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## **From Ronchamp by Sledge: On the Pragmatics of Object References**

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### **ABSTRACT**

References to previous designs and other objects play an important role in the synthesis of new design ideas, but object references are used for a wide variety of other purposes in design thinking. This study reports on the roles that object references played in design meetings in projects developing two very different products: a crematorium, and a hand-held device with a thermal print head for drawing on heat-sensitive paper. These roles depended on the moment-to-moment needs of the participants in the meetings, which varied rapidly within meetings, and which were determined largely by the type of product and the state of the project. Almost all the references used were concise identifiers of concepts or features, or exemplars of categories.

## 0 PREFACE TO THE TECHNICAL REPORT EDITION

This paper is a revised version of a contribution to the Seventh Design Thinking Research Symposium, held at the Central Saint Martins College of Art and Design, London, in September 2007, at which over twenty different groups of researchers presented analyses of the same four design meetings – two each in two very different real-life projects – focusing on different aspects of the participants’ thinking and interaction. The meetings, each lasting one and a half to two hours, were videotaped from three or four different angles and transcribed: quotations from the meetings are identified consistently in all the papers by meeting (A1, A2, E1 or E2) and by line number in the transcripts.

The architecture project was developing a design for a crematorium to be built alongside an existing crematorium in a British city. In the first meeting (A1) the architects discussed a design proposal already worked out in some detail with their chief client (the crematorium administrator), who had already had quite a lot of interaction with the architects; the second meeting (A2), some time later, repeated this procedure with a revised design. This project was a little unusual in having a very knowledgeable client with a well-informed understanding of the requirements the building should meet.

The engineering project, within a company specialising in thermal printing technology, was developing a design for a hand-held device containing a thermal print head, for drawing or making other kinds of marks on heat-sensitive paper. The first meeting (E1) focused largely on how the device itself would work and how it should be shaped to achieve successful contact between print head and medium. The second meeting (E2), a few days later, focused largely on what the device might be used for. This project was quite exceptional in that it was developing a product without either precedents (any other hand-held thermal printers) or a well-defined and agreed purpose, so that the designers could not work by adapting or improving any previous product.

## 1 INTRODUCTION

Designing does not take place in a vacuum: designs for new artefacts are powerfully influenced by other designed artefacts, especially similar products. But the public rhetoric of the creative industries, as well as views of the design process widely held by both laypeople and designers, radically underestimates the variety of roles that references to other objects play in design processes. For instance Leclercq and Heylighen (2002) contrast their observation of 5.8 analogies an hour in episodes of architectural design with a prevailing myth of one analogy per architectural masterpiece.

This study examines some of the ways object references are employed in the development of design ideas in meetings. Idea creation by analogical transfer and the fusion of different concepts played a crucial role in the DTRS7 engineering meetings, as in lines 137 and 160-161 of Extract 1. But the uses of object references in the meetings went well beyond the invention of new design ideas.

### Extract 1, E1, Prepackaged analogies; concept fusion; explicit reflection

136	AJ	... what did you come up with Jack
137	Jack	I ended up with a + hold on + sledge
138	AJ	a sledge excellent
139	All	[ <i>laugh</i> ]
140	AJ	so what did that generate then?
141	Jack	well a sledge manages to keep level by having quite a wide base

and  
 142 then a main force in the middle so unlike a set of skis where  
 quite  
 143 narrow and you go up on an edge-  
 144 AJ yeah  
 145 Jack when you're turning  
 146 AJ yeah  
 147 Jack a sledge is er quite broad and then you have the weight right in  
 the  
 148 middle so they manage to keep both runners on the snow-  
 149 AJ yeah  
 150 Jack more often than say a sledge or a snowboard- a skis or snowboard  
 151 AJ so so would you potential see some some some guiders almost  
 down the  
 152 side of this?  
 153 Jack well I guess the easiest way to keep the pen at a right angle  
 would be to  
 154 have a set of stabilisers on it  
 155 AJ yeah  
 156 Jack like a bicycle or like a sledge  
 157 AJ yeah no problem ++ stabilisers +++ like a bicycle yeah that's a  
 good  
 158 idea any other things that that sort of generated? either for you  
 or for  
 159 anybody else?  
 160 Chad I was thinking that sort of maybe like a flat base with a sort of  
 universal  
 161 joint like a windsurf mast  
 162 AJ yeah  
 163 Chad if the face is quite big but it stays flat but the bit you hold onto  
 can be at  
 164 different angles

## 1.1 Procedure

Our aim was to understand how references to other objects function in moment-to-moment design thinking and design discussion, starting from our own observations of object references serving different functions in coarser-grained studies of design processes (Eckert and Stacey 2003b; Eckert, Stacey and Earl 2005), as well as other studies suggesting different ways to look at how designers use analogies and references to objects (Leclerg and Heylighen 2002; Strickfaden 2007; Schunn and Christensen 2007). Beyond looking for occurrences of different types of object references, we did no specific hypothesis testing.

