ABSTRACT

Selecting and adapting sources of inspiration are both vital parts of designing. This paper reformulates the traditional view of designing as a cycle of problem formulation -- synthesis -- evaluation to give due importance to source selection. It surveys the uses of sources of inspiration in different types of design, and highlights the similarities and contrasts between the use of sources of inspiration by human designers and the use of sources in generative systems for automatic design. In fields with under-specified design tasks, selecting appropriate sources plays an essential part of formulating the problems. Where the tasks are well-specified the locus of creative endeavour is in the adaptation of previous designs and other sources to meet new demands.

INTRODUCTION

The relationship between designs and the sources of the ideas that are used to generate them is paradoxical. The degree of creativity of a design or other intellectual product is typically measured by how much it differs from what came before. But designs are valued only if they are appropriate in their context; for instance clothes must fit into the current context of fashion. Both designers’ and their customers’ perceptions of what is appropriate and admirable, as well as what is possible, are shaped by their own experiences of similar artefacts.

The building blocks of new designs are the memories triggered by the design problem, including those actively acquired in designers’ exploration of sources of new ideas. Sources of ideas both power the creative process and limit it. Designers can often achieve far more by adapting previous designs and other sources of ideas than they could create without them. But designers cannot easily escape the influence of their memories of previous designs, even when they know they need to.

Designers in engineering, architecture, software development, and fashion and knitwear design use their prior experiences in different ways, and the developers of generative systems for design make radically different uses of previous designs. This paper explores the similarities and differences between different industries’ approaches to recycling design experience, and contrasts these practices to the meta-design performed by the developers of automatic design systems. They differ strikingly in how sources of ideas are identified and selected, and in the relative effort-investment and importance given to the selection process versus the adaptation of a given source of ideas (often the most similar previous design) to meet the needs of a new situation. In some situations, notably in the fashion industry, selecting the right sources is the key creative step requiring the most important skills.

Sources of Inspiration

Any kind of perceptual experience or memory can give a designer an idea. “A good designer can draw inspiration from everything” was given as an answer to the question “what makes a good designer?” by many experienced knitwear designers. We refer to the objects, images, phenomena and abstract concepts from which designers draw ideas as sources of inspiration. Both the term and the extremely
broad meaning we give it come from our study of the knitwear industry\textsuperscript{4,5,6,7}, where designers are acutely aware of how they use different types of source for different purposes in developing their designs. Of course in all types of design the dominant influence comes from previous similar artefacts (or designs for them). But the most novel ideas are often triggered by entirely different objects.

**THE DESIGN CYCLE EXPANDED**

It has long been recognised that design thinking is characterised by a cyclic process of reformulating the problem, generating a move in the space of possible candidate designs, evaluating the design, reformulating the problem again, and so on\textsuperscript{8,9,10}. When we can solve a design problem by applying a sound method for deducing a solution from the problem statement, we no longer think of what we do as designing. But this formulation focuses attention on the undeniably important process of developing a ‘single’ design by iterative evolution. In this section we outline an expansion of this traditional cyclic view, sketched in Figure 1, that gives due importance to the selection and adaptation of external sources of ideas.

**Evolution and Adaptation in Design**

The most detailed research on the creative process in design has examined the evolution of ideas, and has used videotapes of episodes of designing in artificial experimental situations. Most of this work has studied architects, and much of it has focused on how designers use sketching\textsuperscript{11}, with notable contributions coming from Schön\textsuperscript{12}, Goldschmidt\textsuperscript{13,14} and Goel\textsuperscript{15}. It has described how ideas emerge from designers’ reflection about their own sketches. The vagueness and ambiguity that makes sketches problematic for communication\textsuperscript{16} facilitates reinterpretation driven by dissatisfaction with the current design\textsuperscript{17}. While this work rightly highlights the role designers’ perceptions of external representations of their own designs play in the cycle of design thinking, it is limited by its experimental paradigm. (This is not to suggest the researchers are so limited: Goldschmidt has written about the roles of precedents and references in architecture\textsuperscript{18,19,}.) Designers are told to design and if possible concurrently verbalise for a given (short) time outside their normal work environment. In these experiments external sources only play a role if the designer can recall them during the design activity. In most normal design situations, designers are free to refer to inspiration objects, and think about their designs outside their offices; they would often activity research solutions to similar problems. As we have found in our observational and experimental work\textsuperscript{20}, knitwear designers interact with sources of inspiration in very similar ways to how Schön and Goldschmidt’s architects interact with their sketches.

