ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

2007-9

LESO-PB

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CISBAT 2007

4-5 Septembre 2007

OPTIMISATION OF BUILDINGS DAYLIGHT AVAILABILITY

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ABSTRACT

Many researchers have the goal of improving buildings daylight availability in order to decrease the HVAC energy intake. Indeed by achieving/identifying sustainable urban forms and their design concepts, the benefits of the solar radiation can be of threefold: 1) placing PV collectors on the roofs and/or facades produces electricity, 2) placing water heating systems on the roofs and/or facades saves fossil fuel, and 3) having well dimensioned windows diminishes the needs of artificial lighting and reduces the heating/cooling bill. The way followed until now to improve the buildings performance was to evaluate it using software like PPF (a simulation programme for predicting urban solar potential) on various urban forms, and choose the best one. A new methodology is presented in this paper; it enhances the performance of buildings without the expense of trial and error in usual simulation software. The methodology, based on evolutionary algorithms, could provide helpful insights for planning solar cities.

INTRODUCTION

The solar potential (radiation available from the sun) has always been a major concern for architects and urban planners as human beings need light in their shelters. The interest is even stronger nowadays as this renewable energy can be converted to heat and electricity. A simulation tool named PPF [1] has been developed to evaluate the solar potential; PPF is RADIANCE [2] based (a backward ray tracing technique to determine radiation availability). This tool has been used in various urban form studies [3-7], assessing the utilisation potential of various solar technologies (passive and active solar, photovoltaic). Recently a parametric study was conducted [8] on built forms to address the best urban configuration from a solar potential point of view.

In this paper, we go further by defining a new methodology to minimise the energy consumption of parameterised urban forms using evolutionary algorithms. It avoids the expense of trial & error with PPF and can explore huge parameter spaces. As a first approximation, minimising the energy intake of urban built forms is maximising their solar potential deduced by their thermal losses. We have chosen winter as our period of interest; indeed an optimal use of the solar potential can have a big impact on the heating needs (for the climate of Switzerland).

METHOD

Environment and study

From the SOLURBAN project [3, 6, 7, 9], 3D information of the "Matthäus District in Basel" is available. In this study, models representing four different types of representative built forms in Basel or in the other European cities are compared for solar potential and thermal losses. These buildings have been designed with standards measures of 10-14m depth on 11-

13m width following the regulation. These measures have been chosen to maximize the daylight inside the apartments. These four urban shapes have been implanted on a parcel in the center of Matthäus district. The built forms studied are presented in Figure 1.

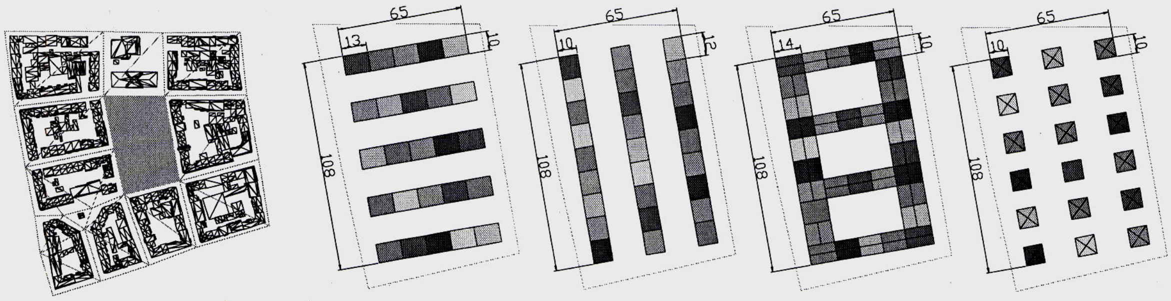

Figure 1: Surroundings in the Matthäus district of the supposed buildable area and four typical urban builts forms studied, respectively Terraces Flat Roofs, Slabs Sloped Roofs, Terrace Courts (2 sided-roofs) and Pavilions (4 sided-roofs) – North is up

Parameterisation of the geometrical features

Each family of built form is parameterised to allow its representation by a vector of real numbers. The Terraces Flat Roofs are represented by a vector ($\vec{x}_1$) of 25 components representing the heights of the buildings composing the terraces. The Slabs Sloped Roofs use a vector ($\vec{x}_2$) containing the heights of the buildings and a parameter that codes for the orientation of the roof and its height. The Terrace Courts and the Pavilions are represented by vectors (respectively $\vec{x}_3$ and $\vec{x}_4$) composed of the heights of the facades and the heights of the roofs. The vectors are shown in equation 1.

