Identification of influential parameters in building energy simulation and life cycle assessment

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Context

- European climate and energy framework for 2030

GHG emissions
- 40 % compared to 1990

Energy efficiency
+ 27 %

Renewable energy
27 % of the energy consumption

European Commission

Consider more environmental problems to avoid burden shifting

- Building : a key sector

40 % final energy consumption	22 % GHG	20 % net water consumption	Waste creation	Various pollution in air, water, soil

→ Need of **eco-design tools** to reduce these impacts

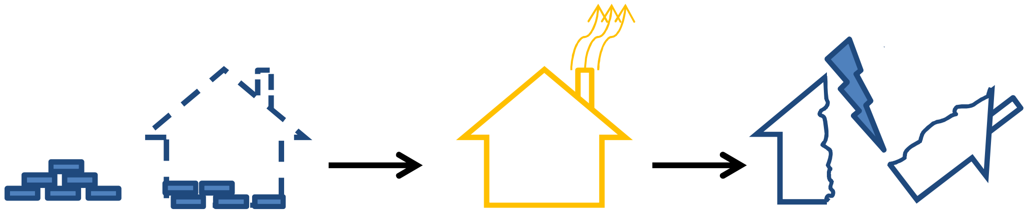
Building energy and environmental simulation at Mines Paris

- Development of eco-design tools since 1990
- Dynamic Building Energy Simulation (DBES)
  - Thermal zones
  - Temperature, heating and cooling loads

Peuportier and Blanc-Sommereux, 1990

- Building Life Cycle Assessment (LCA)

Polster, 1995 and Popovici, 2005



Construction → Use and renovation → End of life

CO_2, energy, water, waste, human health, biodiversity … ➡ **12 model outputs**

Graphic modeling tool *(Alcyone)*

↓ *Building geometry*

DBES tool *(Pléiades + COMFIE)*

↓ *Materials' quantities, thermal load*

Building and district LCA tool *(NovaEQUER)*

Building energy and environmental simulation at Mines Paris

- Model: large number of equations based on heat balance
- Time dependant non linear system
- Computing time

- Model validation
  - Software inter-comparison (e.g. Bestest)
  - Output comparison with measurements
  - Sensitivity analysis (ANR Fiabilité...)

Graphic modeling tool *(Alcyone)*

↓ *Building geometry*

DBES tool *(Pléiades + COMFIE)*

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Current work

- Sensitivity and uncertainty analysis
  - DBES model validation

    Munaretto, 2014 and Recht et al., 2014
  - Model robustness
  - Performance guarantee

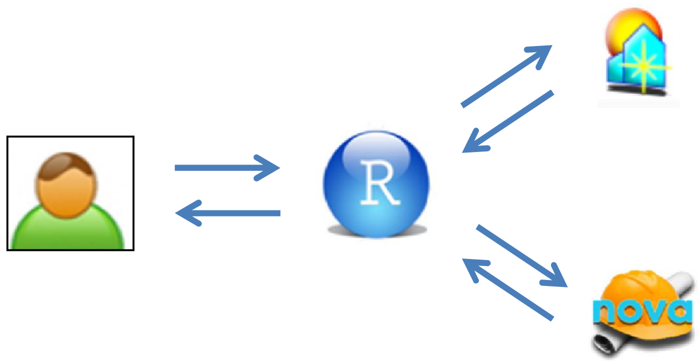
- Calibration (bayesian)
  - Better knowledge on the uncertainties on the building model for:
    - Regulation

      Robillart, 2015
    - Performance guarantee

- Optimisation (genetic algorithm)
  - Best design compromise for building cost and climate change
  - Under constraint: net plus energy building

