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# USER-LED DEVELOPMENT OF AN INTERACTIVE EVOLUTIONARY DESIGN SYSTEM

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## ABSTRACT

This paper includes two distinct but related elements: 1. It raises issues surrounding how Interactive Evolutionary Design (IED) systems are developed and their adoption by industry; 2. It describes an existing IED system known as 'Evolutionary Form Design' (EFD). These elements are linked through the proposal that the EFD system can contribute to addressing the issues raised.

The paper opens with the suggestion that investigation is needed into the disappointing uptake of IED in commercial industrial design. Preliminary enquiries suggest that awareness of the technology in the design community is minimal. Concern is also expressed with the apparent lack of end-user participation in IED development. Reasons for these issues are suggested.

The next section provides an overview of the EFD system's implementation within a CAD system, and its representation employing blended geometric primitives interacting through Boolean operators. Some distinctive features are then described: control of Boolean interaction, edge blending strategies, a team-forming algorithm and machine-based geometric and aesthetic optimization. The section ends by listing the system's strengths pertaining to its suitability for use in the proposed user-trials and outreach activities that are outlined in the last section.

Conclusions re-affirm that the described EFD system overcomes some of the perceived barriers to greater uptake in design practice and will be further developed via inter-disciplinary collaboration and greater user involvement.

## 1. INTRODUCTION

Though some aspects of Interactive Evolutionary Computation (IEC) have been utilised in design exploration [1], IEC has not, as a whole, been adopted in commercial industrial design practice. The documented shortcomings of IEC, principally operator fatigue, [2] partially account for this and work has been done to alleviate these [3, 4]. Preliminary enquiries by the authors suggest there is an instinctive resistance to this technology amongst some design professionals and this is also implicit in the literature [5]. This hypothesis needs further exploration, and if proven, will need to be firmly addressed to enable the substantial legacy of research in this area to be fully exploited. This paper proposes some methods and techniques that could help in this direction.

Good designers, almost by definition, involve users early in the design process. This is the basis of user-centric design and ought to be extended to the development of any interactive product. For the developers of Interactive Evolutionary Design systems, this principle sometimes seems to be overshadowed by the interest in creating ever-more intelligent and application-focused tools. Researchers may feel their prototypes are never quite ready to face their intended end-users. Certainly, greater collaboration between computer programming specialists and other disciplines, as well as the ultimate beneficiaries of IED will help in this regard. Encouragingly, the appetite for collaborative research has increased over the last few years and has spread to this and neighbouring fields, reflected by the take-up of ring-fenced funding for inter-disciplinary research clusters [6, 7]. Such research will be key in overcoming barriers to widespread adoption of IED.

The aims of this paper are to:

- Expand concerns regarding the disappointing uptake of Interactive Evolutionary Computation in industrial design practice. Offer further perspectives on this and propose some countermeasures.
- Describe in more detail an existing interactive evolutionary CAD tool (Evolutionary Form Design – EFD), and substantiate its credentials as a candidate for the field-testing of IED principles within industrial design.
- Propose a variety of outreach and user-trial activities that will raise the profile of IEC in industrial design practice and provide guidance from potential users on how best to further develop the technology.

## 2 IEC IN INDUSTRIAL DESIGN PRACTICE

Concerning the awareness of IEC in industrial design, although no empirical study has been carried out to date, preliminary enquiries have been made in the UK, through the network of designers associated with the Department of Design and Technology at Loughborough University. Although some designers have heard of the technology ‘through the grape-vine’, there is very little awareness of the technology, and certainly no-one contacted is actively using IED.

As part of on-going research, this issue will be investigated more thoroughly. Initial thoughts of potential causes include the lack of publications in general design journals (obviously the majority of publications on IED are in specialist journals), and the ‘look’ or ‘style’ of most IED output. Many of the IED systems presented in the literature carry a particular style [8], being either simplistic [4, 9] (a necessity during the early stages of development), or overtly decorative [10]. Designers are visual people and could be easily turned off by these aspects.

