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Parametric analysis as a methodical approach that facilitates the exploration of the creative space in low-energy and zero-energy design projects

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Most – if not all - methodical approaches found in literature that describe the creation of environmentally sustainable architecture agree on the importance of inter-disciplinarity and the early integration of building system strategies and the importance of the comfort of the user. Today most people agree that it is important, or even crucial, that architects and engineers cooperate from the beginning of the process. But there is still no consensus about how or when this should happen.
This paper discusses how inter-disciplinarity can be achieved in an integrated design process aiming at low-energy or zero-energy building design.
The paper discusses professional differences between two of the main actors involved in integrated design processes; engineers and architects, as well as a methodical approach to investigation and delimitation of the creative space of a specific project.
The paper furthermore discusses the development of tools that support proactive design strategy development.

Keywords: parametric design strategy development, concept development, inter-disciplinary process, integrated design, tool development

1. Introduction

A study of methodical approaches to the creation of environmentally sustainable architecture in a recently completed PhD project [1], led to the conclusion that inter-disciplinarity, project specific concept development and the realisation of these concepts are the keys to success in low-energy and zero-energy building design.

This paper therefore proposes that inter-disciplinary design strategies are important to the creation of low-energy and zero-energy building concepts and that different types of tools can support the design process in relation to two different approaches to the development of project specific concepts; the case-based approach and the parametric approach.

The paper also addresses the inter-disciplinary field of environmentally sustainable building design, where it tries to reframe the understanding of concept development in the cross-disciplinary field between the engineering and architecture professions. This reframing discusses the issues of problem-solving, problem-setting and tool selection, in relation to the formation of inter-disciplinary design teams consisting of both engineers and architects.

The importance of inter-disciplinarity causes the interactions between engineers and architects involved in the design process to change character. This also has an impact on the application of tools and the development of new tools. The paper therefore suggests that tools can be developed for the exploration of the creative space in a project and the development of integrated design strategies and concepts through integration of sensitivity analyses in the tool.

The paper furthermore proposes that a parametric approach is taken to design strategy development as a way of exploring the creative space in a given design project, whilst a case-based approach is taken to the application of the design strategy in the creation of project specific and integrated design concepts where different concept sketches are compared. This approach to concept development is suggested as a way of embracing the inter-disciplinary field of environmental design.

2. Inter-disciplinarity

2.1 Conventional relationships between engineers and architects versus an inter-disciplinary approach to design

The conventional way of building in Denmark is that the architect shares or hands the project over to the engineer when he or she has pretty much finished the schematic design of the building. This leads the engineer to take a reactive role in the design process in stead of the proactive role which is required in an inter-disciplinary approach to design [2].

It is therefore necessary to develop tools that support the engineer when he or she has to take a more proactive role in the inter-disciplinary design of environmentally sustainable buildings.

2.2 Professional differences influencing the success of the inter-disciplinary process

Professor Donald Schön's study of problem-solving situations in the architectural and the science-based engineering design professions showed that their approaches to problem-setting and solving are different:

Table 1: Comparison of problem-solving and setting in respectively engineering design and architecture professions [3]

Engineering design	*Architecture*
• The problem is constant and a hypothesis for how to solve the problem changes as a result of hypothesis-testing experiments. • The solution is dependent on the problem and the investigated hypotheses, and the problem defines the solution.	• The problem is revised and specified in relation to the results of move-testing experiments (i.e. what happens if I do this? Or that?). • The problem and the solution are interdependent, and the solution is the result of iterations between solution and problem.
• The solution is more important than the problem.	

These differences can explain why engineers and architects sometimes have difficulties agreeing about how to approach projects, and why engineers sometimes find it difficult to take a proactive approach to design strategy development – their educational background leads them to take a reactive approach to problems [3, 4].

3. Design concept development

A study of methodical approaches to the design of environmentally sustainable buildings has revealed two approaches to design concept development; 1) the case-based and 2) the parametric.

3.1 The case based approach

The case-based approach represents a reactive approach to design strategy development where the design team performs a comparative analysis of a number of design concepts through the application of an energy calculation tool after which the best solution is chosen, possibly with few alterations.

This is the simplest approach of the two, and it is also the most common.

3.2 The parametric approach

The parametric approach represents a proactive approach to design strategy development, where design parameters are studied for their sensitivity and robustness, e.g. in a calculation tool that determines the energy requirement of the building and the comfort levels inside the building.