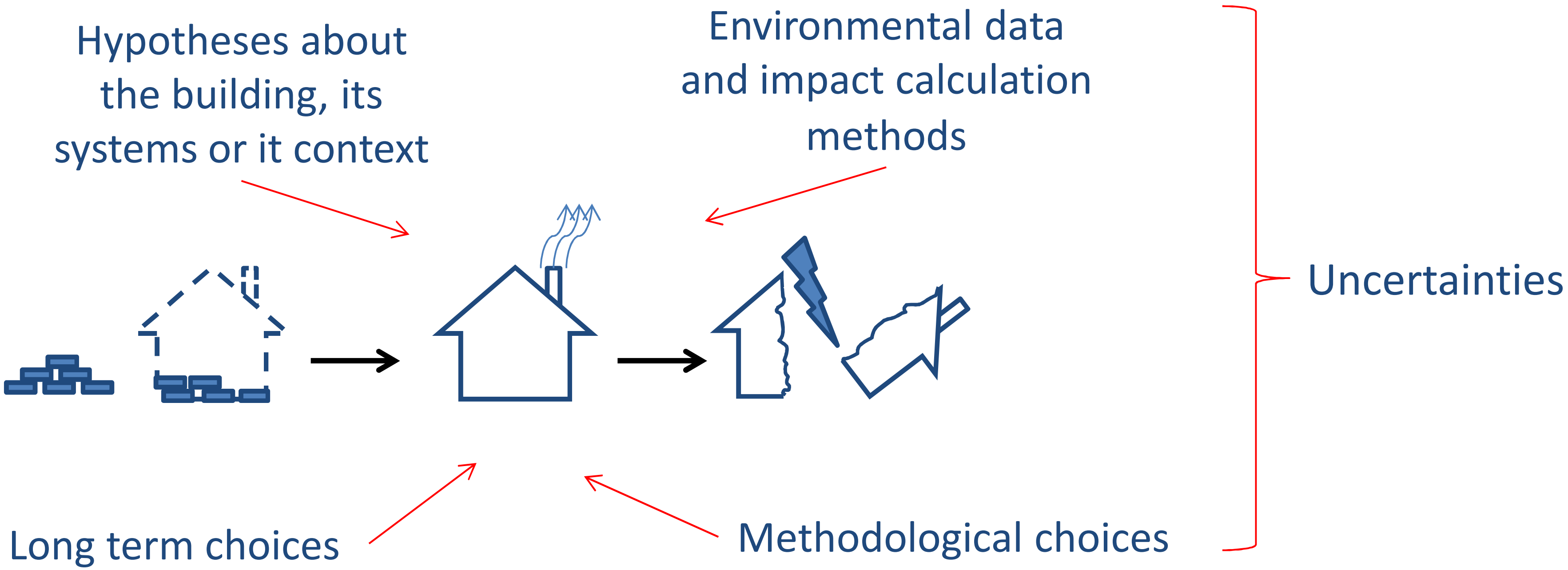
    Recht, 2016

- Development of a multi-simulation platform



Sensitivity analysis in building LCA

- Building LCA tools: need of a robust decision making process



- Variant comparisons
  - More precise definition of the density functions of influential factors
  - Selection of the more sustainable built alternatives

Case study and methodology

- Case study: single family house in concrete (INCAS platform)

22 uncertain factors

- Building envelope
- Occupancy
- Climate and site
- Building lifetime
- Urban characteristics
- Life cycle inventory data
- Life cycle impact assessment methods

> Parameters (insulation thickness...)
> Variables (outdoor temperature...)
> Categorical inputs (time horizon for the global warming potential...)

- Comparison of SA methods
  - Identification of contributors to environmental impacts
  - Selection of the most appropriate methods

SA methods comparison

- Min-max SA (MMSA)

$$S_j = f(x_{1,ref},\dots,a_j,\dots,x_{K,ref}) - f(x_{1,ref},\dots,b_j,\dots,x_{K,ref})$$

  - For categorical inputs: two contrasting scenarios considered

- Plackett and Burman (PB)
  - DoE based on a Hadamard matrix
  - 20 repetitions with changed factors' order to avoid aliasing
  - For categorical inputs: two contrasting scenarios considered

- Standard Regression Coefficient (SRC²)
  - N = 5000
  - Monte Carlo sampling

- Morris screening
  - 100 repetitions and 6 levels
  - Aggregation of linear and nonlinear effects, and interactions