Our method was to identify object references in the protocols by spotting words and phrases referring to 'things' outside the design, classify them according to several coding schemes addressing different aspects of the object references, revise the coding schemes as and when they proved inadequate, and use the classifications primarily as an attention-focusing device in examining how the object references function, rather than for quantitative analysis. The first author did all the coding, with discussion of tricky issues. The coding schemes are examined further when discussing the observations we used them to generate.

We use the term *object reference* to encompass all explicit uses of earlier designs and objects in design processes, without prejudging what these uses are or what exactly the objects comprise. We considered all references to physical objects outside the design itself, unless the surrounding discourse was unconnected to the design, but excluded components of the design, such as power sources for the thermal pen and types of stone for the crematorium. We also collected and coded *implicit references*, where the creation of a new concept combines aspects of the current design with aspects of another conceptual space whose retrieval is not mentioned independently of the new concept. Almost all these implicit references were new potential uses for the thermal pen.

In section 2 we place this study in context by contrasting the different types of studies of the roles of object references. We coded the references for specificity as individuals or categories and in section 3 we look at the range of objects which are used as reference points and sources of analogies. In section 4 we consider how closely the referred-to objects are related to the aspects of the design they are used to develop. We found that classifying the purpose of the reference as idea generation, explanation or problem finding (cf Christensen and Schunn 2007) was insufficient to capture the richness of the purposes of design discourse; so we coded the role the reference served in the discourse separately from what kinds of ideas were being developed. In section 5 we discuss the types of communication through object references we found in the meetings; and in section 6 we relate the communicative and ideational purposes of object references to the types of mappings between mental spaces they involve. In section 7 we examine the types of design information the object references are used to generate.

## **2 METHODOLOGIES FOR STUDYING OBJECT REFERENCES IN DESIGN**

Different methodologies for studying the use of object references provide different kinds of information about design processes and design thinking. Three main research methodologies have been used: experiments on design behaviour in artificial scenarios, close analysis of records of meetings in real design projects (as here), and larger-scale observations and case studies of design processes.

Artificial scenarios remove knowledge of background information and context, especially specialist knowledge of solutions to similar problems affording close analogies. These methods are generally limited to making inferences about universal cognitive mechanisms and processes. Experiments that fix the source objects (for instance Eckert and Stacey 2003a) bypass source-selection processes, and can push designers into more difficult or unnatural transfer processes than they would use in real life. Other research on the role of analogies in idea generation in design has employed experiments allowing free choice of references and analogies, or none, in solving artificial problems (such as Leclercq and Heylighen 2002). In a typical example of this approach, Dahl and Moreau (2002) manipulated the pressure on engineering students to identify and use analogies, and found that the use of distant analogies had a significant positive effect on the perceived originality of their designs.

Ethnographic and observational case studies (for instance Eckert and Stacey 2003b) reveal how design processes are structured and organised, and how the participants themselves see their activities and environments. Such studies can identify types of information and types of thinking that are crucial for important design activities, but skate over the complexity and variety of moment-to-moment thinking. In many areas of engineering design, reasoned comparisons to previous designs and previous projects play a

central role beyond the synthesis of new designs, in process planning, costing, change assessment, the selection of starting points for design modification, and corroborating design proposals. These reasoned comparisons, systematically selected from a small and known set of recent similar designs, function very differently from the spontaneous analogies and comparisons that occur in design discussions.

The close examination of episodes of real life designing embeds the study of individual object references in the rich context of a real project. The strength of this method is that it exposes the variety and subtlety of object references employed in improvising solutions to a wide range of moment-to-moment problems in designing and communicating. An inevitable limitation is that any one situation covers a small subset of the range of problems confronted by different kinds of designers: there is more to be seen in other situations. The problems faced by the participants in design meetings, in both designing and communicating, govern the uses they make of object references. These are very different in the crematorium and thermal pen projects.

The uses we observe in the DTRS7 protocols include some that are absent, or at least not remarked on, in other studies of designers who were concerned with different problems. For instance, Christensen and Schunn (2007) observed 102 explicit uses of analogies over seven meetings held by a design team in the field of medical plastics, and were able to classify the purposes of all of them as: generating solutions, finding problems with potential solutions, or explanation. We found this classification inadequate for the DTRS7 protocols. This is because our participants had different purposes. (According to Ball and Christensen, this volume, the use of analogies to generate new uses for a design, which both they and we observe in the thermal pen meetings, has not been reported previously.) Although any individual study of object references is not 'typical', it is possible to pick out some consistent patterns.

### **3 WHAT? THE RANGE OF OBJECT REFERENCES**

What objects were referred to, and what was their relationship to the design? The vast majority of object references were used to elaborate the designer's understanding of the design problem by creating mappings between the object and some aspect of the design, though the thermal pen and crematorium discussions involved very different kinds of references. A few object references were exemplars of categories, serving to elaborate the categories.

