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PARAMETRIC MODELLING AND DESIGN PROCESSES

Exploring synthesis and evaluation using a Function-Behaviour-Structure perspective

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Abstract. In an attempt to extend our understanding of the design process in the context of computational parametric design tools, this paper explores the relationship between and interaction of synthesis and evaluation. In establishing the importance of their coupling in parametric design the paper then explores its consequence on the design process relative to existing models of designing. A tension between designing as planning, search and exploration in parametric design is highlighted together with a conceptual framework, which draws from a situated Function-Behaviour-Structure model of design. The purpose of the framework is to facilitate these different modes of designing and is targeted at the use of parametric tools.

Keywords. Design processes; parametric design; evaluation; synthesis, design models.

1. Introduction

Designing in the context of computational parametric tools is a nascent area of design research. The complexity and power of parametric design software, such as Digital Project, Generative Components and Grasshopper, and their impact on the design process remains relatively unexplored. Its complexity lie in the need to describe the (often as yet unformulated) design artefact during the early design phases by assigning parameters, identifying their relationships to each other, and defining the criteria by which the design will be evaluated. The designer must consider any potential design solution not as a static artifact, but rather as a flexible system that has varying levels of adaptability, together with the system's capacity to generate divergent alternatives and evaluate them. The power of parametric design software thereby lies in its generative and performative capacities.

However the ability to generate and evaluate alternative design solutions reveals a tension in designing with parametric tools between 'designing as planning', 'designing as search' and 'designing as exploration'. On the one hand, the capacity to generate solutions introduces the requirement to *plan* and to *search* for appropriate solutions whilst, on the other hand, the state space of possible designs to be searched is not necessarily available at the outset of the design process and designing as *exploration* will therefore involve not specifying or even being able to specify all that needs to be known to produce a design (Gero 1998).

Here designing involves finding the behaviours, the possible structures and /or the means of achieving them – yet these are only poorly known at the outset (Logan and Smithers, 1993; Gero, 1994). Consequently, the use of parametric tools in the schematic phase of architectural building design is still quite limited, and in the conceptual design phase even more so. In extending our understanding of the design process in the context of computational parametric design tools, this paper shall first presents case studies of parametric designing, before then considering these examples relative to the interaction between synthesis and evaluation. In establishing the importance of their coupling in parametric design the paper then explores its consequence on the design process relative to existing models of designing. A tension between designing as planning, search and as exploration in parametric design is highlighted together with a conceptual framework, which draws from a situated Function-Behaviour-Structure model of design, and aims to facilitate these modes of designing in a method targeted at the use of parametric tools. The paper closes with a discussion of future work.

2. Parametric methods and processes in architectural design

In the use of parametric design tools, the schematic phase is important, with architects and engineers using planning, search and exploration methods to create alternative architectural solutions. Potential design alternatives are generated and evaluated in order to obtain the most promising design. A parametric approach to designing includes using the computer not only for visualisation, analysis and evaluation, but also for the rapid generation of computable design representations describing alternatives. The following case studies outline some example design workflows that, as we shall argue, emphasise the interplay between synthesis and evaluation.

2.1 EXAMPLE DESIGN CASES

The introduction of analysis software into the design workflow has widened the scope for understanding and assessing design aspects visually during the design process. This capability allows greater confidence in design development by increasing levels of certainty that a design will perform as intended by the designer.

2.1.1 Constructability

The evaluation of constructability is an emerging approach to the use of computation and is becoming an increasingly critical component of architects using advanced technologies during the design process. Gehry Partner's computational methodologies, specifically the concept of surface rationalisation (Shelden 2002), is one such example. The manufacturing limits can be encoded as algorithms and the search for a rational solution becomes automated. Subsequently, in cases of, e.g., façade curvature, the curvature of the skin can be assessed for constructability and iteratively rationalised as required. Hence, a direct connection between the manufacturers' evaluation criteria is formed with the digital model providing a means for the designer to interact and iteratively develop the forms until they comply.

2.1.2 Structure

Sasaki (2008) describes the process of shape evolution on a series of roof structures using the sensitivity analysis method; an evolutionary process involving the adjustment of height values of a given roof mesh with continual structural assessment to generate a minimal stress solution. The form enters into a continual negotiation between the 'ideal' architectural shape and the structural requirements to minimise and rationalise the roof. Critically, during the schematic design phase , both architectural and structural evaluation criterion are present.

