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Low Tech Solution for Smart Cities – Optimization Tool CityCalc for Solar Urban Design

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1 ABSTRACT

Designed as an easily applicable planning and evaluation tool, CityCalc has been developed to assess the energy performance of urban planning projects at early design stages. The tool supports the development of low-tech solutions for smart cities by means of optimising the use of renewable energy on site – including passive and active solar gains.

Currently energy planning and assessment tools for early design stages do not take into account the mutual interactions of buildings such as shading and shadowing from adjoining structures as their focus is on the individual buildings. A great variety of tools for urban solar design exist nowadays, however they are not suitable for architects and early design stages (IEA SHC Task 41). In the future it will be of increasing importance to quantify the passive and active solar gains in order to fulfil ambitious legal and funding requirement and to implement future-oriented building concepts (e.g. passive house, zero energy, zero carbon or plus energy standards).

The objective was therefore to develop an easily applicable energy planning and assessment tool for urban planning projects for the early design stages. The CityCalc tool focuses on energy efficiency - that is, the reduction of energy demand - with the best possible use of site-specific energy sources (gains from solar thermal and photovoltaic plants, wind energy, combined heat and power). In order to ensure a simple, user-friendly usability for architects, a three-dimensional geometry and data acquisition and an interface with energy calculation software is developed. CityCalc is developed for urban development planning, urban design competitions and urban densification. CityCalc can be used on the one hand by architects for optimizing the conceptual design phase and on the other hand, for the energy assessment of urban planning and architectural competitions.

CityCalc combines the simplistic three-dimensional geometry input method of the freely available software SketchUp with proven evaluation algorithms of the energy performance certificate. In addition it refers to a variety of default values for details, which are not defined in detail at this stage of planning. With the assessment tool CityCalc it is possible to assess the potential of active and passive use of solar energy at a very early planning stage. For this purpose, the simplified three-dimensional input of the building and its surroundings in the free software SketchUp is required. CityCalc is available as a plugin for SketchUp.

The developed planning and assessment tool has been tested and validated in selected planning competitions and early design projects. The tool and the experiences of the validation will be presented in this paper. Conclusions are a well-adjusted applicability for an early design stage. System boundaries of the assessment have to be shaped based on the available information as well as the flexible parameters of early design stages. Further aspects of smart cities have been identified to be included in future upgrades of the tool, such as: daylight comfort of indoor and outdoor areas, costs for supply and disposal especially energy supply, embodied energy in materials.

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2 INTRODUCTION

In the context of Smart Cities the focus lies in the efficient and 'smart' interaction and optimisation of the different components within the city. Linking buildings, mobility, energy and industry to achieve an optimum performance in terms of quality of life, comfort, efficiency and greenhouse gas emission reduction for the overall city is considered the ultimate goal. The buildings have in this respect changed from being purely energy consumers to also energy providers by the integration of renewable energy systems into the building. Using the buildings envelope for active systems, the focus is mainly on solar powered systems, such as solar thermal collectors or photovoltaics. In addition buildings can provide a substantial load shifting potential by utilising their thermal mass capacity, building energy systems, which connect and convert thermal and electrical loads and the link to e-mobility in order to store energy and release it when it is needed.

In urban planning aspects for both new built as well as refurbishment projects the objective in terms of energy performance is therefore twofold: Buildings should exploit passive design principles by the utilisation of solar heat radiation and daylighting to reduce the overall energy consumption to a logical minimum. Reducing the thermal loads – in non-residential buildings mostly cooling and in residential buildings mostly heating - represents one of the main aspects of passive design. The location, orientation, size, angle and material properties of the glazed as well as opaque elements of the building skin together with shading elements, compactness and overall area to volume ratio provide the framework conditions for the thermal behaviour of the building. The transparent elements allow for daylighting as well as solar gains and must therefore be carefully designed to balance wanted and unwanted solar gains. On the other hand, the building skin provides ample area for the integration of active systems. The radiation potential can be exploited on all unshaded areas on the building envelope. The choice of thermal or electrical system (or a combination of both) depends mostly on the requirements of the building.

Balancing these requirements on passive as well as active design principles in a quantitative manner provides a significant challenge at an early design stage for large-scale urban planning projects. Shading and overshadowing of building structures can be easily done in almost any standard 3d CAD software. However this provides mostly only a qualitative assessment. To quantify solar radiation on a larger scale for urban planning projects a more accurate analysis is required in order to make design decisions at an early planning stage. Currently there is a lack of assessment tools available, which can quickly compare and evaluate different designs (Horvath 2011).

