Design Synthesis and Shape Generation

1 Fit to the Designing for the 21st Century Initiative

This is a collaborative project spanning four disciplines: architecture, art and design, engineering and computing. The project will result in a common reference framework to inform the definition of future generations of computer aided design systems. The definition of design styles through shape grammars and, if successful, the computation of shapes that conform to a given style, will provide a concrete basis to stimulate new ways of design thinking and provide mechanisms to enable exploration of the consequences of these new ways of thinking.

The proposed work is internationally significant for two reasons.

1) If successful, the project will result in the world's first 3D shape grammar-based design system that can compute curvilinear shapes early in a design activity.
2) The work will result in a software prototype that can be used to demonstrate how future generations of computer aided design systems might augment the activity of designing.

This proposal builds upon the "Spatiality in Design" Phase 1 Designing for the 21st Century cluster (see Section 2) and is related to the "Embracing complexity in design" cluster.

2 Research Questions

Currently available computer aided design systems enable the creation of digital product definitions. Digital product definitions are created after the bulk of [shape] designing has been finished because their creation requires a detailed knowledge of the shape that is to be defined. They offer benefits by providing information for downstream processes such as analysis and manufacturing. Enhancing the act of designing itself requires understanding of how designers create design shapes in the first place [1] rather than how the results of their designing might be represented. To this end, this project will address the questions,

1) How do designers, across a range of disciplines, generate shapes? and
2) What similarities and differences in approach can be observed?

The generation of shapes that conform to particular styles, using shape computation tools based on the mathematics of shape grammars [2], has been demonstrated in a number of domains [3]. Researchers at the University of Leeds have built the world's first and only 3D shape grammar implementation for curvilinear shapes [4]. The basic elements of a shape grammar are shown in Figure 1. The box at the top of the figure shows an initial shape (that seeds the computation) and the two shape rules that are applied during the computation. The shapes at the bottom of the figure show a fragment of the network of shapes that can be computed from the initial shape through the application of the shape rules. The application of a shape rule involves two key steps. Firstly, the shape on the left-hand side of a rule must be identified in the shape from which a new shape is to be computed; this is referred to as "sub-shape detection". Secondly, the rule is applied by replacing the sub-shape from the left-hand side of the rule with the shape on the right-hand side of the rule. Once a sub-shape has been detected, the Leeds system can automatically apply a rule. However, the sub-shapes have to be identified manually because the automatic detection of sub-shapes is an open research question within the shape grammar community.

Significant efforts around the world are being directed towards creating analytic solutions to the sub-shape detection problem but progress is slow. At one of the "Spatiality in Design" Designing for the 21st Century cluster workshops, a presentation by Prof Hogg (CI) initiated an idea that sub-shape detection might be achieved through the application of computational approaches that have been established in the computer vision community. In contrast to analytic approaches, which search for sub-shapes in the mathematical representation of a shape, the method used in this research will look for sub-shapes in visual objects derived from a shape's mathematical representation. Subsequent discussions have led to the conclusion that this is an avenue worth exploring and which, if successful, will be groundbreaking. To this end, the research in this project will address the question,

3) Can computer vision techniques be used to resolve the sub-shape detection problem?

A key benefit of solving this problem is that it will become possible to compute large networks of shapes where more avenues of shape generation can be explored by designers. The size of the potential shape networks is vast. An example using the initial shape and rules from Figure 1 is given in Figure 2. At each step in the computation a designer would select the red shape from which new shapes would be computed. This leads to our final research question, namely

4) How might the ability to compute shapes enhance the act of designing itself?

3 Research Context

Shape and form are perhaps the most influential characteristics in the perception of design outputs such as sculpture, clothing, and consumer products. While various forms of 2D and 3D representations might be exploited in the shape generation process, sketching still forms a key technique for practitioners. Design sketches of shape and form are a particularly interesting category of visual representation because perception and interpretation are bound together with creation and evaluation in the shape sketching process. Fish [5] proposed that indeterminacy or vagueness in sketches exploits a capability of the human brain to make sense of incomplete information. He linked the physical mark-making act to cognitive mechanisms in his proposition that ambiguity may have a positive and deliberate function in design sketches. Sketching appears to have a direct relationship with seeing and 'selecting' in the emergence of design ideas through interpretative and transformational processes [6],[7].