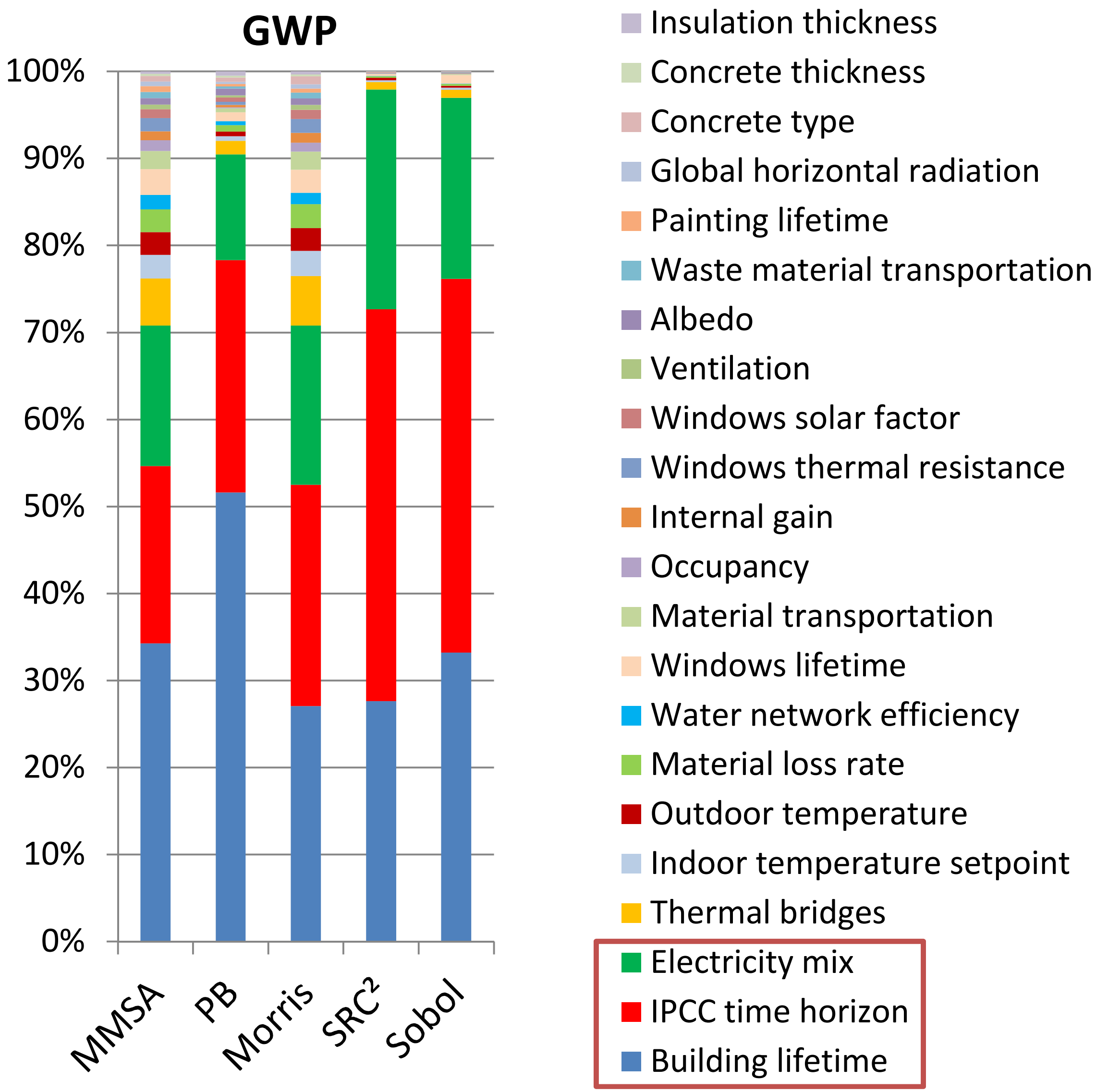
$$d_j^* = \sqrt{\left(\mu_j^{*2} + \sigma_j^2\right)}$$

  - NB: Adaptation of the elementary effect calculation for categorical input

$$EE_{j_{Cat}}^i = \frac{f\left(x_1^i,\dots,x_{j_A}^i,\dots,x_K^i\right) - f\left(x_1^i,\dots,x_{j_B}^i,\dots,x_K^i\right)}{1}$$