The project CityCalc is trying to fill that gap by providing an easy to use planning and assessment tool, which can in a simple 3d model quantify the shading effects of building structures on the energy performance of the design. With the tool the passive and active design aspects can be assessed at an early design stage and different design scenarios can be rapidly compared. The tool can also be used for design competitions, providing quantifiable key performance indicators, which can be used to rate the various designs in a quick and efficient manner.

3 METHODOLOGY

3.1 First step

The first step in the project CityCalc was to provide an overview on current urban planning practices at an early design stage and merge the findings in a state-of-the-art-report. Literature research, experience with urban planning projects and stakeholder feedback have been used to develop the framework for the CityCalc tool. The software program is based on a simplistic three-dimensional geometry input method of the freely available software SketchUp. In order to shape the functionality of the tool and to validate the prototypes in practice, several architectural competitions and similar urban planning procedures have been accompanied during the early design stages. State of the art – Integration of energy efficiency aspects in architectural competitions

The task was to survey current urban planning approaches in Austria, Germany and Switzerland with focus on forms of procedures, involved stakeholders and applicable 3d software tools for energy efficiency assessments. In addition to the literature survey, the project partners delivered substantial contributions based on their experience with conducted architectural competitions:

- 'First design building according to climate, then design HVAC according to the building' (Gertis et al., 2008) has proved its worth as guiding principle for low-tech energy efficient solutions. That means primarily to optimize the geometry and shell of the building regarding minimization of the energy demand for heating, cooling, lighting, ventilation and humidification. The second step, to optimize the HVAC-system according to the building, can be conducted during later planning stages. The principle helps to reduce the amount and costs of technical building equipment and therefore supports low-tech solutions.
- Comparing heating with cooling, in most cases the energy demand for cooling has a higher influence on the energy efficiency of non-residential buildings. This applies as well for the optimization potential and therefore it is important to take window area (especially in roofs) and shadings (of construction and other buildings) into special consideration.
- There is a lack of 3d assessment tools for early planning stages, which can quickly compare and evaluate the energy performance of different designs. Some participants of architectural competitions already perform detailed energy simulations but there are no appropriate tools available which allow fast assessments.
- In many cases the infrastructure of urban development projects causes higher costs than the buildings. Therefore there is a demand for low-tech and cost-efficient urban solutions.
- Architectural competitions are usually very specific regarding scope and objectives. Extensive criteria sets for sustainable building cause a high effort for architects and primary examiners and are hard to comprehend for the jury. Furthermore many of those criteria are not relevant for early planning stages.
- Assessment tools are necessary to integrate energy efficiency criteria in architectural competitions. But prerequisite to that is the technical competence of jury members and their affinity to the topic energy efficiency.

3.2 Urban planning in Vienna – concept and practice of cooperative procedures

A cooperative procedure is an urban planning methodology that has been used since several years in Vienna as an alternative to architectural competitions for urban planning projects. Cooperative procedures are urban planning processes with several planning teams which at least partly cooperate. There exist two basic types of cooperative procedures: Either all participants work together on a project or participants work competitively on different projects but have also a cooperative exchange during planning colloquia, workshops, presentations and discussions. In contrast to common architectural competitions there is no anonymity but usually there exists an anonymous selection procedure before the cooperative procedures starts. Cooperation partners are as well public authorities, selected departments of the municipality and developers. In several cases specific experts (e.g. for wind comfort) are integrated and public participation was realised. (Temel, 2014)

Advantages	Drawbacks
Learning procedures: Involvement of many stakeholders with continuous feedback to objectives, tasks and concepts. Combination of knowhow instead of selection of the best concept. Public participation and transparency. Diversity of procedures. Improved process: higher chances for implementation by higher acceptance of results; reduced revisions; speed. Flexibility: wide scope for stakeholders to change and adjust objectives and tasks. Variety of planners due to relatively easy access.	Risk of results with low quality due to short planning time or due to unclear starting conditions. Compared to competitions the results have no responsible author and the further development has usually no public control. Risk that a partial interest gains too much importance. A high social competence is required by participants. Partly very low fees for planners. Follow-up orders are unclear. Competence of organizer and steering committee.

