CONSIDERATIONS REDARDING DECISION SUPPORT TOOLS FOR CONCEPTUAL BUILDING DESIGN

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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 elaborates the above in more detail and reports findings of two research activities as indicated below. Firstly, this paper summarizes the results of interviews with world leading building services professionals. These results indicate current practice and more importantly wishes for the future. Secondly, the current state of the research on evolutionary and adaptive computational support techniques for conceptual design search and optimization is discussed. The paper finishes with indicating trends for future work.

KEY WORDS

Building performance, optimization, multi-objective, interviews

INTRODUCTION

The paper describes a research area, design generation and optimisation, 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.

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Based on, firstly, a review of state of the art building performance simulation software, secondly, interviews with world leading professionals in the field of mechanical engineering and, finally, a literature survey dedicated to techniques to be of use to optimise engineering solutions a potential solution concept grew which is presented below.

The concept once implemented in the construction industry should have the potential to improve building design and enhance the role of BPS during the design process.

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 revisited 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. Based on identified shortcomings, 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 deemed to be of great importance to autonomously optimise discipline specific designs continuously during the design process from the start to the worked out example.

Depending on the building project and program of requirements the contributing design disciplines are numerous. Whilst following the provided argumentation, the reader will notice that the authors narrow the considered problem area down to two, architecture and mechanical engineering, and finally to three design contributors, architect, climate engineer and mechanical engineer.

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 two key aspects:

1   How do designers feel about computational support, what is the current state and what future developments are needed? [4]
2   How can evolutionary computing be integrated more effectively in the design process/ practice?

METHODS

To answer the above questions, two different methods were put into practice. Firstly, a number of interviews were conducted and secondly, a review of widely ranging literature was undertaken. The literature review was based on comments made by the interviewees. The comments were analyzed and techniques identified on how to make use of those ideas which consequently resulted in a study of evolutionary computation.

Part 1, Interviews with world leading building services professionals

The first part of this work comprises interviews with 15 international building services professionals. Of special interest to the interviewers was the interviewee's use of computational support. The use of computational support during different design stages has been discussed. Continuative, the main shortcomings of current computational support and future wishes considering the use of simulation tools were questioned.

Part 2, Ideas and outcomes of literature review in Evolutionary Computing

The second part of the work was dedicated to developing a proposal to improve concept generation and optimization based on comments made by interviewees. The process was supported by inspirations drawn from an extensive literature survey. [2, 8-9] The techniques read up upon, such as evolutionary design, were evaluated on their suitability to solve the potential shortcomings. Furthermore, it was considered what additional research is required to implement relevant technique to enable project support.

INTERVIEWS

15 interviews with international building services professionals were conducted with: nine mechanical engineers, three building physicists, one civil engineer and two architects. Whilst three of them hold positions in academia the remaining 12 interviewees were practitioners.

Value drivers and value frameworks

During the interviews the authors came across a great variety of different design assessment criteria. Because of their influence on the quality and subsequently the success of the design project these parameters were called value drivers. Typical, value drivers are energy consumption, life-cycle- and investment costs, thermal and acoustic comfort and indoor environmental quality among others.

Different values are allocated to different design criteria depending on the requirements of one specific design discipline and type of design project. It is self explanatory that engineering disciplines rank values differently, why the phrase value framework is introduced. However, as the final product is supposed to work harmonically as one system, value frameworks naturally overlap. The architectural value driver 'user satisfaction', for example, is closely linked to mechanical engineering value drivers as 'thermal comfort' and 'indoor air quality'. (See Figure 2)

Design process

One subject of the interviews was the individual perception of the design process structure Questions were asked, as: "How do you experience the design process (DP)?". It was investigated whether the DP consists of different stages or if the DP is experienced as highly unstructured and iterative, without the presence of clearly defined stages. Another goal of the interviews was to find out what level of experience is required in relation to the impact of decisions needed to be taken. [4]

