EVOLUTIONARY DESIGN TOOLS FOR MASS-CUSTOMISATION

Cristiano Ceccato AADipl MSc(CS) DIC MIEEE
Assistant Professor, School of Design
The Hong Kong Polytechnic University, Hong Kong, China
E-Mail: sdchris@polyu.edu.hk

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Abstract

This paper describes an instance of the author's ongoing research in the field of Generative Design. The work is based on the premise that computer-aided design (CAD) should evolve beyond its current limitation of one-way interaction, and become a dynamic, intelligent, multi-user environment that encourages creativity and actively supports the evolution of individual, mass-customised designs which exhibit common features.

The understanding of fundamental shape-forming processes in nature inspires us to move beyond the existing CAD paradigms and re-examine the way we can benefit from the computers in design. We can use this knowledge to create a new generation of computer-based design tools which use evolutionary search algorithms to generate create a common family of individual designs optimised according to particular criteria, while supporting our design intuition.

The author explores this idea by illustrating a research project between the Hong Kong Polytechnic University and Deakin University (Australia). The project implements a multi-user oriented design tool for evolutionary design, which was tailored to produce a simple object such as door handle. The paper first gives a short historical and philosophical to the work, then describes the technical and algorithmic requirements, and implementation of the system. It concludes by describing an experiment in which the system was used on a "live" test group of people to generate individual, mass-customised designs.

HERRAMIENTAS DE DISEÑO EVOLUTIVO PARA EL DISEÑO MASIVO

Cristiano Ceccato AADipl MSc(CS) DIC MIEEE
Profesor Asistente de la Escuela de Diseño
Universidad Politecnica de Hong Kong, Hong Kong, Cina

El presente artículo describe un ejemplo del estudio realizado por el autor en el campo del Diseño Generativo. Dicho trabajo está basado en la premisa que enuncia que el diseño con ayuda computada (CAD), debe evolucionar más allá de sus limitaciones actuales de interacción en un solo sentido para convertirse en un medio dinámico e inteligente, de usarios multiples, que estimule creatividad y ayude activamente a la evolución de diseños individuales y de uso masivo, que exhiban características comunes.

La comprensión de los procesos fundamentales de formación en la Naturaleza, nos inspiran más allá de los existentes paradigmas del CAD y reexamina la manera en que podemos beneficiarnos en el diseño a través de las computadoras. Es posible utilizar este conocimiento para crear una nueva generación de herramientas de diseño por computadora que utilicen algoritmos evolucionarios de búsqueda, a fin de generar una familia común de diseños individuales optimizados de acuerdo a un criterio en particular, a la vez que apoya nuestra intuición en el diseño.

El autor explora esta idea ilustrando un estudio de investigación entre la Universidad Politécnica de Hong Kong y la Universidad Deakin (Australia). El proyecto implementa una herramienta de diseño para usuarios múltiples apuntada al diseño evolutivo, la cual fue creada para producir un objeto simple tal como un picaporte. Este ensayo presenta primeramente un enfoque histórico y filosófico y a continuación describe los requerimientos técnicos y algorítmicos e implementacion del sistema. Concluye describiendo un experimento donde el sistema fue utilizado en una prueba sobre un grupo de personas en "vivo" a fin de generar diseños individuales y de uso masivo.

Introduction

The idea of being able to manufacture a set of objects or products which have a common foundation in their design, structure and functionality, but are each unique in their individual manifestation, has long fascinated architects, designers and engineers. Different understandings of the notion of 'customisation' and 'product family' have existed in different forms throughout man's history of producing functional (and functionless) form. The basic understanding of a design family has always been tied to the notion that within a family variation is possible, indeed desirable and often necessary. This understanding is always inextricably linked to some form of implicit or explicit collection of 'rules' or 'guidelines' that decree the nature of the produced object. It is the flexibility of operation within the constraints, or 'parameters', of these rules that produces a 'family' of objects, and the voluntary or involuntary breaking of these boundaries which either broadens the range of a family or gives rise to a new one.