As many writers on design have pointed out, designers organise their design processes and reformulate their design problems so as to activate knowledge of how to solve design problems drawn from their prior experiences: sources of different kinds of design ideas. In combination, the sources and the problem trigger the generation of new design elements that are adaptations of the sources. As we have just noted, a lot of designing comprises the iterative evolutionary development of a ‘single’ new design. It is stretching a point to call the current version of a new design a source of inspiration (nor do we, most of the time), but there is a close parallel between the way new design ideas are triggered by considering external sources of inspiration and the way they are triggered by considering the current design. Considering these two processes as the same is a fruitful perspective on design thinking.

**The Design Cycle with Sources of Inspiration**

The flowchart in Figure 1 describes the creation of a new design based on a source of inspiration, as a cyclic process. It asserts that movement down the chart from selection of the source of inspiration to reformulation of the problem happens in the sequence of stages shown here. However movement up the chart to earlier points in the cycle can happen in a variety of ways. This view subsumes the more traditional view of the design cycle, by equating adapting previous designs and drawing on external sources of inspiration with modifying the existing design solely with reference to itself. It highlights the selection of sources of inspiration as an essential factor in design thinking; in some situations the choice is fixed and therefore implicit, in other situations this is the critical activity.
Confronted with a new design task, the designer looks for a starting point in the form of an old design or an external source of inspiration. Each source is analysed and evaluated for its suitability, and discarded if it does not fulfil the need. The analysis can involve nothing more than a fleeting glance at a picture in a book, but might be a detailed investigation of the capabilities and characteristics of a complex product like a machine. For some designs the selection – analysis loop can be repeated many times until a suitable source has been found or enough sources identified. The source, or parts or aspects of it, is then adapted by modifying, adding, or subtracting elements of it, or translating it into a different form that fits the new problem context. This process is conventionally seen as the main design activity. The new design is evaluated as it is created or after it is finished. Sometimes the design is discarded either because the adaptation itself is unsuccessful and needs to be repeated, or because the result fails to meet expectations. In this case the designer returns to the source to create an alternative adaptation, or finds a new source. As the design progresses each evaluation of the current state leads to some reformulation of the problem. The most radical reformulations of the problem become necessary when the design has failed and the designer realises that a fresh look at the problem is required.

In evolutionary design, the current version of the design is the main source of inspiration. Its features, intended or unintended, expected or unexpected, are analysed or directly perceived (appreciated) by the designer, just as the designer appreciates the characteristics of another object. The major differences are (1) that early designs are incomplete, provisional, often ambiguous and sometimes self-contradictory, while typical sources are complete and therefore fixed; and (2) ones own designs cannot be divorced from their intentions, while the intentions motivating the design of external sources is at most implicit. The move in the space of possible designs at the heart of the cycle might be a wholistic synthesis or transformation of a design, but is more typically an incremental modification to part of it. When an external source is used in incrementally developing a design, evaluations of both the source and the design contribute to the perceptions of the design task that trigger design steps.

Of course, complex design processes are only tractable because they are hierarchical, both in space and time. Design tasks are decomposed as far as possible into almost-independent subproblems, and designing complex artefacts often consists of nested loops going through this cycle on timescales ranging from seconds to days. In some industries specialists are employed to perform particular types
of evaluations. Thus the problem reformulation step in the cycle may involve a transition to a new problem space to address a subgoal, either in pursuit of a plan or opportunistically in response to a perceived problem, or a return to a previous goal on completion of a subgoal.

DIFFERENT PERSPECTIVES ON THE ADAPTATION OF SOURCES

Not only do different types of design fields have different perspectives on the role of sources of inspiration, but designers can use different types of sources in the same design, and use the same sources for different purposes. This is striking in knitwear design, in which aesthetic design of form, requiring the sensitivity to fashion context and Zeitgeist of product design, interacts with structural design involving technical considerations similar to those in engineering\textsuperscript{5,6}. While the functions listed below are drawn from different fields, we have observed all of these uses of external objects in the knitwear industry simultaneously or at different stages of the design process. Therefore the term sources of inspiration is used to encompass objects, images and abstract forms used in all of these roles, without restricting any object to any particular function.