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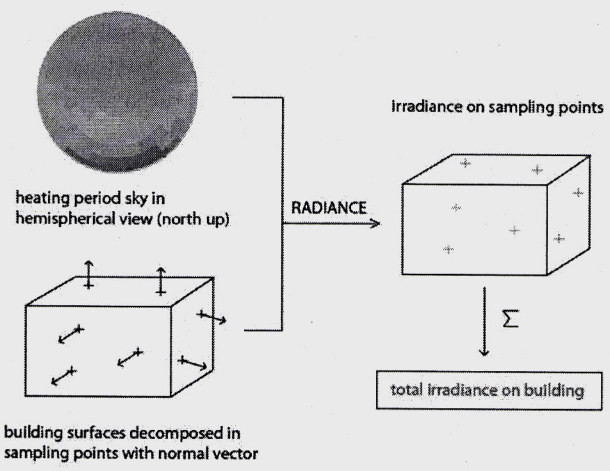
From the regulation of Matthaeus district in Basel, the maximal height of the facades is of 14 meters, and the maximal height of the roofs is 4 meters.

New C++ software *genbuil* was developed to determine the solar potential and the thermal losses of each vector representing a potential candidate for the best energetic building configuration. The following sections address solar potential and thermal losses determination, as well as the optimisation method.

Solar potential determination

RADIANCE [2], a physically accurate backward ray-tracing software, is used to place virtual watt-meters on building faces and roofs. The sampling points are separated by a maximal distance of 1m in order to capture the main features of the irradiance map on the surfaces. A cumulative sky [10] for the period of interest (heating period) is available for Basel from SOLURBAN project. Figure 2 represents the whole process of solar potential determination.



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The thermal losses of a building can be evaluated in a first approximation as proportional to its skin surface (i.e. in contact with the exterior). A global heat transfer coefficient ($U_{building}$ in $W \cdot m^{-2} \cdot K^{-1}$) for all the candidate solutions is used to determine the thermal losses ($E_{thermal}(\vec{x})$ in Wh) of a potential solution $\vec{x}$:

$$E_{thermal}(\vec{x}) = U_{building} \cdot S_{ext}(\vec{x}) \cdot \overline{\Delta T} \cdot (t_f - t_i) \quad (1)$$

Where $S_{ext}(\vec{x})$: surface (m^2) in contact with exterior of potential solution $\vec{x}$

$\overline{\Delta T}$: mean temperature difference (K) between inside and outside when cooler outside on the period of interest

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In our study the period of interest is the heating period (6 months, from November to April) where the mean outside temperature is 5°C. Considering the heating set point at 20°C, we get $\overline{\Delta T}$ = 15 K. The U-value chosen is 0.38 $W \cdot m^{-2} \cdot K^{-1}$ which corresponds to an actual MINERGIE construction (20% in surface of the whole envelope is glazing 1.1 $W \cdot m^{-2} \cdot K^{-1}$ and 80% is opaque material 0.2 $W \cdot m^{-2} \cdot K^{-1}$).

Optimisation

The parameter space of the vector $\vec{x}$ defined in the parameterisation paragraph is explored to find the best set that maximises the solar potential and minimises the thermal losses. In formal terms, we are looking for:

$$\sup_{\vec{x} \in \mathbb{R}^n} \{Ep_{solar}(\vec{x}) - E_{thermal}(\vec{x})\} \quad (2)$$

Where $Ep_{solar}(\vec{x})$: solar potential (Wh) of the candidate solution $\vec{x}$

$E_{thermal}(\vec{x})$: thermal losses (Wh) of the candidate solution $\vec{x}$

The *genbuil* C++ software developed evaluates the energetic values associated with each set of parameters $\vec{x}$. The Non-Linear Programming (NLP) formulation of our problem led to the choice of an advanced genetic algorithm (MOO [11, 12], written in MATLAB) for the maximisation described by equation (2).

