (the location is taken from the epw file and cannot be separately modified). A standard set of 28 predefined materials is available to choose from. It is possible to add own materials (in a somewhat complicated manner) by inserting RADIANCE material definitions into the ‘material.rad’ ASCII file.

Before running the simulation, it must be decided whether a false-colour image or numeric outputs are to be generated. In both cases RADIANCE[30] is used as the computing core.

Generation of numeric results

A computational grid must first be created before numerical results can be generated. The surfaces of interest have to be selected and then the grid-generation parameters (distance of computation points from the surface and distance of computation points from each other) are entered. Thus, the generated grid, always possesses a grid-point spacing that is (up to 20 %)[31] smaller than that specified by the user.

The simulation parameters can be adjusted in detail in a configuration window before the calculation is started (cf. Fig. 33). How long the simulation takes depends significantly on the number of grid points; the number of areas in the scene is of lesser importance.
If all the surfaces of the city model are meshed, a specified grid spacing of 1 m gives the small model with 20 buildings approx. 66 000 calculation points and a computing time of approx. 1.5 hours; in the large city model with 90 building blocks, the meshing broke off with a fault message.

In order to keep the computing times and evaluation effort to a minimum, the surfaces of interest should be individually meshed and evaluated. This would, depending on the number of grid points, also permit

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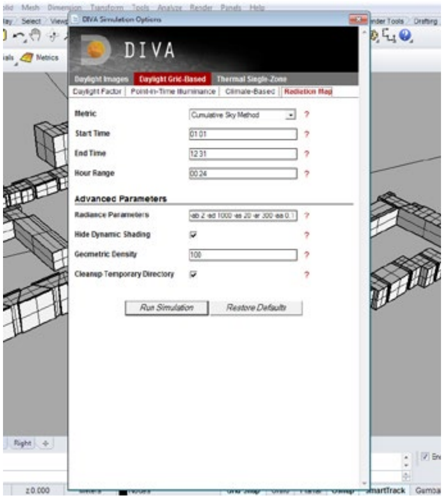
[29] The CitySim Solver is available at http://citysim.epfl.ch/

[30] RADIANCE is available at:
http://radsite.lbl.gov/radiance/HOME.html
https://www.radiance-online.org/

[31] This may be of considerable significance to the evaluation: If the user has specified a grid spacing of one meter and Diva only uses a grid spacing of 0.85 meters in it’s adaptation to the surface geometry, each grid point will only represent 0.72 square meters and not one square meter. Simple addition of the radiation exposure for all grid points in kWh/m² would produce radiation exposure that is significantly excessive.
The mean value must be calculated, then multiplied with the area content and finally, if necessary, the results for the partial surfaces added up to achieve a precise result for each (partial) surface.

simulations with the large city model (2 500 grid points take 30 seconds to compute in the small city model and 33 seconds in the large one).

On completion of the simulation calculation, an ASCII file is automatically generated that shows the total annual radiation sum for each grid point. The results can also be loaded into Rhino and placed as a contour plot in the computational grid (cf. Fig. 34). The output of the results by grid point means that users have to manually calculate the mean values for each surface separately.



Metric: Cumulative Sky Method
Start Time: 01 01
End Time: 12 31
Hour Range: 00 24
Radiance Parameters: -ab 2 -ad 1000 -as 20 -ar 300 -aa 0.1
Hide Dynamic Shading: ☑
Geometric Density: 100
Cleanup Temporary Directory: ☑

Fig. 33: Simulation parameters for a grid-based simulation in Diva.
(Image: Wuppertal University)

