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Probabilistic LCA and LCC to identify robust and reliable renovation strategies

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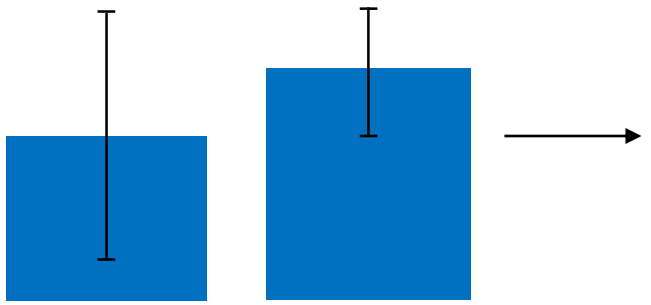
The problem

Buildings are responsible for a large amount of energy and GHG emissions in the world.
80% of the total energy consumption is coming from the operational part

⟶ A need for renovation, but a real system never fully matches the design system.

Uncertainties associated with
- The design
- Uncontrolled parameters



GWP, kgCO2eq.

⟶ Probabilistic modelling needed

The objective

Identify a robust renovation scenario in terms of:

- Life cycle assessment
- Life cycle cost

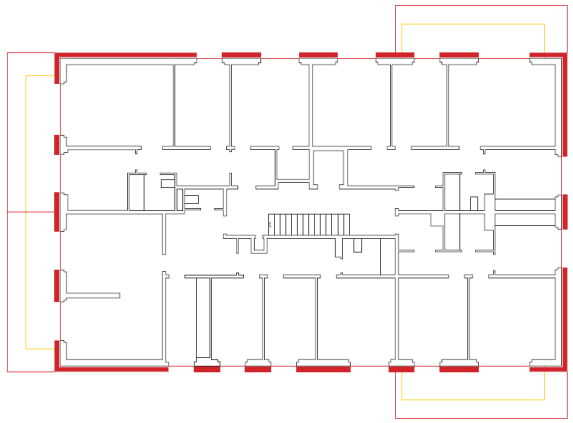
Approach

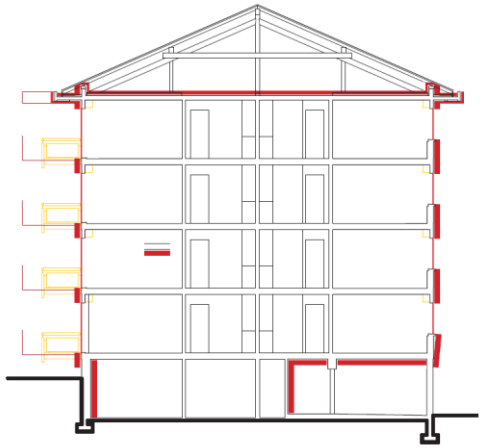
1. Computational model
2. Quantification of uncertainty sources
3. Renovation measures selection
4. Sensitivity analysis
5. Uncertainty quantification on selected measures