Context

Products need to be timely. Their success depends on when they reach the market. It needs to meet current requirements and perceptions of what is appropriate and desirable, and fit into the context of the environment it is used in. While this issue is significant for engineering, and especially for consumer products, it is vitally important for fashion and knitwear designers. A large part of the skill of a designer in a fashion-influenced industry is to identify this context and design the right product for the market. The fashion and knitwear industries have to cope with particularly tight deadlines and fast changing trends. A garment is designed to fit into a fashion context: it must be distinct enough to appeal while being within the space of what is appropriate in a particular culture at a particular time. (Being too early can be a fatal mistake in the fashion industry; similarly Sony have tried and failed three times to market integrated television-video-recorders.) The knitwear designers we have studied actively employ sources of inspiration in the requirement definition stage of design. They systematically research the fashion context, by attending fashion shows, visiting shops, reading magazines, and buying key garments. They collect images of garments and other objects that define the fashion of a new season, that is, spaces of acceptable designs. Without realising they are designing, knitwear designers make fundamental design decisions when planning collections: choosing categories and positions in the spaces of acceptable garments\textsuperscript{4,6,7}. (But planning inspires designing: knitwear designers often imagine relatively concrete designs as placeholders for categories; and the images they collect also serve as a library of design features, or as triggers to find other designs within the space that can be adapted more directly into the designers’ own new designs.)

Starting Points

Most engineering design is adaptive or variant design – making changes to an existing design, or creating a new design on the pattern of a previous one: in these situations the selection of the source of inspiration is implicit in the task. In many companies product ranges evolve over years with no or few radical innovations. Some designs evolve so much that they have little more then the name in common with the original design. For example a 1980 Nimrod only has elements of the airframe in common with a 1951 Comet. However containing the changes required to the original design when designing by modification can require highly creative innovative design of components.

Precedents

Contemporary architects sometimes base buildings on precedent buildings designed by one of a small elite of superstar architects\textsuperscript{19}. Precedent buildings are prototypes in the sense that they are the first in a series of similar buildings, and provide canonical solutions to common classes of problems, that can be adapted. The precedent has normative force in that new designs gain credibility (from the authority of the superstar architect) by following them. The canon of acceptable buildings changes with culture
and time: whereas current buildings are based on contemporary architecture from all over the world, and precedents remain in the canon for only a few years, buildings designed around 1800 were based on Roman and Greek buildings. Goldschmidt argues that architectural designers would be more creative if they broke away from the mould of following normative prototypes and used a variety of buildings as references for new designs. Mass-market fashion and knitwear designers copy the garments of high-status companies as closely as they dare, because that is what the retailers they supply want to sell – the retailers will only accept different-looking products if they have precedents.

Reuse

It pays to reuse existing components. Standard components from catalogues often cost a fraction of the cost of bespoke products. Designers are often strongly encouraged to stick to standard suppliers, which further reduces their freedom. The Volkswagen Group is currently working towards standardising all parts that are not visible to the customer across all of its child companies from Skoda to Audi. Computer support for design reuse in engineering is now a major research area. In knitwear design many texture patterns are re-used to avoid the cost of having to work out the programs for different ones; and new designs are often of combination of elements from many different past designs. Object-oriented programming languages include large amounts of reusable standard code in class libraries. In this case source selection is active, from a deliberately restricted set of options. But it might better be viewed as active selection of subsequent design subproblems. Employing particular existing components often forces designers to redefine the design problem, and generate new design subtasks to find ways to match the standard components to new functions and environments.

Patterns

Designing to solve well-specified problems of many kinds draws on relatively abstract formulations of solution principles, often learned by students as abstractions before they are ever encountered in concrete embodiments. Alexander argues for designing buildings and towns by applying a language of patterns. A pattern comprises a name, a problem that it solves, a solution comprising the elements of a design, and the consequences of adopting the solution. Studies of how programmers program have shown that they recall and adapt skeletal solutions to common problems. This has been systematised and supported by books for software engineers, first with collections of algorithms, and in object-oriented programming by extending Alexander’s concept of patterns to software in the form of descriptions of programming techniques for providing commonly required functionality. Similarly a large part of engineering education is introducing students to standard mechanisms and principles and their scopes of application. Much of designers’ reformulation of ill-structured problems is aimed at imposing decisions about the form of the problems that enable the retrieval and application of solution principles the designers know.

Translation of Sources of Inspiration

Starting points are not necessarily the same type of object as the design. In artistic design fields inspirations are often drawn from a variety of completely different objects or images. Knitwear designers use a wide variety of objects and images: Garments of market leaders or their own past designs; art and craft objects, such as other textiles or fine art; objects from nature, such as shells or fruit; and natural phenomena, such as thunderstorms or sunsets. The Afghan carpet we used in our experimental study of adaptation strategies is a fairly typical source of motifs. Analogies are a fruitful source of ideas in engineering, for example for Unilever’s adaptation of injection moulding of plastics to make chocolate-coated icecream, and sometimes in architecture, for instance Ove Arup’s design for the Kingsgate footbridge in Durham, England, based on the form of a rhubarb stalk.

