Multi-Disciplinary Design Optimisation via dashboard portals

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Summary

This paper will present the opportunities a dashboard-based system provides to gather information on alternatives and display this in such a way that it will help the user making decisions by making use of multi-disciplinary optimisation (MDO) technology. The multi-disciplinary set up of the program will enable the user to understand the communication between the various disciplines involved, as well as being able to explain others parties why certain choices are made and how the design would benefit from this.

Keywords: *MDO; dashboards; communication; presentation; parametric modelling; automation and databases.*

1. Introduction

The design of a building has many disciplines involved, whilst at the same time being driven by the wishes and ambitions of the client. This adds complexity to the conceptualisation of how a building should function. Traditionally a design team would consist of architects and structural engineers. Nowadays however design teams will often include other areas of expertise, such as urban planners, landscape-architects, along with environmental and building services engineers.

It is in the multi-disciplinary design space that a lot of improvement is possible. It is necessary to understand the relations between constraints and their consequences, thereby adding value through the cooperation achieved within the designing parties. This process enables well founded decisions to be made, which take into account the information supplied by the various disciplines involved.

The starting question for this research project was; “Is it possible to design a computational tool that supports multi-disciplinary optimisation, doing this by providing a platform upon which any of the experts involved are able to see their influence on the total design process?”

2. The design process

Designing is a complex act, this results in a process that is not necessarily structured or easy to understand, thereby causing a kind of design mystique that designers/artists embrace. Especially the conceptual design part, which is the most crucial part in the engineering product development cycle, is very intriguing. It can be seen as an iterative process in which multiple parties can be involved. All parties have different skills and different tastes therefore they will influence the design in a specific way.

Because it is hard to understand how a design process works, there exists substantial disagreement which resolves in several theories describing the process. Two basic but fundamentally different ways have been identified by Table 1[1]: The *Rational Model* and the *Reflection in Action Model*.

Table 1: The rational problem solving paradigm and the reflection-in-action paradigms summarised [1].

	Rational Problem Solving	Reflection in Action
Designer	Information processer (in an objective reality)	Person constructing his/her reality
Design Problem	Ill defined, unstructured	Essentially unique
Design Process	A rational search process	A reflective conversation
Design Knowledge	Knowledge of design procedures and 'scientific' laws	Artistry of design: when to apply which procedure/piece of knowledge
Example Model	Optimisation theory, the natural sciences	Art/ social sciences

In this research project the approach of the Rational Model has been followed.

2.1 The Reflection in Action Model

The main idea behind the Reflection in Action Model (developed by Schön 1983) is that:
Every design problem is unique, since the ambition, location and budget of every design problem is different. Thereby the design team will differ in structure and the focus within the group will shift depending on the persuasiveness of the team members. One of the talents of the experienced designers should be to know how to tackle a design problem and work with the group. The design team will set its direction and come up with the approach of the problem at hand. Every team will have a different approach and depending on the character of the persons a design specific solution will be developed to take action and improve the current situation [1].

2.2 The Rational Model

The Rational Model (developed by Simon in 1969) is that reasoning will be used to come up with solutions for the design problem; therefore the logic will be similar to the positivistic framework of science which is used for the classical sciences such as physics. Set steps to conduct can be come up with and the same process can be used for different design problems. Much attention is paid to the rigour of the analysis, and the generic or objective nature of the process.

Simon quotes the optimisation theory as a prime example of what he believes a science of design could and should be. This very logical and structured or plan driven approach of designing would probably not suit the situation as most designers, in different fields of expertise, see the design process. One of the reasons is that the goals are uncertain at the start since the focus on the requirements and constraints change during the design process. Every time more knowledge is gained about the design, alterations will be made and some will influence all the previous work.

If the approach of the reflection in action process was taken as a starting point, every design query would be different and there would be no use of trying to automate the process. Nevertheless every step within the rational model could exist of a reflection-action type set of steps.

