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Robust and reliable sustainability assessment tool for building renovation strategies

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ABSTRACT

Selecting the best energy-efficiency measure for retrofitting existing buildings is difficult due to the uncertainties of events during the life span of the building. This project will propose a robust and reliable assessment of various renovation strategies for the building stock in Switzerland based on life cycle assessment and life cycle costing. Through statistical calculations for uncertainty propagation, the project will provide an insight on the uncertainties, which might occur during the life stage of the building. Different renovation packages will be defined. For each of them, the uncertainty of the relevant input parameters will be evaluated to identify the most robust solutions. Finally, the results will be used to provide guidelines on robust renovation strategies for Switzerland that can be used by architects, clients and policy makers.

Keywords: building renovation, life cycle assessment, life cycle cost, uncertainty quantification

1. INTRODUCTION

Buildings are one of the largest energy consumers and greenhouse gas emitters in the world (UNISTATS, 2010). As the biggest part of the energy consumed by the existing non-insulated building occurs during operation stage (Sartori and Hestnes, 2007), retrofitting the building stock is important to reduce the environmental impact. To evaluate total environmental impact from the material excavation through operation stage to the building demolition and recycling, it is important to assess the whole life cycle. Life cycle assessment (LCA) and life cycle costing (LCC) are common approaches for full building evaluation. Several studies proposing combined LCA and LCC for achieving the optimal renovation were performed (Almeida and Ferreira, 2015; Ott et al., 2017; Périsset et al., 2016). However, due to the long lifespan of a building, there are many uncertainties on which events might occur during life cycle of the building. The uncertainties associated with external or internal parameters can lead to deviations in the results that could be higher than the difference between deterministic values (Fawcett et al., 2012). Hence, to be able to propose a robust information regarding different renovation scenarios, uncertainty quantification and assessment are needed.

The objective of this project is to create a robust and reliable assessment of different renovation strategies for existing building stock of residential buildings in Switzerland. The proposed method includes the uncertainty sources identification related to LCC and LCA, uncertainty propagation of these sources and establishment of the sources with highest contribution to the results (so-called *sensitivity analysis* (Sudret, 2007)). The idea of the project is to demonstrate that simulations that take into account only most probable values are inefficient in a long term perspective due to uncertainties (See Figure 1). The goal is to develop a method to decrease the uncertainty through a rigorous statistical treatment and compare different renovation solutions for existing the building stock.

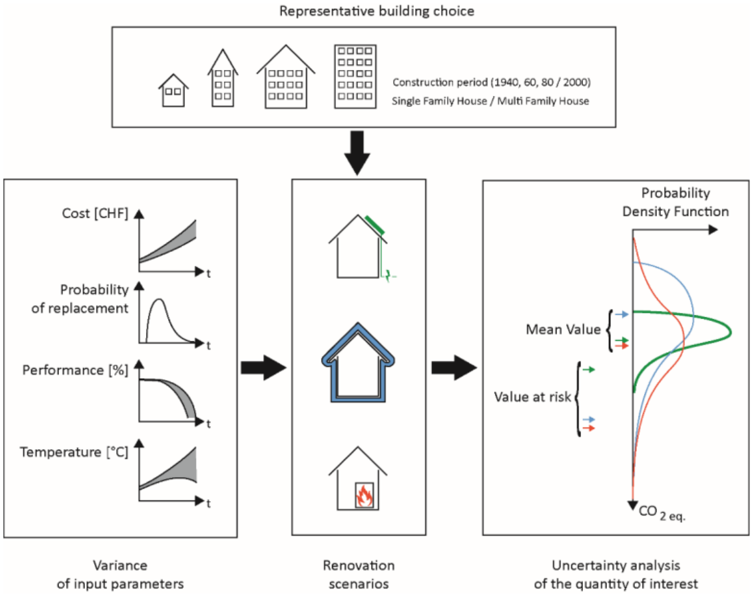

FIGURE 1 – SCHEMATIC DESCRIPTION OF THE PROJECT

2. METHOD

The focus of the project is on three quantities of interest (QoI) – LCA, LCC and thermal comfort. The analysis will be performed for the whole life cycle of the building and include uncertainties associated with future scenarios, *e.g.* external temperature, solar irradiation, financial parameters, material service life, nature of the energy carriers, etc. as well as uncertainties associated with the design: true dimensions of the real system, material properties and performance loss.

The project will be performed in several stages. The first and current stage is the computational model creation for all the QoI. The identification of the model parameters, which define the future scenarios, is essential for further uncertainty propagation. The heating demand will be calculated according to the Swiss standard for energy calculations (SIA 380, 2001). The overall environmental impact including the replacement stage will be analysed using LCA. In addition, the life cycle costs will be evaluated using the net present value (NPV) approach.

For the second stage, the identification of the parameters type and variation with statistical moments (*e.g.* mean and standard deviation) are needed in order to perform uncertainty propagation. *Polynomial chaos expansions* (PCE) will be used for uncertainty propagation and sensitivity analysis, because they are a reliable and comprehensive method for highly parameterized and complex models (Le Gratiet et al., 2017, Hover and

Triantafyllou, 2006). The advantage of PCE compared to other statistical approaches (for instance Monte Carlo simulation) is the low cost: the PCE is fitted from a set of runs of the complex simulator (called DOE, design of computer experiments), usually a few tens to a few hundreds; Once the PCE is built from this data, it is used as a surrogate model, which can then be evaluated millions of times at no cost.

Using the PC expression of the various quantities of interest, sensitivity analysis, which aims at quantifying which input parameters of the model influence the most the model outputs, can be carried out: sensitivity indices known as Sobol' indices (Saltelli et al., 2008) can be computed from the PCE coefficients analytically (Sudret, 2008). This will allow to simplify the overall modelling, *i.e.* to fix to deterministic best-estimate values all the parameters which do not influence the quantities of interest.

Uncertainty propagation also allows to determine the probability distribution functions of the quantities of interest as well as their statistical moments.

In parallel, the detailed characterization of the existing building stock in Switzerland will be performed with the focus on the construction period and the structural material. This will be done to identify the reference buildings, which will be representatives for the building stock. The building renovation packages for each of the building types will be determined with regards to the envelope renovation, heating system or energy production systems and various combinations of these measures.

3. CONCLUSION

The calculation of uncertainties is necessary to compare two renovation strategies due to the long life cycle of the buildings. This project proposes a method for the evaluation of building renovation strategies in terms of robustness and reliability. In the end of the project, the detailed assessment of the renovation packages will be achieved and the most relevant parameters with the highest effect on the model response will be identified. Finally, the results will be used to provide guidelines on robust renovation strategies for Switzerland that can be used by architects, clients and policy makers.

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