There is also the more thorny issue of attitudes and prejudices. It is easy to assume that some designers would feel threatened by this technology, but at this stage of investigation it is not possible to make any strong claims in this regard. In section 4, a number of outreach activities, trials and experiments are proposed that will shed some light on these areas.

## 3 THE EFD SYSTEM

### 3.1 Background

An Interactive Evolutionary Design system, known as Evolutionary Form Design, originates from doctoral research conducted at the Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University [11, 12]. The research was based around the comparatively modest goal of

providing an evolutionary tool for industrial designers to use during conceptual form exploration.

### 3.2 Implementation

The EFD system runs within the UGS NX (formerly Unigraphics) CAD environment, where a Genetic Algorithm (GA) interfaces with the CAD system’s geometric modeller via its API (Application Programming Interface). The system, although conceptually simple, has been thoroughly developed and enables users to evolve aesthetically interesting and useful forms intuitively. Some outputs including consumer products, seating designs and sculpture are shown in figure 1 at the end of the paper.

Users’ primary method of interaction is via selecting or scoring objects from small populations (typically 14) presented on-screen, as shown in figure 2. Selecting favorite objects via the mouse is a quick method where users can work quickly through, say, ten generations in a few minutes. Scoring allows a more considered approach to influencing which objects are selected to generate the next population, while still allowing a degree of explicit control: a score of zero removes any chance of an object being selected and a score of ten guarantees selection.

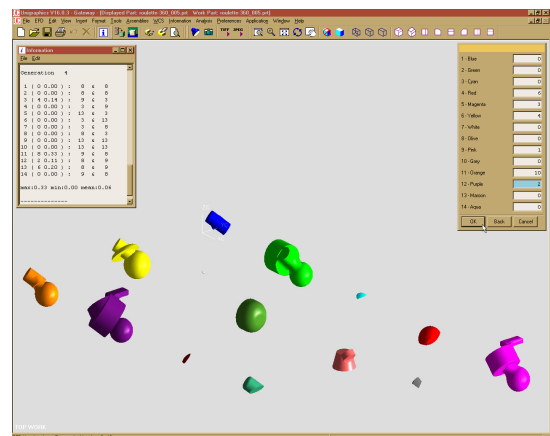


Figure 2 – EFD system screen-shot

### 3.3 Representation

Geometric primitives (blocks, spheres, cylinders and cones) interact through Boolean operators (unite, subtract, intersect) and are subjected to various blend radii applied to their edges. Each object is constructed from five primitives, which are associated in either of two ways, a standard mode or a ‘team-forming’ mode (described in section 3.4.3 below).

### 3.4 Noteworthy Features

Features distinct to the EFD system that will be outlined in this section are as follows:

- Object *construction* via Boolean interaction
- Edge *blending* strategies
- The *team-forming* algorithm
- *Automation* of geometric & aesthetic optimisation

Detailed figures illustrating these features can be accessed at [efdresearch.co.uk](http://efdresearch.co.uk) via the keywords highlighted above.

#### 3.4.1 Control of Boolean interactions

Objects are built up from a collection of geometric primitives. Basic sequential creation methods, where Boolean operations are carried out as the primitives are introduced one-by-one, have several limitations. For example, if a primitive is introduced that is intended to be subtracted from preceding bodies, and there are none that over-lap, then this primitive will end up not being used. A more adaptable Boolean interaction method produces better results; the essence of the method being that all primitives are *created* first, and only then are their Boolean instructions applied. A further refinement is the addition of a four-bit gene for each primitive, encoding a list dictating the other primitives with which it can interact. This technique produces by far the most interesting, varied and adaptable objects.