2.3 Multi-disciplinary design

2.3.1 Knowledge management in teams

Most design queries are becoming more complex and therefore different disciplines work on the same design. So besides the design process itself, multi-disciplinary design has to do with creating and sharing knowledge getting to understand what knowledge the other involved parties contribute. This could be a problem since not often people are aware of the knowledge they possess and how it can be valuable to others.

If multiple people are in a design process together it isn’t necessary to have the same knowledge, but it is very important to know whom and when to ask. To gain this knowledge, transferring of (tacit) knowledge between different parties in the design process is of great importance.

The main goal from a design process is to create new knowledge, often realised by sharing knowledge, and to come up with a new design for the question at hand. Therefore a knowledge creation process as described by von Krogh et al [2] is helpful in defining the steps to be taken by the team. According to them this process can be broken down to a number of stages:

1. Sharing tacit knowledge,
2. Creating a concept,
3. Justifying the concept,
4. Building a prototype,
5. Cross-levelling knowledge.

When these steps are taken the process is structured in a logical way and all parties can pull their weight in the process. So even though the design problem is new to some degree and it can be categorised as an ill-structured problem. The road to solving this can be structured [3].

This is where a visual communication tool could be very helpful. The tool can then help the different disciplines to use the same medium and, whilst still in the process of sharing knowledge, test the outcome of possible combinations and make decisions about the next steps. If the tool is flexible in its outset, it could cater for different purposes and be functional in different stages of the design process.

2.3.2 Optimisation

Optimisation of design is originally carried out with respect to one governing objective, for example, cost, weight, sustainability, buildability, etc. Or to put it another way, optimisation is done via a function which represents the measure of performance, and independent variables spanning the design space [4]

A typical building design involves a wide range of disparate disciplines – architecture, structures, building services, landscape designers, master planners, fire engineers, etc.- working together, although sequentially, for a relatively short period on the design of a building [5]. All or at least most of these disciplines are trained and educated discipline-wise, meaning they have little or insufficient knowledge about the other domains. This leads to a rigid and large team unable to respond to new gained insight from the other parties and being merely performance driven to their own discipline. However when the design process is completed it is evaluated with respect to its performance over all areas.

A first step into the right direction came with the introduction of computer-aided design, allowing designers to quickly modify and analyse their designs. This made it possible to react upon the other parties without extensive extra analysis, enabling the designer to supplement intuition with computational tools in order to verify the validity of the new concepts. The next step is to have collaborating teams with experts from multiple disciplines working on the same project. These cross-functional teams are mandatory to develop multi-disciplinary products. The focus could then shift towards more economic driven design, leading to optimising the criteria (mostly cost, or aesthetics) with all disciplines involved.

The complex nature of building design is characterised as multi-parameter, multi-discipline and multi-objective. Therefore when designs become more complex and decentralised, it requires much effort from multi-disciplinary design teams. Multi-disciplinary design optimisation allows the design teams to incorporate all the relevant disciplines simultaneously, considering the interaction between the disciplines. This way they can find an optimum of all disciplines together instead of sequentially optimised disciplines added together. Although this leads to a better global optimum of the problem it does introduce a higher, non linear, complexity to the solution with many local optima.

The interaction between different disciplines is the key factor here, but it is hardly possible to quantify the influence or importance of each discipline separately.

A well 'integrated' design cannot be achieved by concentrating on the 'parts', since each part may pull the project in a direction that might seem regressive to the other 'parts' [5]. Where a global optimum solution with all constraints set to their combined maximum might lead to very low values compared to their individual maximum. This is because this approach focuses on maximizing the joint probability of the objective with all constraints being satisfied, instead of individual optima.

This is where dashboard technology can prove itself very useful in visualising and communicating the different possibilities and 'objectively' scaling the total score of the alternatives.

2.4 Visualisation of data

To be able to compare alternatives and really start to understand what influence is caused by which choice it is preferable to have many options available. Manually working through all options is a very tedious and time-consuming job, hence parametric design can be a helpful tool in rapidly creating multiple adaptations of the same basic idea. These alternatives can then be used to display graphically and compare the differences.