It was found that academics assessed the design process differently from practitioners. Academics assessed the current design process structure as highly inflexible and insufficient, causing additional design iterations. The research area of addressing those insufficiencies is of great interest to academic research. [15] Practitioners,

however, expressed the need to allow for greater flexibility within the experienced structured process. Design stages were deemed to be of importance to be able to account for provided services and to progress the design. Design stages can be differently well-defined depending on project type and character. [11] (See Figure 1)

It was confirmed by academics and practitioners that decisions at earlier phases of the design have a bigger impact on the building performance than measures taken at later design stages or during building operation However, extensive design experience is required to educate the design team during those early stages as the available extend of design information is very limited.

Computational support

To gain a better understanding of the application of BPS - tools, it was discussed which tools are used, how complex these tools are and in which manner they are used (visualization/ simulation/ results presentation). The interviewees were asked where they identify a lack in the performance and application of existing BPS - tools and what they wish for in the future. [4]
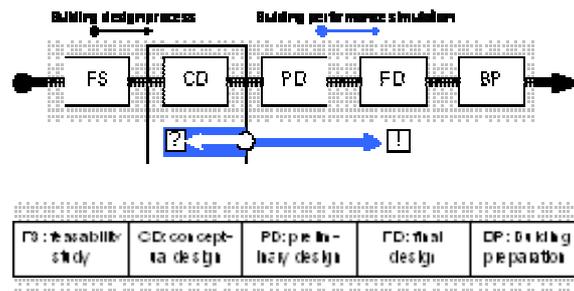
Figure 1.Design process analysis

Whilst feedback from academics included the statement that priority should be given to improving the design process, all practitioners responded positively to the question concerning the usefulness of computational support during the design process. However, most of them develop initial concepts based on design experience using computational support towards the end of the design process although the most design influencing decisions are made before. [4]

The interviewees stressed the point that tools to be used during early design stages should have the potential to inform the design team about issues related to the building performance and initiate a discussion to pinpoint the most favorable concept. Because of the lack of information during the conceptual design stage, almost all interviewees prefer building related tools over system related tools in the beginning.

One aspect, which was revealed during the interviews, was that most of the tools dedicated to the conceptual design stage were perceived by the users to address only one value driver. Furthermore, it was found important by these users that BPS - tools should offer the possibility to consider more than one value driver and to allow for their prioritization based on the project type and design discipline.

All interviewees agreed that design experience is essential for developing design concepts. It was stated that the use of simulation tools enables an impact assessment of different parameters. However the use of BPS - tools without experience in of building performance simulation does not bring the benefit aimed for as users run the risk to produce results which do comply with the domain characteristics. [4]

The comments made on expectations for future developments of BPS – tools can be allocated to two domains: firstly, the concept generation, at the beginning of the conceptual stage; and secondly, the design optimization performed during the design process from conceptual to final design. For each of the two domains, the most important subjects discussed are listed below.

Concept generation:

1   Import of partial and/or full model objects to generate/ compile a dedicated concept to reduce the error margin and speed up the modeling process.
2   Concept definition and comparison based on a wide range of prioritized value drivers to support the creative process and expand the search space.

Design optimization

3   User level implementation accounting for design experience levels to match comprehensiveness level of interface to tool user.
4   Responding design detail consideration to reduce explicitness degree of problem domain to design stage.

Integrated design team

Although not originally formulated as a question to be asked, many practitioners expressed the need to integrate design disciplines into the design process from the very early stages. One difficulty repeatedly encountered by engineers was the fact that the design stages are barely synchronised across disciplines as it is difficult for design disciplines to understand the impact of their design on the works of others. Another aspect identified was that not including specific design disciplines early enough in the design process might cause the design team to make uneducated decisions, risking sub-optimal solutions or additional design iterations.