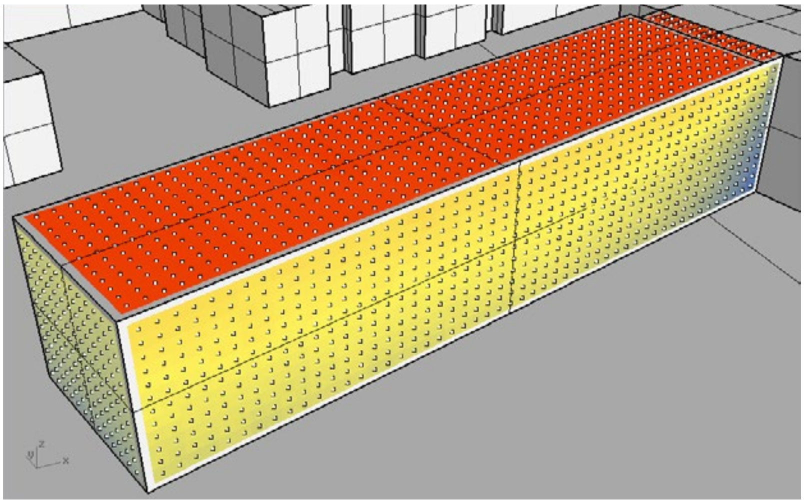
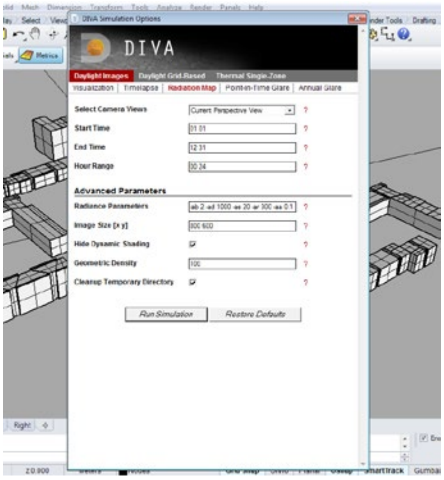


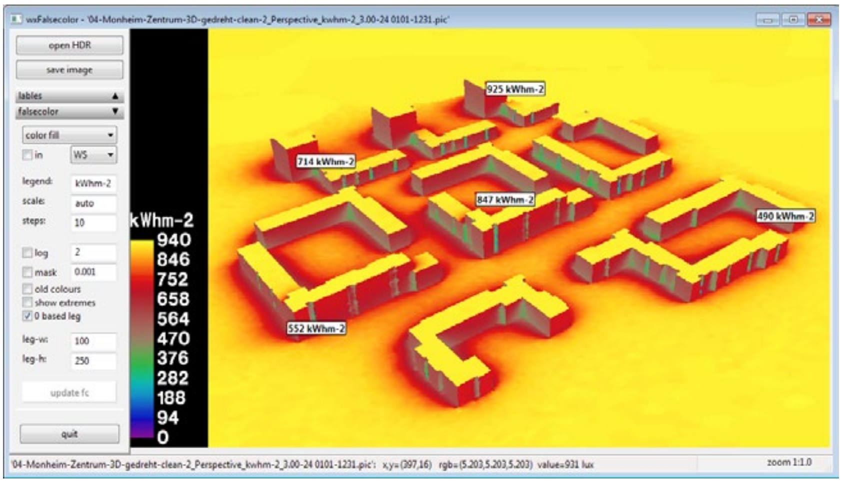
Fig. 34: Graphic representation of the results from a grid-based irradiation simulation. (Image: Wuppertal University)

Generation of a false-colour image
No calculation grid is required to render a false-colour image. It is sufficient to specify the simulation parameters to start the rendering.
Depending on the resolution of the results image, the calculations for the small city model (20 buildings) take between 18 minutes (800 x 600) and 26 minutes (1600 x 1200); the computing times for the large model (90 building blocks) range between 35 and 56 minutes, see figure 35.



Select Camera Views: Current Perspective View
Start Time: 01 01
End Time: 12 31
Hour Range: 00 24
Radiance Parameters: -ab 2 -ad 1000 -as 20 -ar 300 -aa 0.1
Image Size [x y]: 800 600
Hide Dynamic Shading: ☑
Geometric Density: 100
Cleanup Temporary Directory: ☑

Fig.35: Simulation parameters for false-colour rendering in Diva.
(Image: Wuppertal University)



color fill
☐ in: WS
legend: kWhm-2
scale: auto
steps: 10
☐ log: 2
☐ mask: 0.001
☐ old colours
☐ show extremes
☑ 0 based leg
leg-w: 100
leg-h: 250

'04-Monheim-Zentrum-3D-gedreht-clean-2_Perspective_kwhm-2_3.00-24 0101-1231.pic': x,y=(397,16) rgb=(5.203,5.203,5.203) value=931 lux

Fig.36: Rendered representation of the annual solar irradiation in the false-colour editor. (Image: Wuppertal University)

The results image is automatically loaded into the RADIANCE false-colour editor when the calculations are completed (cf. Fig. 36). The image may be adapted to the user‘s requirements here (e.g. the colour scale and legend may be adapted). The false-colour editor also offers an option to set ‘measuring points’ and so display numerical simulation results for selected points in the results image. On completion of the job the image may be saved in various image formats (HDR, PNG, JPEG, TIF, BMP, etc.).

