Frameworks for Practical Parametric Design in Architecture

Roly Hudson
The University of Bath
rh243@bath.ac.uk

Abstract. This paper is aimed at the development of a theoretical framework that addresses practical applications of parametric design that have been observed in architectural practice. Existing theoretical frameworks are not aimed at addressing this specific use of parametric tools but do provide a set of key themes. Based on these themes a simplified structure is presented here as a means for tackling architectural design development tasks. This is then used in order to examine a case study; the parametric design tasks involved in the design development and documentation of the new Lansdowne Road Stadium in Dublin Ireland. This project was undertaken in collaboration with HOK Sport Architects. The findings from this examination are used to discuss proposals and implications for a practical framework for parametric design in architecture.

Keywords: Parametric; Practice; Theory; Case Study; Lansdowne Road Stadium.

Introduction

The potential benefits of parametric tools in practice have been acclaimed while simultaneously acknowledged as increasing in complexity and time required for the design task (Aish and Woodbury 2005). A survey of recent papers (from conferences such as this) dealing with completed projects demonstrates the increasing popularity of parametric tools in architectural practice. These papers also provide evidence of the potential of parametric tools through descriptions of the process that led to the final product. However the means for arriving at that final process is often not explored, instead descriptions given focus on detailed stages of design and documentation. Published theory concerned with architectural parametric design tasks typically focuses on conceptual design tasks. While observations from practice show that parametric tools are typically being applied to design development problems rather than the early conceptual formulation of the design.

Other design disciplines focusing on application of parametric design to non architectural design tasks provide detailed descriptions of problem solving methodology. Typically these are aimed at problems from a mechanical engineering origin where the goals and means are well defined at the outset. Architectural problems often consist of unknown means and goals and can be described as ill defined tasks or even wicked problems. (Rowe 1987)

While design theories from architecture or other disciplines do not directly relate with observed practical parametric design it is argued that they can form a basis for a theoretical framework for such a task. The aim of this paper is to provide a brief description of a set of key recurring theoretical elements relating
to parametric design problem solving. This simplified framework is then used to examine the case study. Where the abstract theory and case study correspond practical examples provide illustration. Where there is no correspondence proposals are made for developing existing theory to apply to parametric architectural design development tasks.

Case Study Description

Lansdowne Road site was highly costrained by boundary conditions (figure 1). These dictated rights-to-light planning restrictions and horizontal expansion limits defining a possible volume for development. Internally 50,000 seats and a natural grass pitch were required.

The key consideration for the architects was to retain overall geometric control of the stadium. This was achieved by using a combined model, the core component of which was a spreadsheet containing all numeric parameters. This was accessed by a GC script file that described all geometric rules and relationships for constructing the stadium geometry. This package could then be issued to the engineers. The underlying geometric construction method used an array of similar curved sections arranged radially around the building footprint (figure 2). Variation in these sections was controlled by a set of control curves that mapped the horizontal or vertical change of each of the points defining the section. Each sectional curve defined the centre line key structural roof members.

The structural model developed by the engineers was also parametric, and it used the architectural parametric model as a starting point. Real constraints could be assigned as parameters and used to ensure that the resulting structure is compliant with these rules by definition. Through an interface using Microsoft’s Visual C# programming language. An export routine was written in C# and embedded within the GC environment which created a data file for the structural engineering analysis software.
The initial geometric system described above defined centerlines corresponding with the roof structure. For the cladding design solution this definition could be subdivided to define centre lines of a secondary structure to support the cladding panels. A series of initial panelisation studies indicated areas of geometry requiring manipulation to avoid high surface curvature, which would make cladding detailing problematic, and where the local surface gradient was low, which could cause drainage issues. The cladding system consists of a folded polycarbonate profile panel of equal width but varying length, fixed to a standardised bracket system with two axes of rotational freedom (figure 3). These axes of freedom allow the planar panels to follow the stadium geometry. Panels were detailed with a flexible gasket to allow tolerance as they overlapped the panel below. A third axis of rotation allowing panels to be rotated to any position between 0° (closed) and 90° (open) was defined along the long axis of panels. Air intake and exhaust requirements for air handling units could gradually be incorporated into the façade by feathering the rotational angles of the surrounding panels. Data sheets of all three rotation angles and panel length were produced for construction documentation. For further detail descriptions of this project see Shepherd and Hudson 2007.