Table 1: Advantages and drawbacks of cooperative procedures (Temel, 2014)

3.3 Stakeholder opinions

Interviews and workshops with stakeholders produced a critical feedback and a detailed wish list for the tool:

- The chamber of architects raised high concerns regarding the reasonability and effectiveness of an assessment tool for the energy efficiency in architectural competitions. Reasons were the fear of higher efforts for architects, primary examiner and jury as well as bad experiences of previous attempts to integrate this topic into competitions.
- Primary examiners in architectural competitions had some experiences with 3d modelling from special competitions with the task to optimise the shading of skyscrapers on surrounding buildings: The 3d models of the participants varied in quality. Some models were too complex with too much elements and complicated the interpretation. Other models were too sketchy and had to be completed or re-drawn. There is a lack of framework for the content and structure of 3d models in architectural competitions.
- Several architects showed interest in the development of a planning support tool for early planning stages, which should be web based, open source and compatible with other software. Additional information created by 3d planning should be used e.g. to determine construction volume and surfaces, excavation volume, daylight quality of public spaces, ground sealing, infrastructure demand, embodied energy etc.

3.4 Framework for the CityCalc tool

The most important requests of the stakeholders were integrated in the development of the tool but others had to be omitted in order not to lose the focus of the initiative. Nevertheless, a modular structure was aimed at, to integrate further aspects at a later date. By means of the state of the art research the scope of the CityCalc tool was elaborated. The target applications are not only urban architectural competitions but also general urban planning processes and the aim is to generate a support tool for planners. This should expand the target group and help to disseminate the tool. Furthermore the tool should be open source and based on SketchUp. The calculation methodology refers to the Austrian building code (OIB, 2015), which is based on the European Energy Performance of Buildings Directive (EPBD). The assessment results should be presented with easily understandable figures e.g. on a coloured scale (green to red). Further results (e.g. construction volume, floor areas, etc.) should be produced in order to generate additional value and reduce effort for participants and primary examiners.

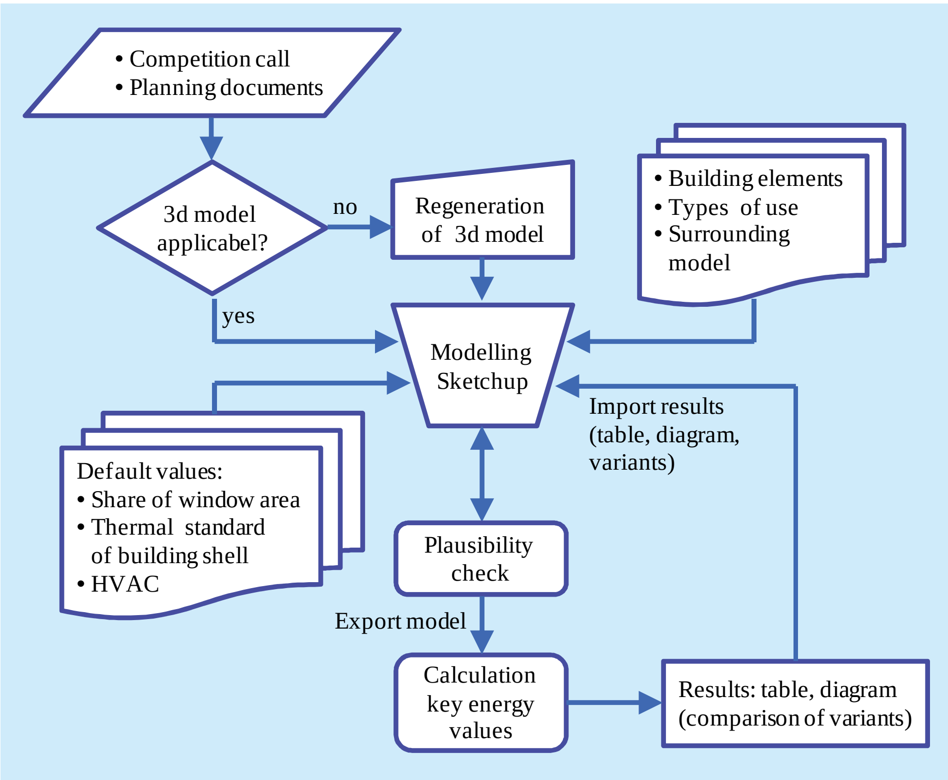

Fig. 1: CityCalc structure. Flow chart of the modelling and assessment process.

