Optimising Energy Use in Masterplanning

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ABSTRACT: SUNtool (Sustainable Urban Neighbourhood Modelling tool) represents a new approach to an integrated architectural design and environmental simulation tool. It has been developed by 6 European institutions under the EC's Fifth Framework Programme "Energy, Environment and Sustainable Development" (NNE5-2001-00753) and was completed in early 2006. This paper discusses the innovative features of SUNtool and how these support a fast moving planning process. Using a case study the application of the SUNtool software suite for the analysis, design and development of sustainable masterplans and also the upgrade of existing neighbourhoods is demonstrated. The benefits of an easy to use and customisable tool for evaluating resource flows, i.e. thermal and electrical energy, water and waste from the early design stage onwards by architects and planners are shown. It is concluded that the resource flow modelling facility provided within SUNtool can provide an important planning contribution to mitigate the environmental consequences of urban growth by establishing framework guidelines early on in the masterplanning process.

Keywords: simulation, masterplan, energy, water, waste

1. INTRODUCTION

As architects and planners experience an ever growing demand to incorporate sustainable energy and resource flow strategies into the built environment, individuals must acquire new knowledge on sustainable development and apply new tools for the evaluation and optimisation of design alternatives. Practice shows that collaboration with specialised consultants still often begins only after strategic decisions have already been made and moreover often lacks the interactivity needed in a rapid design process. The majority of currently available simulation tools are not suitable to overcome the fragmented planning process since they require specialised technical knowledge and thus are not incorporated in the daily routine of most architectural practices. In addition, most of these existing tools are suitable primarily for analysing individual buildings in isolation. At this time there is no comprehensive design tool available to evaluate strategically more important large scale urban developments from the very start of the design process.

SUNtool aims to fill this gap by providing an integrated architectural design and environmental simulation tool ("modelling tool") as well as a web based information tool ("educational tool").

The integration of a 3d sketch design tool and a rapid simulation facility allows evaluation of urban neighbourhoods in terms of (i) passive environmental design principles and renewable energy production combined with microclimatic analysis, (ii) the study of efficient small scale energy production, and (iii) the resource flows of water and waste depending on stochastic modelling of human behaviour.

The user and planning process-oriented graphical user interface (GUI) only requires such levels of specification that matches the information available at the different project phases. The GUI has been developed through a dialogue with an independent steering group made up of leading practicioners. Thus SUNtool becomes a flexible tool that can be used at a very early design stage to: quickly evaluate fundamental spatial layout alternatives; perform detailed studies at advanced project phases; or even to analyse existing developments. Its novel parametric engine allows automated testing of design variables and is consequently capable of informing the optimisation of layout, shape, construction etc. according to the user's specifications.

The web based information tool (www.suntool.net) supports the design process by providing additional information regarding the masterplanning process in general and the impact of urban development on the community and individuals' quality of life. Furthermore site selection criteria and guidelines relating to energy, water and waste flows within urban developments, sustainable technologies, and transportation help users to make informed design choices. Case studies, links to related research and European legislation as well as an interactive user forum provide a platform for wider discussion and research.

SUNtool's combination of several new techniques that enable non-expert users to achieve reliable and quantifiable simulation results quickly (Fig. 1) are described the following chapter in more detail. Their application is demonstrated in the case study in chapter 3.