The Primary Generator

Designs can be inspired by negative forms - the environments into which they fit - as much as by positive forms - examples of similar objects. Darke argues that the designs produced by the archi-
tects she studied were shaped by the aspects of the design problem that are explicit and salient in the architects’ minds when they generate the essential features of their conceptual designs, and that the most prominent aspect of the problem situation is typically the physical characteristics of the site a building is being designed for. In designing components of machines, a rich understanding of the constraints imposed by spatial and functional contexts is essential. The corresponding negative form in knitwear and fashion design is the space of other garments that a new design will be worn with.

Reference Points

Many designers in visuospatial fields like architecture, mechanical engineering, and fashion and knitwear design are very strong visualisers, who find it difficult to think in terms of disembodied abstractions, and who create detailed visual images of designs even when they are considering relatively abstract issues. Engineers doing conceptual design often think about concepts in terms of individual objects that embody them, remembered or imagined in much more detail than they need, when they are concerned with the underlying principles rather than shapes and sizes. Similarly knitwear designers imagine individual designs when considering what types of garments they require in a season’s collection. We have found that that knitwear designers use individual designs (their own and those they have encountered in their assimilation of the fashion context) as reference points, both to think both about new designs, and to express design ideas to colleagues as variants of known designs. Individual designs function as exemplars for a much richer and more subtly differentiated set of categories than can be described in words. Communication breaks down when the references are not recognised.

COMPUTER USE OF SOURCES OF INSPIRATION

Computer systems for design use previous designs and components in various different ways. An important role for computer support tools for designers is identifying and presenting possible sources of ideas. Applications include visual databases of buildings for architects, and component retrieval systems for engineers. Automatic design systems incorporate and exploit knowledge of previous designs in ways corresponding to different human uses of case knowledge. For instance Gero proposes organising design knowledge in prototypes for classes of designs. AI systems can be used not just to produce finished designs, but also to generate sources of inspiration for human designers.

Case-Based Reasoning

Case based reasoning is concerned with the analysis and solution of problems using information about one or several previous cases. It consists of the following steps: (1) assess situation, (2) index target problem, (3) retrieve similar case, (4) assess similarity, (5) adapt case to target problem, (6) assess solution, (7) store solution. Steps (3) and (5) are the core operations of case based reasoning. Case-based reasoning systems have been applied to a wide variety of design problems.

Evolutionary Systems

Systems using genetic algorithms and other evolutionary methods to solve optimisation problems are widely used in engineering, and are being applied to conceptual design. Evolutionary systems make use of previous design experience in two ways: the systems create new designs by combining and randomly modifying previous designs; but the design of the system incorporates experience about how to formulate the problem. The selection and representation of parameters, the combination and mutation rules, and the functions for selecting the best designs, constitute an implicit theory of the structure of appropriate designs, which can be tailored to fit specific requirements.

Generative Systems

Systems using shape grammars (visual calculi comprising sets of rewrite rules for shape elements) have been used to capture designers’ knowledge in the aircraft industry, to analyse stylistic change, and model the styles of architects including Palladio and Frank Lloyd Wright, in product design,
and in structural and mechanical engineering, where grammatical generation of conceptual designs has been combined with evolutionary optimisation. Technical correctness is built into the rule sets. While shape grammars make no explicit use of previous designs or other sources of inspiration in the design generation process, the developers of shape grammar systems use sets of previous designs to guide their formulation of sets of rules.

![Diagram of Design Cycle for Shape Grammars](image)

**Designing through algorithms**

We can view what automatic design systems do as humans (the system developers) designing through algorithms. The transformation of the sources of inspiration (the examples used to create and test the system) into new designs passes through an intermediate representation: the generative algorithm and its parameters. In this type of designing, the designer’s effort and creative thinking is concentrated entirely in the analysis of source phase, while the adaptation phase (running the system) is trivial. In designing through algorithms, the design effort is clearly focused on specifying desired classes of artefacts, rather than on the subsequent process of creating individual members of those classes.

Building generative systems requires making explicit problem formulation, source analysis and generation steps, that for humans are often the application of tacit skills. This makes explicit design choices and ranges of possibility that may only be implicit in a human designer’s habitual procedures. The selection of the range of previous designs that a generative system should generate is critically important, in the same way as the selection of the sources of inspiration that set the fashion context in knitwear design. But by contrast knitwear designers develop an understanding of the space of acceptability by developing a perceptual pattern-recognition skill: repeated encounters with a feature reinforce it as typical, while unusual features stick out as different. While this is a conscious activity, knitwear designers are unable to articulate all their tacit knowledge of what is fashionable.