Solar Potential Analysis

The simulation calculations can be commenced in Solar Potential Analysis immediately after the buildings have been modelled and the weather data has been selected (the geo position is copied from the weather dataset and cannot be altered).

At the beginning of the calculation process, a grid with a resolution of one computational point per square meter is generated internally[32]. Adaptations are not intended as a result of the didactic orientation of the tool.
The calculation is carried out using a computational kernel developed at the Karlsruhe Institute of Technology (KIT). After completion of the simulation, the results are placed as contour plots on the geometries (cf. Fig. 37). There is also an option to export the simulation results by surface into an ASCII file. In addition to the calculation results, the corresponding building and the respective cardinal directions are also indicated for each surface to facilitate assignment.

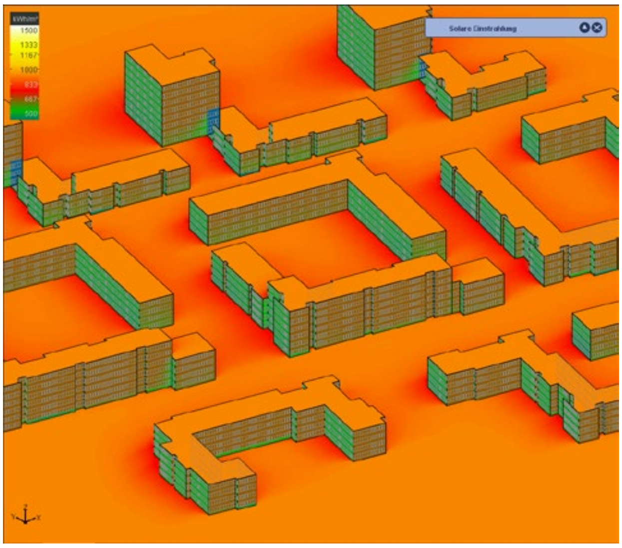


Fig. 37: Graphical results output in Solar Potential Analysis. (Image: Wuppertal University)

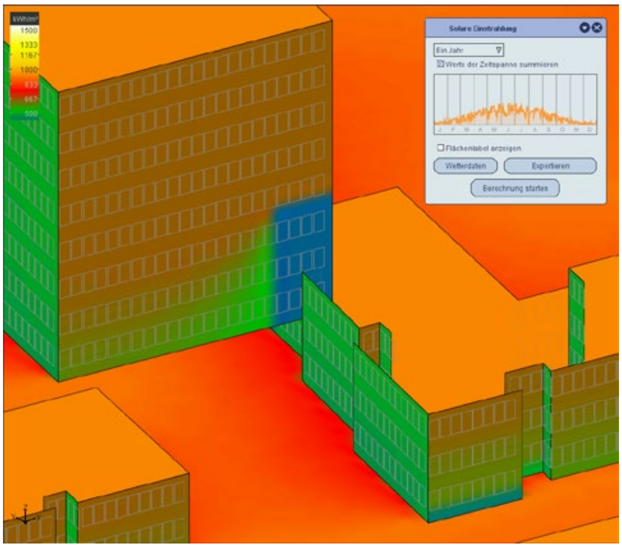


Fig. 38: Shadow cast on to an eight-storey façade by a building adjoining from the south. (Image: Wuppertal University)

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[32] The computational grid is not displayed in the graphical user interface.

6. 5. Comparison of results

The annual solar radiation totals for 11 façades and two roof surfaces are compared as an example. For this purpose, surfaces with different orientations in different shadow and reflection situations are selected (cf. Fig. 38). The summary of the simulation results are shown in Table 7.