Examples of this can be found in the most varied forms of human construction and manufacturing endeavour. A simple example is the Pyramids in Ancient Egypt. By nature of the 'rules' dictated by the Ancient Egyptian religion, with its cult of the sun, deification of the Pharaoh, and projection of all worldly activities to the afterlife, the Pyramids invariably took on a common set of traits. It is these traits by which we consciously or subconsciously recognise them as Egyptian Pyramids, each is unique in particular ways. Similarly, the development of Christianity is clearly legible in the development of church design: we can all recognise a Catholic church, through the universal components of apse, transept, choir, altar, etc. The interior configuration of a Protestant or Anglican church closely reflects the underlying changes in these denominations' view of Christianity. Thus, by nature of the variation of elements within a fixed scheme, every church is unique, and yet immediately recognisable as such.

Shipbuilding is another good example of individual designs being borne out of common lore of effective design elements. This lore would periodically manifest itself in 'ship classes', or families of related design, in which the basic root scheme reflected the general function of the ship. Brigantine, Cruiser, Battleship, etc. all define a 'class' of discernible designs, but the fascination lies in the way how the different designs find different functional advantages, while remaining within their respective classes. In fact, each battleship design, even within a closely related class, was unique, reflecting the newest military knowledge or specific requirements. However, to integrate each of these unique features meant altering, or *customising*, the root design. It is of particular interest, then, to observe the dissipation of acquired knowledge in time through the *evolution* of successive designs.

The Industrial Revolution and the invention of conveyor-belt mass-production quickly introduced man to a vision of the world governed by mechanical efficiency, driven by the economic need to produce more goods competitively. It is generally argued that the Industrial Revolution was instrumental in making a wide range of basic goods and services broadly available. In fact, it was a stepping stone on a long journey to a point where machines would be able to address the desired of man, and not man limit himself to the capability of machines. Henry Ford is credited with inventing the production line, and his famous quote about his Model T, "*they can have it in any colour as long as it's black*", reflects the streamlined yet inflexible vision of industrial manufacturing as it was understood throughout the 20^{th} century.

Mass-Customisation

The idea of Mass-Customisation is not a new one. Elements of flexible manufacturing at both the design level and the assembly level have been increasingly evident in the last thirty years. Again, these are driven by economic considerations. A good example is the aircraft industry. After the Second World War, manufacturers could no longer afford to offer a different aircraft for a different requirement. The speed at which markets developed meant that it was faster and cheaper to derive *variants* of an existing design, *modified* to fulfill new needs (e.g.: Boeing 707 → Boeing 730, KC-135, E-3A). This has become even more evident in the latest designs, in which not individual models, but whole *families* of aircraft are launched, consisting of an array of *related* models, which share parts, manufacturing, and flight-training *commonality* while containing enough 'room' for growth within the *root* design (e.g.: Airbus A330/A340). This is also evident in the automotive industry, where individual users (customers) are able to specify a wide range of components. In the end, each *instantiation* of, for example, a VW

Golf, is unique in its combination of chosen components, from basic inexpensive model to muscled sportscar, while remaining a true Golf.

The emergence of new manufacturing methods, from CNC machining and CAM to flexible moulding and robotic production lines, means that we are poised to make a new quantum leap, a paradigm shift in what is achievable and understandable within ‘industrial production’. The last great revolution before the Millenium, the rapid diffusion and development of Information Technology has much more to offer to the process of design and manufacturing than just computerised control of factories and assembly lines. The ability to combine an understanding of creative rule-based design systems with flexible methods of production will enable a new form of manufacturing which is freed from predefined geometric constraints and which efficiently translates rules which govern a design into tangible form. By varying these rules, we are able to achieve a broad family of interrelated, industrially manufactured, individually unique products.