In order to improve the concept integration and communication several commercial institutions established a profession, which refers to itself as climate or environmental engineers. The "new" profession is meant to build a bridge between mechanical engineers and other design disciplines involved in the very early design stages like clients, architects etc.. The authors argue that in addition to the traditional value drivers considered by mechanical engineers, climate engineers consider a combination of value drivers from different value frameworks.
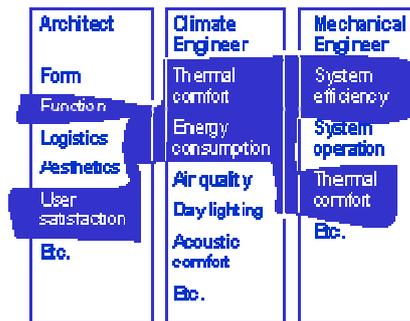
Figure2. Value drivers and value frameworks Visualisation; (Exemplary allocation of value drivers to design discipline)

EVOLUTIONARY COMPUTING

To generate new design concepts and to optimize their performance, the strategy of 'evolutionary design' gains more interest. In this strategy the evolution processes known from biology are translated into algorithms and made available for concept development and optimization. First publications on their application to product design appeared in the mid 1980's. Ever since a number of different algorithms have been developed and evaluated.

Exemplary methodologies are Evolutionary Programming (EP), Evolutionary Strategies (ES) and Genetic Algorithm (GA). Although the algorithms origin from the same idea their applicability to potential problem areas differs based on their characteristics represented by mutation, fitness, recombination and selection.

The most commonly used algorithm in evolutionary product design is the GA. GA's distinguish themselves from others as they are not self-adaptable, recombination being the main operator resulting in mutation being the background operator. [1, 14]. Differently to EP or ES as "traditional" optimization methods the GA uses constraints such as "parametric optimization values" encoded in the chromosome character string of the parent individuals. Whilst the optimization processes as ES and EP use the entire, usually randomly selected, population, which is perturbed finally, GA's use a parent population which was subject to a selection based on fitness prior recombination of their genetic information and finally mutation. [16]

Wright and Loosemore advocated in [12] the use of GA's for finding the Pareto set of solutions as "traditional" methods require a sequential and thereby computational intensive approach. The Pareto optimum, by Vilfreto Pareto 1848 - 1923, represents an optimum that is not dominated by any other solution. The utilization of GA's makes it often possible to identify the members of a Pareto optimum after one run of the algorithm.

Evolutionary Design in Architecture

Numerous publications are available reporting on research being conducted to make use of evolutionary design in architecture. [5-7, 10] The focus thereby lays on automating the optimisation the space topology and layout generation with respect to the architectural design. Michalek et al. report in [7] the successful use of a hybrid search algorithm integrating simulated annealing (SA) and sequential quadratic programming (SQP) for geometry generation. The aim of this research was to overcome the limits set by local search and to find solutions of global quality. The hybrid set up thereby takes advantage of the global qualities of SA and the efficiency of SQP. Furthermore the space topology was subject to optimisation using a GA. This optimisation process includes two different stages:

Generation of geometry: modelling units in defining different using types, sizes, dependencies, number and size of windows etc.. Search criteria like minimising heating, cooling and lighting costs are optionally available.

1   Optimisation of space topology: finding the best set of relationships between rooms in a building.
2   The combination of these two algorithms supports the identification of the mathematical geometric optimum under predefined constraints.

Evolutionary design in Mechanical Engineering

The research effort being invested in evolutionary design has not gone unnoticed by mechanical engineering. The concept generation and optimisation using genetic algorithms has been applied to mechanical systems and their control mechanisms. In [13] Wright et al. come to the conclusion that GA's show a potential being of use to optimize the topology of HVAC components in an Heating Ventilation and Air Conditioning (HVAC) system based on criteria as capital costs or energy use.

Research has also been published [12] investigating the feasibility of applying more than one assessment criteria simultaneously to the search for the mathematical optimum. Exemplary, the designer has the possibility to assign a weighting factor to assessment criteria such as thermal comfort and system efficiency. The weighted sum will form a single design criterion which will result in the best discipline dependent

most suitable solution for the specific problem area. The implementation of different value drivers or assessment criteria for design concepts is called multi-objective genetic algorithm (MOGA).