Case study

Morges, Switzerland

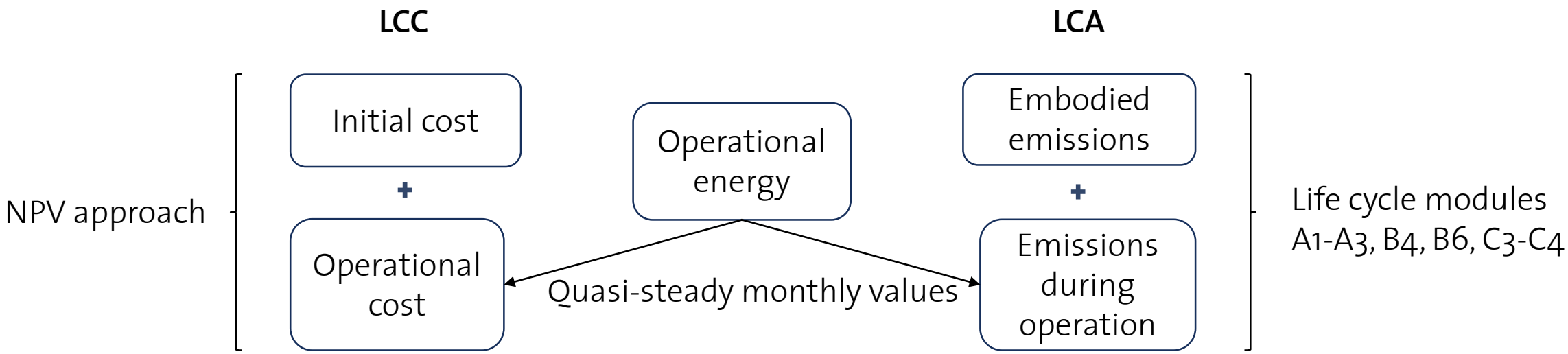
ERA = 1400 m2





Element	Before renovation
Exterior walls	4cm mineral wool U = 0.56 W/(m²K)
Walls against technical room	Not insulated U = 1.76 W/(m²K)
Walls against fallout shelter	Not insulated U = 2.3 W/(m²K)
Floor against technical room	1cm cork U = 1.53 W/(m²K)
Floor against shelter	1cm cork U = 1.36 W/(m²K)
Ground slab	Non insulated
Ceiling against attic	6cm mineral wool U = 0.5 W/(m²K)
Windows	Double glazing with low-E layer, PVC frame Uf = 2 W/(m²K) Ug = 1.1 W/(m²K) gp = 0.55 W/(m²K)

Computational model 1



Uncertainties in energy –related building renovation 2

Exogenous parameters (cannot be influenced by designer)

Uncertainties associated with future scenarios:

- Material service life
- Financial costs of renovation
- Technological progress
- Nature of the energy carriers
- Climate change
- etc.

Uncertainties associated with the system:

- True dimensions of the real system
- Material properties
- Performance loss (degradation)

Design parameters (selected by designer)

- Envelope
- Heating system
- Renewables

Possible renovation scenarios and uncertain parameters 2 3

Design parameters

Envelope

- Exterior walls — 44 components
- Roof — 12 components
- Ground slab — 26 components
- Windows — 16 components

Heating system

- Boiler
  - Oil
  - Gas
  - Wood pellets
- Heat pump

Exogenous parameters

- Service life
- System performance
- User-oriented parameters
- Elementary env. impact
- Elementary costs
- Embodied impact