Evolutionary Design

Evolutionary Design grew out of the debate on Artificial Intelligence (AI), Artificial Life (Alife) and the growth of CAD and CAM computing technologies in the 1980s and 1990s. It was pioneered by various digitally minded architects around the world, in particular John Frazer at the Architectural Association. Evolutionary Design describes the methods by which a common set of properties is parametrically encoded and manipulated using generative design methods to create a new sets of similar objects. Various rule-based generative systems, such as Cellular Automata (CA), L-Systems and Fractals, are used to parametrically generate form and spatial structure. These processes are turn controlled by search methods that seek specified goals or optimise data according to certain criteria. The ability to autonomously elaborate a useful dataset or recognise patterns is often referred to as machine learning, and is achieved using methods such as Artificial Neural Networks (ANN) and Genetic Algorithms (GA). These tools, when combined to form intelligent or self-regulating generative engines, produce a wide variety of forms that embody the desired criteria specified in the process.

Ongoing Research

The notions of Evolutionary Design and Mass-Customisation draw their inspiration from different sources, but complement each other very efficiently and creatively. In support of this idea, and that it may foster new developments in intelligent computer-assisted design and manufacturing, a joint research project was initiated between Deakin University in Geelong, Australia and the Hong Kong Polytechnic University. The goal of this project is to provide an in-depth analysis of the potential of design driven by rule-based systems and flexible manufacturing methods by developing a set of supporting computational tools and deploying them in an empirical test situation. At Deakin University, Prof. Mark Burry and his team provided insight into algorithmic form-generation and manufacturing techniques. At the Hong Kong Polytechnic University, Assistant Professors Alvise Simondetti, Lorne Falk and the author contributed, respectively, expertise in rapid prototyping and CAD/CAM, design theory and rule-based generative design systems. As of the time of writing (July 1999), the research is classified as ongoing, and the final results will be published at a later date.

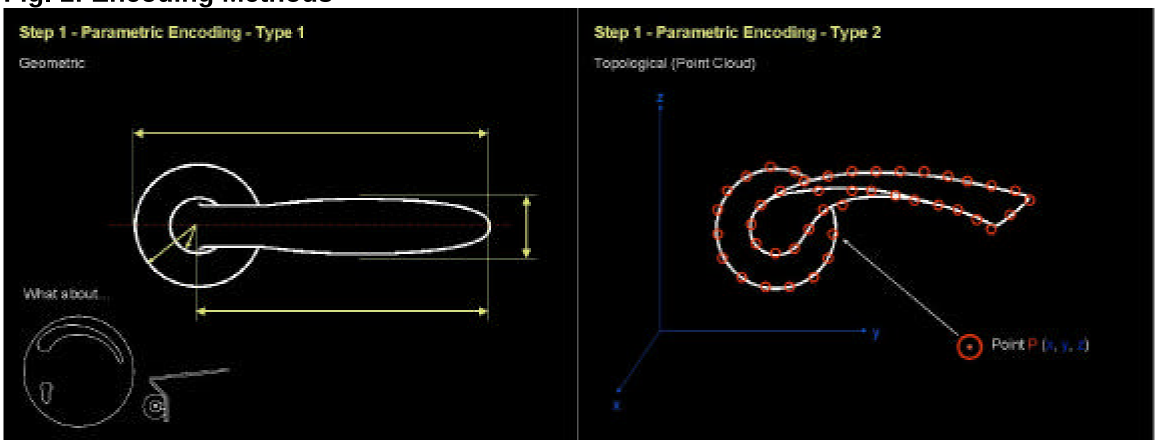
The goal of the project was to create a set of tools that enable the generation of related families of objects based on user interaction. The project was deliberately kept of a small size in order to ensure an effective exploration and implementation. As a specific object, we chose to engage the topic of door-handle design, due to its self-contained limitations as well as the challenge of designing a functionally tactile rather than visual object. Furthermore, several of the team members had engaged the topic of door-handle design before: Alvise Simondetti in Rapid Prototyping experiments at MIT, and the author through a design commission manufactured in Germany by FSB. This presented an interesting opportunity in which to compare approaches. The project can be broken down into several parts:

1. **Establish Encoding Methods:** In order to operate on the design numerically through generative tools, the door-handle must be able to be ‘digitised’ as a three-dimensional object. There are different understandings of

how a design should be encoded in terms of the description of its form and geometry. *Figure 1* describes this as **Step 1** in the overall process. Methods include:

- Type 1: Parameters are assigned to definition curves which define spline-surface which make up the handle object
- Type 2: The handle object is treated as a topological surface which is defined by a cloud of surface points

Fig. 1: Encoding Methods



2. **<u>Clarify Design Criteria</u>:** Concentration on the tactile rather than visual aspect of door-handle design. This challenged us to transcend our architect's intuition and engage the design in a more critical way. The qualities of 'grip' and 'feel' have been assimilated into a '*lore*' of door-handle designs by FSB. In order to evaluate these qualities, the participation of a body of users is necessary to determine in which design they are emerging in a desirable way.

Issues about designing door handles:

- Looks ('design')
- Feel ('Haptik')
- Material (cost!)
- Construction (geometry)
- Construction (factory process)
- Fire Regulations

Scientific…
Objective vs.
Subjective?

3. **<u>Determine Generation Parameters</u>:** A generative design tool uses a Genetic Algorithm to extract information which makes up a successful design by breeding families of related forms and testing them against a selective environment. In our project, the parameters driving the generative process are described as follows:

- Establish evalutaion criteria: Grip
- Establish scoring (value) system: Feel
- Determine data type: Handle Geometry
- Encode data: Geometric Description

- Ensure good test environment: People!
- Feel free to intervene: Maintain Control

4. **Generative Cycle**: The cyclical process of encoding, generating and evaluating outputted forms through a generative system is described graphically in Figure 2 below. The steps are:
   - **Step 2 – Obtain Seed Population:** The root of any generative process requires a seed – an initial set of data which is then modified. Given FSB's acquired knowledge of door-handle design and fabrication, a selection of their best-known pieces in production was used as a starting population. The designs are codified by using a 3D scanning system (3D digitiser) or by configuring existing CAD data obtained from FSB.
   - **Step 3 – Perform GA Sequence**: The core step of the generative process. The GA generates a new population of form data by generating a child population using breeding, crossing over and mutation of the initial data.
   - **Step 4 – Evaluate Population**: The generated data is translated into tangible form through the use of CNC/CM or rapid prototyping machinery (at HK PolyU, Stereo Lithography or FDM or 3D Actua Printing). The manufactured door-handles are test in a real environment – in this case, a collection of 'demo' users consisting of students, colleagues and outsiders. Each of these users is required to give a verdict on various tactile and possibly visual aspects of each handle, on a scale of 1 – 10. These values are compounded to a 'score value'. These values are used as *fitness* value for the GA in the next generation. A repetition of this sequence soon generates a collection of door handles which reflects the user group's preferences within the design.

Conclusion

The task of combining Evolutionary Design and Mass-Customisation efficiently requires considerable computing expertise, time as well as a commitment to determining feasible form generation and production methods. The discourse on how to best encode a tactile, three-dimensional form and manipulate the resulting data is equally if not more of philosophical nature than technical. Furthermore, geometric and parametric manipulation methods have a fundamental influence on the nature of the resulting forms. Maintaining full flexibility becomes a technically demanding issue, and increases computational development time greatly. In our case, we determined a simple, if effective, generation method in order to achieve tangible results within in the project's time frame.

At the time of writing of this paper, the project is still ongoing, and it is hoped that the final results of the form generation cycle will be published at a later date. However, feedback from colleagues and students is very promising, in particular with regards to the fundamental idea of using sophisticated computational methods to support a simple goal: to sustain intuition in creating individual, customised objects using automated manufacturing technologies.

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Fig. 2: Generation Sequence