#### **3.1 Abstraction**

Other authors have noted that the analogies used by designers differ in their level of abstraction; notably Ball, Ormerod and Morley (2004) found that in an experiment, expert engineers used more schema-based analogies (activating directly applicable solution principles) and fewer case-based analogies (requiring the construction of a mapping from a solution to a concrete problem to the new situation) than novices. In the present study we looked at a separate issue: how abstract were the 'things' participants in the meetings referred to.

The overwhelming majority of the 70 coded object references in the first thermal pen meeting were to categories of designed objects (55, of which 43 mapped to some aspect of the design), rather than individual designs (8, all mapped to the design) or other things, people or situations. In the second thermal pen meeting as many of the 119 coded references related to information or images the pen might produce (34) or to other

elements of the product-user-environment-activity system (37) as to the thermal pen itself (34), but only 6 were to individuals rather than categories.

The category labels that the designers used were consistently concise ways to name an exemplar concept embodying the feature sets the designers intended to compare or transfer to the design, for instance the windsurfer mast in Extract 1, 160-161. In the cases where more general or precise categories could be described, they would be difficult or verbose to describe. The individual machine designs mentioned are either singleton categories, because unique embodiments of a solution principle (the customised Avro Lancasters referred to in Extract 2, which were at the correct altitude to release their bouncing bombs when two searchlights pointed at the same spot), or unique in the speaker's experience.

**Extract 2, E1, Solution principle with unique exemplar; confirmation and explanation**

- 652 Rodney you could project something onto the paper in front of  
the pen
- 653 Tommy like DAMBUSTERS ( )
- 654 Rodney yeah
- ...
- 668 Rodney I was going to say an optical mouse if you lift it off the page you  
can
- 669 actually see its got the pattern it creates separates into two areas  
so its when
- 670 it's actually on the surface two points meet

However references to exemplars were used to convey category concepts for applications and contexts, when they could communicate object categories more concisely and powerfully than category descriptions. Thus the object reference in "You're never gonna draw a whole pic – you're never gonna draw – paint the Sistine Chapel" (E1, 914-915) indicates the space of artworks beyond the capability of the thermal pen. Similarly, "things like Pac-Man" (E2, 897) communicates the concept of a computer game producing information needing to be recorded in an unforgeable way.

A few object references served as concrete exemplars of already-understood categories. These were suggestions of images the thermal pen might draw (five, for instance "holly leaves" (E2, 776) or text it could reveal (two: "teddy" and "snowman" as characters in stories, E2, 448), which served to elaborate understanding of the space of images the thermal pen *could* draw. The extensive discussion of possible applications in the second thermal pen meeting included several very specific applications, but the only other examples of concrete cases serving as exemplars for larger categories in generative thinking are "go to Jail... Monopoly" and "Snakes and Ladders" in Extract 3 (discussing possible applications of writing not controlled or predicted by the user).

**Extract 3, E2, Generative exemplars, concept fusion, confirmation**

- 614 Stuart could it give you instructions go to jail or something like in  
MONOPOLY
- 615 Sandra yeah
- 616 Tommy erm you could build it into a game
- 617 Stuart SNAKES AND LADDERS or something you've got to have go up a

618 snake go  
 up [laughs]  
 619 Tommy er kind of like CHANCE cards yeah?

The crematorium meetings differed in that a majority (31) of the 57 design-relevant object references were to individual buildings, with 18 to groups or categories of buildings. But these individual buildings were either unique embodiments of particular features, or a succinct way to refer to them, apart from two exemplars of buildings with stained glass designed by a professional artist (A1, 1423-1424). Most of the references to broad classes of buildings – “chicken huts” (A1, 1268), “Tescos” (Extract 4), “Nissen Huts” (A2, 1518) – were intended to convey experiential properties that are the consequences of their overall appearance. Anna the crematorium registrar made several references to the shared characteristics of categories of other crematoria, mainly to point out aesthetic or practical problems with design possibilities.

**Table 1. Targets of the object references**

	Arch One	Arch Two	Eng One	Eng Two
<b>Product itself</b>	21	21	53	34
<b>Other part of system</b>	1	3	4	37
<b>Other obj reference</b>	9	3	9	14
<b>Output of product</b>	n/a	n/a	4	34
Total	30	27	70	119

### 3.2 The range of targets: whatever needs elaborating

Most of the object references in the DTRS7 protocols were related to the product being designed, but the participants in the meetings used object references to elaborate whatever aspect of the design problem was of interest (see Table 1). Of 57 object references involved in design thinking in the crematorium review meetings, 42 mapped to some aspect of the design, 3 mapped to the current crematorium, and 3 were comparisons to previous object references. Three others are shown In Extract 4, where modern crematoria generally are compared to McDonalds and Tescos buildings; then the Nottingham crematorium (shown in a photograph) is compared to McDonalds and Tescos as an exemplar of modern crematoria, to buttress an assertion by providing an illustration.

