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OPTIMIZATION OF URBAN SYSTEMS TO MAXIMIZE PASSIVE SOLAR INPUT

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SUMMARY

The need to save energy at the urban scale leads to study how numerical simulation and optimization methods can help the architects to design buildings having the best possible energetic performances, regarding daylight, warming or cooling, and photovoltaic capacities. The present work uses a physical model of irradiance to estimate the solar radiation received by the external surfaces of buildings; an evolutionary algorithm has been adapted to optimize the position and the global geometry of buildings inside a fixed area, in order to increase the total solar radiation received during a given time period; a hierarchical approach is used to manage the design variables which control the repartition of the buildings and their shapes.

Key Words: shape optimization, urban system, solar energy

1. INTRODUCTION

The environmental performances of a building depend on a large variety of factors, which are often classified in passive and active components. Active components refer to heating, cooling, ventilation systems, which have to be efficiently controlled along the day in order to minimize the energy consumption, while passive components refer mainly to the insulation properties of the walls, the roofs, or the windows. For existing buildings the energetic performances are largely related to the quality of the materials used, but in the context of designing new districts, it is evident that the geometrical aspects such as the shape and orientation of the houses or the size of the streets could deeply influence these performances. The optimal configurations provided by an optimization procedure are far from a real description of the city, but they could be used by the architects or urbanists as starting points in architectural projects.

In this paper we focus on the problem of optimizing the shapes and orientation of a set of neighboring buildings in order to increase the direct solar radiation received by all the walls and roofs surfaces. As a first approach, we choose to maximize the cumulated incident energy evaluated during the shortest day of the year, taking into account the influence of the surrounding buildings:

$$J = \int_{T_1}^{T_2} \int_{x \in S} I_{s\alpha} V(x,t)\, dx\, dt$$

$[T_1, T_2]$ is the time interval considered,
S is the total surface of the buildings (walls and roofs)
$I_{s\alpha} = I_{s0} \cos\alpha$, where I_{s0} is the power generated on a surface element normal to the ray of sunlight and α is the angle between the ray of sunlight and the facet normal,
$V(x,t)$ is the sun visibility function (binary, 0/1), which is evaluated at every point and every time step by projections and polygons intersections.

2. HIERARCHICAL OPTIMIZATION OF AN URBAN GEOMETRY

To validate the optimization approach, a very simple model of houses is considered: a first discrete design variable $h = (h_1, \ldots, h_n)$ controls the space distribution of a given volume described as N hexahedral blocks and a second set $y = (y_1, \ldots, y_m)$ controls the shapes of each building: center location, scaling factors in two orthogonal directions and orientation angle (Figure 1).

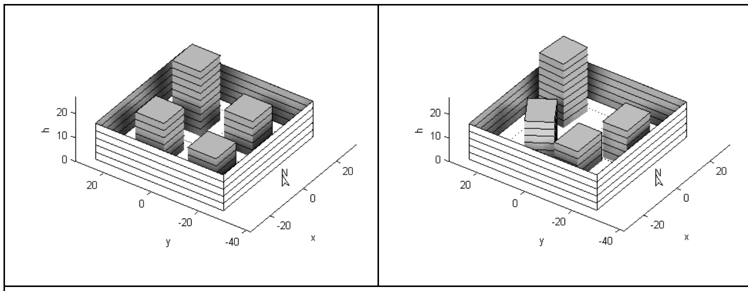

Figure 1 - Optimal volume repartition and optimal shapes, 4 buildings test case, March 21th

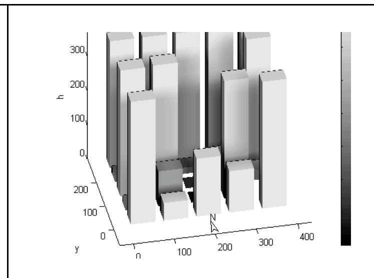

Figure 2 - “Manhattan” configuration

We solve two problems: the first step is a global optimization taking into account only discrete design variables; as several equivalent solutions generally exist, an evolutionary algorithm is applied, using specific operators for crossover, mutation and reparation.
The second one can be global or local optimization dealing with discrete or continuous parameters. The geometrical constraints such as non intersection of buildings are taken into account by explicit projection of the design variables values onto the admissible space.

3. CONCLUSIONS

The definition of the optimization criteria is discussed on the test case “Manhattan” defined in [2]. We show that breaking the optimization in two levels allows to obtain global topologies of a district and the general shapes of the buildings in a reasonable computer time; the energetic performances of a set of buildings can be improved significantly with this approach.

REFERENCES

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[2] Kämpf JH, Robinson D, 'Optimisation of building form for solar energy utilisation using constrained evolutionary algorithms', Energy and Buildings, 2010, pp. 807-814