2.4.1 Parametric and associative design

Parametric design and optimisation are becoming common terms in the current building atmosphere. One of the reasons being the extra computer capacity and improved computational skills; these are leading to new ideas and new drivers for design.

Parametric and associative design is the process of designing in an environment where changes are effortless, replacing singularity with multiplicity in the design process. Parametric and associative design is performed with the aid of parametric models, a visual computer representation of a design constructed with entities, often geometrical, that have properties (or relations) that are fixed and others that can vary. The user-variable attributes are called parameters and the fixed attributes are called constraints. The parametric model can provide a consistency in design logic via the prebuilt rules and relations, called associations. This facilitates the different parties involved with the understanding of what can or will change. The basic sophisticated start idea will still carry on even though changes in the parameters are made, and at the same time the outcome is displayed in the CAD program to provide an image of the possible outcome.

2.4.2 Dashboards

Visual means are very important to the qualitative and quantitative aspect of designing; they make it possible for the non-expert people to 'understand/see' what the idea is. Communicating alternatives, optima or why one favours a solution becomes very vivid and realistic when you can 'see' and have discussions about them. The visual representation of different solutions can be provided as a means for capturing and enabling designer insights. This could allow the designer to make decisions before, during or after analysis or optimisation, in order to effectively steer the solution process.

The graphical or visual representation could lead to a better solution in less time by exploiting the knowledge and expertise of the expert. Complex design could then be broken down to tipping points, black swans and interrelations that stand out or just provide convincing pretty pictures.

Dashboards are excellent tools for summarizing data on one single screen (website) and allowing users to comprehend what is otherwise information overload. By making the dashboard interactive and combine the strength of parametric and dashboard technology, this will result into a real-time data visualisation, delivering answers on the spot and combine designing with optimising.

A dashboard displaying the 'actionable' information would be highly suitable for situations where graphs are used to find interrelations and optima as shown in Figure 1.

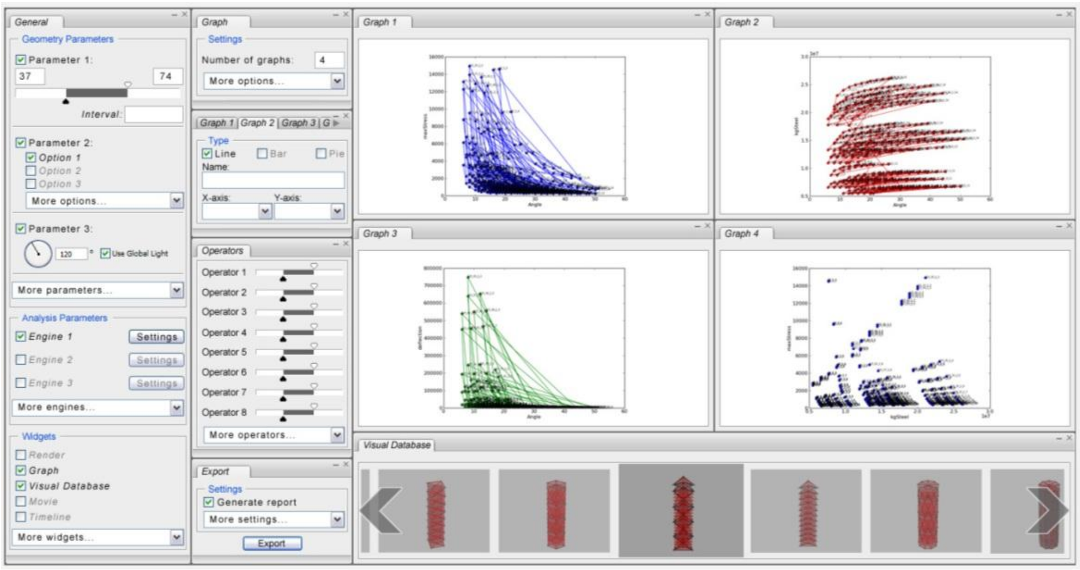

Figure 1: Possible layout for a dashboard with multiple parameters

Dashboards can display the real-time information with only the most important graphs or gauges and some additional text. Besides real-time information they are extremely suited to compare information, dates from the past compared with current values, or just a comparison between multiple alternatives. They can provide the business intelligence digging deep into the data without interrupting the workflow, performing bidirectional communication with the data-sources.