Studies of cognitive processes in design [8] and shape cognition [9] have identified differences between design disciplines. Wang's studies, for example, found that shape perception tendencies between architects, industrial designers and graphic designers are different. Architects reveal an ability for identifying emergent shapes associated with transformational processes, whereas industrial designers had a superior ability for interpreting volumetric sub-shapes from two dimensional representations. Thus studies of sketching are viewed as potentially revealing for this project.

Over the last thirty years, efforts have been made in various disciplines, including art and design, architecture, and product design, to apply shape grammars to the analysis of styles and the generation of design families. Chau [4] provides a comprehensive diagram (reproduced in Figure 3) plotting existing applications along a timeline. These have demonstrated the viability of generative techniques to capture and reproduce styles in a range of design domains.

This project will explore the use of shape grammars to realize what Smyth and Wallace [10] refer to as a "form synthesis engine" within their model for the synthesis of aesthetic product form. Some progress has been made towards this goal. Tapia [11] demonstrated a robust implementation using straight lines in 2D and Chau et al [4] describe a 3D shape grammar implementation using both rectilinear and curvilinear elements. Jowers et al. [12] report success in 2D Bezier curves. A key problem in all of these systems lies in the detection of the sub-shapes to be used in the computation of new shapes. For example, in Chau's system, human intervention is needed to identify the sub-shapes from which further shapes are to be generated whilst Tapia's system solved the problem for 2D lines but in a way that cannot be extended to the 3D freeform curves that typify today's consumer product designs.

In parallel, researchers in the computer vision community have established a range of techniques that enable the identification of shapes in real-world situations: for example, the use of statistical learning algorithms for modeling and recognizing new object categories [13,14]. This project will explore the application of the techniques used for the recognition of visual objects to sub-shape detection in shape grammar-based design systems.

Coupling learning about how designers generate shapes with understanding of principles of shape computation will provide insights into potential interplays between shape computation technologies and design practices. Even without the experimental prototype, the project will enhance design creativity by enabling the construction of solution spaces - so enabling designers to explore them more extensively and systematically than is presently possible. If we are successful in applying the software prototype to a selection of design cases we will be able to demonstrate how shape computation systems can expand the design space that designers consider, so augmenting design activity and enhancing their creativity.

The designers who participate in the project will gain insights on how they generate shapes and this, through reflective practice, is likely to contribute to their personal professional development. For people who are not participants in the project, the outcomes of the research are, in the short term, likely to be of most interest to design educators since understanding of how designers generate shapes could be used to strengthen theoretical underpinnings of design pedagogy. If the investigations into the use of vision recognition techniques provide positive results then CAD system vendors are likely to be interested in the research results. In the longer term, when shape synthesis systems are available on the market, design practitioners will have access to new tools which, by highlighting possible avenues for shape generation, will enhance their creativity.

4 Research Methods

How do designers, across a range of disciplines, generate shapes?

This question will be posed in three discipline settings: art & industrial design, architecture and consumer product design. Design case studies, involving both professional and student designers, will be established in each discipline. For example, in product design, case studies will be drawn from undergraduate product design work that is mentored by experienced product designers. One case that will be delivered in 2006/07 will focus on the design of a martini glass using the brief from the 2006 Bombay Sapphire Designer Glass Competition (www.designerglasscompetition.com). It can be seen that the designs in Figure 4 all have styling that makes them identifiable as martini glasses (and which could be captured in a set of shape grammar rules) but each design also has its own individual characteristics. This aligns well with early work by Prats et al on the synthesis of wine glass shapes [15]. Some early shapes that he has computed are shown in Figure 5. In contrast, the art and design cases will be drawn from practitioners across a spectrum including sculpture, fashion and graphics. The architectural cases will study practitioners working on spatial aspects of complex projects.