- Variance based SA
  - Sobol total indices
  - N = 1000
  - LHS sampling

Results comparison of the SA methods



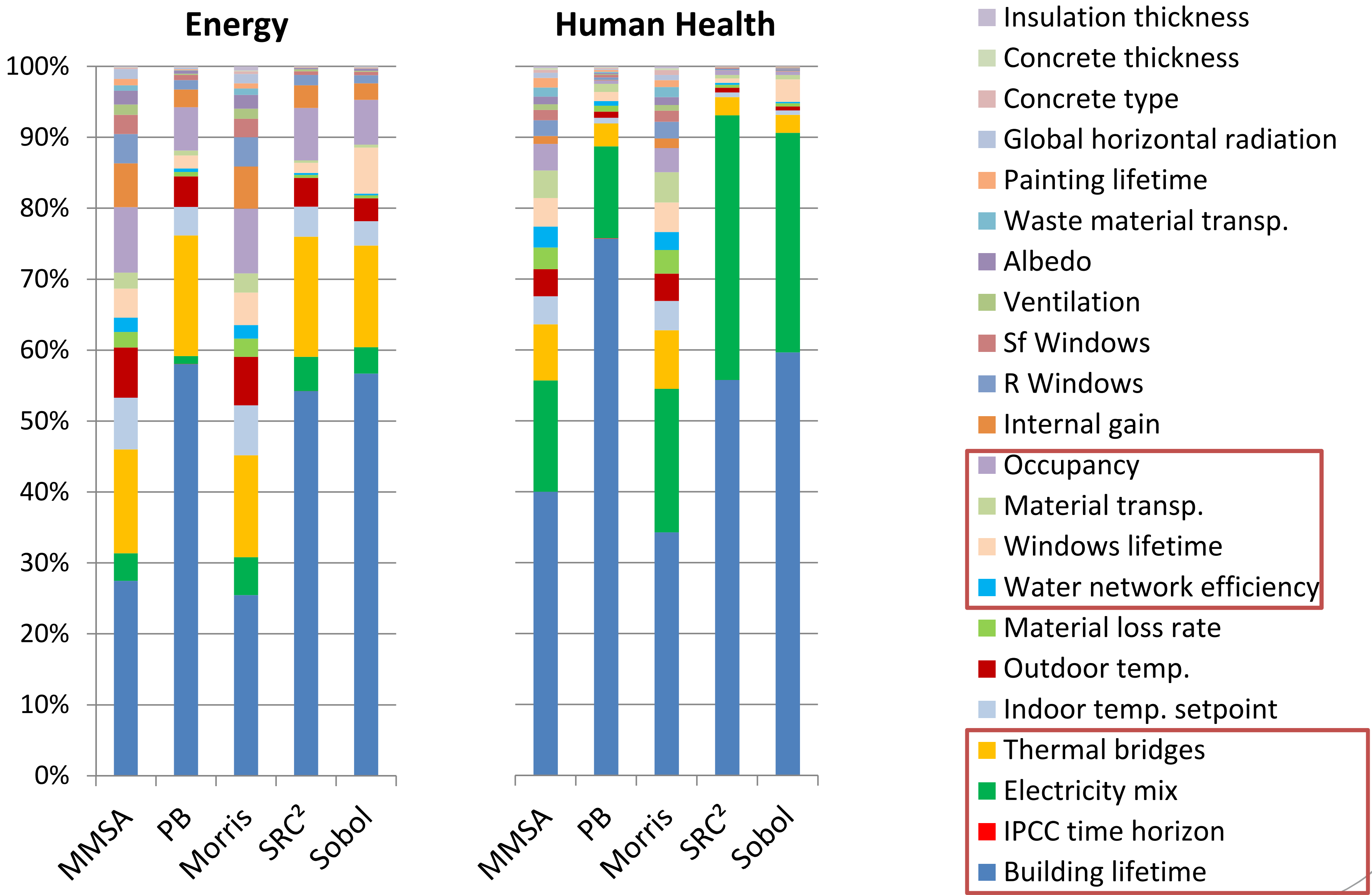
- Influence of one factor relatively to the sum of the influence of all factors

- Factors identified by Sobol: also identified by other methods

Calculation time

MMSA: 4 min
PB: 40 min
Morris: 2h40
SRC²: 5h30
GSA: 30h

Results comparison of the SA methods



Differences in the relative influence

	Interactions and non linearity	Levels	Underlying distributions	Quantification of uncertainty
MMSA	✗	2	Uniform	Effect
PB	✗	2	Uniform	Variance
Morris	✓	6	Uniform	Effect
SRC^2	✗	∞	Normal	Variance
Sobol	✓	∞	Normal	Variance

- Methods comparison with
  - More level for PB
  - A uniform distribution for the GSA methods
  - Computing variance for the Morris screening