3. Coupling synthesis and evaluation

The above examples reveal an interesting but core aspect of not only parametric design but design in general: the coupling of synthesis and evaluation and the benefits of coupling the evaluation criteria into the synthesis stage. For architectural design, the importance of evaluation criteria in the setup of the parametric model becomes more complex. The logical ordered processes of well documented and often cited design methods break down in favour of a more flexible model more akin to descriptions of designing based on the co-evolution of problem and solution spaces (Maher et al 1996).

What distinguishes designing in the context of parametric tools is the reliance on the interaction between the synthesis and evaluation. That is, the representation (and re-representation) of the design solution and the continual development of sets of evaluation criteria. The examples presented in §2 illustrates the early and recurrent coupling of the design representation and evaluation criteria and how this diffuses distinctions between typical stages of the design process. To explore this aspect further the following section shall discuss some well known models of designing.

4. Models of designing

The historical approach of understanding design processes have spawned from formal methods of logic, mathematics and operations research into models of designing (Alexander, 1964; Mitchell, 1977). The introduction of artificial intelligence concepts are an attempt to expand those approaches (Coyne et al, 1990), and now tools from cognitive science are providing more insight into aspects of human designing (Lawson, 1990; Cross, Christiaans and Dorst, 1996). Gero defines designing as a sequence of acts which may be described through processes (Gero 1998). The act of designing has therefore been modelled at various levels of abstraction by researchers in the design methods community. This section explores two well known models and discusses them in relation to parametric design.

4.1 ASIMOV'S MODEL

Perhaps the earliest of the widely accepted models of designing is described by Asimov (1962) who divided all designing processes into three classes: Analysis, Synthesis and Evaluation. Asimov and others ordered these as processes as shown in Figure 1.

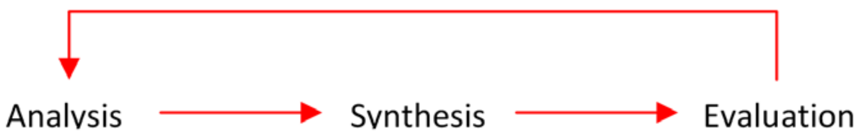

Figure 1. The analysis, synthesis, evaluation model, source Gero (1998).

This model has been used to explain what it is that designers do when they are designing. The processes involved in this view of designing use a terminology which is no longer widely accepted. The term "analysis" has been replaced by "formulation" or similar terms and "analysis" is now used to refer to a precursor of evaluation.

4.2 FUNCTION-BEHAVIOUR-STRUCTURE MODEL

There have been numerous models developed related to Asimov's original description of designing, as well as a number of formal theories and methods. However one model that distinguishes itself is the function–behaviour–structure (F–B–S) model as it abstracts the processes of designing even further (Gero, 1990). The schema represents design knowledge in the form of the three abstract notions of function (F), behaviour (B) and structure (S) of a design object. These three notions are defined as follows:

- The function (F) of a design object is defined as its teleology.
- The behaviour (B) of a design object is defined as the attributes that are derived or expected from its structure.
- The structure (S) of a design object is defined as its elements and their relationships.

The F–B–S model, shown in Figure 2, provides a framework for eight processes, namely:

1. formulation: F → Be	5. documentation: S → D
2. synthesis: Be → S via Bs	6. reformulation - 1: S → S'
3. analysis: S → Bs	7. reformulation - 2: S → Be
4. evaluation: Bs↔ Be	8. reformulation - 3: S → F via Be

Processes 1 through 5 match with those that appear in earlier models such as the Asimov model, where behaviour is bifurcated into expected behaviour, Be, and behaviour derived from structure or actual behaviour, Bs. The class of processes represented by processes 6 through 8, described in detail in §5.1, although recognised, have not been well articulated in many models, partly because they have not been well understood (Gero 1998).

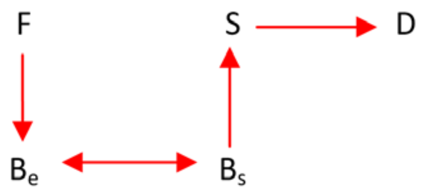

Figure 2. F-B-S model, source Gero (1998).