The researchers will collect data from the designers that illustrates how shapes are generated and/or the results of shape generation activities. Precisely what data will be collected depends upon what is available and may well be discipline specific. Through analysis of this primary data, and interviews with the designers themselves, we will draw out answers to the question we are posing.

What similarities and differences in approach can be observed?

A short series of workshops will be held where the findings from the design cases in each discipline will be compared. The team has some experience in such comparisons through work that is scheduled for publication in early 2007 [16]. The workshops will include both researchers and designers who participated in the discipline based investigations. The goals of the workshops will be to compare and contrast findings on how designers in different domains generate shapes. We anticipate that the research on shape recognition mechanisms will provide tools to support these workshops.

Can computer vision techniques be used to resolve the sub-shape detection problem?

The feasibility of using computer vision technology in sub-shape detection will be explored. Early discussions have concluded that the approach is feasible but a number of possible problem areas need to be investigated. As a result, software-based experimentation will be used to address the following questions.

- Computer vision recognition systems detect visual objects. In this research shape presentations will be used as the visual objects. To what extent will the granularity of the shape presentation influence the precision with which sub-shapes can be detected?
- Shape representations are the computational construct to which rules are applied. Shape presentations are derived from shape representations. What relationships will be needed between a visual object and its shape representation to enable the application of shape rules?
- As shapes are detected and rules applied, the underlying shape representation is likely to become fragmented. If so, how can this problem be overcome?

This is the riskiest part of the project but, if successful, will have a groundbreaking significance in the shape grammar and design systems research communities. Our goal is to produce, in experimental prototype form, a software tool that includes the Leeds shape grammar system and a so-called "design shape recognizer" that is built upon visual recognition technology.

How might the ability to compute shapes enhance the act of designing itself?

For at least one design case per discipline, shape grammar rules will be extracted and codified in a form suitable for use by the experimental software prototype. (If the experimental prototype is not realised then we intend to use a combination of the existing Leeds software and paper-based studies.) These rules will then be used to compute a network of design shapes which will be compared with the source design case data. This will be an iterative process involving a shape grammar specialist, a representative of the design discipline concerned and, where possible, the designers who generated the source data. We anticipate that participation in this process by designers will facilitate reflective practice and make them aware of the regions of the design solution space to which their initial design activity related.

5 Project Management and Structure

This is a Multi-Fellowship Grant spanning three universities.

- **Leeds** (Dr Alison McKay (Principal Investigator), Dr Hau Hing Chau, Em Prof Alan de Pennington, Prof David Hogg): experience of shape computation and an interest in product design practice;
- **Open University** (Prof Christopher Earl, Dr Steven Garner): art and design-related practice or research, and expertise in shape computation;
- **Strathclyde** (Dr Scott Chase): architectural design-related practice or research, and an interest in shape computation.