Table 7: Comparison of the simulation-specific properties

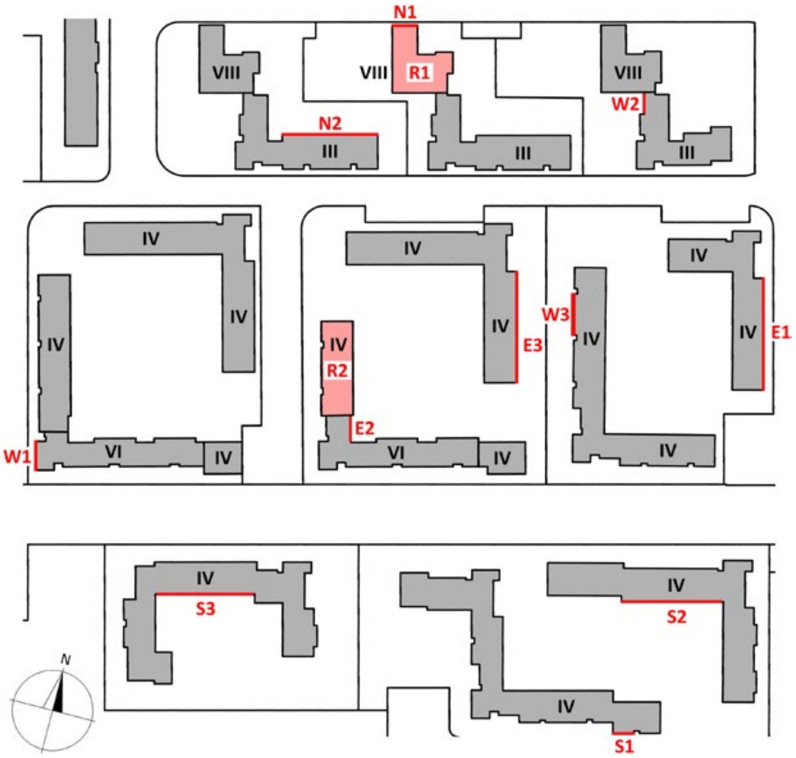
	CitySim Pro	Diva for Rhino	Solar Potential Analysis
Horizon shade	Yes	No	No
Distance between calculation points	Encircling sphere diameter divided by 8 192	Set by user	1 m
Computational kernel	CitySim	RADIANCE	Own kernel
Sky model	Perez	Cumulative sky method	Radiation model from THERACLES1)
Consideration of			
- shadows for			
- direct radiation	Yes	Yes	Yes
- diffuse radiation	Yes	Yes	No
- Short-wave reflections	Yes	Yes	No
- Long-wave radiation exchange	Yes	No	No
Computation time			
- Sub-scene (20 buildings, 645 surfaces)	Approx. 2 min	1.5 h f. num. results2) ca. 25 min f. rendering	3 h
- entire town district (90 building blocks, 129 000 surfaces)	Approx. 100 h	Num. results not possible because max. number of grid points exceeded ca. 70 min f. rendering	not tested
Utilisation of several CPU cores	Yes	No	No
Output:			
- Results image	Screenshot	Rendering	Rendering
- Num. results	ASCII file, by surface	ASCII file, per grid point	ASCII file, by surface
- Results allocation	Surface ID that can only be read in the GUI	Grid point	Surface IDs that can be displayed in the graphic representation of the results.
Other:			
- Thermal simulations	yes (1 thermal zone per building)	Yes (1 thermal zone per file)	in planning (1 thermal zone per building)

1) THERAKLES is a software developed by the TU Dresden for thermal building simulation of single-zone models. It is available at: http://www.bauklimatik-dresden.de/

2) The computing time for the entire town model has been inserted for comparison purposes only. It is more useful to calculate and evaluate the surfaces of interest individually in Diva.

The surfaces N1, E1, S1, W1 and R1 (see figure 39) whose solar irradiation is neither affected by reflections from neighbouring façades nor by shadows cast from surrounding buildings through the year are used as references. The simulation results from the tested tools for these surfaces were compared with corresponding simulation results from the validated building and plant simulation software TRNSYS 16.1 using the Perez sky model.

On the other surfaces, irradiation is affected to varying degrees by the surrounding buildings. In the absence of a geometric radiation model in TRNSYS 16.1, no comparison values could be generated for these surfaces.