The OSMOSE platform [13] allows to link MATLAB with external software. It has been chosen to link the optimizer MOO with the developed *genbuil* software.

RESULTS AND DISCUSSION

We fixed the maximal number of evaluations of potential solutions by defining the amount of time available for the optimisation. With an average of 3 minutes per candidate solution, we chose 6000 evaluations for a total computing time of 300 hours.

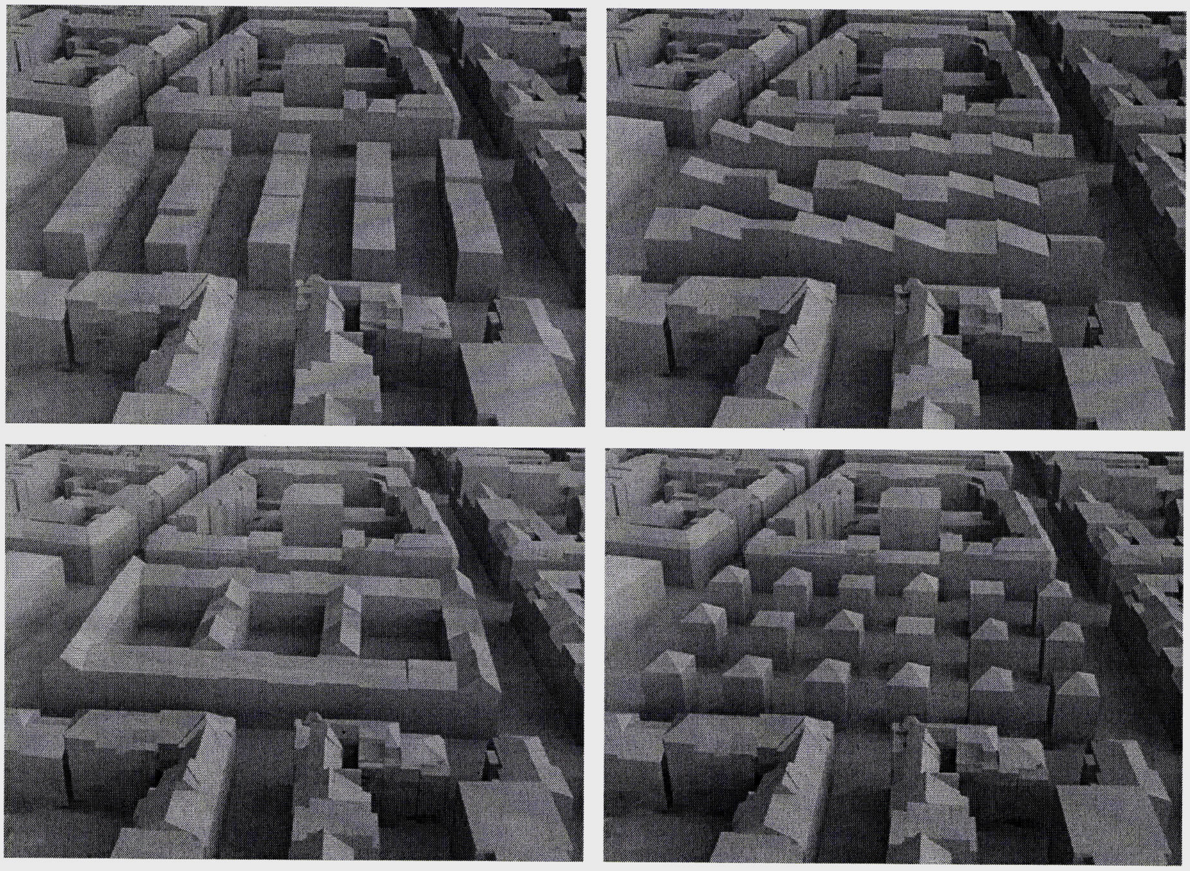

Figure 3: Shape resulting of the optimisation of Terraces Flat Roofs, Slabs Sloped Roofs, Terrace Courts and Pavilions

The solar potential evaluated by our *genbuil* software is compared to the one obtained by PPF method (see Table 1). The results show good accordance between the two methods, which is very satisfying as PPF method has been used many times in the past.