References

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Visual Evidence

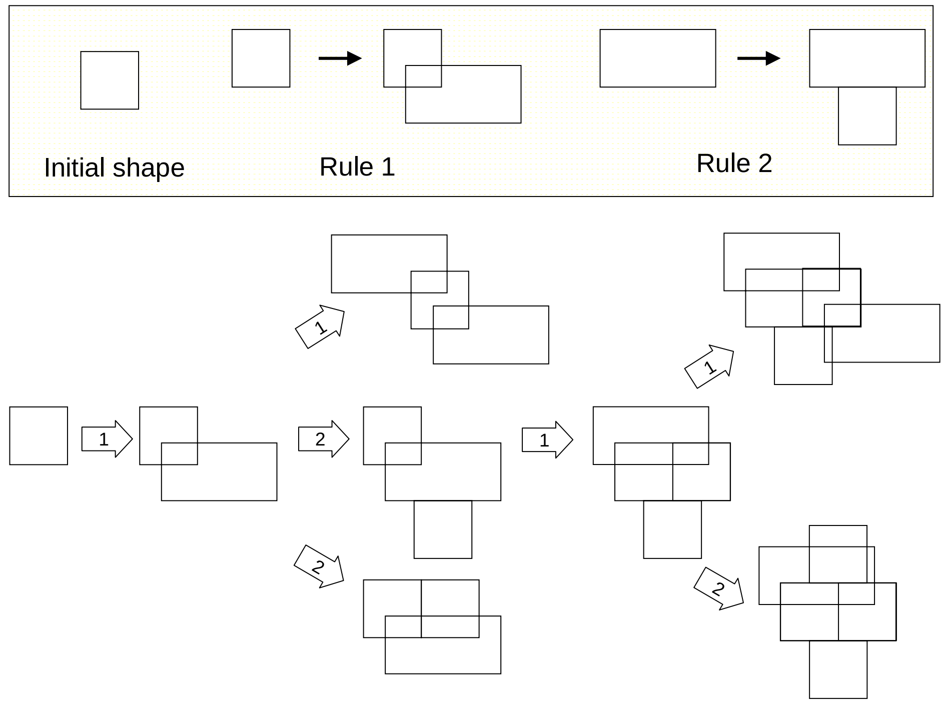

Figure 1: A simple two rule shape grammar

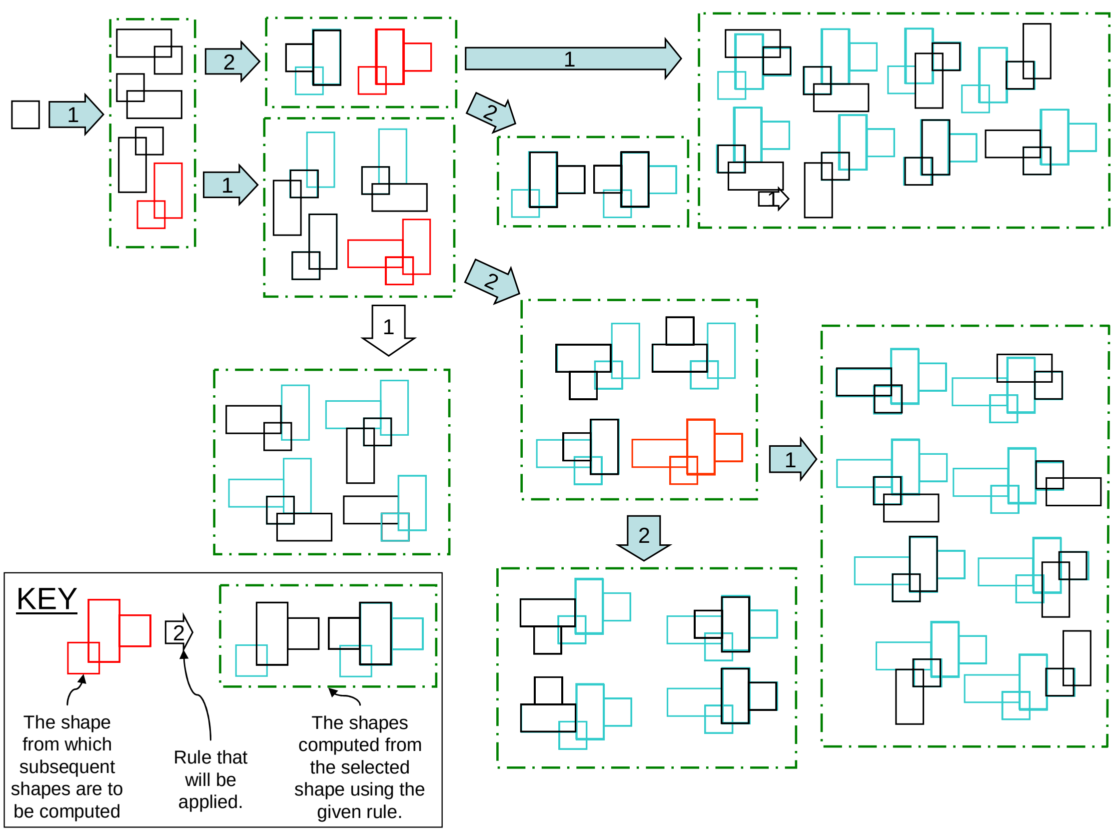

Figure 2: A network of pathways through a solution space