#### 3.4.2 Edge blending strategies

The union, subtraction and intersection of geometric primitives can create a variety of curved edges and surfaces; elliptical, parabolic and hyperbolic curves are all possible. However, the edge blending operator, naturally available through the underlying solid modeller, produces the most interesting, unexpected and diverse forms. Where large blend radii are applied (much greater values than would just produce a rounding off of an edge) shapes are produced that belie the forms' humble origins. This particular use of large blend radii is not a technique CAD designers use, and greatly contributes to the originality of the EFD system's output.

Maintaining visible inheritance between populations is the major challenge here, albeit helped by needing only small amounts of data to describe the blending. Just a blend radius is needed for each edge – there is no need to describe geometry mathematically, as the CAD modeller carries out the geometric operations.

There is a balance to be achieved between strong inheritance and the creation of the most interesting forms. In practice the user is given the choice of two modes of operation, simple (pre-Boolean) blending or whole-object (post-Boolean) blending, the former producing strong visual inheritance and the latter, a better range of forms. Given that the latter method

generally provides the most useful forms, it is important to provide the best possible visual inheritance to enable sufficient usability. This means overcoming several obstacles.

Each primitive has 18 radii values available, enough to cover most eventualities. One issue for whole-object blending is the matter of which primitives' genes to use for new, 'shared' edges that are formed through Boolean operations. Several options have been trialed to date, the best of these is to alternate which primitive contributes its blending gene to their shared edges. A number of other options have yet to be tried.

#### 3.4.3 The team-forming algorithm

User interaction necessitates using small populations, so there is a compulsion to maximise the potential of all objects within a population. There is also, as always, the drive for efficiency – minimising the number of generations or time spent on a task.

In this case, an object's fitness is dependent on, amongst other things, the grouping, interaction, and order of creation of constituent geometric primitives. In the standard mode of operation, the five-primitive objects are the phenotypes (members of the population) and are defined by one long genotype (string of data) made up of a sequence of five repetitions of the same data structure. An alternative method, the team-forming mode first introduced in [13], has been partially explored. In this mode, individual primitives are the population members, which then group together in teams of five to form the objects, according to an evolving set of tactics. The five primitives share the fitness rating of the whole object.

The ideal is that having more control over how primitives group together enables a co-operative and complementary use of the available primitives, controlled by an evolving set of rules, analogous to team forming in society. In reality, the representation employed makes it difficult to explore the potential of this technique, and more work needs to be done to refine the team-forming tactics so that inheritance across the generations of teams is more strongly maintained.

Some Evolutionary Computing researchers have used comparable techniques to improve their own algorithms, whenever objects/solutions are described by several repeated data-structures. Further investigation of these techniques could benefit the development of the EFD team-forming algorithm.

#### 3.4.4 Automation of geometric and aesthetic optimisation

In terms of quantitative optimisation, the EFD system is able to assess the geometric properties of objects, such as volume, surface area and centre of gravity, by utilising functions available within the CAD system.

This provides a demonstration of the potential of automated optimisation and offers some assistance to users who need to consider such factors in their particular design tasks. It has also provided some interesting insights into the adaptive nature of the evolutionary search when faced with tasks to evolve objects with particular properties, e.g. bounding box dimensions or volume to surface area ratios. Solutions to these types of problems (between one and three) are achieved with populations of 14, in between 10 and 17 generations, to an accuracy of between 0.03 – 0.67%.

Geometric optimisation has enabled the EFD system to be adapted for further work, on the study and integration of aesthetic considerations, by other researchers [14]. In this research, aesthetic evaluation has been encapsulated within the system, and can be prompted by one or a combination of measures, such as simplicity, stability, smoothness, hardness etc.. The system has been evaluated and improved through the use of user-surveys.

### 3.5 Strengths

- The EFD system is generic, and is not focussed on any particular product. This offers flexibility across a wide spectrum of design (consumer products, furniture, architecture, sculpture etc.).
- It requires no preliminary modelling, parametric or otherwise, and as such bypasses users' preconceptions. This also means that users need no prior experience in using CAD modelling tools (although familiarity with basic viewing functions – zoom, rotate etc. is advantageous).
- The system is conceptually simple, so users can quickly grasp how their interactions control the evolutionary process through selection, reproduction, inheritance etc..
- The EFD system's output carries less of an inherent 'style' than other IED systems, and is genuinely capable of creativity-enhancing and innovative form design.