Methods adaptation

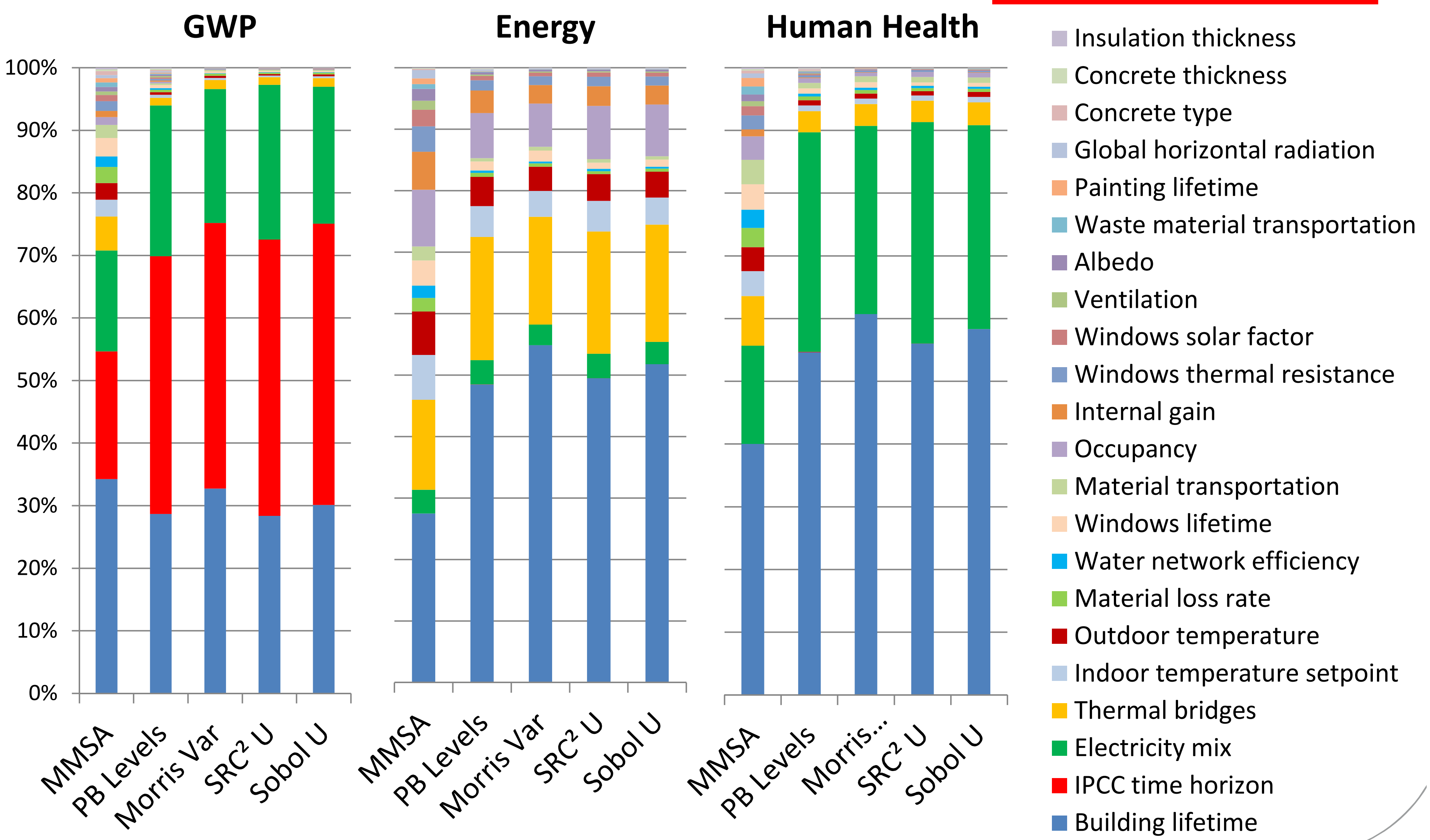
- Increasing the number of levels for PB
  - 6 levels (similar to Morris screening)
  - At each repetition:
    - Change the factor order
    - Change the couple of 2 levels for each factor

- Computing variance for Morris method
  - For each repetition r : $EV_i = \left[f\left(x_{j_{level\_l}}\right) - f\left(x_{j_{level\_l+\delta x_j}}\right) \right]^2$
  - Mean of the squared difference : $V_j = \frac{1}{r} \sum_{i=1}^{r} EV_i$
  - Influence : $Influence_j = \frac{V_j}{\sum V_j}$