Based on the achieved knowledge about the robustness and sensitivity of the parameters a design strategy is developed in relation to the possibilities of the specific project. The parametric analysis thus enables the creation of a project specific design strategy for which design principles to focus on in the concept development phase.

The parametric approach can therefore be seen as a method that can enable engineers to take a proactive role in the development of integrated and inter-disciplinary design strategies and concepts.

3.3 Pros and cons of the two approaches

Table 2: Comparison of the strengths and weaknesses for the two approaches to concept development

Case-based	*Parametric*
+ Enables hypothesis testing + Is applicable in the conventional design process - Does not explore possibilities outside the selected cases → does not facilitate integrated design solutions or inter-disciplinarity	+ Enables exploration of possibilities in the solution space framed by a number of selected cases → facilitates creative move-testing within a mathematical model - Time-consuming and requires a parametric approach to design, i.e. and approach where the decisions involved in building design are regarded as parameters (e.g. the sizes and orientation of windows).

4. An integrated design process

At Aalborg University (Denmark) a new type of engineering education was established in 1997, which is now situated in the Department of Architecture and Design. The education bridges the intermediate space between the architectural and building engineering educations in Denmark, with the aim of bridging the professional gap between the architecture and engineering professions.

For the specialisation in Architecture a process description entitled The Integrated Design Process (IDP) was created by Associate Professor Mary-Ann Knudstrup [9], which suggests an iterative approach to environmental building design where parameters from engineering disciplines are integrated in the architectural design process in a hydride design approach.

The IDP runs through five phases of the design process where it deals with different tasks relating to design projects in general as well as tasks relating to environmental building design [9]:

Table 3: Phases and tasks in the Integrated Design Process

Phase	Tasks
Problem formulation	Formulation of problem
Analysis	Analysis of site, urban development plans, company/user/client profile, chart of functions, principles of energy consumption, indoor environment and construction. Aim and programme.
Sketching	Architectural ideas are linked to principles of construction, energy consumption and indoor environment, as well as, functional demands to the new building.
Synthesis	Architectural and functional qualities, the construction and demands for energy consumption and indoor environment flow together, and more qualities may be added. A new building has been created.
Presentation	Final project is presented in a report, drawings, a cardboard model and IT-visualisations.

The approach was integrated in the study guide for the 6th semester in 2000-02 and today the Integrated Design Process is applied on most semesters in the master programme for the architecture speciality and on some semesters in the bachelor programme.

When applying the integrated design process in practice in a Danish context the process diagram might look like the process displayed in fig. 1:

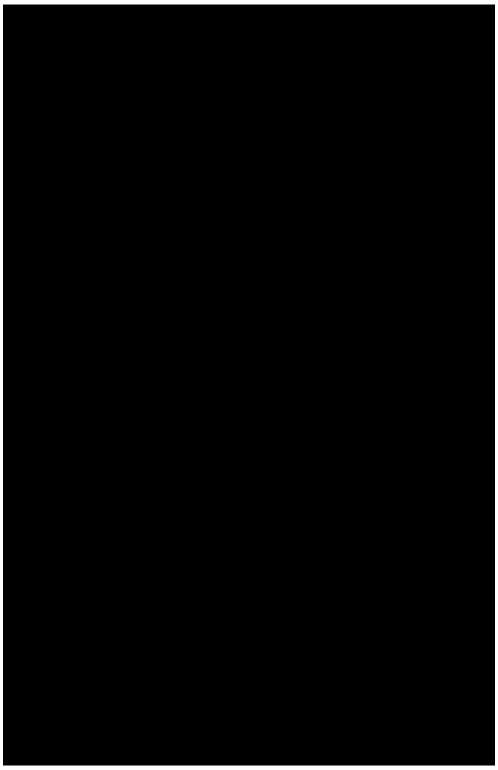

Fig 1. Process diagram for IDP applied in practice

5. Method applicable for parametric analyses

Sensitivity analysis is a well documented methodical approach to parametric analyses. [6, 7]

5.1 Process

The process involved in parametric analyses usually consists of the following stages [1, 5]:

1. Investigation of clients wishes and programming of the building and site.
2. First sketches are used to decide which parameters to investigate in the parametric analysis and the range of investigation for each parameter.
3. Selection of a reference building for analysis.
4. Choice of which computer programme to model the reference building in and how to perform iterations.
5. Global sensitivity analysis where the parameters are varied simultaneously
6. Analysis of the results of the sensitivity analysis → Design strategy development
7. Design strategy → design concept development