4 RESULTS

CityCalc was programmed as a SketchUp plugin with a modular structure. The model was reduced to the most necessary elements that are relevant for early planning stages. Several parameters were pre-set as default values: heat transfer values (thermal protection standard) of the building shell, HVAC system, energy supply system and share of window area. These default values can be adjusted according to the scope of specific urban development projects.

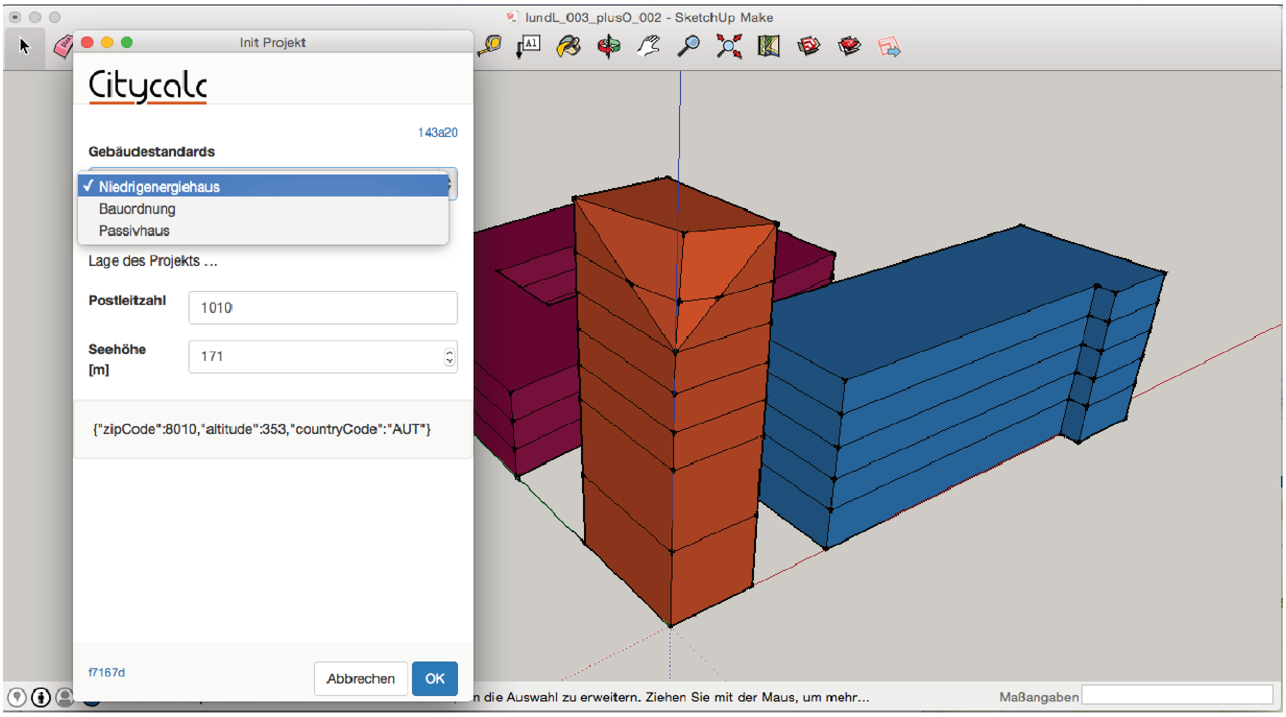

Fig. 2: CityCalc prototype. Modelling a simple urban test area: Setting location, orientation and thermal protection standard

Different types of use can be modelled and shown by different colours. The CityCalc tool automatically calculates floor areas and volumes for each use area.