79 parameters

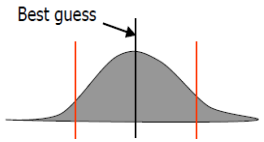
Polynomial chaos expansion (PCE) 4 5

Quantification of sources of uncertainty

Models of the system

Uncertainty propagation

Random variables

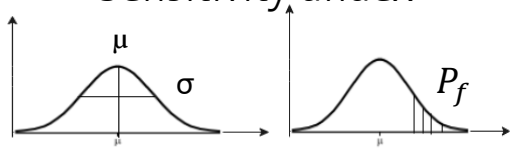


Computational model

Cost

Environmental impacts

Moments, Response PDF
Sensitivity index



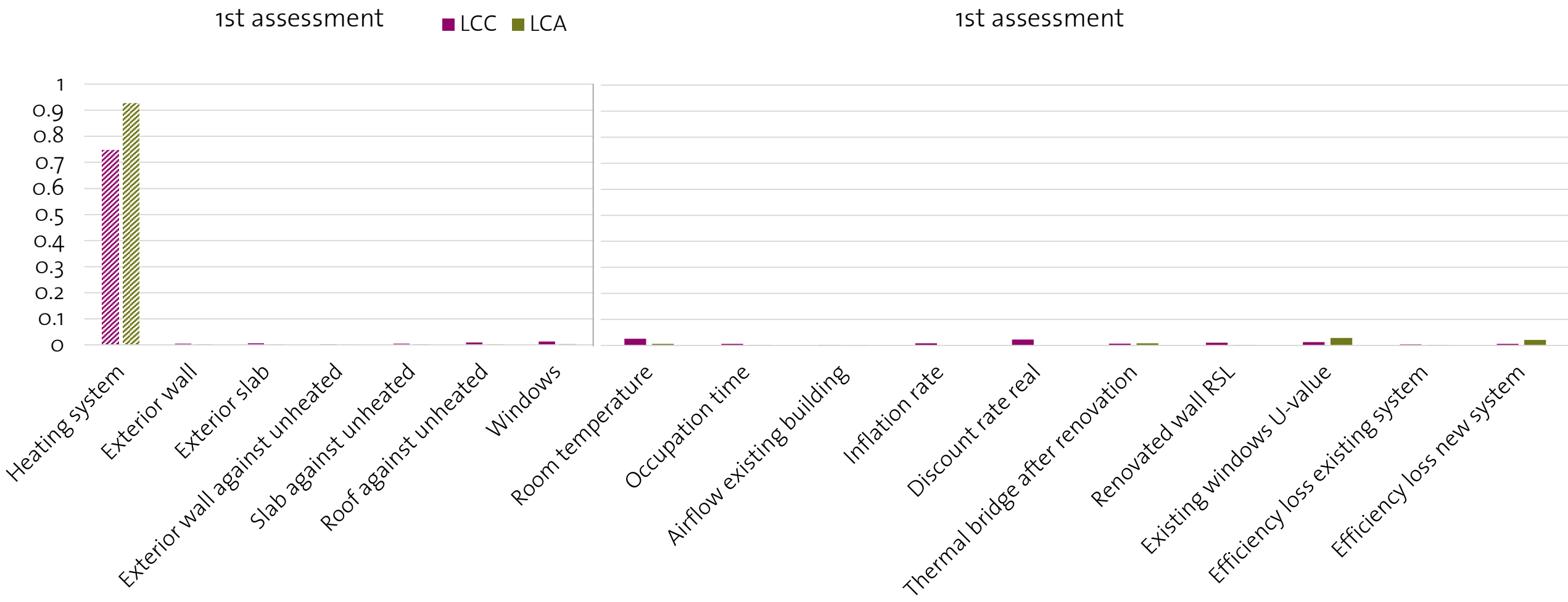
PCE model or surrogate $\mathcal{M}^{PC}$

MC-based sensitivity index = n (M+1),
n – size of the simulation, M – number of parameters

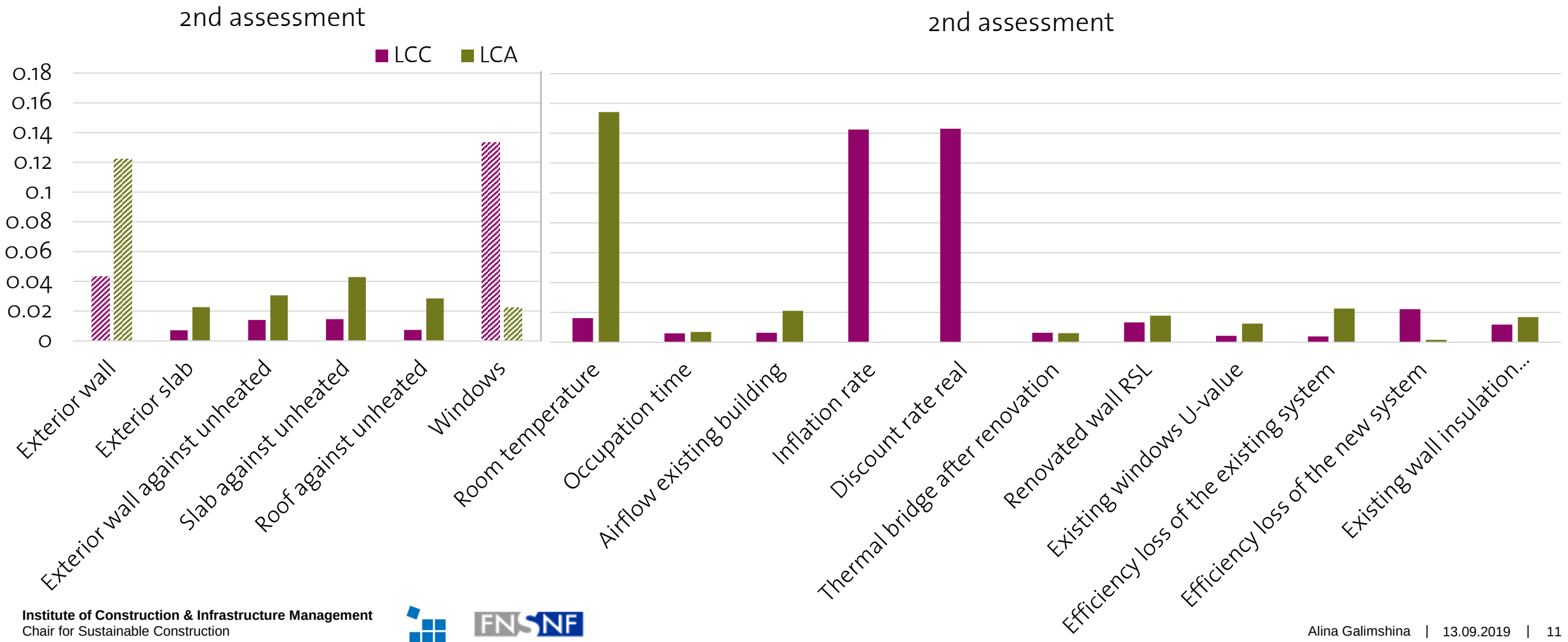
Sobol indices can be achieved as a postprocessing of PCE coefficients analytically at no computational cost

