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

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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 m² educational institution. The "variability" of 10 design parameters are described by uniform distributions (Table 1). Quasi-random sampling (Sobol’s LP) is used to sample 5,000 simulations. The simulation software contains a non-linear model (ISO 13790) to assess energy demand and "overtemperature". In addition, a regression model is used to assess daylight factor in lecture rooms.

<table>
<thead>
<tr>
<th>Input parameter</th>
<th>Unit</th>
<th>Uniform</th>
<th>Discrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window facade area</td>
<td>m²</td>
<td>40 – 60</td>
<td>40, 50, 60</td>
</tr>
<tr>
<td>Solar gain factor</td>
<td>-</td>
<td>0.7, 0.8, 0.9</td>
<td>-</td>
</tr>
<tr>
<td>Reflectance, non-reflect.</td>
<td>-</td>
<td>0.4 - 0.6</td>
<td>-</td>
</tr>
<tr>
<td>Solar heat gain coeff.</td>
<td>-</td>
<td>0.25 - 0.32, 0.41 - 0.45</td>
<td>-</td>
</tr>
<tr>
<td>Side blocks (external)</td>
<td>-</td>
<td>3 - 45</td>
<td>-</td>
</tr>
<tr>
<td>Side blocks (internal)</td>
<td>m²</td>
<td>40 x 40</td>
<td>-</td>
</tr>
<tr>
<td>Heat capacity, building</td>
<td>kWh/m²</td>
<td>100, 50, 100</td>
<td>-</td>
</tr>
<tr>
<td>Vents</td>
<td>-</td>
<td>1 - 3</td>
<td>-</td>
</tr>
<tr>
<td>Roof pitch</td>
<td>-</td>
<td>4.5 - 10°</td>
<td>-</td>
</tr>
<tr>
<td>Window size</td>
<td>m²</td>
<td>40 - 100</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 splits the entire set of simulations, into the behavioural set Sb and non-behavioural set Sn. Each time a filter is applied, we calculate and compare the relative sizes of the maximum distances Di between the cumulative distributions of the Sn and Sb for every (non-filtered) parameter. The results are illustrated with bar plots just below the PCPs on Figure 3. It works both with inputs and outputs.

Table 1. Distributions for 10 design parameters

Test models (TOM)

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

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

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

C) Non-additive (from [1])

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