Key themes from theory

Knowledge

The role of domain or task knowledge (experience or heuristics) is a theme that extends across much of the literature on problem solving and parametric design. Design itself has been defined as a “knowledge based problem solving activity” (Chandraskaran 1990). While some practice based observations have found that design proceeds in a series of fragmented heuristic episodes (Rowe 1987). Newell Shaw and Simon (1957) define heuristic as “any principle procedure or other device or other device contributes to the reduction in the search for a satisfactory solution”.

More specifically the ways in which knowledge can improve efficiency in design have been identified (Motta and Zdrahal 1996). Firstly knowledge can be used to reduce the complexity of problems by ruling out ranges of possible solutions. Secondly knowledge of a task can result in identification of key parameters (those having greatest effect on design) from the multiple parameters which may exist. Lastly key parameters have valid ranges these can also be specified through knowledge of the task type. The starting point in parametric problems will also be influenced by knowledge. The starting state is defined either by choice of an existing solution or similar solution from a similar problem, or by specifying an initial set of parameters. Drawing analogy between the current problem and previous solutions in the designers memory is described as case based (Motta and Zdrahal 1996), case retrieval (Chandrasekaran 1990) or recall (Woodbury and Burrows 2006). The notion of recall has been related to problem analysis and selection of initial “prototype” (Gero 1990) (analytical descriptions of a problem) based on knowledge of a library of previous prototypes. This prototype is then adapted to suit the new problem based on knowledge of the new condition.

The prototype includes descriptions of relational,
qualitative, computational knowledge and context knowledge.

Once a design has been evaluated it may or may not satisfy constraints and requirements. Through knowledge of the task the designer must either select to try and improve the design or reformulate the problem. If the design is to be improved a method or operator (Motta and Zdrahal 1996) must be selected and applied in order to fix a design so that it does satisfy some constraints. Choice of method or operator is determined by knowledge of the behaviour of the problem. If reformulation is selected (this is common for architectural problems) the analytical stage of the design must be revisited and parameters and constraints adjusted.

The role of knowledge reaches deeply into aspects of parametric design problems. In order to tackle more detailed aspects of work on parametric design it is useful to break design problems into three stages; analysis, synthesis and evaluation. This model of design is discussed in detail by Lawson (2006) where the interdependency between the three stages and iterative shifting between them is stressed.

**Analysis**

Gero’s (1990) “prototypes” are analytical descriptions of a problem or design task detailing function, behaviour and structure. Functions are a set of requirements that must be transformed into a design. Examples of some functions in the design of a window are the provision of daylight and views while controlling heat loss and noise transmission. Structure relates to the components or elements that will be transformed to produce the design in the case of the window example the glass, sealants, framing extrusions and hinges. Behaviour concerns the performance of the structure. In the case of window design behaviour would relate to properties such as light and thermal transmission. Providing this analytic description leads to an understanding of behavioural and structural variables or parameters. This type of problem description defines the problem specification (Motta and Zdrahal 1996). This consists of parameters, value ranges, constraints, requirements, preferences, and global cost function. Valid designs are described as a combination (or set of relationships) of these.

**Synthesis + Evaluation**

One broad class of methods for moving towards solutions given the specification of a problem is “propose critique and modify” (PCM) (Chandrasekaran 1990). Within the framework described by Chandrasekaran methods in this class are either based on decomposition solution re-composition (DSR), case retrieval or constraint satisfaction. Particular emphasis is given to the DSR process. Once a proposal is established it is verified to ensure satisfaction of functional requirements. The proposal is then critiqued and failures located. Based on the failures the proposal is modified which involves changes to (or adding and removing) requirements, parameters, parameter ranges or constraints. In this way the problem definition can be made more complete.