#### **Extract 4, A1, Emergent properties: categories and category exemplar**

54 Anna no the new ones yeah well that – no I said to you they all look  
 like TESCOS  
 55 but ANDY said to me you know what they look like are  
 MCDONALDS drive  
 56 through and they do they do look like that they look awful look  
 that’s the  
 57 new one up in NOTTINGHAM no inventiveness

Two more references, in Extract 6, elaborate understanding of the context of the design problem, by articulating Anna’s understanding of other people’s understanding of it. The other three design-relevant object references in the crematorium meetings mapped to other parts of the product-user-environment-activity sociotechnical system; two of these were

exemplars of the range of music mourners might ask for. The remaining case is shown in Extract 5. Here the mapping is to users of the crematorium, with difficult interpersonal relationships, interacting with each other in the physical environment provided by the crematorium.

**Extract 5, A1, Human behaviour as part of the system being designed**

- 143 Anna yeah and they sit separately in the chapel as well it's all to do with  
144 money and you know they've left someone something wonderful  
145 that's most of the time what it is or they – the other family are  
cross because  
146 one family has arranged it and they used they never visited her  
while she  
147 was alive and how dare they get involved with this and it all  
escalates  
148 Peter it's like east EASTENDERS [*all laugh*]  
149 Anna indeed I mean yes it can escalate to sort of violence at times not  
here so  
150 far but threats of it at times so the idea that number one we have  
people  
151 for other services arriving perhaps at the same time they want to  
keep  
152 separate families like to keep separate ...

The thermal pen meetings contained a wider variety of references: the discussions of how the device might work or what shape it would be featured object references serving as analogies to aspects of the design itself, as in Extracts 1 and 2. The extensive discussion of what the thing might be used for included references suggesting alternative components of the product-user-environment system: for instance “Monopoly” in Extract 3 indicates both context and purpose, as do “Library” (E2, 918) and “Post Office” (E2, 922). Many of the references were to objects that suggest possible uses for heat sensitive paper, such as Sudoku games with hidden answers (E2, 644); images the thermal pen might draw: “clock” (E2, 539); or alternative heat sensitive media, such as “the cat” in Extract 11, or “mugs” and “fabric” in Extract 10, which we discuss further in section 6.

When the object reference was related to an aspect of the design itself, the context made clear which aspect of the design was intended. The retrieval of referents from memory appeared to be guided by the direction of attention to particular aspects of the design or the product-user-environment-activity system. The designers appeared to use object references to elaborate any aspect of the representation of the design situation that needed it.

#### **4 HOW FAR? SOURCES OF OBJECT REFERENCES IN AND BEYOND THE DESIGN CONTEXT**

Studies of the use of analogies and sources of inspiration have examined the reach of designers' reference-finding using cognitive interpretations of closeness, as conceptual distance from the source of an analogy to the target; and cultural interpretations of closeness, as contextual closeness to the designing situation.



## 4.1 Analogical distance

In experimental research on analogical mappings in design, attention has focused primarily on two issues, what the analogy is for (which we will come back to in sections 5 and 7), and how similar or different the source object is from the target object (see Dahl and Moreau 2002; Casakin 2004). In their *in vivo* study, Christensen and Schunn (2007) divided their 102 explicit analogies into within-domain and between-domain. Our observational work on large-scale engineering design (Eckert, Stacey and Earl, 2005) leads us to the conclusion that there is another distinction that is crucial for how other designs are used to create new ones: between “within-domain” objects, and objects that do the same job in the same way as the new design, so they are candidates for adaptation (other crematoria for a new one; there are none for the thermal pen).

All the 57 object references related to design thinking in the crematorium meetings were ‘within-domain’ in the sense that they belonged to the same category of entity as the part of the design they were being mapped to. These were mostly buildings (49, of which 22 were crematoria). Close mappings to elements of the product-user-environment-activity system included artworks in the extensive discussion of stained glass windows, the groups of people in Extract 5, and stump cameras in cricket (A2, 1317) to corroborate the possibility of unobtrusive static cameras to film funerals. The references, in Extract 6 line 1359, to possible styles for the stained glass window, cite relatively vague category concepts formed from experience of within-domain objects.

### Extract 6, A1, Abstract references for styles

1354	Adam	well what I'd like to do is something contemporary perhaps even
1355		cubist or whatever something that is contemporary and architectural
1356		that has lots of colours in it and maybe I could have a go at that having
1357		just taken on board what you've said and then have a go at that
1358	Anna	yes I mean most people when they think of stained glass they think of
1359		sort of gothic patterns or actual church stained glass ...

The peculiarity of the thermal pen design problem, where no product performing the same task exists, makes deciding what qualifies as ‘within-domain’ rather difficult. The obvious domain is thermal printing technology: The first thermal pen meeting included one reference to a previous design members of the team had worked on, in Extract 7; the second contained eight references to thermal printing technology. Almost all the object references in the first thermal pen meeting were to types of machines (a couple of them fictional), which were the closest or most obvious embodiments of the particular solution principles the references convey, as were the outside-engineering references to gloves and finger puppets. The participants in the thermal pen meetings were adept at retrieving ‘distant’ analogies, such as bicycles with stabilizers (in Extract 1) and aircraft (in Extract 2), that matched aspects of the thermal pen problem at the level of the system of relationships between elements of the situations, when they had the system of relationships in mind to cue the retrieval. These systems of relationships can be quite subtle: consider the discussion of sledge versus skis in Extract 1. This corroborates the structure-mapping view of analogy (Gentner 1983), and Dunbar’s (2001) observation that people perform more impressively in natural analogizing, where they start with the abstract relationship structure, than they do

in laboratory experiments, where they start with superficial features of a situation and need to find the right set of relationships between them.