2. KEY INNOVATIONS OF SUNTOOL

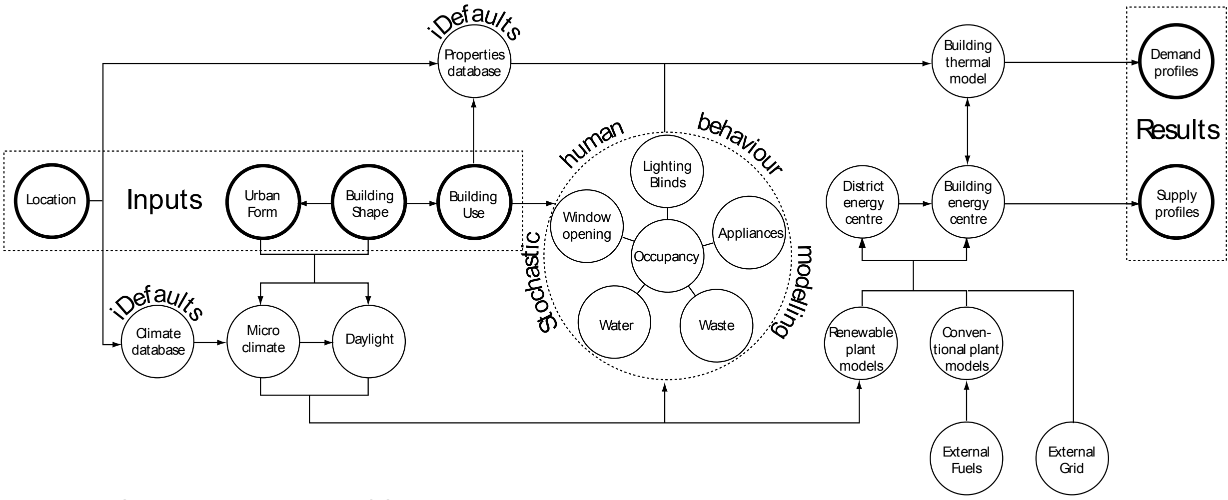

Figure 1: Schematic illustration of SUNtool's integrated solver combining intelligent object attribution mechanisms (iDefaults), stochastic human behaviour modelling and dynamic thermal modelling with resource supply modelling.

2.1 Integrated Solver

SUNtool's advanced integrated Solver (Fig. 1) combines several simulation modules for more realistic representation of interactions within the urban environment. This includes in particular the microclimate models: as we move away from simulating a single building to simulating an urban neighbourhood, the interactions of the buildings with each other through short wave and long wave radiation exchange between buildings and ground surfaces, and shading from direct and diffuse solar radiation become increasingly important. The microclimate models capture many of these effects. Finally the plant and renewable models simulate the energy supply strategy specified by the user at an individual building and district level.

At every (sub-)hourly time step the demands generated by human behaviour and performance of fabric and systems within buildings are compared with the available energy supply including high efficiency technologies such as CHP, heat pumps and mechanical ventilation with heat recovery as well as intermittent generation from on site renewable energy sources such as PV, solar thermal, or wind power. Supply side modelling addresses both individual buildings and also district energy centres.

This holistic approach consequently provides better insight into flows of all resources in large urban developments.

2.2 Attribution by iDefaults

SUNtool takes object-oriented design to the macro-scale of the masterplanning level. A SUNtool object is defined as an entire building consisting of attributes, which are automatically applied from a powerful database - the Suntool 'iDefaults' (intelligent Defaults). Object properties are pre-selected for the building envelope via country specific datasets based on building regulations, typical construction preferences and existing characteristics of residential and non-residential building stock. The user defines in SUNtool primarily the position and shape of buildings and especially their use, since this will allow conclusions on occupancy schedules, appliance density and internal spatial layout. The relevant information is again drawn from the iDefaults database and is supported by embedded demographic and socio-economic statistics.

The attribution process described above simplifies and accelerates the preparation of virtual models. The scene as shown in Figure 4 can be created by an inexperienced user within 15-20 minutes. SUNtool's value for the masterplanner is in its extremely quick way of reaching simulation results whilst shielding the user from the underlying complexity of all the necessary attributions required to create building objects. This is particularly true at the beginning of a project when most object properties are still unknown, the designer is not burdened with detailed questions but can instead concentrate on the design of the masterplan layout and building form and evaluate its potential effect on the resource flows.

As the design progresses and more information becomes available and more detailed simulation results will be desired, SUNtool's tiered attribution structure enables refined definition of the object's sub-elements by overriding the default values (e.g. values for building elements, mix of sub-uses etc.)and gives users considerable flexibility to create more detailed models of new and existing buildings.

2.3 Behavioural Modelling

SUNtool integrates novel stochastic models of human behaviour for simulating occupant interaction with the building itself, its control systems and use of appliances and is based in part on monitoring of real buildings. Each occupant is treated as an individual actor and behaves differently to others. This results in a more realistic estimation of the effects of the occupants on a site's resource consumption as opposed to the traditional approach of applying idealised deterministic schedules repeated hour upon hour and day upon day.

At the heart of these models is the occupancy probability model, which determines when a unit is occupied and by how many people. Several sub-models - which account for variations in external and internal environmental conditions, simulate interactions with blinds and shades, opening of windows, the use of artificial lights and consumer or office appliances as well as the consumption of water and the production of waste.

Behavioural modelling on the scale of a masterplan generates more realistic estimation of peak loads and relieves the user from defining repetitive deterministic schedules. At the same time SUNtool provides a profile generation facility in case specific use patterns are known.

2.4 Parametric Simulations

As outlined above, the many interdependent variables influencing the resource supply and demand profiles of an individual building have to be multiplied for a scene consisting of many buildings in a masterplan. On one hand this significantly increases the difficulty in optimising resource flows but equally it allows tradeoffs between different buildings' performances and gives the planners choice and potentially more design freedom.