ID	Orientation	Surface
N1	North (15°)	336 m^2
N2	North (15°)	295 m^2
E1	East (105°)	491 m^2
E2	East (105°)	286 m^2
E3	East (105°)	428 m^2
S1	South (195°)	748 m^2
S2	South (195°)	688 m^2
S3	South (195°)	687 m^2
W1	West (285°)	595 m^2
W2	West (285°)	306 m^2
W3	West (285°)	511 m^2
R1	Horizontal	941 m^2
R2	Horizontal	877 m^2

Fig. 39: Site plan of the surfaces investigated. The roman numerals indicate the number of floors in the buildings. (Image: tim-online.nrw.de with modification by Wuppertal University.)

Table 8: Comparison of simulation results

ID	**CitySim Pro**			**Diva for Rhino**			**EnOBLernnetz**			**TRNSYS**
	Total radiation	Difference to TRNSYS	Effect of shadows	Total radiation	Difference to TRNSYS	Effect of shadows	Total radiation	Difference to TRNSYS	Effect of shadows	Total radiation
	[kWh/(m^{2}a)]	[%]	[%]	[kWh/(m^{2}a)]	[%]	[%]	[kWh/(m^{2}a)]	[%]	[%]	[kWh/(m^{2}a)]
S1	748	3.3		731	0.9		640	-13.1		724
S2	688		-8.0	641		-12.3	625		-2.3	
S3	687		-8.2	627		-14.2	638		-0.4	
E1	491	2.3		461	-4.1		518	7.3		480
E2	286		-41.8	234		-49.2	515		-0.6	
E3	428		-12.9	386		-16.3	511		-1.4	
W1	596	3.2		579	0.4		495	-16.5		577
W2	306		-48.6	403		-30.4	471		-4.9	
W3	511		-14.3	468		-19.2	464		-6.2	
N1	336	-0.2		312	-7.9		377	10.6		337
N2	295		-12.2	243		-22.2	376		-0.2	
R1	941	-0.2		924	-2.1		938	-0.5		943
R2	877		-6.9	857		-7.2	909		-3.1	

The results data from Table 8 may be represented graphically as follows:

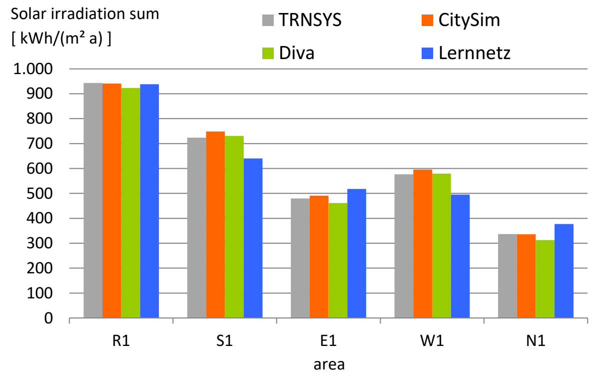


Fig. 40: Simulated solar irradiation on unshaded roof and façade surfaces.

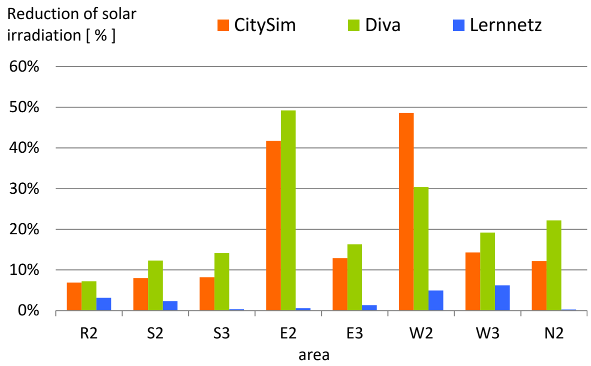


Fig. 41: Influences of surrounding buildings on the solar irradiation of selected surfaces.

The simulation results that CitySim and Diva produced for unshaded reference surfaces S1, E1, W1, N1 and R1 constitute a good match with those produced by TRNSYS. Solar Potential Analysis produced greater variances; it was not possible to establish the cause of these variances by the report‘s editorial deadline.

