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DESIGN OPTIMIZATION DURING THE DIFFERENT DESIGN STAGES

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ABSTRACT

The A/E/C (Architecture, Engineering, Construction) industry is very traditional. In contrast to other industries (e.g. car or ship industry) no prototypes are trialled and tested before manufacturing. Each building is unique, thereby excluding large scale production.

Over the past thirty years, computers have become ubiquitous even in the AEC industry. Yet in building design we are still exchanging data and making design decisions as a century ago, with paper drawings and reports. Although building design support tools are used for design confirmation at the end of the design process, important decisions are already made in the conceptual design stage.

This paper reports an ongoing research which focuses on the different stages of the design process, their needs and key issues.

Depending on the distinction of the design stages, literature review was done in the field of Multi-objective evolutionary algorithms. The variability in the definition of their fitness-function, the difference of inheritance, mutation etc. could add benefit to one specific design stage.

The paper finishes with indicating trends for future work.

1. INTRODUCTION

The paper describes a research area in the domain of building performance simulation (BPS) that, to the author's current knowledge, has not yet been of extensive interest to the academic community.

Research, which was done by the authors before was a review of state of the art building performance simulation software and interviews with world leading professionals in the field of mechanical engineering. The results are summarized in earlier work by Hopfe et al. (4, 5).

A literature survey dedicated to techniques to be of use to optimize engineering solutions is presented below.

During the design process a great number of decisions need to be taken. Typical design assessment criteria are spatial flexibility, energy efficiency, environmental impact as well as thermal comfort, productivity and creativity of occupants among others (4).

Decisions, once taken, are rarely reviewed as design iterations are costly. Therefore non-optimal decisions made during the early design phases of a building most certainly form the base to detail design concepts. As soon as it becomes clear, that a worked out design does not fulfil the requirements of the client and/or end user the design process is repeated iteratively. Earlier decisions will be reconsidered, concepts changed, and numerical values rectified. It becomes self evident that an educated concept generation process at the early design stage, employing state of the art techniques, would significantly contribute to reducing design iterations. Furthermore, it is assessed to be of great importance to autonomously optimise discipline specific designs continuously during the design process from the start to the worked out example.

In order to elaborate the necessity of the improvement of building performance simulation (BPS) and formulating new ideas to achieve this aim, this paper addresses one important key aspect: How can a certain type of evolutionary computing be integrated more effectively in a particular design stage?

2. PROBLEM DESCRIPTION

The use of building performance simulation in current building design projects is limited.
Although there is a large number of building simulation tools available, the application of these tools is mostly restricted to the detailed design stage.
One capability, design optimization, was found to be important is missing from a large number of tools.
Many of the building performance tools that are currently in use are legacy software tools that have a monolithic software structure and are becoming increasingly hard to maintain.
The use of BPS tools requires expert skills to set up a model and run an analysis that the right output is generated from which the desired performance data can be extracted.

3. CONCEPT

In literature the building design process can be structured as follows: feasibility study, conceptual design, preliminary design, final design and building preparation. The building performance should be

optimized from different perspectives: at the beginning of the conceptual design and at the end of the detailed design stage.
Each design stage is characterized by a number of value drivers (VD) and parameters (P), which vary dependent on the discipline of the design team participant. VD's are for instance thermal and acoustic comfort, energy consumption, costs etc.
The VD-P ratio decreases during the design process, meaning the number of parameter increases whilst the number of value drivers remains constant. The consequence is that parameters are assigned more value. The optimization process in the beginning of the design process compared to the preliminary or even detailed design stage needs to be considered different.

4. CONCEPTUAL DESIGN (CD)

Value drivers in the conceptual design are more important than parameters. Each existing value driver has a big influence on the decision making during this design stage compared to parameters. However, parameters gain on value during the detailed design stage.

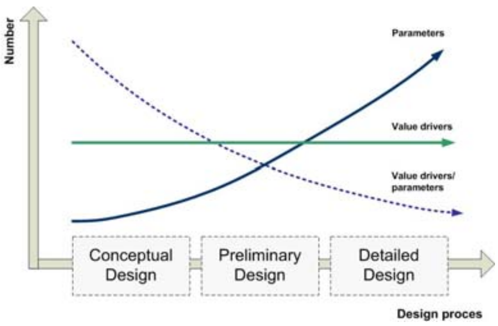

Figure 1:Relation Value driver- parameters

5. DETAILED DESIGN (DD)

Looking at the detailed design stage the number of parameters rises. Value drivers like energy consumption, costs (running/ operation), environmental quality need to be regarded more specifically.
Exemplary one purpose of this design stage could be the optimization of the energy use: reducing heating, cooling, lighting loads, employ renewable energy sources (day lighting, passive solar heating etc.), specify the HVAC and lighting system, type of glazing (single/ double glazed) and optimize system control strategies etc.
Another important value driver -the indoor environmental quality which must be maintained or even enhanced- also includes many different parameters. Subjects to be discussed, considering indoor environmental quality, are e.g. creating a high performance luminous environment (integration of natural and artificial light), avoid usage of material with pollutants, prevent airborne bacteria and mould through heating, ventilating etc.