Through these strengths, the EFD system is well suited to exposure to a wider audience.

### 3.6 Limitations

- Lack of hands-on control – the objects cannot be edited directly using the CAD interface and then returned to the population for further evolutionary development.
- The process can be fairly 'hit-and-miss' in the early stages of evolution, especially if the user is aiming for a particular form.
- There are obvious restrictions to the range of 3D forms that can be produced - designers of consumer products rarely use simple solid modelling these days, tending to use hybrid surface/solid modellers.

These first two limitations are not inherent to the system and would naturally be subjects for further development. The matter of representation is a more fundamental but, it is felt, necessary restriction.

## 4. PROPOSED OUTREACH ACTIVITIES AND USER TRIALS

A programme of visits, workshops, experiments and industrial collaborations making use of the EFD system are proposed. The aim of these will be to engage a broad range of people outside the research community; from design professionals in a variety of fields, through young people in schools and higher education, to consumers and the public in general. The prime benefit of these and related activities will be the knowledge of how best to develop the EFD system and Interactive Evolutionary Design in general, to meet the needs of designers and the other people associated with the groups listed above.

### 4.1 Engaging Design Professionals

The intention is to apply the EFD system in a variety of industrial and product design fields, including consumer products, furniture, automotive styling, architecture and sculpture. Those designers that are most receptive will be invited to a workshop where a more in-depth and hands-on experience will be offered. The results of the workshop and any subsequent work will be compiled and exhibited, increasing the profile of IED within the design community.

Interviews will be carried out to ascertain designers' views on IED in principle, and on the potential of the EFD system presented. It should be possible to establish the strengths and weaknesses of the technology, what sectors of design practice could benefit most, and ultimately to what extent Interactive Evolutionary Design enhances creativity within commercial design.

### 4.2 Creativity experiments

A complementary approach is to conduct experiments, comparing different groups of people carrying out a design task under controlled conditions. Potential comparisons would include designers versus non-designers, both using the EFD system; and a group who use the system versus a group that use other form-finding techniques. Results would be judged via an exhibition and on-line poll.

### 4.3 Schools and creative engagement

The majority of people that have used the EFD system to date have enjoyed it, thus prompting the potential for engaging young people in schools, as an early exposure to CAD. The system has also been used to produce virtual sculpture art prints, and it is envisaged that this kind of design activity could be carried out in a domestic setting, as a creative recreation activity.

Evolved forms can easily be allocated material properties and rendered before printing in 2D, or produced in 3D using Rapid Prototyping techniques.

#### 4.4 User-integrated design

The system will also be used to investigate the potential of using IED to involve the end-user in the styling of consumer products. Similar work has been attempted previously [15] but was inhibited by the users' lack of ability in CAD form creation. The EFD system would overcome this obstacle through its automatic form generation technique. The main point of interest will be how well the outputs from non-designers can be integrated into customised consumer products by professional designers.

#### CONCLUSIONS

This paper has been broadly descriptive, discursive and propositional, hence there are no firm conclusions to report as such. However, several issues that have been explored throughout are worth distilling.

The authors believe there is good reason to apply principles of user-centric design to the development of IEC, and increased efforts should be made in involving end users. This will have the additional benefit of increasing awareness of IEC amongst the design community, and should create more of a pull for the technology. Building on the positive trend for collaboration between disciplines, especially in this case computer science and human science, will provide a boost to the progression of IEC research. Allied with other emerging technologies, IEC does have potential to contribute to a change in the way things are designed, and the way users can be involved in design processes.

These principles will be firmly adopted in ongoing development of the EFD system, which is felt is an ideal candidate for such research methods.