SUNtool's novel parametric engine is capable of supporting the evaluation of many different configurations in an automated manner. The parametric solver allows users to specify the upper and lower bounds as well as the step increment in which the parameters are to be varied. In this way users will be able to investigate the relationship of a number of parameters and their influence on the resource flows in the scheme.

With parametric properties modification designers can explore the impact of changing surface properties (e.g. solar reflectance etc.), construction properties (e.g. u-value, thermal lag etc.), and façade configurations (e.g. glazing ratio, etc.) or the mix of residential and non-residential uses. The former variables might lead to identifying demand reduction strategies and the latter to finding the appropriate mix of uses for the efficient CHP performance. The study of these properties can inform local or project specific planning guidelines and assist councils or city governments in meeting CO_2 emissions targets.

By overlaying two variables complex investigations can be performed and many design alternatives can be tested and evaluated in an automated manner.

2.5 Results Analysis

The results are presented in sets of relevant categories (CO2 emissions, Thermal Energy, Electric Energy, Water, Waste, Climatic Analysis, Planning Statistics and additionally users can customise their own graphs) in SUNtool's own results analysis facility. Multivariable graphs are used to display the relationships of parametric simulations.

3-D false-colour mapping can be applied on the life scene to display the individual buildings performances and can be used to quickly highlight areas or objects of low or high performance. This technique is particularly useful as it reduces the potentially huge amount of output data to quickly accessible visual information allowing the user to focus on key buildings within the scene.

3. CASE STUDY

Several Case studies concentrating on different aspects were undertaken to demonstrate the versatility of SUNtool at the end of the research project. The case studies focused particularly on (i) stochastic modelling, (ii) parametric modifications, (iii) renewable energy systems, (iv) energy efficiency and CO2 reduction, (v) plant modelling, and (vi) water and waste resource flow. In the following section the case study considering energy efficiency and CO2 reduction shall be reviewed:

3.1 Case Study Context, Prague - Repy

The Repy housing estate (Fig. 2) lies to the west of the city centre and is in its urban layout and building typology a typical example of the socialist public building programmes carried out from the 1960s to the 1990s.

Figure 2: Aerial view of Prague Repy

Figure 3: Original apartment block (left) and refurbished apartment block (right)

Residential buildings are typically based on a modular external panel system and rise to 8-12 storeys (Fig. 3), with internal layouts roughly as follows:

- Plant rooms, stores and laundry facilities are located in the basements;
- Communal spaces and storage for bicycles, prams etc. on the ground floor;
- Above this the buildings are divided into 3 to 5 adjacent vertical residential blocks, but with

separate entrances, lifts and stairs. There are typically 2 to 3 flats per block per floor, with individual flats often having their own balconies on one façade.

Regeneration of the Repy district started in 1995 and is on-going. Key aspects of this process have been to: upgrade the building fabric (Tab. 1) (e.g. improving thermal insulation by adding insulation to the walls); replacing windows; glazing balcony areas. The roofs of the buildings were comparatively well insulated and hence refurbishment works have focussed on the facades. Internally thermostatic valves (TRVs) on radiators were introduced.

Table 1: Upgrading of building fabric for refurbished buildings in Repy

Construction Element	**U-Value** (Original) [W/m²K]	**U-Value** (Refurbished) [W/m²K]
External Wall	1.12	0.26
Windows	2.55	1.60
Intermediate Floor/Ceiling	1.14	0.57
Roof	0.28	0.28
Internal (Partition) Walls	1.36	1.36

The buildings are served by a district heating scheme with heat exchangers located in plantrooms within each individual building serving low temperature hot water (LTHW) radiator circuits supplying the flats. All flats have dedicated water meters, which record consumption of both hot and cold water. Hot water demands are met by a central storage tanks in each building.

The buildings (particularly the earlier constructions) have suffered from both “under-heating” in the winter and “over-heating” in mid-season and summer, due to inadequate levels of thermal insulation, “leaky” constructions and high levels of exposure to sun and wind. This has been exacerbated by the fact that operation of the district plant is not 24hrs per day, it is switched off from around the end of April until October (even if there would have been a demand for space heating in the interim), and that in many cases residents were unable to regulate heat output from radiators due to absence of controls, so that if flats became too warm they would have to resort to opening their windows.

Refurbishment of some of the oldest buildings has therefore been occurring on a building-by-building basis since the late 1990s. This clearly has two main purposes: to improve the thermal comfort and health (quality of life) of the residents and to reduce energy costs.