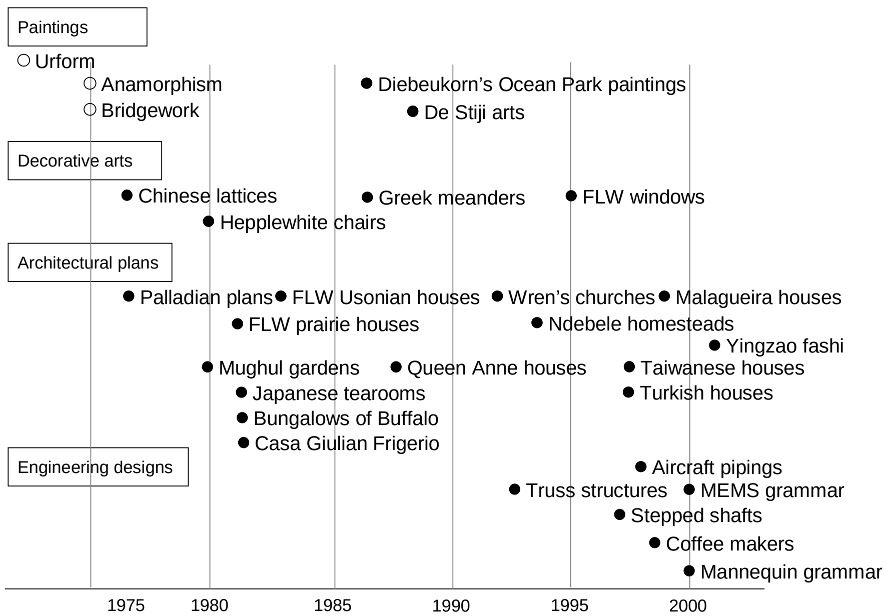

Figure 3: Shape grammar applications to designs [4]

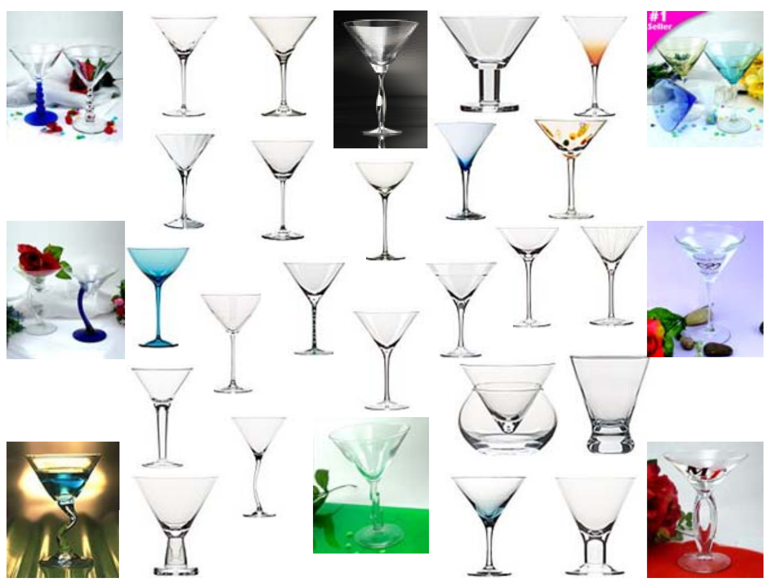

Figure 4: A corpus of martini glass designs

Figure 5: Glass designs generated by a shape grammar [15]