6. APPROACH

There exist several approaches towards applying evolutionary computing to multi-objective problems.
There are all specific in structure, decision variable space (fitness function), object function space (crossover, mutation rate) etc.
As described each design stage addresses a great variety of value drivers and parameters. This means each design stage needs to be regarded separately and needs therefore a different approach for optimization.
Thus, different multi- objective algorithms are compared regarding their structure and their applicability to different design stages is discussed. The research is still in progress.

7. RESULTS

The results are summarized in table 1 in the Appendix. Ten different multi-objective algorithms were considered: HLGA, NPGA, NPGA2, NSGA, SPEA, SPEA2, SPEA2+, MPGA, MOPSO and parEGO.

In the beginning, there were compared regarding their similarity. After that the definition of the fitness function, ranking of the population, selection etc. was considered more extensively. As this is an ongoing research, the results are summarised in the table 1. The implementation of one or two algorithms to prove the assumptions made will follow.

8. PRELIMINARY CONCLUSION

The different character of the design stages and the increasing number and complexity of the parameters requires a separate consideration of each stage.
During the conceptual stage, for instance, different value drivers need to be considered more precisely. Some of them complement one another whilst others conflict. This results in the necessity of a VD ranking feature. Algorithms like NSGA, SPEA2 or MPGA occur to be applicable to this phase of the design process.
During the detailed design stage a sensitivity analysis adds value by assessing design uncertainties. Algorithms which occur to be of value are, for instance, parEGO, MOPSO and SPEA2+.

9. FUTURE WORK

Future work will comprise of an analysis if the assumptions made are suitable for the different design stages by implementing the algorithms to existing software tools specifically addressing the design stage of concern.

REFERENCES

1. Bäck, T., Schwefel, H.-P., 1993, “An Overview of evolutionary algorithms for parameter optimization’’

2. Bentley, Peter, 1999, “Evolutionary Design by computers”

3. Hensen, J.L.M., 2004, Towards more effective use of building performance simulation in design, Developments in Design & Decision Support Systems in Architecture and Urban Planning, edited by Jos P. van Leeuwen and Harry J. P. Timmermans, Eindhoven University of Technology, Department of Architecture, Building and Planning, Eindhoven, the Netherlands.

4. Hopfe C., Struck C., Ulukavak Harputlugil G., Hensen J., Wilde P. de, 2005 “Exploration of the use of building performance simulation for conceptual design”

5. Hopfe C., Struck C., Ulukavak Harputlugil G., Hensen J., 2005, “Computational simulation tools for building services design- professional’s practice and wishes”

6. Kicinger R., Arciszewski T., De Jong K., 2005, Evolutionary Computation and Structural design: a Survey of the State of the Art

7. Meyer D., 2002, Mombes- multiobjective modelbased evolution strategy, Forschungsbericht Kuenstliche Intelligenz

8. Nassif N., Kajil S., Sabourin R., 2004, Optimization of HVAC Control System Startegy Using Tw0-Objective Genetic Algorithm

9. Parmee, Ian C., 2001, “Evolutionary and Adaptive Computing in Engineering Design”

10. Wright, J., Loosemore, H., 2001, “The multi-criterion optimization of building thermal design and control”

11. Wright, Jonathan, 2004, “Building system design synthesis and optimization” ASHRAE

APPENDIX

Table 1: Summary of the results

Name	Date	Pareto	similar to	CD	DD	Extra
HLGA	1992	non		X		ranking possible, knowledge of input/ parameter- vd necessary
NPGA	1994	yes	NPGA2,MOGA,NSGA		**X**	fitness sharing; competition selection; pareto domination tournaments; constraints not possible
NPGA2	2001	yes			**X**	uses degree of domination as determining score
NSGA	1994	yes	NPGA, NPGA2	**X**		ranking of the entire population
SPEA	1998	yes	NPGA, NSGA		**X**	no fitness sharing parameters required (new niching method); clustering to reduce number of non-dominated solutions; all solutions participate in selection, pareto dominance
SPEA2	2001	yes		**X**		nearest neighbour density procedure: precise guidance of search process; in fitness assignment and selection different than SPEA,NSGA2,PESA; else the same
SPEA2+	2004	yes	SPEA2	**X**	**X**	strong elitism; similar to SPEA2, except more efficient crossover and diversity of objective AND decision variable space!
MPGA	2003	yes/ no	half MOGA, half VEGA	**X**		two stages; stage 1 based on MOGA(weight vector to unify multiple objectives), stage2 based on VEGA(n parallel populations): multistage search, each stage with its own strengths
MOPSO	2003	yes			**X**	region based selection instead of individual selection; extension of PSO from single to objective; fully search of decision space
parEGO	2005	yes			**X**	evolutionary search and detailed internal model; reduce uncertainty about search landscape