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Regionalized sensitivity analysis with respect to multiple outputs - and an application for real-time building space exploration

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Background

Building design involves a large number of design parameters and performance indicators. The Monte Carlo method enables the modeler to perform thousands of building performance simulations representing a global design space. To explore such multivariate data (Factor Mapping [1]), the parallel coordinate plot (PCP) is a popular tool, because it is easy to use in “real-time” – even for multiple decision-makers. However, the PCP becomes unmanageable if it contains many variables, e.g., more than 10–15. Since building simulations typically involve a lot more parameters, we would like to reduce the number of variable inputs (Factor Fixing [1]) while considering their influence towards multiple outputs. Moreover, we would like a method to highlight changes in the PCP, which would allow us to use more variables in the PCP.

Ideas

The ideas are to apply the Kolmogorov-Smirnov two-sample statistics (KS2) to:  
1) rank inputs with respect to multiple outputs (denoted TOM)  
2) highlight changes in the PCP in real-time (denoted TOR)

Building case study

To test the proposed sensitivity measures, TOM and TOR, we consider the design of a 15,000 m³ educational institute. The “variability” of 10 design parameters is described by uniform distributions (Table 1). Quasi-random sampling (Sobol’s LP) is used to sample 5,000 simulations. The simulation software consists of a normative model (ISO 13790) to assess energy demand and “overtemperature”. In addition, a regression model is used to assess daylight factor in lecture rooms.

Table 1. Distributions for 10 design parameters

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>Unit</th>
<th>Uniform</th>
<th>Discrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window façade area</td>
<td>m²</td>
<td>[0.4, 50]</td>
<td></td>
</tr>
<tr>
<td>Solar panels</td>
<td>m²</td>
<td>0; 100; 200</td>
<td></td>
</tr>
<tr>
<td>Reflectance, non-duct</td>
<td>–</td>
<td>0.4 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>Solar heat gain coeff</td>
<td></td>
<td>0.25 ± 0.3; 0.4 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>G-value (solar)</td>
<td></td>
<td>0 ± 45</td>
<td></td>
</tr>
<tr>
<td>U-value, windows</td>
<td>W/m².K</td>
<td>0.65; 0.65; 0.65</td>
<td></td>
</tr>
<tr>
<td>Heat Capacity building</td>
<td>W/m²</td>
<td>40; 70; 80; 100</td>
<td></td>
</tr>
<tr>
<td>Venting</td>
<td>cfm</td>
<td>0.8 ± 1.8</td>
<td></td>
</tr>
<tr>
<td>WC</td>
<td>cfm</td>
<td>0.8 ± 1.8</td>
<td></td>
</tr>
<tr>
<td>Kiln</td>
<td>m²</td>
<td>0.06; 0.01; 0.0</td>
<td></td>
</tr>
</tbody>
</table>

Real-time highlight of changes in the PCP (TOR)

With the TOR approach, we suggest using KS2 to highlight the coordinates that changes the most when users apply filters in the parallel coordinate plot [2]. The user-defined filters split the entire set of simulations, S_a into a behavioural subset S_b and non-behavioural subset S_n. Each time a filter is applied, we calculate and compare the relative sizes of the maximum distances D_j between the cumulative distributions of the S_b and S_n for every (non-filtered) parameter. The results are illustrated with bar plots just below the PCPs on Figure 3. It works with both inputs and outputs.

Test models (TOM)

To assess the quality of TOM, we apply it to three test models from literature.

A) Highly skewed, non-linear (from [3])

\[ y = x_1/x_2 \]

B) Non-monotonic, non-linear (from [4])

\[ y = \sin(x_1) + 4 \sin(x_2) + 2 x_1^2 \cos(x_2) \]

C) Non-additive (from [1])

\[ y = \sum_{i=1}^{N} W_{ij} Z_i ~ N(w_{ij}, \sigma_i^2) \]

Discussion

The methods seem promising for different applications. Future work includes more testing. This includes:  
• More test models (non-linear)  
• Tests with more inputs and outputs  
• Threshold values to avoid Type I errors  
• Assess choice of sets for KS2 tests  
• Other statistical tests (e.g. Anderson-Darling)  

Thanks to Thierry Mara for valuable feedback!

References


Authors

Torben  
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(Here at SAMO)