With regard to the shading effect of surrounding buildings, the differences between CitySim and Diva are generally small. Diva generally projected a greater shading effect for façade surfaces, i.e. reduction of solar irradiation, than CitySim. The reason for this discrepancy is to be sought in the different methods that the two tools use for calculating ground reflectance: while Diva resolves the shading of adjacent ground surfaces from the geometric model in a spatial resolution, CitySim calculates the reflections from ground without shade[33]. Coverings of the ground (and sky) by surrounding buildings are taken into account in CitySim by view factors.

For the W2 facade surface, Diva predicts a significant lower shading effect respectively higher solar inputs than CitySim. The variances are apparently the result of differences in the calculation of reflections on the south façade bordering the north. A possible cause could be specular reflection of direct radiation on to the adjacent south façade. (While CitySim only calculates diffuse reflections, Diva / RADIANCE are able to calculate specular reflections.) But this is contradicted by the fact that the RADIANCE materials used are defined as diffuse reflecting. It could not be established whether it is specular reflections or differences in the calculation of diffuse reflections that are causing these variances.

The extraordinarily small effects that shadows have in Solar Potential Analysis may, on the one hand, be attributed to the fact that shadows are only calculated for direct radiation while a horizon without shadow is always assumed for diffuse irradiation. On the other hand, the errors in the radiation model discussed above could have an effect.

The lack of reference data means that it is not possible to draw a final conclusion in regard to which of the tested programs maps the effects from surrounding structures the most realistically.

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[33] The CitySim version dated 22 June 2017 introduced an option to define surfaces in the 3D model as ground surfaces by manually editing the XML model file. Then a purely geometric model is, as in Diva, used for calculations of ground reflections, which means that the shadow situation is also taken into account in CitySim. It was not possible to test this function by the editorial deadline.

6.6. Conclusion

CitySim Pro is the best for simulations at district level among the programs tested here. It requires just a few parameters to make it possible to produce simulations with little effort. The computing times and the required resources are low. The simulation results investigated for this report appear plausible although the estimates for reflections on shaded ground surfaces are too high. Since CitySim version dated 22 June 2017 ground shadows can be taken into account.

Slight weaknesses in CitySim Pro are evident in the DXF import (only “3DFaces” are imported which requires the triangulation of polygonal surfaces), in the lack of a function to flip surface orientations and in the graphical representation of results with only five colour gradients without displaying numerical results. The latter makes a numerical evaluation of the simulation results indispensable. If the areas of interest are highly fragmented, for instance by triangulation, the evaluation is considerably more difficult. It would be advantageous for numerical evaluation if the surfaces could be named in the program interface. In addition to radiation calculations, CitySim Pro may also be easily used to carry out thermal building simulations at district level (with one thermal zone for each building).

Diva for Rhino is particularly suitable if the solar potentials of individual surfaces in a city district are to be investigated. Diva offers more functions and editing options than CitySim Pro. Thus, users are able to define the computational grid themselves and specular reflections, e.g. on glass façades, as well as diffuse reflections are computable. Familiarisation with the program, however, takes longer than with CitySim, particularly if own materials need to be defined.

To identify surfaces with high solar potentials, false color images of entire districts can be rendered in Diva for Rhino. The surfaces of interest may then be analysed in greater detail using the numerical outputs from grid-based simulations. The calculation of false-colour renderings takes considerably longer than the corresponding simulations in CitySim. The computing times for the grid-based simulations depend significantly on the number of grid points (Diva recommends to use a maximum of 5 000 grid points). The more accurate calculation of ground reflections means that the simulation results are a little more precise than those from the CitySim version tested here.

The numerical evaluation in Diva is made more difficult by its grid-point-based output of results (instead of by surfaces). The software is suitable for determining solar potentials but it is especially useful for analysing the visual and thermal comfort of single rooms. Various light-simulation models and a simple thermal room simulation (single-zone model) are available to this end.

The Solar Potential Analysis was developed as teaching and learning software. It is the only program tested that can be used entirely free of charge. Due to the early stage of development, it offers fewer features than the other programs tested. Especially the import and export of geometry data would be desirable. The inaccuracies in the calculation of radiation revealed during the investigations are currently being analysed. If it is possible to eliminate these ‘teething problems’, the tool will fulfil its purpose of education and training. The fact that there is no import option means that the tool is not for planners.