The first thermal pen meeting included 2 references to other heat producers, including the statement “It could be a soldering iron” (E1, 85), and 16 references to different kinds of pens and marking devices, plus 5 to computer mice and 3 to writable surfaces (in Extract 10). The second thermal pen meeting contained 3 references to heat producing devices, 2 to other kinds of printers, 7 to handheld marking devices, 8 to computer pointer technology, 7 to writable or information-revealing surfaces (including “wet t-shirt” (E2, 247) but not counting imagined applications), as well as many that were outside engineering but within the domain of children’s activities.

**Extract 7, E1, A reference to a previous design**

1539	Tommy	yeah the thing that we did a few years ago which had a kind of sort of – we termed it a
1540		forced balanced print head we tended to do it on fairly wide print heads to try and
1541		keep them in contact with the medium it appears a bit different less
1542		controlled

**4.2 Object references as the shared culture of several communities**

In an investigation of the ‘cultural capital’ product designers bring to their work, Strickfaden (2006; Strickfaden and Rodgers 2007) coded the references design students made in discussions of their projects as ‘local’ or ‘universal’ (that is, shared globally by a community of expertise); and as inside or outside their design environment, that is, inside or outside the knowledge or experience acquired through training and working as a designer, as opposed to the experiences shared by designers and non-designers. Boundaries are hard to draw, but these two dichotomies define four quadrants to categorize the specificity of an object reference to a designer’s local culture. The engineers make references to objects in all four quadrants, though only two references to the company’s thermal printers (in Extract 7 and at E2, 518) and the reference to an alternative proposal for the current design at E2, 548 are Local-Inside. The type of project determines how many Local-Inside references are actually possible; the thermal pen project is extreme in how different the product is from any precedents in the designers’ own experience and thus how little they have to draw on beyond general knowledge. Beyond Anna the crematorium registrar’s arcane knowledge of Britain’s crematoria, applying Strickfaden’s quadrants to the object references in the crematorium project becomes too arbitrary. Our view is that the categories make more sense as dimensions: How local? Which community of expertise? ‘Universal’ isn’t as universal as all that: the cultural capital used by the participants of both the thermal pen and crematorium projects was distinctively British.

Shared understanding of object references depends on life experiences, and is often unpredictable. Tommy’s “Dambusters” reference in Extract 2 made perfect sense to Rodney but confused others in the meeting. The thermal pen and crematorium meetings illustrate the active development of shared cultures within both projects: for instance, the Kimbell Art Museum (A1, 15, 1481; A2, 1364) is a reference point all the participants in the crematorium project are already familiar with; and the discussion of characteristics of another crematorium in Extract 4 is only indirectly related to design thinking, but creates shared awareness of possibilities and requirements. The participants in the thermal pen

brainstorming session were encouraged to look for sources of analogies and bring these to the meeting. Not sharing the necessary reference points can cause serious problems in design processes: we (Eckert and Stacey 2001, 2003b) found that knitwear designers work in a culture that gives them a remarkably uniform set of shared reference points, and that this gives them a means to communicate ideas to other designers by object references that they could not easily communicate otherwise, but their technicians often do not share enough of their cultural knowledge to interpret their designs correctly (Eckert and Stacey 2000).

## 5 FOR WHOM? GENERATION, COMMUNICATION AND CONFIRMATION

Designers use references to other objects, whether as analogies, sources of inspiration, precedents or reference points, both in developing ideas on their own and as tools for communicating ideas to others. We coded the object references according to *whom* they conveyed new information. We found that ‘inventing’ and ‘communicating’ did not cover the ways object references were used in the DTRS7 protocols, so we coded the expressive purpose of the references in the discourse into five categories: Generation (of new ideas), Explanation (of existing ideas), Confirmation, Prepackaged, and Other (just three: two references to the current crematorium building, that helped establish context (A1, 1445; A2, 593); one audiovisual system mentioned as having been recommended by consultants as an example of their work (A2. 1105)).

Where ideas are developed communally, generative and explanatory references are intermixed, and not always easy to distinguish, as in Extract 8.