4.3 MODELS OF DESIGNING AND PARAMETRIC DESIGN

Whilst these approaches were promising, claiming the ability to handle complex design scenarios through systems logic and rationality, the failures of these methods are well documented due to their inability to successfully operate when it comes to the realities of designing. To highlight the constraints of these models relative to parametric design tools it is useful to distinguish three modes of designing: designing as planning, designing as search, and designing as exploration. Whilst it is understood that there are differing definitions for modes of designing, this particular classification demonstrates succinctly a range of design modes which associate well with parametric design processes.

4.3.1 Designing as Planning

With its conceptions rooted in artificial intelligence, planning is understood as the determination of a sequence of actions required to progress from a starting state to a goal state. Planning has been used to model design (Gero 1987). Implicit in its framework is a bounded state space which limits the consideration as a model for designing to detail or routine designing. Parametric design software has been idealised as the solution to rationalising design, however the time invested in the planning and construction of these systems cannot keep up with the changing pace of the design workflow (Burry 2003). Parametric systems require an investment into the planning and construction of the design logic or rules, hence there is considerable development of the 'formulation' stage of the design process which results in the ability to generate solutions.

4.3.2 Designing as Search

Search as a computational process for designing capitalises on a history of artificial intelligence techniques (Coyne et al, 1990). The limiting factor of search for design is in the basic and often implicit assumption that the state space of all possible designs is defined a *priori* and is bounded. In the use of parametric design tools, the searchable state space can be mapped onto the parametric system setup and the criteria used to evaluate the state map onto behaviours, hence corresponding to the F-B-S model.

The designing process focuses on means of traversing this state space to locate either an appropriate or the most appropriate solution. The advantages of modelling designing as search include the ability to search spaces described symbolically rather than only numerically, referencing a core principle of parametric design, i.e. the ability to abstract design into a symbolic representation of nodes and relationships allowing it to be instantiated into new situations (Woodbury, 2010). In this model of designing, there is a focus on both the search methods and the relevant criteria to be used. However, the assumption that the space is defined prior to searching relegates this model to detail or routine designing (Gero 1998).

4.3.3 Designing as Exploration

Designing as exploration recognises that necessary information required to construct a state space of possible designs is not always available at the outset of the design process. In this model, designing involves an exploration of behaviours, possible structures and/or the means of achieving them (Logan and Smithers, 1993; Gero, 1994).

Designing as exploration provides another dimension in the use of parametric design tools that relates to the idea of non-routine designing: not specifying or even being able to specify at the outset all that needs to be known to produce a design. For example, parametric designers often do not know at the outset the limitations of a system until it is constructed and tested. Designing has long been recognised as belonging to the class of problems called "wicked" problems (Rittel and Webber, 1973), exploration is an attempt to deal with this issue and is an essential part of the process when designing with parametric tools.

4.4 INADEQUACIES OF DESIGN MODELS

As early as 1970, the difficulties of systematic procedures, defined by models of designing, to account for the design situation was acknowledged. Jones claims that "losing control of the design situation once one is committed to a systematic procedure, which seems to fit the problem less and less as designing proceeds" (Jones 1970). Researchers have since highlighted the inability of these models to address a range of phenomenon significant to the design process, including among others the concepts of situatedness and constructive memory. Situatedness (Clancey, 1997), in contrast to the static world inherent in a large extent of the artificial intelligence view of knowledge, has its major concern of locating everything in a context. Hence decisions that are taken are a function of both the situation and the way the situation is constructed or interpreted. The notion of constructive memory fits well with the concept of situatedness, with the understanding that memory is constructed in response to any demand on that experience (Rosenfield, 1988). Thus the memory of an experience may be a function of the situation in which the question, which provokes the construction of that memory, is asked (Gero, 1998).

5. Toward a framework for designing with parametric tools

The ability of parametric tools to generate alternatives and evaluate their suitability can be characterised by the three forms of designing described in §4.3 i.e., by planning, search, exploration or any combination of the three. Understanding the design workflow as a constant flux between formulation, synthesis, analysis and evaluation represents the typical workflow of parametric designing.