Motta and Zdrahal (1996) propose a design task structure which fits within the PCM model. This structure involves a set of generic tasks which begin with selection of a starting design. Following this a method for modifying the design is chosen. The choice depends on the completeness of the design and the particular current focus (what specific aspect of design is being addressed). The focus determines the choice of a specific operator selected from a set. This operator is applied and the design evaluated. The new design then forms the starting point for the next iteration.

**Decomposition**

While Decomposition Solution Re-composition is a specific method described by Chandrasekaran (1990) the idea of breaking problems into more manageable chunks is a common theme. Jigs or Patterns (Woodbury et al 2007) involve a reduction to the simplest possible description that represents the problem being tackled this implies abstraction and can also be considered a decomposition task. Each
jig is a generic solution to a well described problem. Rowe’s (1987) observations in practice found that the design process was unintentionally fragmented suggesting the decomposition task is something that takes place subconsciously. Simon (1996) suggests creative problem solving tasks follow hierarchical structures consisting of assemblies of sub-assemblies which in turn are assemblies of components.

**Representation**

In *The Sciences of The Artificial* Simon (1996) argues the need for consideration of type of problem representation and the need for multiple simultaneous representations. Kilian (2006) agrees but with particular emphasis for designers to reduce their dependency on geometric representation and engage with symbolic diagrams and programmatic descriptions. Woodbury + Burrows (2006) warn of the dangers of too much programmatic focus and argue for intentional and partial representations. By intentional Woodbury + Burrows mean that a representation is deliberately about other objects and partial because the representation is not a complete description of the design.

**Task Analysis with Case Study Examples**

The Lansdowne Road case study project is considered here as two connected tasks. These are described as envelope and cladding. The envelope task involved production of a model that defined geometric relationships and allowed the control of parameters influencing roof and facade geometry. The cladding task is the development of a cladding solution based on envelope geometry. Details from the development of the two tasks are used to illustrate aspects of the theoretical outline described above.

**Knowledge**

Experience from structural engineers of steel façade construction determined that façade geometry should be determined using tangential arcs. This reduced the range of possible types of primitive geometric elements for defining the geometry and also indicated what parameters were needed. The precise descriptions of relationships between geometric elements emerged through development and use of the model. Initially the geometric relationships were judged aesthetically to not deliver enough curvature to sections (figure 4). The relationships were reformulated and new a new parameter added to allow control of section curvature. The valid ranges of this new parameter were discovered through manipulation of the model.

For the envelope a set of starting parameters were roughly defined by a non-parametric model created by the architects as part of the initial design phase. This model was analysed and parameters extracted from this static state were used as the starting point. This was then iteratively refined, knowledge of methods for modification defining choice of operators gradually developed as familiarity with the model increased.

**Analysis**

The cladding task demonstrates how the analysis of problem can develop through experimentation. Initial studies demonstrated the interdependencies

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**Figure 4.**
Section curvature.
between geometry and cladding. Early models indicated rain water run off from panels and also areas of extreme curvature in the envelope geometry. Envelope geometry was modified to reduce concentrations of curvature and ensure rain water direction was not towards the pitch.

Other early cladding studies focused on the setting out methods for panels. These were evaluated on aesthetic and constructability criteria and preferred solution chosen. As manufacturers and sub contractors became involved knowledge of the cladding task structure (the choice of components increased). Panels had to be planar units this constraint led to the development of a standardised assembly of components (figure 3) (panels, support brackets and a double arm bracket) designed to tolerate the envelope curvature. The knowledge of behavior of the panels also developed as the task progressed. Each unit could rotate on its axis to provide ventilation to the spaces behind the process of defining rotation angles while controlling ventilation and preventing wind blown rain is described below.