3.2 Modelling

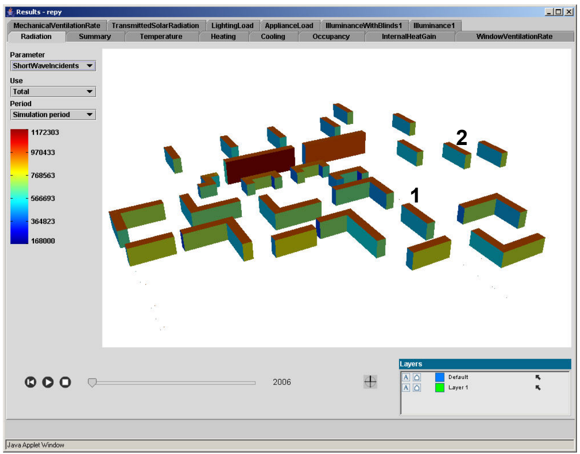

Figure 4: Irradiation mapping of case study area model.

SUNtool studies have concentrated on the south-eastern quarter of Repy as shown below (Fig 4). The building geometries were traced from an imported dxf site plan and automatically attributed using the iDefaults dataset for the Czech Republic. Since detailed building surveys were available the initial generic fabric attribution was updated to match the real conditions.

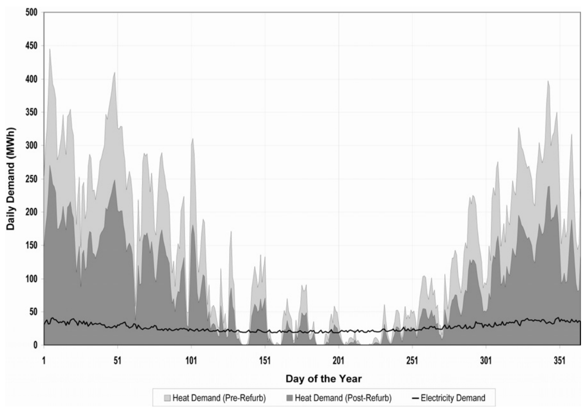

Figure 5: Variation of cumulative energy demand for south-east quarter of Repy, pre and post refurbishment.

Initial demand side studies (Fig. 5) indicated that by upgrading the building fabric alone (a major task in itself) delivered energy in kWh/m² could potentially be reduced by over 40% through successful refurbishment. By analysing the heat and electricity load profiles (base loads etc.), it was also possible to investigate the potential of a number of hypothetical options in terms of energy supply, e.g.: replacing the district heating boilers with a combined heat and power unit; mounting small wind turbines and solar thermal collectors on the roofs of individual buildings and so on.

Interestingly, some measurement data was available for Building 1 (non-refurbished) and Building 2 (refurbished) which have the same orientation (Fig 6) giving actual heating energy consumption on a monthly basis for a recent year. They are 8-storey residential blocks divided into 3 sections containing 48 flats overall. These showed a 36% reduction in annual space heating energy consumption – the SUNtool predictions for the individual buildings also showed reasonably good comparison in absolute terms – within ±25% - after normalising for different weather sets. As ever there will be many factors that differ between these two buildings and indeed between reality and the assumptions used within the Modelling Tool (e.g. the quality of construction work and control and operation of heating system; internal temperatures (set-points) may be higher during the heating season post-refurbishment; the level of internal gains within the buildings seems lower than predicted by the Modelling Tool when looking at balance point temperatures (degree day analysis, etc., etc.). However, the results are nevertheless encouraging.

4. CONCLUSION

The paper introduced the novel software suite SUNtool consisting of modelling and educational tools for evaluation of energy and resource flows within masterplans. Innovative key features were presented and their value for architects and planners faced with the task of creating efficient and sustainable developments were explained.

The application of the tool was demonstrated in an evaluation of a real life case study. The comparative analysis showed encouraging congruence of results whilst pointing out that software tools cannot and are not meant to recreate reality but can significantly improve the decision process and lead designers in the right direction. It is acknowledged that this simulation software provides a valuable tool for planners but it is their responsibility to interpret the results correctly. In doing so the tool can be used to establish framework guidelines in masterplanning that ensure efficient resource and energy management whilst not restricting design freedom for the planners of individual buildings within such a masterplan.

SUNtool's unique modelling capability and the speed in which quantifiable results can be achieved make it a useful tool for planners in addressing problems created by rapid urbanisation and exponential growth of population by including resource demand and supply evaluation right in the beginning of the urban design process. This is particularly true in the perspective of developing countries and limited resources or supply-side infrastructure.

SUNtool is free for all simulation software and can be downloaded from the project website www.suntool.net.

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