INCLUDING UNCERTAINTY IN BUILDING ENERGY PERFORMANCE CALCULATION METHODS

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ABSTRACT

In building design, energy performances are commonly predicted based on deterministic stationary or dynamic calculations. However, many contributing parameters are inherently uncertain, resulting in potentially unreliable values for the performance indicators. To overcome this, a probabilistic design method is recommended to take uncertainties into account. Such uncertainty-based optimisation often requires many simulations, making it extremely time-consuming. To avoid this, meta-modelling can be of interest. A meta-model mimics the original numerical model with a simplified fast model. The current paper presents a global probabilistic design methodology to take different kinds of uncertainty into account in building energy performance calculation methods.

KEYWORDS

probabilistic analysis, robust design, energy performances, meta-modelling, optimisation

1 INTRODUCTION

The energy efficiency of dwellings is becoming increasingly important in view of climate change and fuel depletion challenges. At present, newly built dwellings should be low-energy, while passive and nearly zero energy buildings will become the standard in the near future. To calculate the energy demand and life-cycle cost of dwellings in multi-criterion decision making, deterministic simulations are commonly used. User behaviour and workmanship of building envelopes and services are however inherently stochastic and neglecting these uncertainties may lead to excessive deviations between design and reality. Such excessive deviations are undesirable, both from the point of view of the building occupant and of society in general: inhabitants require confidence in the return on their investments in energy efficiency, governments want guarantees that their subsidy programs have a correct impact. To minimise such deviations, the development and promotion of robust cost-efficient building envelopes and service solutions is an important step. Therefore, a reliable probabilistic robust design method is suggested in this paper.

2 PROBABILISTIC DESIGN METHODOLOGY

The probabilistic design methodology consists of four steps (see Figure 1): preprocessing, preliminary screening, updating and probabilistic design. These steps analogously select the input parameters and distributions (step 1), determine the most dominant input parameters and develop a meta-model to improve calculation efficiency (step 2), update the input distributions (step 3), and finally perform the actual probabilistic design (step 4).

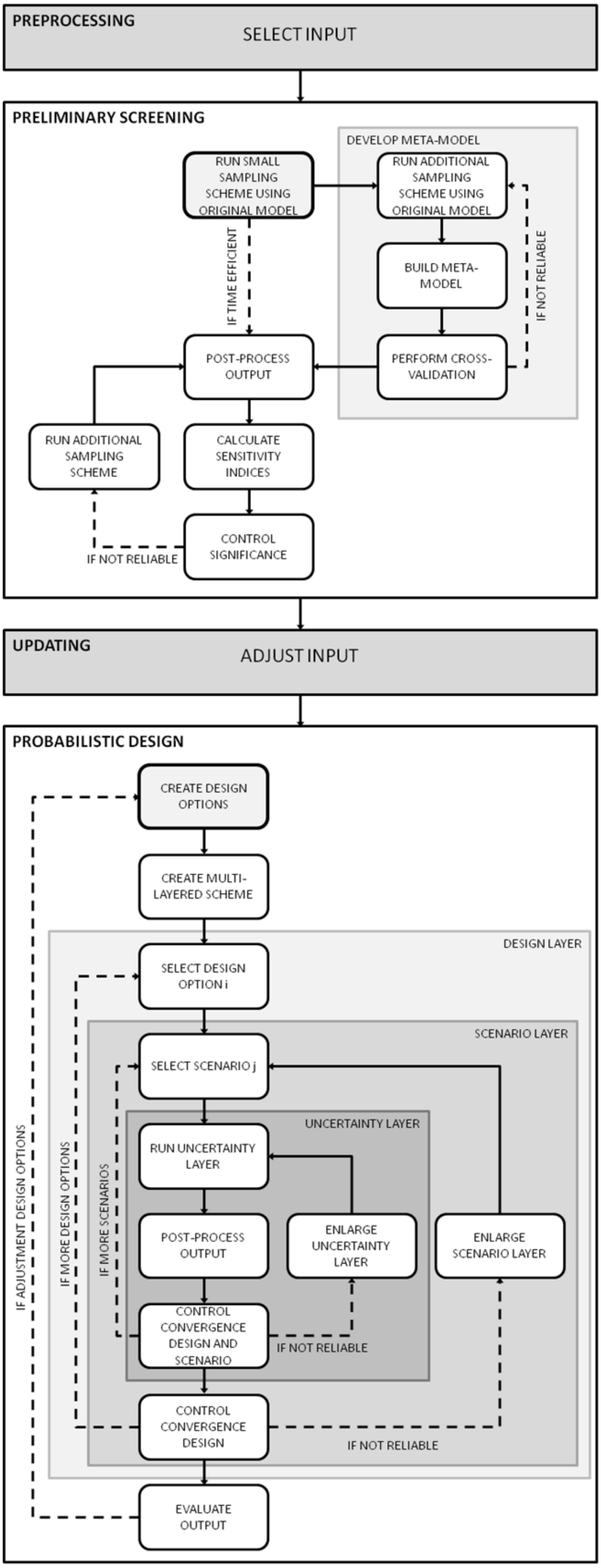

Figure 1: Methodology flowchart

Contributing input parameters of this probabilistic design can be divided into three categories. Design parameters, such as the preferred air tightness or thermal resistance, the type of ventilation system,… are fully controllable. They are the unknown parameters in the design process, but once a design option is selected, the parameter values are known. Inherently uncertain parameters, such as workmanship and user behaviour, are uncontrollable by the designer as their values are neither known in the design process nor after, but they can significantly influence the design performance. Finally, scenario parameters are inherently uncertain parameters dealing with potential future scenarios, such as economic or climatic evolutions, for which an explicit evaluation is wanted.

The probabilistic design (step 4) is therefore performed through a Monte Carlo loop with a multi-layered sampling scheme which enables sorting parameters by their conceptual meaning. By ascribing these parameter categories to a different layer in a multi-layered sampling scheme as shown in Figure 1, all design options are subjected to the same uncertainties and a direct comparison for several future scenarios is enabled. As a result, this probabilistic design can be used as an effective decision tool.
Prior to performing such a probabilistic design, the problem is first preprocessed (step 1) to select the output parameters needed for decision making and a suitable simulation model. Both stationary or dynamic, and simplified or complex models can be chosen. Contributing input parameters are determined and fixed values or (provisional) input distributions are ascribed for respectively deterministic and stochastic parameters.

Since the proposed multi-layered sampling scheme significantly increases the needed number of runs, time-inefficient models are preferably replaced by a meta-model in the preliminary screening (step 2). Therefore, training and validation sets are run in the original model to construct and validate the meta-model. Due to the extent of the multi-layered scheme, smaller sampling sets are used. These sets are also used to calculate sensitivity indices to rank the input parameters from most to least influencing the output distributions.
Based on this sensitivity ranking, the provisional distributions of most influencing parameters are updated (step 3), while the less influencing parameters can be omitted. Limiting the number of parameters eases collecting the required input distributions as this can be time-consuming. Moreover, this improves sampling efficiency and limits the number of considered design options in the multi-layered scheme. This stresses the importance of the preliminary screening in addition to the actual probabilistic design.
To enable numerical evaluation of these schemes, effectiveness and robustness indicators are proposed, inspired by robust design. Effectiveness is defined as the ability of the design option to optimise the performance, while robustness is defined as the ability to stabilise this performance for the entire range of input uncertainties. The proposed method appears to be very effective in comparing both effectiveness and robustness of multiple performance criteria for numerous design options with Pareto optimality or the weighed sum method.

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