MODELLING THE CITY THERMAL BEHAVIOR
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OUTLINE

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2-Direct problem modelling
3-Inverse Problem: Optimization
4-Discussion
1-ABSTRACT

Sky Contribution → Geometry Choice → Model → Balance

Test

No

Improving Geometry

Yes

Optimal Geometry
2-Direct Problem Modelling: HELIODON
Variables

- B = urban zone considered, buildings, streets, squares...
- a = design variables = architectural parameters
- I = radiosity
- INPUT: sky radiosity and vector a
- OUTPUT: radiosity of all the elements of B
Sky contribution

- $I_{\text{sky}}(y,t)$ = total radiosity of the point $y$ of the sky at time $t$ (Joules m$^2$/s)
- Decomposition: $I_{\text{sky}}(y,t) = \{I_{\text{sun}}(y,t), I_{\text{diffuse}}(y,t)\}$
- $I_{\text{sun}}(y,t)$ = radiosity of the sun at time $t$ and in the sky position $y$
- $I_{\text{diffuse}}(y,t)$ = contribution of the diffuse sky (clouds)
Thermal model

\[ I(x, t) = \int_{D} f(a, x, y, t).I_{sky}(y, t).dy \]

\[ t = time \]

\[ x \in B, B = \text{set of buildings} \]

\[ y \in D(x), D(x) = \text{subset of the sky visible from } x \]

\[ f(a, x, y, t) \text{ shape factor from } y \text{ to } x \]
Decomposition

\[ I(x, t) = \text{Area of } D(a, x) \cdot I_{\text{diffuse}}(t) + \text{cover}(x, t) \cdot \text{Visibility}(x, a, t) \cdot I_{\text{sun}}(x, t) \]
Algebraic structure

\[ T(a) : I_{\text{sky}}(y,t) \rightarrow I(x,t) \]

\( T(a) \) Transmittance linear operator depending on the architectural shape parameters \( a \)

After spatial discretisation: \( I_B(t) = [T(a)].I_{\text{sky}}(t) \)
Data Evolution in USA

1991 - 2005 Update
- Class I
- Class II
- Class III
- Measured Solar

1961 - 1990 NSRDE

U.S. Department of Energy
National Renewable Energy Laboratory

GSU-Equipe
AVENUES

Laboratoire Roberval
Unité de recherche en mécanique
National Solar Radiation Data Base

- **Data (NSRDB, 2010)**
- The following data products are available:
  - Daily Statistics Files (NOTE: These files are MONTHLY averages of daily totals)
  - Hourly Data Files
  - Solar Radiation Data Manual for Buildings
    - 30-year (1961-1990) average of solar radiation and illuminance for each month
  - Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors
    - Averages of solar radiation for each of the 360 months during the period 1961-1990
    - 30-year (1961-1990) average of solar radiation for each month
    - Atlas for The Solar Radiation Data Manual For Flat-Plate and Concentrating Collectors
  - Typical Meteorological Year (TMY2) Files
University of Oregon, USA

- Eugene Station data (as cited in Allen, 2006)
  - Global  1975 - 1995
  - Direct normal 1977 - 1995
  - Diffuse  1977 – 1995

- Montana Station data
  - The same from 2003 to the present

TEMPORAL AND SPATIAL VARIABILITY
Illustration of the decomposition

Direct Radiation projected onto Horizontal Surface in Eugene Station, Oregon, USA (1983)
Geometrical computation
The visible sky at point x: D(x)
Area(a, x, t)
Visibility of the sun (heliodonogram)
Shadow visualisation
Urban Area Geometric Data (B)

Computation of the visible sky $D(a,x)$ for each $x \in B$

Heliodongrammes

Shape Factors Computation $\text{area}(a,x); x \in B$

Shadow Computation $\text{visibility}(a,x,t); x \in B$

Sky Radiosity Data

$\text{Isky}(y,t)=\{ \text{I}_{\text{sun}}(y,t), \text{I}_{\text{diffuse}}(t) \}$ $t \in [0,T]; y \in \text{Total Sky}$

Radiosity Computation $I(x,t); t \in [0,T]; x \in B$

Output: BALANCE
3-Inverse Problem: Optimization

Sky Contribution → Geometry Choice → Model → Balance

Improving Geometry → Test

Optimal Geometry → Yes

No
OPTIMUM CRITERIUM

Additive terms:
Objective main term + realization cost + energetic cost + ...

\[ J(a) = \int_0^T \int_{x \in B} \left| I_{\text{model}(a)}(x,t) - I_{\text{target}}(x,t) \right|^2 \, dx \, dt \]
Improvement procedure

- Old configuration -------> New configuration
- Mapping expression

\[
\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} x'_g \\ y'_g \\ m_{33}z_g \end{pmatrix} + \begin{bmatrix} m_{11} & m_{12} & 0 \\ m_{21} & m_{22} & 0 \\ 0 & 0 & m_{33} \end{bmatrix} \begin{pmatrix} x - x_g \\ y - y_g \\ z - z_g \end{pmatrix}
\]

\[(m_{11} m_{22} - m_{12} m_{21})m_{33} = 1\]

\[0 < s_{\text{min}} \leq m_{11} m_{22} - m_{12} m_{21} \leq s_{\text{max}}\]

vector parameter \(a = (x'_g, y'_g, m_{11}, m_{12}, m_{21}, m_{22}, m_{33})\)
Properties of the mapping

• Preservation of the polyedral shape
• Preservation of the volume
• Preservation of the basement
• Stability by composition
Steric Constraints: [A].\{a\} \leq \{b\}
Choice of the optimization algorithm

• Non convex problem
• One configuration at each step
  – Sequential Quadratic Programming
  – Simulated annealing
• Multiple configuration at each step
  - genetic algorithm

Multicriteria analysis
CONCLUSION and COMMENTS

• Simplified model: no emissivity of the architectural elements, no thermal convection inside the buildings, no aerologic influence.

• Polyhedral shapes

• Linear mappings

• Individual volume preservation

• Use of meteorological data basis instead of a sky model