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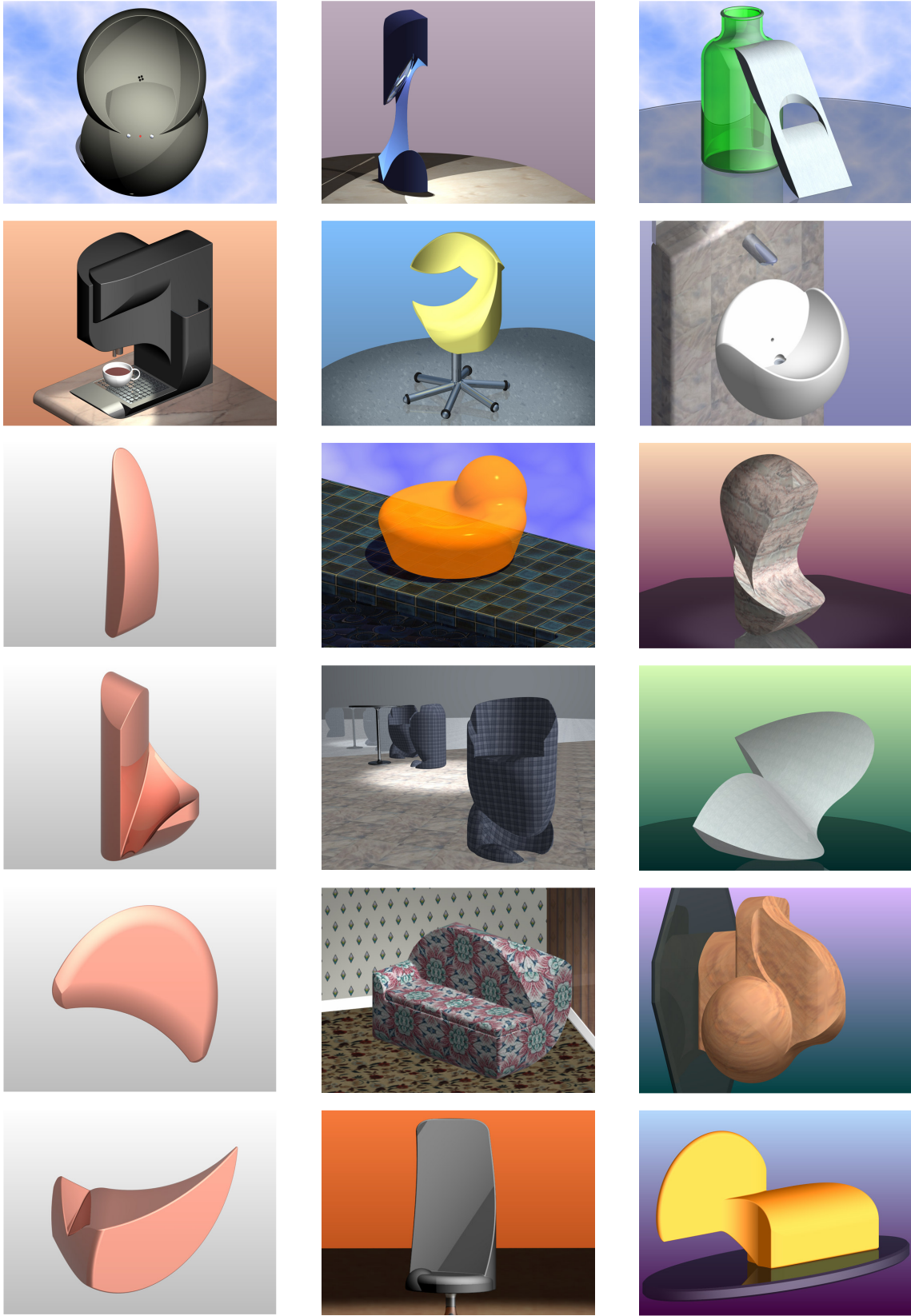


Figure 2 – Forms evolved using the EFD system