Energy (MWh)	**Terraces Flat Roofs**	**Slabs Sloped Roofs**	**Terrace Courts**	**Pavilions**
Floor area (m^2)	12'392	14'166	19'931	7'933
Envelope irradiance (*genbuil*) Envelope irradiance (PPF)	2'057 1'996 (-3%)	2'236 2'049 (-8%)	2'389 2'363 (-1%)	1'650 1'651 (< -1%)
Envelope Irradiance per m^2 (kWh)	167	158	120	208
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Total Total *classical form*	1'727 (+1.3%) 1'705	1'865 (+3.0%) 1'811	2'005 (+1.2%) 1'981	1'350 (<1‰) 1'350
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2. The complicated surfaces (not rectangular) in genbuil are subdivided in triangles that are sampled uniformly with virtual watt-meters. In PPF a coarser approach is used.

The comparison of the solar potential deduced by the thermal losses between the classical form (all components of the vectors at the maximal value) and the optimised form (see Table 1) shows the improvement in buildings daylight availability obtained by evolutionary algorithms. The gain is up to 14.5% of the thermal losses.

In this paragraph we try an explanation of the resulting shape of the optimisation procedure. The thermal losses in the four cases are less than 20% of the incoming radiation on the envelope; they seem to play a minor role in the results, but anyway they act as a limiting factor in the skin surface of built forms. The Terraces Flats Roofs have almost all parts at the maximal allowed height, except where the lower parts let southern solar rays hit the next facade. The last terrace is at full height as the shadow on the next group of buildings is not taken into account. The Terrace Courts seem to follow the same logic. The Slabs are almost oriented North-South; they seem to have a small shadow impact on each other unlike the Terraces. They look symmetrical along the middle slab. It seems that the roofs are oriented in a way to favour inter-reflection between the slabs (solar collector shape). Finally, the Pavilions are exploiting their full height range to get as much sunlight as they can. The shadow impact on each other is tiny and the same for all pavilions.

In the following lines, we compare the four urban built forms. Taking into account the solar potential and the thermal losses, the best configuration is the Terrace Courts, as they have a big volume of solar captation and they are compact enough to minimise thermal losses. Its shape is very similar to other buildings that can be found in the Matthäus district, and compared to the other solutions the construction costs are inferior. According to the solar potential and the thermal losses related to the floor area, the best solution is the Pavilions. They maximise the daylight availability, minimising the self-obstructions of solar radiation. Looking at the construction costs, they are very high due to the high ratio of floor area and facades surface. This solution needs the biggest amount of energy conversion technologies, which are expensive. In the district of Matthäus, the pavilion shape is not well architecturally integrated; it is very different from the surroundings. The Terraces Flat Roofs and Slabs Sloped Roofs can be seen as a good compromise between the two others in terms of measured performance. They are compact and can be easily integrated in the neighbourhood. They have open spaces between the buildings that could be public areas.

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The methodology presented (parameterisation, optimisation of the parameters for an improved performance) is very general and can be extended to handle any shape of urban built form. Its solar potential determination is compatible with the results of PPF, but also faster in computing time which allows the use of evolutionary algorithms for optimisation. The results seem to follow some logical rules, which would be interesting to study more deeply.

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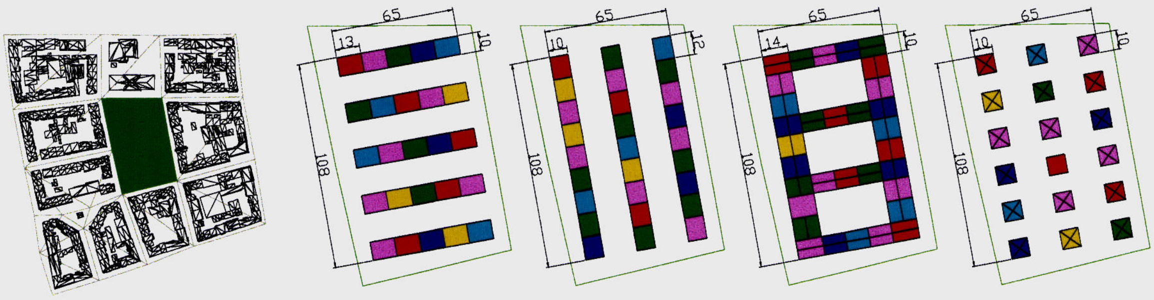