### Extract 8, A1, Generation versus explanation

492	Adam	if you want to we could puncture the wall with some – some more ++ holes if
493		you like what I’m thinking of is like LE CORBUSIER’S chapel at
494		RONCHAMP I’m not sure if you’re familiar with that but this chapel has some
495		[ <i>begins to sketch</i> ] holes that might have a tiny bit of stained glass in them
496		but might in three dimensions look something like that so that if that’s the
497		outside and this is the inside you got small amount of covered light
498		reflecting itself off the walls

A feature of both the crematorium review meetings and the thermal pen brainstorming meetings was the appearance of several prepackaged analogies: object references that appear to have been generative analogies for the designers working on their own before the meeting, then used as tools for explanations. As Bo Christensen (personal communication) points out, a prepackaged analogy is a combination of Generation (earlier) and Explanation (current); however explicit reporting of a prepackaged analogy conveys information about when and how the idea was generated, plus information about the speaker’s activities. In the thermal pen case, the generation of prepackaged analogies was explicitly requested before the meeting; in the crematorium case, they reflect a lot of earlier

thinking about issues and the development of a shared project culture. Extract 1 illustrates both explicit reflection on the use of analogies and a more subtle purpose: offering the prepackaged sledge and windsurfer analogies to the group for further exploration.

**Table 2. Expressive purposes of the object references**

	Arch One	Arch Two	Eng One	Eng Two
<b>Generation</b>	4	4	37	81
<b>Explanation</b>	19	10	13	19
<b>Prepackaged</b>	4	9	8	6
<b>Confirmation</b>	2	2	12	13
<b>Other</b>	1	2	0	0
<b>Total</b>	30	25	70	119

In the crematorium meetings, explanatory and prepackaged object references predominated, while the large majority of object references in the second thermal pen brainstorming session were generative (see Table 2). But another type of reference played an important role in the thermal pen meetings: confirmations – analogies from the design to an external object, used to confirm that an explanation has been correctly understood. Extract 2 includes both a confirmation reference: “Dambusters” (showing correct understanding), and an explanatory reference: “optical mouse”; as does Extract 9: “paintbrush” and “roller”. Extract 3 includes a generation reference: “Monopoly”, and a confirmation reference: “Chance cards”.

The crematorium meetings, dealing with much more concrete plans and well-understood concepts, contained four confirmation references, one of which is discussed in section 3.2 and shown in Extract 5; two checked understanding of design features: “Dovecote” (A1, 2020), “Coventry Cathedral” (A2, 825); and one checked understanding of an engineering technique: “Albert Hall” (A2, 1200).

## **6 HOW? MAPPINGS BETWEEN MENTAL SPACES**

Many aspects of thinking involve the construction of coherent combinations of mental entities (see Thagard, 2000), and many of these, not just the use of similarities and analogies in reasoning, involve making mappings between different mental spaces comprising different sets of conceptual entities and relationships between them (Fauconnier, 1997). Holyoak and Thagard (1989, 1995) argue that analogical mappings are constructed through a process of constraint satisfaction that optimises similarity, structure (similarity in the system of relationships between features), and appropriateness to purpose; the construction of coherent mappings is extremely fast.

### **6.1 Mappings and expressive purpose**

Observations of the ways object references are used in the crematorium and heat pen meetings reveal a variety of different types of mapping. Classic generative analogies like the windsurfer in Extract 1 involve creating a mapping between corresponding features and relationships in the two situations, then extending the mapping to include matches between elements of one situation to elements that are newly conjectured to be in the other situation (a universal joint to link the print head to the handle of the thermal pen). Confirmation analogies like the “Dambusters” reference quoted in Extract 2 employ mappings that are complete in the sense that the initial mapping between corresponding

known elements of the two situations contains all the information needed for the task – confirming that the mapping is possible – so that no new elements need to be conjectured by analogical transfer. Whether explanatory analogies like “optical mouse” in Extract 2 involve transfer as well as alignment depends on the knowledge of the hearer. A large fraction of the object references in the crematorium and thermal pen meetings are *contrasts* (for instance sledge and skis in Extract 1): mappings between very similar elements force mappings between alignable differences and direct attention to them - often to communicate the point that the way that the design is different from the contrasting situation is important for the success of the design, as in Extract 9.

Many of the object references were simply mapped to some aspect of the design or product-user-environment-activity system. However, some mappings were not binary, but created a more complex structure comprising mappings between three or more objects, as in Extract 9.

**Extract 9, E1, Three-way mapping; confirmation and explanation; contrast**

819 AJ the other thing to think about is in almost all cases when I  
look at pens  
820 the apart from re-wired sort of micropens the the tip is actually  
the  
821 narrowest part of the product whereas in what we're looking at it  
could  
822 actually be as wide or wider  
823 Tommy mmmm  
824 AJ than  
825 Chad so its more like a paintbrush isn't it? like a DIY paintbrush  
826 AJ yeah  
827 Tommy it's more like a roller like a roller yeah

**6.2 Implicit references**

We included in our analysis implicit references where an object is named but only as part of a new possible product-user-environment-activity system: the explicit reference depends on a conceptual combination including elements mapped from an external object. For instance, “thermal wallpaper” in Extract 11 depends on the idea of wallpaper. 6 of the 70 references identified in the first thermal pen meeting and 30 out of 119 in the second were coded as implicit. Almost all were proposals for new applications of the thermal pen (see Extract 11) or alternative components for the product-user-environment-activity system, as in Extract 10. There was only one in the crematorium meetings: “I see it as a spiritual modern art gallery flavour sort of space” (A1, 1389).