B. Sudret, *Uncertainty propagation and sensitivity analysis in mechanical models – contributions to structural reliability and stochastic spectral methods (2007)*

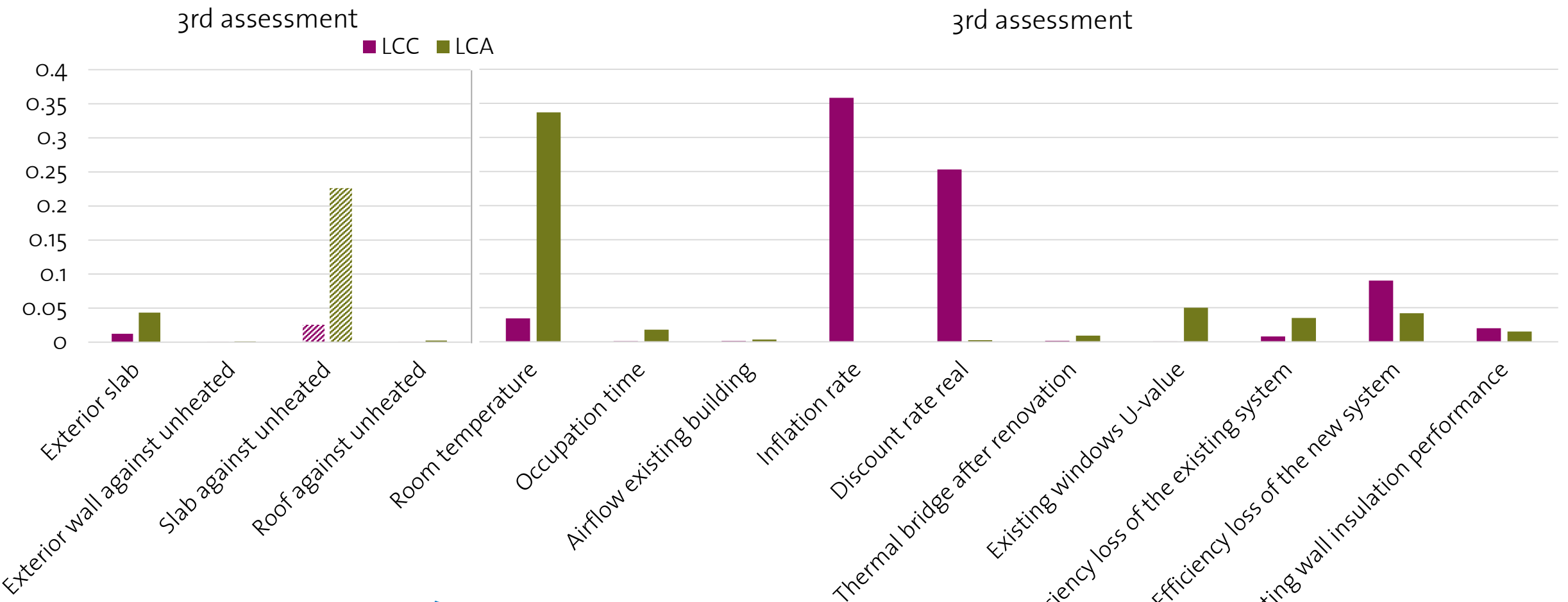
Results, Sensitivity analysis 4



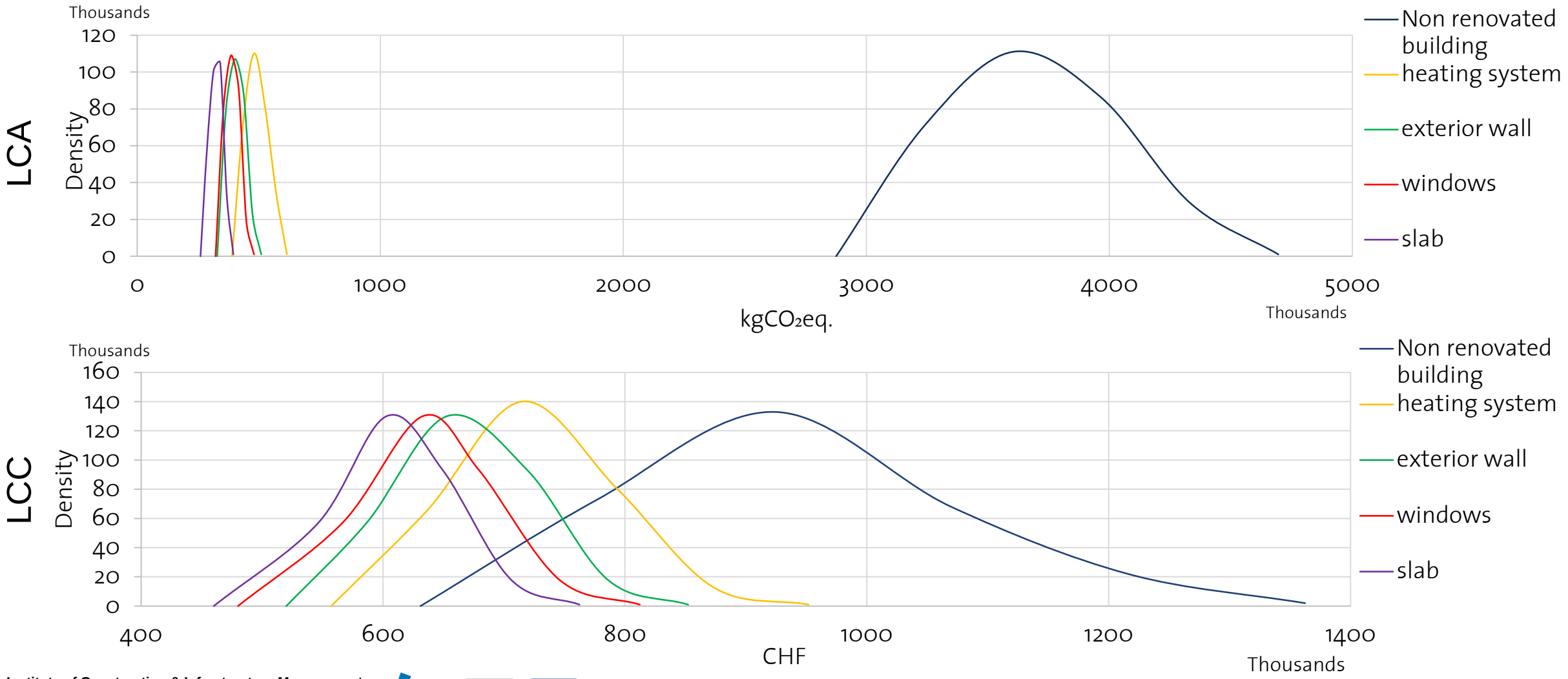
Results, Sensitivity analysis 4



Results, Sensitivity analysis 4



Results, Uncertainty quantification 5



Conclusion

Advantages

- The current method allows to prioritize the renovation scenario during the early design stages
- Current method also allows to evaluate the renovation scenario in terms of robustness and reliability.

