Performance-based selection of sustainable construction solutions for external walls

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specialists iterative “handwork”...

Decisions photo Mel Stoutsenberger in flickr
Performance-based design

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Abstract

Even before Louis Sullivan coined the phrase ‘Form Follows Function,’ architectural researchers have sought, to no avail, a causal relationship between these two primary constituents of the building enterprise. This paper attempts to explain why this quest has been futile, and proposes a performance-based design paradigm, instead of the prevailing process-based paradigms. It suggests that the driving force behind any design activity is the desire to achieve a qualitative solution for a particular combination of form and function in a specific context. Furthermore, it suggests that quality can only be determined by a multi-criteria, multi-disciplinary performance evaluation, which comprises a weighted sum of several satisfaction/behavior functions. The paper develops a performance-based design methodology and demonstrates its application in an experimental, knowledge-based CAD system. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Design methods; Design process; Paradigms of design; Design knowledge; Performance evaluation
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ICD (A. Menges) & ITKE (J. Knippers) Stuttgart University, ICD/ITKE Research Pavilion 2011

why?
why?

source: European Comission (visited 13.sep.2016)
why?

building lexicon

functional requirements

finetune

optimization of performance

LCA

Swiss Re Building, London, 2004 arch. Foster + Partners photo Marc Ginesta in flickr
drawbacks:
resources / project scale
information vs early stages

why?

method:
  simple
  expeditious

assessment:
  early
  viable

global index:
  environmental impact
  functional performance
reinforced concrete
hollow brick
thermal brick
solid brick
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What?

- reinforced concrete
- hollow brick
- thermal brick
- solid brick
- cork
- extruded polystyrene
- rock wool
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reinforced concrete
hollow brick
thermal brick
solid brick

cork
extruded polystyrene
rock wool

mortar render
plasterboard

90 construction assemblies
### How?

<table>
<thead>
<tr>
<th>1 global index</th>
<th>Environment</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$IS_G$</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>2 indicators</th>
<th>$IS_E$</th>
<th>$IS_F$</th>
</tr>
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<tbody>
<tr>
<td></td>
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<table>
<thead>
<tr>
<th>2 parameters</th>
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<tbody>
<tr>
<td>embodied energy per wall unit surface area</td>
<td>$EE_s$ [$MJ/m^2$]</td>
<td>heat transfer coefficient</td>
</tr>
<tr>
<td>embodied carbon per wall unit surface area</td>
<td>$EC_s$ [kgCO$_2$e/m$^2$]</td>
<td>net superficial thermal mass</td>
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2 design scenarios  |  #1 cold climates

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<table>
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<tr>
<th>2 parameters</th>
<th>embodied energy per wall unit surface area $EE_s [MJ/m^2]$</th>
<th>heat transfer coefficient $U [W/m^2.K]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>embodied carbon per wall unit surface area $EC_s [kgCO_2e/m^2]$</td>
<td>net superficial thermal mass $M_{tsu} [J/m^2.K]$</td>
<td></td>
</tr>
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</table>

- $IS_E$: Environment
- $IS_F$: Performance

- $EE_s$: 50%
- $EC_s$: 50%
- $U$: 90%
- $M_{tsu}$: 10%
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how?

2 design scenarios | #2 hot climates

1 global index

Environment

Performance

IS

IS

2 indicators

IS

2 parameters

embodied energy per wall unit surface area

\[ EE_s [MJ/m^2] \]

50%

heat transfer coefficient

\[ U [W/m^2.K] \]

10%

embodied carbon per wall unit surface area

\[ EC_s [kgCO_2e/m^2] \]

50%

net superficial thermal mass

\[ M_{tsu} [J/m^2.K] \]

90%
2 design scenarios

#1 cold climates
#2 hot climates

1 global index

Environment

Performance

2 indicators

50% IS

IS_E

IS_F 50%

2 parameters

embodied energy per wall unit surface area $EE_s$ [MJ/m$^2$]