**Extract 10, E1, The substrate as part of the system being designed**

129 Sandra is it is it only paper you're thinking about or could it be other  
things like  
130 mugs or fabric or pottery  
131 Jack it could be anything

### 6.3 Novel concepts

A large fraction of the object references in the thermal pen meetings were used to generate new concepts by combining features of the thermal pen with features of other objects or situations, especially new applications for the thermal pen in the second meeting. Most of the implicit references reflected concept fusion.

For instance “lottery tickets” (E2, 183) creates a new concept fusing the structural features of non-forgable marks on heat-sensitive paper with the functional features of a lottery ticket; “Monopoly” in Extract 3 matches a proposed behavioural feature of the thermal pen, that it should generate writing not controlled by the user, with the feature of Monopoly that it involves unpredictable instructions (involving an alignment of elements and relationships to do with performing an action to reveal hidden information), to create a merged concept combining board game with the heat-pen and heat-sensitive paper.

In Extract 10, an analogy is constructed from a component of the product-user-environment-activity system (the heat sensitive paper) to potential alternative components (mugs or fabric) sharing the essential abstract property of having a writeable surface. Substituting the analogous objects creates new concepts: mugs and fabric with heat-sensitive coatings. Several times one object reference creating a fused concept triggered an analogy to another object with similar features and the same relationship to the thermal pen: for instance “Advent calendar” and “branching stories” (E2, 438-443).

Extract 11 shows the fusion of heat-sensitive paper, wallpaper and writing on walls, to create the concept of thermal wallpaper. This involves an analogy between using a thermal pen inappropriately (on the cat) and using a pen inappropriately, to draw on walls – a pen or pencil is part of a mental space contributing to the blend but is not explicitly mentioned.

#### Extract 11, E2, Envisionment of misuse; concept fusion

- 1470 Patrick using it on the cat or something  
1471 Tommy [laughs]  
1472 Tommy yes at least you can't draw on walls and things with this can you  
+ it's just - - on wire  
1473 [laughs]  
1474 Jack that's another point  
1475 Tommy thermal wall paper for kids bedrooms

There is no *a priori* reason why concept fusion of the sort discussed here should involve analogy, in that each mental space might only provide elements to fill roles that the other leaves open, rather than the alignment of features and relationships in both. Nonetheless the cases in the thermal pen meetings all appear to involve some element of analogical mapping between corresponding features. However the “spiritual modern art gallery sort of space” (A1, 1389) appears to create a conceptual combination in the same way as a metaphor.

## 7 WHY? THE PURPOSES OF OBJECT REFERENCES

Most research on the use of analogies in designing has focused on its role in the synthesis of new design elements. But our observations of the uses of other designs as reference points in complex engineering projects shows that object references can play an important part in analytical activities as well (Eckert, Stacey and Earl 2005). Christensen and Schunn

(2007) restricted their analysis of their medical plastics project to clear-cut cases of analogical transfer, and found that all the analogies that weren't used for idea generation or explanation were employed to find problems with designs. In analysing the DTRS7 protocols we chose to be more inclusive, and found that matters weren't quite so simple. We coded the ideation purpose of the object references – what sort of information they were used to produce – as Synthesis or Analysis. Drawing on the set of analytical activities identified by Eckert, Stacey and Earl (2005) in which object references can be used, we divided Analysis purposes into Requirements, Constraints, Functions, Corroboration, Problems, and Use. These purposes are often closely linked, as envisionment of use directs attention to constraints and problems, making it difficult to accurately identify a single purpose in every case; for this reason we are reporting broad patterns rather than counts.

The first thermal pen meeting was dominated by synthesis activities directed to meeting a small number of central requirements and constraints, so the large majority of the object references were used to generate design elements, as illustrated in Extracts 1 and 2. Extract 1 also illustrates synthesis by exclusion: the reference to skis narrows the imagined solution space by indicating what is not intended.

Much of the second thermal pen meeting was devoted to finding possible applications for the thermal pen. We coded object references for this purpose as Analysis of Function, but this activity might be viewed as synthesis by composition of new product-user-environment-activity systems. Unsurprisingly, none of the object references in the crematorium meetings were concerned with analysis of function.

The thermal pen meetings included object references being used in a range of analysis activities, including envisioning the use of the product – Extract 11 shows envisionment of misuse to identify potential problems. (See Lloyd, this volume, for a consideration of how the participants in the meetings discussed potential misuse.) Object references were also used in the analysis of requirements (“like a pen”: an assumption about shape framing a discussion of what controls the thermal pen should have, E2, 988), and for corroboration, that is, using an example of a comparable situation to show that a proposal is feasible (cost of heat sensitive paper compared to fax paper and till receipts, E2, 385-395). There was only one reference in any of the meetings used in the analysis of constraints separate from a discussion of a problem with a particular proposal (a light emitting diode used previously, in a discussion of the limitations of LCDs, E2, 1750). Several suggestions of things the thermal pen might draw appeared in envisionments of use (“fat ducks” and “skinny ducks” depending on how quickly the pen was moved, E2, 147-9).