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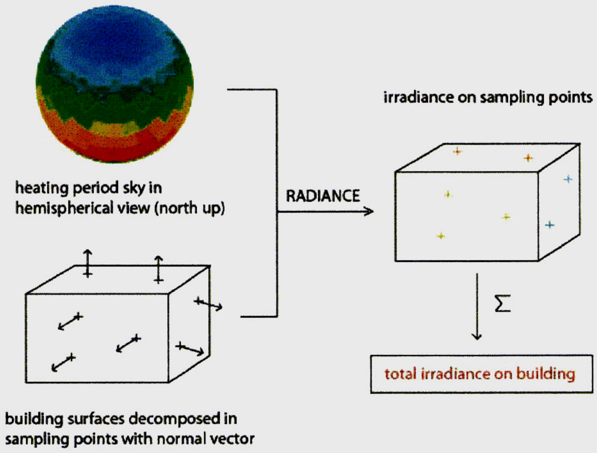

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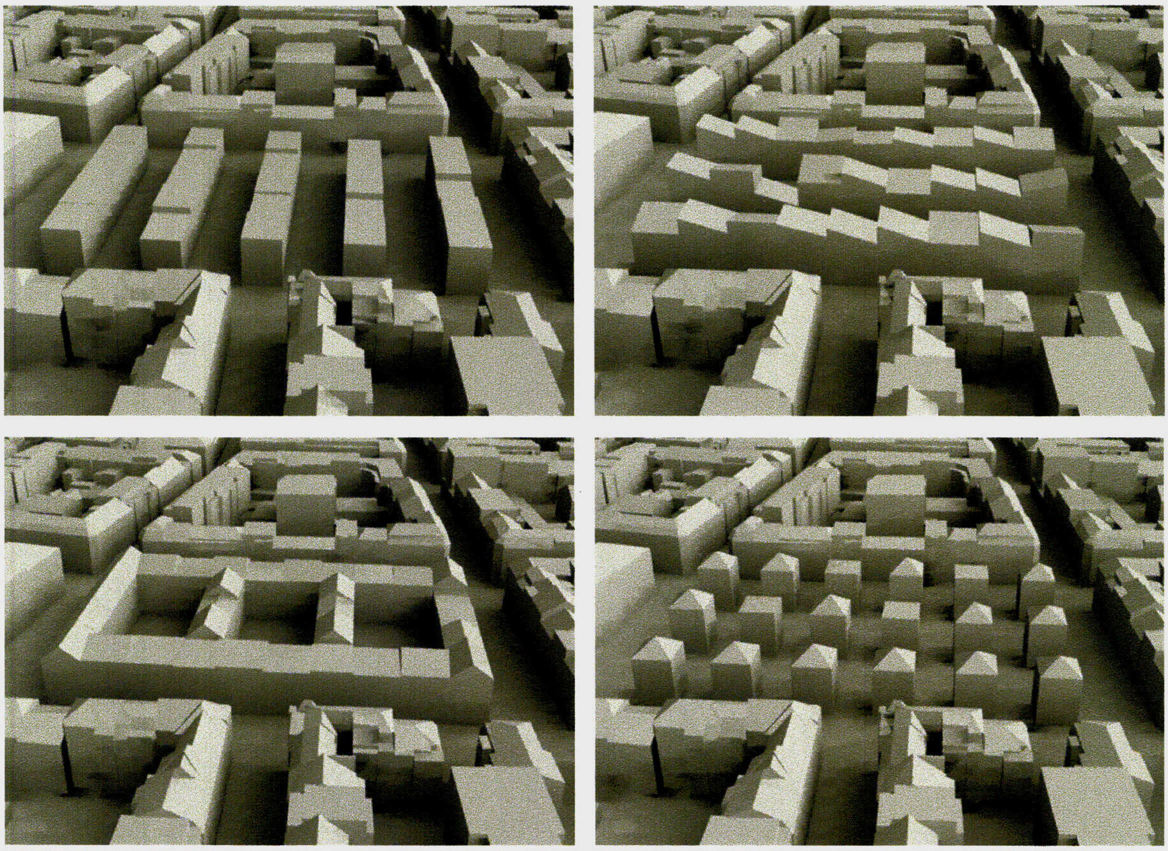

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