What this paper emphasises is that these typical processes that underpin parametric design place greater attention on the analysis method and how it is defined relative to expected behaviour. Setting up a parametric rig forces not only the synthesis of expected behaviour into structure , but also defines how any potential design solution will be evaluated, i.e., how its actual behaviour will perform. These case studies demonstrate that the coupling of synthesis and evaluation tend to limit the design workflow to *Designing as Search* and hence restrict the effectiveness of parametric tools, such as Generative Components and Grasshopper in helping designers solve non-routine design problems. From this perspective, Gero's *situated* F-B-S model has much to offer in developing an understanding of and augmenting the processes of parametric designing.

5.1 THE SITUATED F-B-S MODEL AND PARAMETRIC DESIGNING

The F-B-S model provides a framework which remains unchanged by the introduction of situatedness into designing. Gero illustrates that the most obvious and most interesting place to locate situatedness is in the reformulation phase. What can be inferred here is the significance of evaluation in any reformulation process, both in terms of the criteria utilised and the outcome of evaluation. Of the eight design processes listed earlier in §4.2 three were concerned with reformulation (labelled processes 6, 7 and 8) and have direct implications in parametric designing.

The first of these, reformulation – 1, occurs when the structure state space is modified. Here the role of the situation is to provide opportunities to source new structure variables, Figure 6a. In the use of parametric design tools, a typical process resulting from evaluation is the use of induction. However, this will be dependent on both the perception of what can be the source in induction and/or whether the source is defined by any initial evaluation criteria.

Design process 7, reformulation – 2, figure 6b, involves redefining what expected behaviours are proposed as a result of evaluation since they bring with them their own ancillary behaviours. Alternately, new behaviours may be derived from evaluation methods. Existing behaviours may be dropped if they are shown to play no discriminatory role.

Design process 8, reformulation – 3, involves redefining what the functions are to be as a consequence of evaluation, Figure 6c. Redefining functions for an artefact has the potential to change the expected behaviours as well as the resulting structure. New functions are derived from the situation.

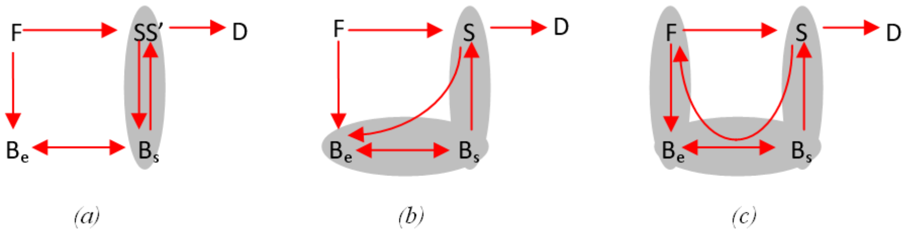

Figure 3. (a) Transforming S to S' is based on the situation (b) Transforming the expected behaviours is a function of the situation which exists in terms of the structure synthesised up to this point and the discriminatory capacities of the existing behaviours, (c) Redefining the functions or purposes of the artefact is dependent on the situation.

The situated F–B–S model provides a conceptual framework for parametric designing which has the capacity to explain as well as describe. That is, the model can be used to develop methods which support parametric designers whilst they are working at both the early and later stages of designing by providing a means by which to direct activities and on which to build and refine evaluation techniques.

6. Discussion

This paper claims that in designing with computational parametric tools and establishing the parametric system, or 'rig', during the early fuzzy front end that the tensions between 'designing as planning', 'designing as search' and 'designing as exploration' is produced due to the need to assign not only parameters and relationships but also the need to define some basis for evaluation during the formulation phase. It is furthermore essential that evaluation criteria are understood and can be developed throughout each phase of designing, i.e., during reformulation in conjunction with formulation, synthesis, and analysis, relative to the design's function, behaviour and structure.

In developing the conceptual framework in future stages of this research, three further questions are raised: (1) what evaluation techniques are available to designers, (2) how can evaluation criteria be imputed throughout the development of the parametric system, and (3) what sets of quantitative and qualitative evaluation criteria can be identified and amalgamated to support the three types of reformulation processes identified? These topics will be considered in further studies with the overall goal being, if evaluation criteria can be understood computationally as an integral part of the reformulation processes of design, there is an opportunity to achieve some of the original aims of computational design systems, precisely the ability to generate innovative and advanced non-routine design solutions.

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