MOGA is different to GA as it includes a concept that deals with constraint functions. The constraints apply a force the solution to guiding the process towards a feasible region. Wright et al. explain in [12] that the increasing number of constraints make it increasingly difficult to construe the resulting pay – off characteristics. Therefore they propose to aggregate the constraints in one single criterion.

Proposal

The publications referred to indicate potential benefits using evolutionary computing in both design disciplines architecture and mechanical engineering exemplary for the construction industry.

An important outcome of the interviews was the argument that currently available BPS – tools do not support the integration of different value frameworks as required by climate engineers/ environmental engineers i.e.. The interview results go inline with findings of a software review conducted concluding that the BPS – tools considered are mainly dedicated to analyse energy consumption and thermal comfort classified as value driver in the domain of mechanical engineering. [3,4]

GA's are awarded the advantage of being able to compute the members of a Pareto optimum with less expense compared to "traditional" methods. Also taking into account the availability of a multi - objective optimization algorithm makes GA's appear as the most suitable algorithm for inter value framework design optimization.

The authors suggest the application of multi-objective genetic algorithms to bridge discipline specific value frameworks, as for example architecture and mechanical engineering.

To make use of the technique it is important to clearly understand the impact of different discipline specific value drivers on one building design. In order to understand which value drivers are important and how they are weighted and allocated, design team meeting observation are planned for the next months.

CONCLUSION AND FUTURE WORK

Based on the interviews it was concluded that building industry still works in a traditional manner using a design process that is not always flexible enough to be satisfyingly adapted to a specific problem domain. However, commercial institutions take measures to overcome problems as unsynchronised processes and ill structured design teams by using highly experienced staff to act as bridge between design disciplines.

Experience by people bridging disciplines, here exemplary called climate or environmental engineers, show that traditional BPS – tools are limited in its use as they typically only address one value framework.

The interviews conducted resulted in the conclusion that using multi-objective genetic algorithms could have a potential benefit to generate and optimise integrated design concepts. The resulting application is meant to bridge design disciplines allowing for the integration of more than one value framework.

The next step towards integrating value frameworks will be to observe design team meetings to identify important value drivers and their weight and allocation during the design process.

It is expected that enabling the integration of different value frameworks into one computational tool will make building performance simulation more useful during the early design stages resulting in better performing buildings.

ACKNOWLEDGEMENTS

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., 2005 "Exploration of the use of building performance simulation for conceptual design"

[5] Jagielski, R., Gero, J.S., 1997, "A genetic programming approach to the space layout planning problem"

[6] Jo, J.H., Gero, J.S., 1998, "Space layout planning using an evolutionary approach"

[7] Michalek, J.J., Choudhary R., Papalambros P.Y., 2002, "Architectural Layout Design Optimization"

[8] Parmee, Ian C., 2001, "Evolutionary and Adaptive Computing in Engineering Design"

[9] Parmee, I. 1996. "Towards an optimal Engineering Design Process using Appropriate Adaptive Search Strategies", Journal of Engineering Design, Vol 7:4, Carfax Pub.

[10] Schwarz, A., Berry, D.M., Shaviv, E., 1994, "Representing and solving the automated building design problem''

[11] Wilde, Pieter de, 2004, "Computational Support for the Selection of Energy saving building components"

[12] Wright, J., Loosemore, H., 2001, "The multi-criterion optimization of building thermal design and control"

[13] Wright, Jonathan, 2004, "Building system design synthesis and optimization" ASHRAE

[14] Wright, J., Alajmi, A., 2005, "The robustness of genetic algorithms in solving unconstrained building optimization problems"

[15] Zeiler, Wim, Quanjel, Emile, 2003, "Babylon Voorbij", Onderzoek Integral Ontwerpen Sammenvatting

[16] Heitkötter, Jörg, 1993, The Hitch – Hiker's Guide to Evolutionary Computation (FAQ for comp.ai.genetic)