50%

heat transfer coefficient $U$ [W/m$^2$.K]

90%

embodied carbon per wall unit surface area $EC_s$ [kgCO$_2$e/m$^2$]

50%

net superficial thermal mass $M_{tsu}$ [J/m$^2$.K]

mass 10%

90%
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**2 design scenarios**

- #1 cold climates
- #2 hot climates

### Environment

1. **1 global index**
   - \( IS_G \)

2. **2 indicators**
   - 75% 50% IS\(_E\)
   - 25% 50% IS\(_F\)

3. **2 parameters**
   - **Embodied Energy per Wall Unit Surface Area**
     - \( EE_s \) [MJ/m\(^2\)]
     - 50%
   - **Embodied Carbon per Wall Unit Surface Area**
     - \( EC_s \) [kgCO\(_2\)e/m\(^2\)]
     - 50%
   - **Heat Transfer Coefficient**
     - \( U \) [W/m\(^2\).K]
     - 90%
   - **Net Superficial Thermal Mass**
     - \( M_{tsu} \) [J/m\(^2\).K]
     - 10%
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### How?

#### 2 design scenarios
- #1 cold climates
- #2 hot climates

#### 1 global index
- **Environment**
  - *IS*$_G$

#### 2 indicators
- **IS*$_E$
  - 100%
  - 75%
  - 50%
- **IS*$_F$
  - 0%
  - 25%
  - 50%

#### 2 parameters
- **Embodied energy per wall unit surface area**
  - $EE_s$ [MJ/m$^2$]
  - 50%
- **Embodied carbon per wall unit surface area**
  - $EC_s$ [kgCO$_2$e/m$^2$]
  - 50%
- **Heat transfer coefficient**
  - $U$ [W/m$^2$.K]
  - 90%
  - 10%
- **Net superficial thermal mass**
  - $M_{tsu}$ [J/m$^2$.K]
  - 10%
  - 90%
#1 cold climates

Environment 50%
Performance 50%

EXT. INT.

6cm thermal brick 19&24cm

Environment 75%
Performance 25%

EXT. INT.

4cm hollow brick 20cm
6cm thermal brick 19
#2 hot climates

**Environment 50%**
Performance 50%

- EXT.
- **6cm**
- concrete 20cm
- INT.

**Environment 75%**
Performance 25%

- EXT.
- 4cm
- hollow brick 20cm
- INT.
- 6cm
- thermal brick 19

results...
Environment 100%

EXT.

<table>
<thead>
<tr>
<th>4cm</th>
<th>hollow brick</th>
<th>20cm</th>
</tr>
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<tbody>
<tr>
<td>6cm</td>
<td>thermal brick</td>
<td>19</td>
</tr>
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INT.
cold climates
    single brick masonries
    type of brick depends on environmental relevance

hot climates
    concrete OR single brick masonries
    (depends on environmental relevance)

cavity walls are not among top ranked

thermal inertia vs. environmental impact

simple method + effective data = informed selection
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thank you!...
\[ EE_s = \sum_{i} (M_{si} \cdot EE_i) \]

\[ EC_s = \sum_{i} (M_{si} \cdot EC_i) \]
\[ U = \frac{1}{R_{si} + \sum_{i} \frac{e_i}{\lambda_i} + R_{se}} \]

\[ M_{tsu} = \frac{\left( R_{se} + \frac{R_1}{2} \right) \cdot M_{ts1} + \sum_{i=2}^{n} \left[ \left( R_{se} + \sum_{j=1}^{j=i-1} R_j + \frac{R_i}{2} \right) \cdot M_{tsi} \right]}{R_T} \]
\[
\overline{P_i} = \frac{P_i - P_{i^*}}{P_i - P_{i^*}} \forall i
\]

\[ IS_j = \sum_{i=1}^{n} \left( \overline{P_i} \cdot w_i \right) \]

\[ IS_G = IS_E \cdot w_E + IS_F \cdot w_F \]