If we shift our focus from the design to the system that generates it, we see that system developer’s creative activity is isomorphic to scientific theory building. A shape grammar is a theory of the form of a class of objects, created to explain a body of data, that can predict what unobserved members of the class should look like (notably, the Palladian grammar generated a design that its developers didn’t know Palladio had produced himself). Developing a grammar comprises a cycle of inventing a causal structure in a form far removed from the data it aims to explain, and comparing the consequences it predicts against observations. During the development and testing of a grammar new designs are gen-
erated and evaluated. The analysis and adaptation of the source are indivisible and the evaluation returns straight to the analysis of the source. This process is illustrated in Figure 2.

THE IMPORTANCE OF SELECTION AND ADAPTATION

Adapting sources of inspiration is an essential part of creative design in two rather different situations. (A) Under-specified problems, where an essential part of solving them is reformulating them as much more tightly constrained problems that it is meaningful to try to solve; thus implicitly restricting the possible solutions to a manageable range. Sources of inspiration can suggest the form of a problem by suggesting the form of a solution. (B) Well-specified problems that cannot be solved by methods available to the designer. Sources of inspiration can suggest a novel approach by analogy. Both occur frequently in many design processes, and novel solutions depend on designers having wide exposure to potential sources. Under-specified problems tend to occur during conceptual design, while well-specified hard problems often occur during embodiment design and detail design when the overall design cannot be changed to accommodate a standard component. Standard design process models divide design into stages with a clear cut between conceptual design, embodiment design and detail design. However the design of a complex product, such as a helicopter, comprises many nested design process. Even quite late in the overall process, a novel problem can come up which requires a conceptual design approach, for example when testing reveals unforeseen flaws.

Creativity can reside anywhere in the design cycle presented in Figure 1: in choosing the right starting point; analysing a source in a new way; adapting it differently; or evaluating it against new criteria. However, common perceptions of creativity focus on adaptation as the most visible part of design activity. The act of adapting an existing design or other source of inspiration into a new design, by generating a sketch, a formal drawing, or (as in the case of knitwear design) a computer program, is the most obvious output of a design process. Perhaps because the act of generating something is seen as the essential component of creativity, many people conclude that design creativity is a solely human activity; and computer generated design are not seen as creative, solely because they are generated by a computer. This view has far more to do with personal metaphysical assumptions than the quality or novelty of the output. But human design synthesis can have much in common with the actions of generative systems. Routine design involves the application of learned procedures for constructing standard types of designs in standard ways; designers can lose their effectiveness if their procedures become inappropriate in a different situation.

Selection and adaptation cannot be fully divided. Recognising that a particular source can be adapted into an effective and appropriate design involves imagining (some of) that adaptation. This is a matter of luck in some industries, but in knitwear design it is an essential skill. Searching for potential sources of inspiration is a vitally important part of a knitwear designer’s work. Knitwear designers comment that when searching for sources they sometimes immediately translate a source of inspiration into a new design. Indeed the selection of a source often happens through an evaluation of the mental adaptation. The main skill of a knitwear designer lies in a feeling for the context of a new design collection by understanding where fashion will go and what their own target customers require. Many designers, especially head designers and design consultants, never generate any representations of designs themselves, but use their design understanding to guide other designers or technical staff. The creativity lies in finding interestingly unusual and non-obvious regions in the spaces of currently acceptable designs.

Generating a new design can be relatively straightforward. We have found that knitwear designers actively pursue strategies when using sources of inspiration to create designs. Either the source suggests a certain type of design to the designer, or a design element is selected according to the requirements of a plan. The source driven adaptations range from designers picking the most salient feature of the sources and using it as similarly as possible, to re-interpretations of the essential spirit of the design. In knitwear design, adaptation involves the selection of elements within the source as a design is elaborated. In the adaptation process designers apply tacit perceptual skills; in knitwear design they work out details of balance, proportions and colours of design components. As their actions are guided
by perceptual recognition of characteristics of designs and sources that have no verbal labels, designers can rarely express or justify their actions.\(^7\)

In many design processes the selection and adaptation of a source of inspiration are divided between people and are separated by a big time gap. For example in helicopter design, the decision on which version a new design will be based is made during tendering. Different people will adapt elements of it later. It is good practice – though not always possible – to clearly define the interface between different components of the design. Thus the external constraints and requirements for a design are fairly clear (though customers can change their minds). The challenge lies in meeting the requirements starting from the chosen previous design. The creativity is in solving well-specified hard problems.

The contrast between sweaters and helicopters is the contrast between domains with under-specified problems, where the selection of sources of inspiration is central to formulating the problems so that solving them is easy, and domains with well-specified problems, where the creative focus is on adaptation, and where source selection becomes significant when innovative solutions are needed.

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