論文の内容の要旨

論文題目　A study of the uncertainty considered decision-making framework using sensitivity analysis and Gaussian process in the early stage of architecture environmental design

（感度分析とガウス過程による不確実性を考慮した建築環境設計初期段階における意思決定フレームワークに関する研究）

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The energy saving potential of architectural design in early stage has been widely recognized. Quantitative energy performance analysis has been introduced into the early stage of architecture design. However, the gap between estimated energy performance in design stage and the measured in operation stage has been revealed by many researchers. Researchers have pointed out that this gap comes from the uncertainties of the input parameters. The real values of some parameters, in the operation stage, can hardly be precisely predicted in the design stage. Besides the uncertainty issues, there are also some other problems in the early stage of architecture design, such as low efficiency of trial and error process, time cost of simulations, decision-making assistance problems and troubles caused by unexpected interactions between parameters.

The purpose of this research to find a high-efficient decision-making framework for the early stage of architecture environmental design that is able to incorporate the uncertainties of parameters and solve other problems pointed out above.

Through the literature review, we found that, with proper assumed distributions of the parameters, Monte Carlo method is usually used to reflect the uncertainties in parameters. Sensitivity analysis and meta-modeling (regression) have been used to reduce the time cost of simulations. Interactive data visualization can help designers make decisions. However, the robustness of Gaussian process regression (GPR) when dealing with noisy data has not yet be fully utilized. Interaction analysis has not been introduced into environmental design. Moreover, these techniques and knowledge are still fragmented. A framework is necessary to integrate them.

In this research, we defined 2 pairs concepts, Targeted parameters and Non-targeted parameters, Variety and Noise. Targeted parameters (TPs) mean those parameters designers want to study, such as WWR, insulation level. Variety means the changing of a criterion with the changing of TPs. Non-targeted parameters (NTPs) mean those uncertain parameters whose values cannot be precisely predicted in the early stage. Though they are beyond the

study targets, as they influence the energy performance, designers should take them into consideration. Typical NTPs can be AC setpoints, occupancy schedule, internal heat gain, etc. Noise means the variability of a criterion caused by the uncertainties of NTPs.

A 4-phased framework was proposed. The first phase is ‘Pre-process’. Designers will firstly decide the criteria, building mass, master plan and environmental design strategies. Based on the design strategies, types and ranges of TPs will be decided, as well as types and distributions of NTPs. In the next ‘Dimension reduction’ phase, the sensitivities of all parameters, including both TPs and NTPs, will be quantified. Less important parameters will be ignored, to reduce the dimension. The interaction of left parameters will be quantified, based on which parameters will be separated into groups. So that a high-dimensional problem will be decomposed into several low-dimensional problems. The next phase is named ‘Meta-modeling’. GPR models will be trained using simulated data for each group. A polynomial named PCP will be used to combine predictions for different groups if necessary. In the last phase ‘post-process’, a large amount of data will be drawn out from the trained GPR models and visualized interactively to help designers in decision-making.

In this research, we mainly gather data from simulations. Therefore, how to enhance the efficiency of executing simulations is also a key point. Therefore, we developed EPPiX and Ultimate EP Executor for EnergyPlus, GH2FD and PyFD for FlowDesigner.

Sobol first-order indices and Morris method were tested in sensitivity analysis. Sobol second-order indices and Expanded Morris method were tested in interaction analysis. The performance of Sobol indices and Morris methods in both sensitivity and interaction analysis were similar. But Morris methods required less samples so that they were more efficient. Therefore, Morris methods were used in this research.

Compared to other meta-modeling methods, GPR is able predict the possibility distribution of $f(x)$ for a given x, rather than a single value. A trained GPR model can predict the Variety caused by TPs and the Noise caused by NTPs. Therefore, GPR is the most suitable meta-modeling method with uncertainties of NTPs considered. However, it was found that in the situation that Noise is much larger than Variety, the necessary sample size to train a decent GPR model, which lead to high time cost. To solve this problem, we proposed a stratified sampling method named ‘Single sample of Targeted parameters paired with Multiple samples of Non-targeted parameters (STMN)’. Using STMN method, decent training of a GPR model can be performed with a relatively smaller sample size.

The proposed framework was demonstrated with a case study, an imaginary office building located in Tokyo. The efficiency of the proposed framework has been proved with this case study. It took in total about 24 hours to run simulations, train GPR models and make interactive data visualizations. In another word, we performed a nearly full-set exploration within several days. Sensitivity analysis helped us found a blind point, the north openings. As the interactions between parameters were analyzed, even with north façade largely modified, there was no need to restudy the south and east façade. The make interactive data visualizations could help designers make decisions and benefit the communications.

Certainly, there are several limitations in this research. Correspondingly, we proposed future work in the last section. We noticed problem of the correlations between criteria, so that we proposed coregionalized GPR as future work. We also plane to integrate Robust optimization with GPR and GA. In the near future, we will also positively introduce this framework into real projects.