7. Prospects

The usage of software tools is widespread. In each discipline, many different tools are applied for solving various research questions. Especially in the field of architecture, urban and energy planning the software developers provide many tools with several specifications. Some tools are relevant for energy designers, some tools are made for urban planners and other tools have a didactical aspiration in educational usage. The main problem regarding these software tools is the missing link between the disciplines working together on a common project. More project-related tools which are usable in diverse disciplines and scales are needed.

The future of academic education of solar energy use in urban planning is strongly related to the impact of building information modelling (BIM) on education. Investigating urban 3-D-modells with an artificial sun or sky in the first study phase may be followed by the use of software tools as explained in this report. As many universities do not have an artificial sun or sky, the software approach is the only option for personal experience. Simplified, stand-alone learning tools, such as the EnOB Solar Potential Analysis, may serve as first stage education.

The more complex and commercialised software tools allow much more flexibility in the size of the investigated areas and the resolution as well as presentation of the results. On the other hand, the whole process is much more challenging. If BIM will be established as the usual approach in future academic education of architects and urban planners, these challenges should be handled.

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- Research Council Norway

10. Appendix

Appendix 1: Questionnaire on Solar Tools in Education (Source: University of Wuppertal)

IEA Task 51
Solar Enery in Urban Planning
STB - Evaluation of Calculation Tools

Tool:

Author:

class	**topic**	**description**	**rating (+) 1-2-3-4-5 (-)**	**reason for rating**	**possible improvements**
general					
	website				
	year of publication				
	current version (12/2013)				
	target group				
	support, hotline				
	documentation, tutorials, online help function, ...				
	languages				
	operation system				
	user forum - adress, acticity				
	structure - only for solar energy evaluation or part of package				
	costs - student version, educational licence professional license				
	experience with installation				
input / editor					
	terrain input or import				
	input of shading objects outside the planning terrain (mountains,..)				
	input of building geometry and options for import from CAD software				
	tools for modifying imported geometrie data				
	weather data import - formats and standard sources				
	definition of surface properties - light and solar reflection, specularity, ...				
	librarys for materials and objects				
calculation					
	modell(s) for estimating insolation on inclined surfaces, fixed or variable?				
	typical simulation time step, possibility of modification				
	grid size on surfaces and options for individual sizing, automatic adjustment ?				
	accounted objects: far distance environment , terrain, buildings, fixed shading structures vegetation... and degree of details				
	accounting for surface reflection and specularity for calculation insolation on surfaces?				
	integrated engine for parameter studies or optimization?				
	typical simulation time for annual calculation with minimum 1 hour time step				

output		
	external: name the typical calulation results per grid point outside of buildings (total, direct, diffuse radiation or light, sunshine hours,....)?	
	internal: name the typical results per grid point within a building (daylight factor, daylight autonomy,...)?	
	further output options: glare in the urban environmanet, visibility of opjects, urban micro climate, ...	
	further output options related energy: PV yield, building heat demand and interfaces to energy simulation tools	
	time resolution of output	
	typical data format	
	grafical output options	
	cinematic output options	
	renderings and degree of detail	
	export formats	
summary		
	software stability	
	user friendliness	
	required knowledge level with respect to energy issues and simulation know how	
	cost/benefit balance in general	
	coupling to urban design process	
	coupling to urban energy planning process	
	target group education - resume incl. cost/benefit balance	
	target group professionals - resume incl. cost/benefit balance	

IEA Solar Heating and Cooling Programme (IEA SHC)

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives (“Implementing Agreements“) of the International Energy Agency. Its mission is to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050.

The members of the IEA SHC collaborate on projects (referred to as “Tasks”) in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

A total of 59 projects have been initiated, 51 of which have been completed. Research topics include:
- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat or Industrial or Agricultural Processes (Tasks 29, 33, 49)
- Solar District Heating (Tasks 7, 45, 55)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42, 58)

In addition to the project work, there are special activities:
- SHC International Conference on Solar Heating and Cooling for Buildings and Industry
- Solar Heat Worldwide – annual statistics publication
- Memorandum of Understanding – working agreement with solar thermal trade organizations
- Workshops and seminars

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