As the crematorium meetings were review meetings discussing modifications to fairly detailed proposals, uses of references for synthesis purposes, as in Extract 8, were infrequent. Contrasts were used for the analysis purposes of identifying a problem with a design proposal, as in Extract 12; and elaborating a requirement, as in Extract 13 – an amorphous aesthetic requirement clarified by exclusion.

#### **Extract 12, A1, Comparison for analysis: identifying a problem**

- |      |         |   |
|------|---------|---|
| 1154 | Adam    | ... I've always wanted to do a stepping stone                       |
| 1155 |         | type bridge across a pond but maybe this isn't                      |
| 1156 | Anna    | perhaps we can put glass inserts in you know they can it looks like |
| 1157 | Charles | it would be very slippery +++                                       |
| 1158 | Anna    | oh he's poo pooing the idea I don't know but yes it would be        |

nice to  
 1159 have that I don't see that that's a problem but I can see that in  
 the end  
 1160 what will happen it will have to be probably sort of taken away  
 as a – as just a design and /()\  
 1161 Charles /there is one a very\ small one of these there was in erm the  
 winter  
 1162 garden wasn't there  
 1163 Adam was there  
 1164 Charles wasn't there a winter garden in central milton keynes  
 1165 Adam I know the big (common) you mean I didn't know there was a  
 1166 stepping stone running across it  
 1167 Charles there was a stream  
 1168 Adam oh right so you could walk through it  
 1169 Charles there was a stream running across and you came down into the  
 winter  
 1170 garden down the steps and you had to go across stepping stones  
 across  
 1171 a stream and this was to a health club remember and they had so  
 1172 many accidents people twisting their ankles or ( ) that they've  
 actually  
 1173 filled in the gaps between them

**Extract 13, A1, Comparison for analysis: elaborating a requirement**

1607 Adam so you know we could reduce this if you like to make it work but  
 what  
 1608 I was trying to do was to really open up this end of the site to  
 make it  
 1609 more useful  
 1610 Anna yeah well it it needn't also there it's nice 'cause it balances the  
 1611 building doesn't it there's got to be a certain amount of balance  
 1612 between the building and the design features otherwise it looks  
 sort of a  
 1613 bit lost in nothingness around it which is what STEVENAGE has  
 got just  
 1614 two little bays in front of it really they've got this lovely big  
 building  
 1615 and then they've got these two little boxed bays in front of the  
 building  
 1616 which are awful

## 8 CONCLUSIONS

The most striking feature of how the participants in the DTRS7 crematorium and thermal  
 pen meetings used references to other objects is how diverse the references were, both in  
 the range of what was referred to, and in how the references were used to alter the  
 participants' understanding of the design situation. The uses of object references go well  
 beyond idea generation and well beyond classic analogical transfer.



The participants in the meetings covered a wide range of issues in a short period of time, mixing synthetic and analytical thinking. The types of analytical and synthetic thinking they performed were dictated by the moment-to-moment needs of the situation, and their memories for other objects and situations served as a resource for whatever reasoning they were doing. This resource was used both in planned and calculated ways and opportunistically. Object references were used to develop the designers' understanding of the design situation, but depending on need object references were used in constructing the design itself, the requirements it must meet, envisionments of how it will be used or the environment it is used in, and so on. But references to external objects are not ubiquitous: they are absent from the DTRS7 protocols for quite long periods.

Object references were used both as sources of features introduced into mental representations of the design through analogical transfer, and as comparison points. When object references serve as contrasts, the purpose-relevant features of the target are not constructed but already known, but highlighted as similar to or different from the corresponding features of the referred-to object. In some cases this sharpens understanding of the target by narrowing the range of possibilities for what it might be by saying explicitly what it is not.

In the architecture project, two other types of object reference appeared: exemplars of an understood category, used to elaborate and sharpen understanding of its features; and examples of objects with particular features, used to support envisionment of the feature in the new design in analytical thinking.

The participants in the meetings used the most succinct descriptions they could of objects embodying particular features; in the engineering project these were usually fairly general classes of objects, such as 'optical mouse' or 'windsurfer', and references to individual designs were frequently to unique exemplars of particular features – and thus the most succinct category descriptions. The object references were seldom more specific than they needed to be. This corresponds to our observations of knitwear designers' use and naming of garment categories, which is frequently by reference to individual designs (Eckert and Stacey 2000). Which features were intended to be mapped was either clear from context or explicitly stated, so the hearer's attention was directed to the features essential to the comparison. While many of the object references in the thermal pen meetings were 'distant' from thermal printing technology, they were close and obvious matches to the sets of often relatively abstract features and relationships that they shared with the target. What the use of object references in the crematorium and thermal pen meetings indicate is that given a system of relationships between the elements of a situation, people are adept at retrieving matches to it (cf Dunbar 2001).

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