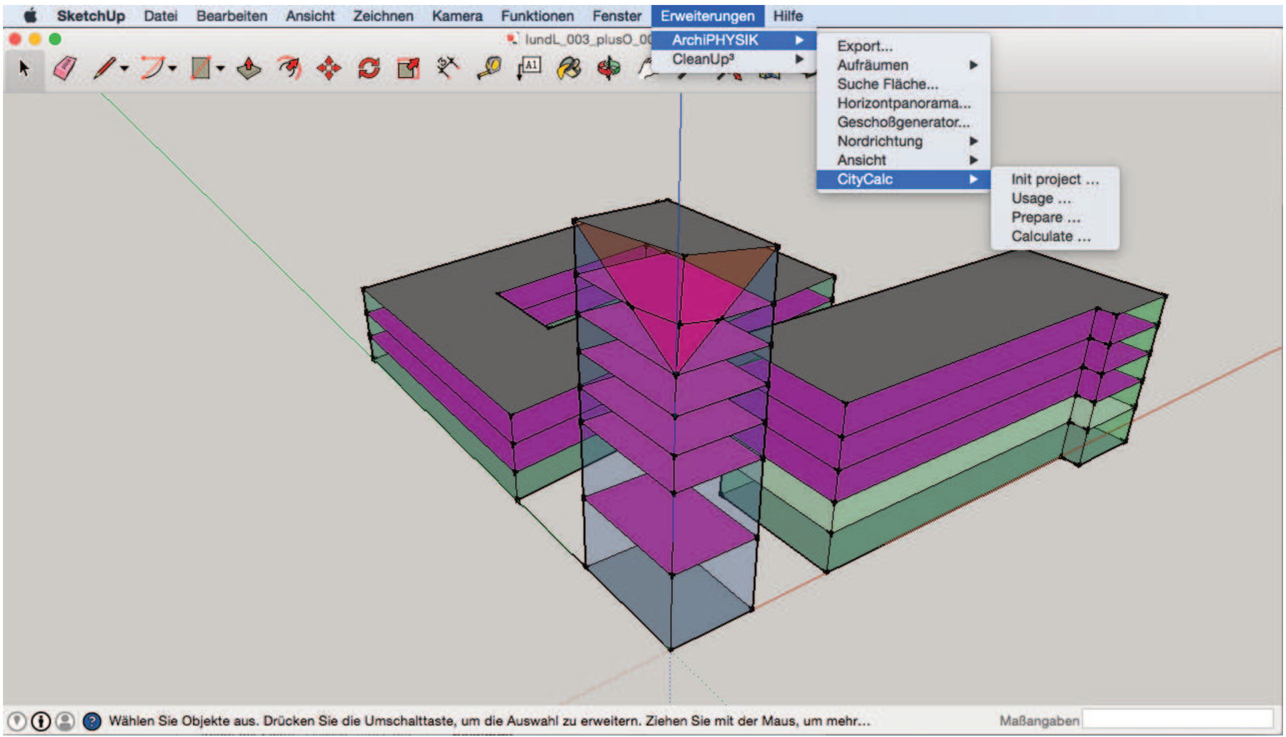

Fig. 3: CitaCalc prototype. Automated calculation for floor areas and volumes for different use areas

For the calculation of energy efficiency figures the model is exported to the Archiphysik server and the calculation results are automatically re-imported for each building. In the CityCalc prototype the results for useful energy, primary energy, greenhouse gas emissions and solar potential are shown in a table and it is possible to compare the effect of variants.

5 CONCLUSION

The CityCalc tool provides with a plugin for the well-known software SketchUp an easy to use and readily available assessment platform to analyse, compare, rate and visualize different urban planning scenarios during the initial design stages. Solar radiation, shading effects as well as energy performance indicators as used in energy certificates can be easily calculated and visualised in a virtual 3d model.

At an early design stage of urban planning projects there is usually not enough information available to assess the energy demand of individual buildings in detail. The urban morphology of districts is nevertheless largely energy relevant as the structure, compactness, orientation and material of the building skin influence the energy performance of the buildings. In the context of urban environments the shading from adjoining structures and thus the context of each building within its urban environment impacts on the overall energy performance of the district and city. Being able to quantify on a large scale shading effects of building structures and solar radiation in urban planning projects is therefore imperative in order to maximise the benefits of active and passive solar design. At an early design stage, adaptions in terms of orientation, context and compactness can still be more easily undertaken. Quantification and the visualisation of the performance indicators can thus contribute to positively influence the decision process.

From the cooperative planning project ‘Oberes Hausfeld’ in Vienna learnings have been derived how to adjust and implement CityCalc in cooperative procedures. The presentation and interpretation of the energy performance indicators should be visualized directly on the virtual 3d models of the buildings. This provides an important support in discussions and consultations and helps the planners to make informed decisions on their design. Energy related results, which are displayed in graphs and charts detached from the 3d visualisations are harder to read and relate to the respective designs by the planners. Being able to see the impact of shading and overshadowing effects directly on the 3d surfaces can accelerate and positively influence the planning process.

CityCalc has thus been developed to be a successful accompanying tool for the early design stages where the comparison of different scenarios is imperative in order to arrive at an energy optimised design scenario. Further urban planning projects will be accompanied in order to validate and adjust the tool. Following the initial implementation phase of CityCalc it is envisaged to add other aspects such as life-cycle and eco-analysis to the capabilities of the tool.

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