Identification of influential uncertain factors

○ Results comparison of the SA methods for three indicators

Adapted methods



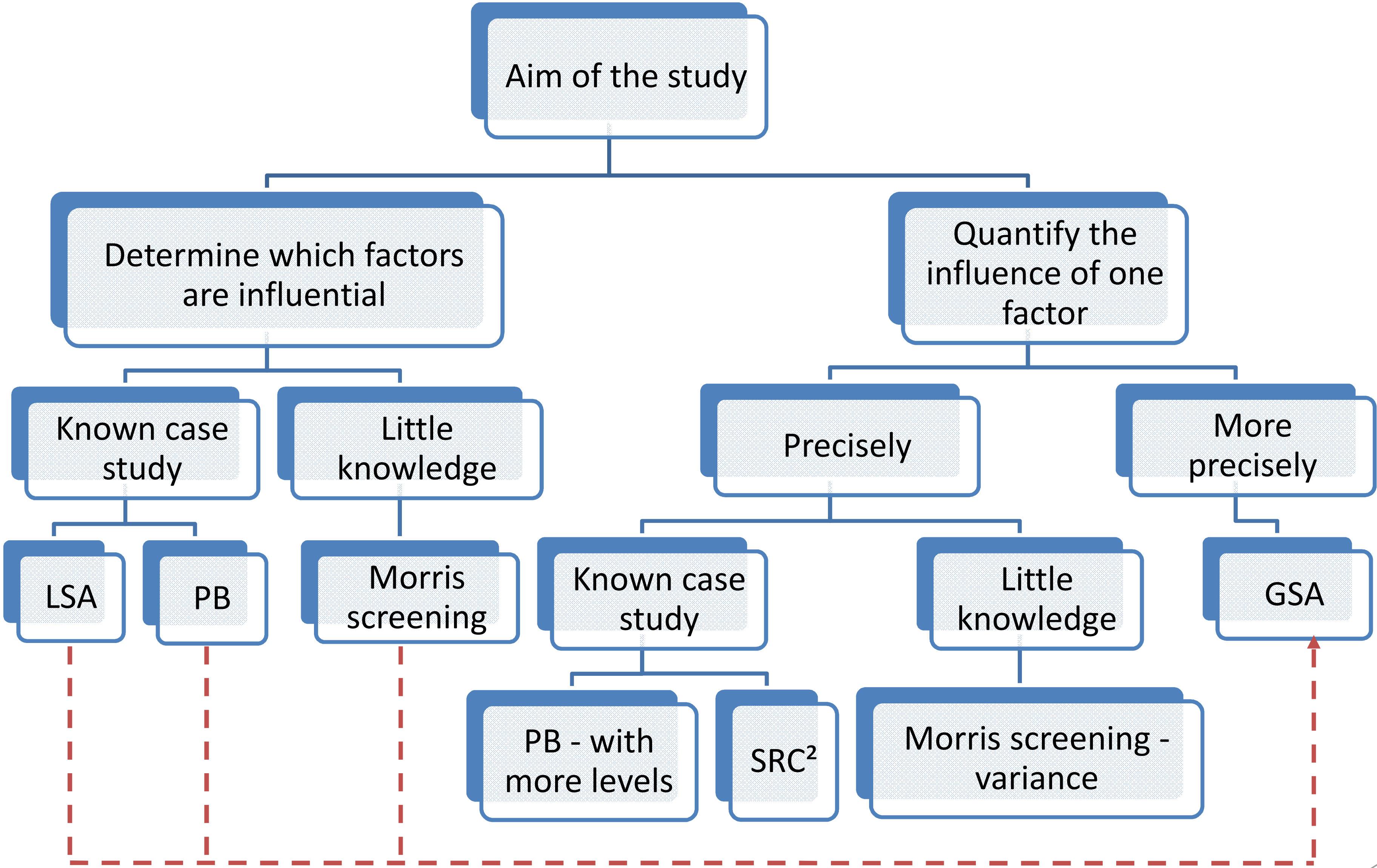
Identification of influential uncertain factors

○ SA methods selection criterions

	Precision	Calculation time	Case study (assumption of linearity)
MMSA	- -	+ + +	Well known
PB	- -	+ +	Well known
Adapted PB	+	+	Well known
Morris	- -	+	Little knowledge
Adapted Morris	+	+	Little knowledge
SRC^2	+	-	Well known
Sobol	+ +	- -	Little knowledge

Identification of influential uncertain factors

- SA methods selection criterions



Conclusions and perspectives

- Identification of influential factors
  - Simplification of the data input
  - Results robustness

- Different methods for different objectives
  - Possibility to get quickly results that are close from those of the GSA methods

- Future work
  - Application in variants' comparison
  - Include more uncertain factors in further studies
  - Larger scale (district)

Thank you for your attention

Appendix

Current indicator set

- Human Health (EI99)
- Biodiversity (EI99)
- Global warming potential (GWP100, IPCC)
- Acidification potential (CML)
- Eutrophication potential (CML)
- Photochemical ozone formation potential (CML)
- Malodorous air (CML)
- Depletion of Abiotic Resources (CML)
- Primary Energy demand (CED)
- Water consumption
- Radioactive waste
- Waste generation

Multi simulation platform