The efficient way of presenting information can then be used to gain insight in the matter. Problem areas and opportunities are highlighted, encouraging the user to take action; this is the primary job of the dashboard. This action could be taken by either clicking on the graphs for drilling down and entering new levels, or navigating to the underlying information within the system itself, but this time knowing where and what to look for.

3. Dashboard portal as multi-disciplinary design optimiser

3.1 Workflow

It is in the forming of a concept that computers can be of great help. Once the restraints are explored and the first ideas are created, a computer can easily generate alternatives based on the presumptions/relations that have been set. This doesn't necessarily lead to a concrete concept, but still allows for freedom in changing the parametric model should an important insight come to light. It is also possible to use a computer to explore certain aspects of an initial idea, and later combine these in the design by hand.

Justification of the concept is also an important process in which a computer can be of help. Once the geometry of many conceptual alternatives has been generated (1), these can be analysed with different discipline specific add-on modules. These alternatives and their results should then be stored in a database and a selection can be made preserving the most favourable ones (2). To do this an algorithm, filtering and testing the alternatives and displaying the solutions, should be written. Displaying these options in an easy comprehensible way is the next step (3), being able to tweak the boundaries, parameters, that are set, and present ones preferences on the dashboard.

Breaking it down into steps, the tool will consist of three separate phase elements

1. Generating the alternatives, with the use of parametric software. Here you can use grasshopper to create a parametric building, in which you are able to change several pre-set parameters to generate multiple possibilities, all leading to a different outcome, satisfying the geometric constraints. Within the model link the geometry with analysis software and calculate results for the other disciplines.

2. The database containing all this data will be used to feed this to the dashboard to be presented as useful information. A selection can be made via search criteria, specifying the constraints to apply and filter the obsolete.

3. The selection from the database that is then presented on the dashboard, acts a visual interpretation, leading to a relation between the influence of the constraints and the outcome, enabling the user to analyse and interpret the results to their liking.