Disadvantages

- This method does not optimize the renovation scenario but maximize the robustness of the result

Challenges

- Uncertainty data

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Thank you!

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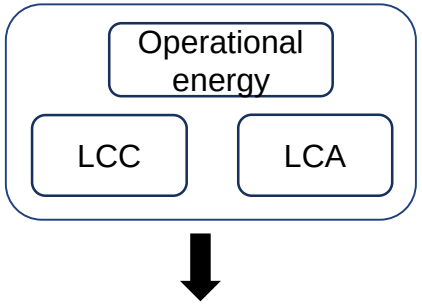
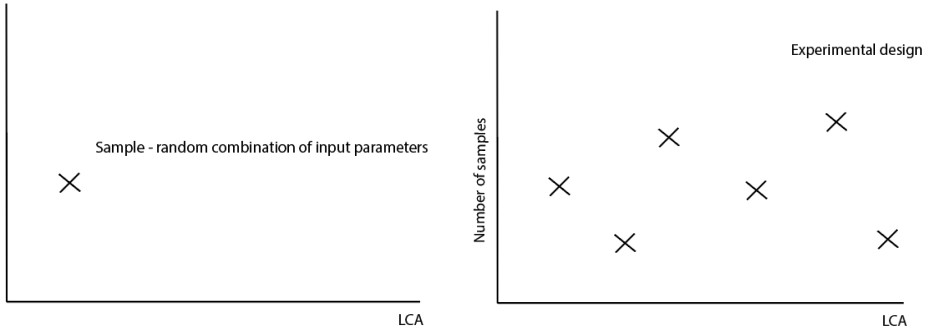
Uncertainty quantification

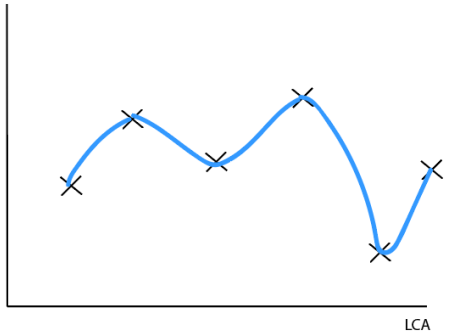
Polynomial chaos expansion – *non intrusive spectral method that allow the analyst to compute the PC coefficients from a series of calls to the deterministic model*.*



Sampling

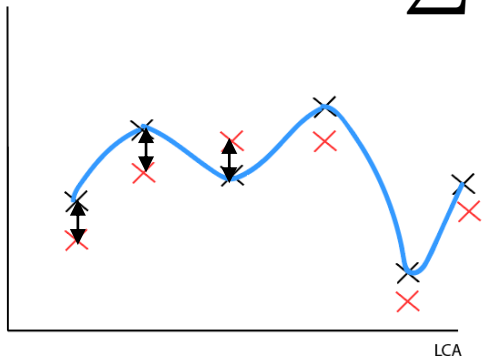


Surrogate model (polynomial function)



Error calculation to define a size

$$Error = \sum (y_1 - \widehat{y_1})/_n$$



• Sudret B. 2007. Uncertainty propagation and sensitivity analysis in mechanical models – Contributions to structural reliability and stochastic spectral methods. Université Blaise Pascal, Clermont-Ferrand, France.

PCE

$$Y = \sum_{\alpha \in \mathbb{N}^M} y_\alpha * \Psi_\alpha (\boldsymbol{X})$$

Ψ_α - a set of multivariate orthonormal polynomials
y_α - coefficients to be computed
$\boldsymbol{X}$ - random parameters within selected distributions (dimension)
Each univariate polynomial belongs to a classical family of polynomials

Global sensitivity analysis aims at quantifying which input parameter(s) (or combinations thereof) influence the most the response variability (variance decomposition)

Sobol indices can be computed analytically by post-processing the PCE coefficients:

- First order Sobol' indices: Quantify the additive effect of each input parameter separately
- Second order Sobol' indices: Quantify the interactive effect of inputs taken as pairs
- Total order Sobol' indices: Quantify the effect of one variable, including interactions with other variables