5.2 Conclusions from PhD project

Sensitivity analyses were tested in the PhD project as a methodical approach to design strategy development through parametric analyses. The conclusion of the experiment was that parametric analyses enable analysis of the sensitivity of selected design parameters. However, despite the simultaneous variation of the selected parameters the results are still dependent on the parameters in the model that are not changed during the analysis. This is why parametric analyses must be applied every time one does a project with different presumptions for the non-variable parameters or with a different setup of the variable parameters.

In its current form parametric analyses are very time-consuming. The method should therefore be integrated in a tool that supports design strategy development, which enables project specific identification of the most influential parameters in the early phases of a project.

In its current form the global sensitivity analysis is very time-consuming, because one has to go through the process of:

1) Determining the investigated parameters, and their ranges and distribution functions.
2) Inserting these into a statistical simulation programme (e.g. SimLab) which develops a matrix for different variations of the parameters.
3) Inserting the different variations in an external model (e.g. an energy performance calculation programme) and develop a matrix for insertion of the results from the external modelling in the simulation programme

4) Import of the matrix with the results from the external model into the simulation programme and simulation of the sensitivity.

It was therefore the conclusion of the PhD project that the method should be integrated in a design strategy development version of e.g. the BuildDesk programme or preferably in a three-dimensional design programme, which provides a three-dimensional interface of the simulations performed in the statistical analysis.

The strength of having an external programme like SimLab performing the Monte Carlo Simulation is that one can combine different results from different programmes like energy calculation (BuildDesk) and daylight levels (DialEurope) in the same analysis. It is, however, very time consuming to do this and it would therefore be better to integrate the consideration of daylight levels and the resulting energy consumption for artificial lighting in one programme.

6. Tool development

Currently only few tools exist that support design strategy development. And only few of these facilitate parametric analysis.
At Ramboll Denmark a simple tool for parametric analysis has been developed which supports parametric analyses of parameters influential to the energy requirement of buildings. The calculations are made in accordance with the European norms for this type of calculations (prEN ISO 13790:2005, prEN 15316 and prEN
15193-1).

6.1 Variable parameters for parametric tool

The parameters suggested in table 4 are the result of an analysis of the design principles applied in best practice examples of low-energy and passive housing and the possible parametric variations in the Danish energy requirement calculation programme ‘Be06’ [1].

Table 4: Suggestion of variable parameters for analysis of low-energy building design

Design of building envelope	• No. of stories • Average room height • Window to floor area ratio • Effective U-values windows • Effective U-values building envelope • Shade from surroundings • Distance between glass and outer edge of façade • Rotation of building
Ventilation	• Ventilation rate winter • Ventilation rate summer • Heat recovery winter
Materials	• Heat capacity / thermal storage
Use	• Hot water consumption • Internal heat gain people • Internal heat gain appliances • Comfort temperature
Renewable energy	• Area, angle and orientation of PVs • Nominal COP of heat pump • Area, angle and orientation of solar panels

6.2 Results

The results of sensitivity analyses are presented in a column diagram indicating which parameters are the most sensitive and robust in relation to whether the parameter has a positive or negative impact on the energy requirements of a building.