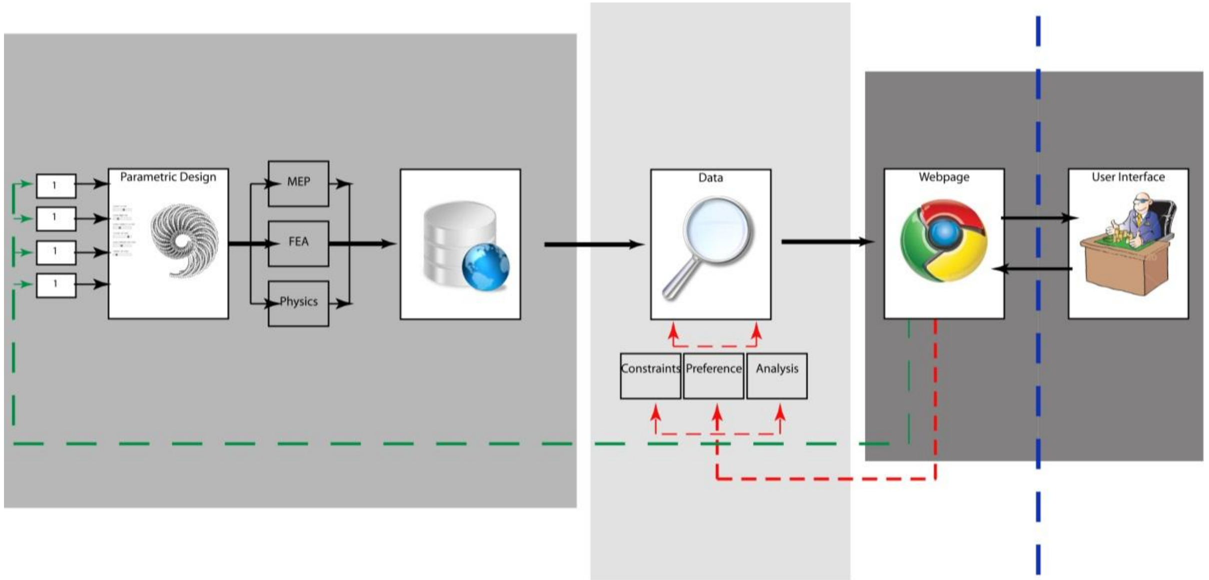

Figure 3: Design Scheme used for the MDO approach

3.2 Dashboard layout and possibilities

Depending on personal preference and discipline, different types of dashboards can be used either focused on visualisations, numeric values or any combination. The dashboard is set up in such a fashion that it functions as a coarse grained filter. Every step the decisions made will lead to more insight in the data.

The idea is to build a modular tool, in which new modules can be added or changed. All modules will work separately but need to be joined on a framework. This framework will function as the main tool translating the separate pieces into useful data and pushing it from on level to the next.

3.2.1 Widgets

The operators are the most influential part of the dashboard. They function as the interaction between the stored data and the output on the dashboard. The optimisation of the project and the success of the dashboard rely on these operators. To prevent endless amounts of operators clogging the dashboard, a widget system can be of great help.

This system is introduced to have the individual user decide which data he would like to look for and how he wants this to be displayed. The widget system is set up in a modular system any type of widget can be added later on. The user is free to choose which and how many widgets he wants and thereby how he wants to visualise the data on the dashboard.

Where the widgets determine the layout of the dashboard, the operators determine the content of the dashboard. All the data is in the database, the layout of the dashboard chosen, searching through the data and selecting the data you need is the next step.