**Synthesis and Evaluation**

The initial use of the envelope geometry model illustrates how the PCM method applies here. The starting point described above was iteratively refined using mainly a graphical verification (figure 5). Geometry was extracted at each loop of the process and verified by overlay in 2d as elevations and 3d via viewing in a modelling package. Numeric and graphic data and reporting roof fall angles was also produced. The results of this process resulted in the change in parameters until a satisfactory solution was found. The process of setting the rotational angles for panels on the façade described below provides a detailed example of this kind of synthesis and evaluation combining varied types of representation.

**Decomposition**

The case study is already defined as two broad but related tasks; modelling the envelope geometry and the cladding system. Effectively it would have been possible to have these in a combined model and this was the architect’s initial goal. As the project moved from the general task of defining the envelope geometry to developing the cladding system there was no need for a single model. Higher level geometry gradually converged on a final state and this formed the starting point for the cladding task. Both the envelope and cladding tasks were further sub-divided. The envelope consists of a series of nine subtasks that involve combining reference geometry with parameters stored in spreadsheets and fusing these two using programmatic scripts to produce the stadium geometry.

**Representation**

The models comprise of a varied range of representation the product of both main tasks is a set of geometric objects which are the result of a combining numeric data from excel with rules and relationships defined as a script with a visual two-dimensional graphical control mechanism. The process of setting the rotational angles on the façade provides an example of how representational methods were combined for synthesis and evaluation.

Cladding panels are designed to rotate along axis to provide air intake and exhaust to and from air handling units in located in specific areas on the façade. The final state they are fixed in position (figure
All panels can rotate along axis so units that need to be open can be blended with façade. However if panels not over plant areas are opening wind blown rain may enter building. This design problem is a trade off between three conflicting requirements; aesthetic requirement to blend open panels with surrounding panels, the need for openings on the façade sections over plant areas and the need to reduce façade openings over areas not housing plant.

An abstracted elevation was created in a spreadsheet each cell represented one panel on the façade (figure 7). A set of initial rotation values were defined. This was used to produce a 3D model that is aesthetically evaluated in a modelling package. The ventilating area is measured as the planar area between a panel and the one below, for each panel this value is written to a cell in the spreadsheet (figure 7). Wind blown rain is deemed only to be a problem if the bottom edge of one panel is vertically above the upper edge of the panel below (there is now overlap in elevation) this dimension is also written to cells in the spreadsheet (figure 7). Cells are given a conditional colour scale format to give a visual impression of the results of rotating each panel. In an iterative manner a solution was found through aesthetic evaluation and studying the colour scale mappings generated in the spreadsheet.

**Discussion**

Much of the reviewed literature suggests a very deliberate and formal process. This was not the case here. The analytic prototypes proposed by Gero (1990) are particularly deliberate where as in this study understanding of the functional, behavioural and structural aspects of the problem came about through working on the problem. This demonstrates that starting with an incomplete description of the problem is possible for this type of parametric design task. This seems to represent an acquisition of knowledge through what has been described as tinkering (Chandraskaran 1990) or exploration (Kilian 2006).

While this type of knowledge grew as the task
progressed other types of knowledge had significant impact on the solutions. Aesthetic knowledge or knowing what looks ‘right’ forced certain geometric relationships to be revised and additional parameters to be included. Knowledge of designing cladding systems from both architects and subcontractors informed the definition of new types of component assemblies. Knowledge of a larger scale of production the curved mullions and constraining the definition of these to arcs greatly reduced the geometric options and therefore reduced the range of possible solutions.

The level to which the process of decomposition solution re-composition applies is deep. Decomposition is either so inherently embedded in this type of task that it does not need mentioning or that it is so crucial, the process deserves more detailed description in relation to architectural design tasks. One aspect of a more detailed handling of decomposition is interdependencies between sub problems.

A highly simplified version of existing theory is presented, this has been used to examine an abridged version of a practical case study. Some of the initial conclusions demonstrate the potential for learning through theoretical reflection on a practical activity in architecture. However the simplification may lead to some misunderstanding and therefore demands a more detailed future study.

References

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