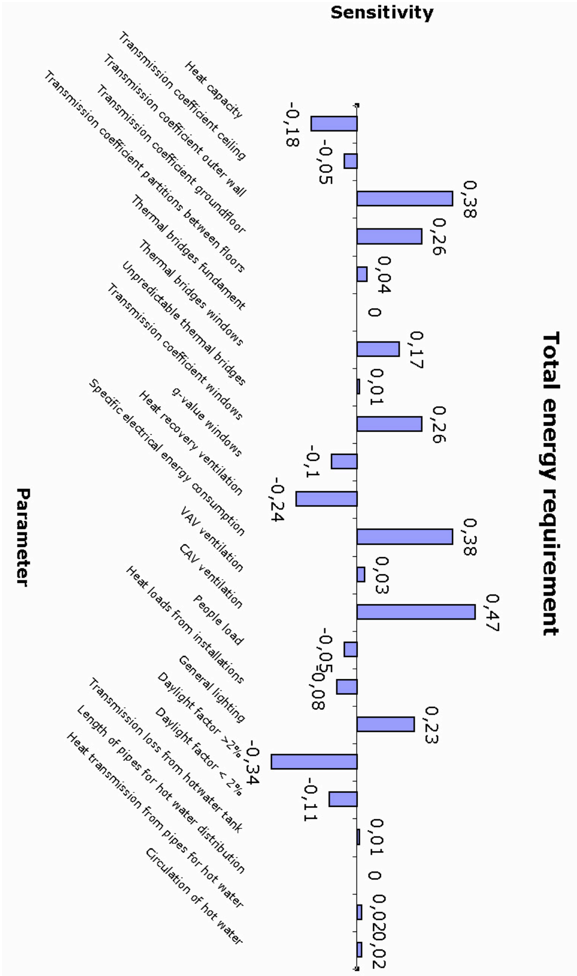

Fig. 2 Example of result of sensitivity analysis

The analyses also result in an understanding of whether there is a risk of inter-correlation between some of the investigated parameters.

The results are used to set up strategies for which parameters to use actively to reduce the energy consumption in the project through changes made in the initial sketches of the building design. In other words the analysis is used to set up strategies for how to develop an integrated design concept for the specific building.

7. Implementation of sensitivity analyses in engineering practices

As mentioned earlier sensitivity analyses have already been implemented in Ramboll Denmark in the form of simple models. These models will be developed further in the future through application in specific projects.

Parametric analyses are also currently tested in the design of one of Ramboll's own offices, and the results of the concept development will be ready later this year.

Simultaneously Ramboll Denmark is developing a model that facilitates the measurement of the sustainability of building projects through application of sensitivity analyses for screening and detailed investigations. The model should be ready for application in the beginning of 2009.

8. Conclusion

8.1 Sensitivity analysis as a methodical approach to design strategy development

It was the conclusion of the PhD project that sensitivity analysis is very relevant as a methodical approach to the development of project specific design strategies and design concepts, because it provides qualitative information about the sensitivity and robustness of selected input parameters in a project specific situation.
The sensitivity analysis does not result in an 'optimum' solution for changes to the reference building, which means that it does not restrict the creative freedom of how the designer achieves the values applied in the analysis. The idea of applying sensitivity analysis as a methodical approach to parametric analysis is, that it enables the engineer consultant to take a proactive role in the building design, where he, or she, provides the architects with some guidelines about what they should consider in the building design.

It was also the conclusion of the PhD project that the selection of the variable input parameters needs careful consideration, and that these should be determined through a study of the design principles suggested in design strategies for best practice examples of e.g. office buildings or institutions described in publications, as well as a study of the applied design principles in these buildings.

It was, furthermore, the conclusion of the PhD project that the methodical approach of sensitivity analysis is too time-consuming in its current form and it, therefore, needs to be integrated in a digital design strategy support tool. This integration can either happen via the development of one of the existing tools or a new tool which enables investigation of more than the predicted energy consumption in buildings. This tool development could be inspired by the Arup SPeAR tool which takes a holistic approach to sustainable design.

Future development of digital tools that support parametric analyses
The development of tools that support parametric analyses requires a thorough study of the relationship between architectural building design and the calculations performed by the tool (e.g. energy requirement of buildings, comfort, daylight, Lifecycle assessment etc.) to determine which parameters should be variable in the tool.
A lot of effort should also be placed on the development of an interface which supports the cross-disciplinarity required for the design of low-energy and zero-energy buildings, so the tool supports the investigations made by the different actors involved in the process. A suggestion of what these variable parameters could be is presented in table 4.

8.2 Achieving architecture

Parametric analyses do not ensure that architectural quality is achieved in the building design, it merely enables the designer to get an overview of the sensitivity, robustness and possible inter-correlations of the design parameters considered in a specific project. The further development of the suggested tool might enable the designer to test his or her different architectural ideas, presuming that the development integrates a geometric interface (thereby turning the tool into both a design strategy tool and a design support tool), but even this does not ensure architectural quality in the building, because the ability to achieve this is embedded in the designer.

8.3 The integrated design process

So far the Integrated Design Process has primarily been utilised for teaching, but experiences with practical application of the method will be available for analysis in the immediate future. This will facilitate a practice targeted version of the process diagram shown in fig. 1, and a revision of the diagram in relation to practical application, as well as a more detailed description of how the process can work in practice.

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