SUSTAINABLE DESIGN OF VEGETATED STRUCTURES: BUILDING FRESHNESS

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Urban heat island

Air temperature at 2m height on 10 Aug. 2013 at 6am

(Credits: APUR/EPICEA, 2014)

Vegetation of private and public spaces in the inner suburbs of Paris

(Credits: APUR, 2010 – Louise Gerber, Mathilde Riboulot)
Blue-green solutions

- Acoustic insulation
- Well-being
- Air purification
- Urban vegetation
- Urban cooling
- Thermal insulation
- Stormwater management
- Biodiversity
- Urban vegetation
• Issues for convincing stakeholders
  (ecosystem services are not properly quantified – i.e. the real « performance » of blue-green solutions is unclear)

• Dense cities: lack of space

• Issues related to retrofitting existing buildings
  (technical regulations, costs, long-term consequences)

How to enhance greening of cities?
Vegetated elastic gridshells
Research questions

• How is vegetation relevant for urban cooling?
  → What are the main mechanisms for mitigating urban heat island effects?
  → How does the spatial arrangement of blue-green solutions influence geophysical fields/human comfort at different scales?

• What are the costs (e.g., material resources, polluting processes) and benefits (ecosystem services, biodiversity) of implementing urban vegetation?
Energy balance and cooling mechanisms

<table>
<thead>
<tr>
<th>Absorbed radiation ((\phi_{\text{abs}}))</th>
<th>Emitted radiation ((\phi_R))</th>
<th>Sensible heat flux ((\phi_H))</th>
<th>Latent heat flux ((\phi_L))</th>
</tr>
</thead>
<tbody>
<tr>
<td>((1 - \alpha)S_\downarrow + \varepsilon L_\downarrow)</td>
<td>(\varepsilon \sigma T_s^4)</td>
<td>(h_{\text{ch}} (T_s - T_{\text{air}}))</td>
<td>(LE)</td>
</tr>
</tbody>
</table>

\[ z = 0 \]

\[ eC \frac{\partial T_z}{\partial t} \]

Internal energy variation

\[ z = e \]

Conduction into the soil \((\phi_G)\)

\[ -\lambda \left( \frac{\partial T_s}{\partial z} \right)_{z=e} \]

Energy balance:

\[ \phi_{\text{abs}} = eC \frac{\partial T_s}{\partial t} + \varepsilon \sigma T_s^4 + h_{\text{ch}} (T_s - T_{\text{air}}) + LE - \lambda \left( \frac{\partial T_s}{\partial z} \right)_{z=e} \]
Energy balance and cooling mechanisms

\[ \Phi_{H,\text{vegetation}} + \Phi_{H,\text{shade}} \leq \Phi_H \]
Elastic gridshells in composite materials: Construction process
Elastic gridshells in composite materials: Construction process
Instrumentation plan

- pyranometers ($S_{\downarrow}, S_{\uparrow}$)
- pyrgeometers ($L_{\downarrow}, L_{\uparrow}$)
- Sensors ($p, T, RH$)
- Sensors ($T$)
- Load cells ($m_{\text{water}}$)
Connecting models

Formfinding
- Marsupilami
- Karamba

Structural engineering

3D modeling tool + visual programming language for parametric design
- Rhinoceros
- Grasshopper

Environmental design
- Ladybug
- Honeybee
- Butterfly
- Dragonfly

Building physics +

CFD
- OpenFOAM

Life cycle assessment
- openLCA
Life cycle assessment

OpenLCA + Ecoinvent 3.2

System boundaries as per NF EN 15804 standards

Material production
Transport
Construction
Use
End of life

Benefits and loads beyond the system boundaries
## Life cycle assessment

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Gridshell</th>
<th>Vegetated Gridshell (30 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidification of soils and water (kg (\text{SO}_2) eq.)</td>
<td>2.9</td>
<td>3.0</td>
</tr>
<tr>
<td>Ozone depletion (kg CFC-11 eq.)</td>
<td>(6.3 \cdot 10^{-5})</td>
<td>(6.3 \cdot 10^{-5})</td>
</tr>
<tr>
<td>Eutrophication (kg (\text{PO}_4^{3-}) eq.)</td>
<td>0.46</td>
<td>0.47</td>
</tr>
<tr>
<td>Photochemical ozone formation (kg ethylene eq.)</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Air pollution (m(^3))</td>
<td>1700</td>
<td>1700</td>
</tr>
<tr>
<td>Water pollution (m(^3))</td>
<td>(4.8 \cdot 10^5)</td>
<td>(4.9 \cdot 10^5)</td>
</tr>
<tr>
<td>Global warming (kg (\text{CO}_2) eq.)</td>
<td>690</td>
<td>40</td>
</tr>
<tr>
<td>Mineral and fossil resource depletion (MJ)</td>
<td>(1.0 \cdot 10^4)</td>
<td>(1.0 \cdot 10^4)</td>
</tr>
<tr>
<td>Non-fossil resource depletion (kg (\text{Sb}) eq.)</td>
<td>(1.4 \cdot 10^{-8})</td>
<td>(1.4 \cdot 10^{-8})</td>
</tr>
</tbody>
</table>

### Impact Categories

- **Acidification**
- **Ozone depletion**
- **Eutrophication**
- **Photochemical ozone formation**
- **Air pollution**
- **Water pollution**
- **Global warming**
- **Mineral and fossil resource depletion**
- **Non-fossil resource depletion**

The diagram illustrates the contributions of different resource types to each impact category, with GFRP rods, Connections, Pot, and Braces indicated by different colors.
Perspectives

- Assessing experimentally the urban cooling provided by one kind of vegetated urban furniture
- Evaluating the geophysical fields by means of CFD models
- Refining costs and benefits attributed to these vegetated structures through their whole life cycle so that this data can be used to establish trade-offs between outdoor thermal comfort and environmental impacts

https://hmco.enpc.fr/
https://navier-lab.fr/
http://thinkshell.fr/en/

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