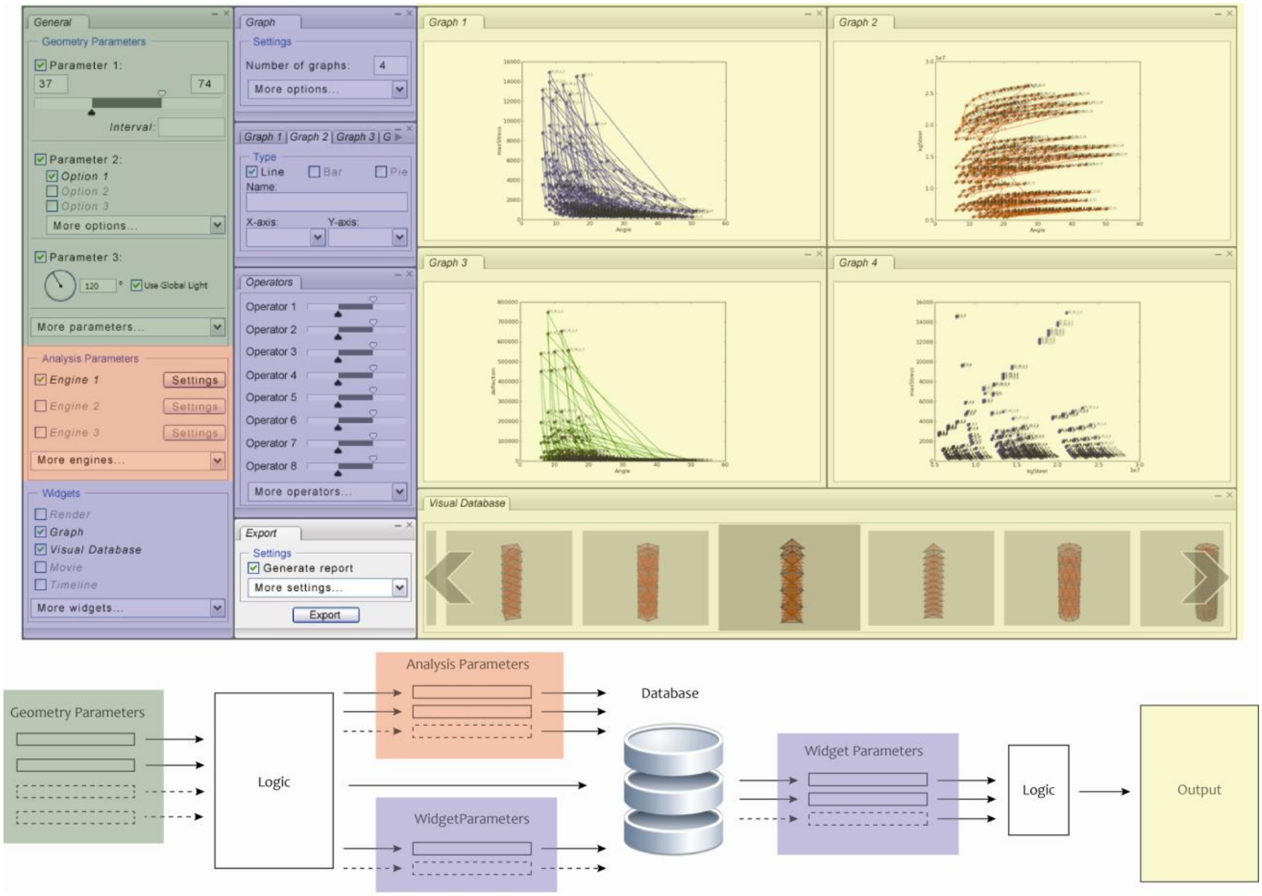

Figure 4: Design Scheme of filtering data with the help of widgets and operators

3.2.2 Browsing through the data

The operators can be seen as the input and outcome from the parametric models, their analysis and added fields of interest. They display which variables are chosen to optimise and show the values of the minimum and maximum value derived by the data from the database. Data then becomes information and the information becomes knowledge.

Each time one of these filters is applied a smaller set of 'results' are presented in the layout selected via the widgets. Eventually, after all filters are applied, all options displayed on the dashboard satisfy the criteria. Subsequently there are a few possibilities, one is to activate the "Export" widget and export the results into an automated report, which could then be handed to the client, or be discussed within the group. Another option is to save the settings but change the dashboard layout and dig deeper into the resulting results. Now new widgets can be selected and this provides the option to look at the chosen set with a different perspective. By doing this it is possible to maintain and work with a very large dataset but bring it down to a manageable amount of data.

4. Discussion

To test this 'conceptual' tool a mock up has been built using different systems mainly coded in *Python*. The MVC framework that was used for the implementation is *Django.* The parametric part was developed for *Rhinoceros*, combined with *Grasshopper* and *Salamander (Arup software).*

The dashboard tool, in a very conceptual state, proved to be highly effective in searching through large datasets (in this case about 3000 options). It was possible to see relations between the different parameters that could easily be overlooked.

A very important point to note is that it is a decision supporting tool and by no means does away with the need for people to design a project, transform it to a parametric model and then with this tool verify the results with their own knowledge and expectations.

5. Conclusions

Multi-parameter and multi-discipline solutions are often hard to reach in an ambience of mutual understanding. Nowadays the structure of the process in building design can have a high impact on the relations between the different parties, forcing people away from their own specialisations into taking on a more multi-disciplinary designer role.

The advantage of generating every possibility available is that we enlarge our knowledge about a specific design, which can then be coupled with the idea of "what we do is based on what we know" and enables us to make thoroughly considered choices. Generating every alternative available is also very useful in exploring options that might not have come to mind if only 'sensible' options were to be considered based on hand calculations. A drawback however is that this technique requires a lot of computational power and still a lot of 'parametric' technology to enable this must be build.

This way of analysing large datasets will make the design process more tangible, and once this is understood better it will be easier to convince people that the outcome is the highest optimum according to the set requirements This culminates in beautiful projects that incorporate and synthesise the various specialities involved, both in process as well as in the final result.

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