Descriptive models of creative design: application to an example

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Descriptive Models Of Creative Design: Application To An Example

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Abstract The 'creative leap', in which a novel concept emerges - perhaps quite suddenly - as a potential design solution, is widely regarded as a characteristic feature of creative design. This paper is based on an example of a 'creative leap' which occurred during a recorded study of the activity of a small design team. The characteristics and context of this 'creative leap' are reconstructed from the recorded material. The procedures underlying generic descriptive models of creative design are used to provide further insight into the example. Observations are made on implications for computer modelling of creative design. It is concluded that the perceptual act underlying creative insight in design is more akin to 'bridging' than 'leaping' the chasm between problem and solution.

Keywords creativity, creative design, design behaviour, product design, case study

Significant innovations or novel design concepts are often reported as arising as sudden illuminations. This idea of a 'creative leap' has for some time been regarded as central to the design process [1]. Some would argue that all design, by its very nature, is creative. However, there are times when a designer will generate a particularly novel design proposal, and there is evidence that the level of 'creativity' of a design proposal can be reliably assessed, at least by peer-groups [2, 3]. In this case, creative design is related to product-creativity, rather than process-creativity.

In some other fields, the 'creative leap' is characterised as a sudden perception of a completely new perspective on the situation as previously understood. This is the basis of Koestler's [4] model of 'bi-sociation' to explain creative insight. In creative design, it is not necessary that such a radical shift of perspective has to occur in order to identify a 'creative leap'. There might be no unexpected dislocation of the solution space itself, but merely a shift to a new part of the solution space, and the 'finding' there of an appropriate concept. This is what characterizes creative design as exploration, rather than search. Unlike bi-sociation, creative design is not necessarily the making of a sudden 'contrary' proposal, but is the making of an 'apposite' proposal. Once the proposal is made, it is seen to be an apposite response to the given, and explored, problem situation. It creates a resolution between the design requirements and the design structure of a potential new product. The sudden illumination that occurs in creative design is therefore more like building a 'creative bridge' than taking a 'creative leap'.

1 An Example

This example of a creative insight occurring in a design context comes from one of the protocol analysis studies used in the Delft Design Protocols Workshop [5]. In an experimental session, a 3-person team was asked to design a carrying/fastening device for mounting and transporting a hiker's backpack on a mountain bicycle. This device would be something like a special bicycle luggage rack. A 'creative leap' seems to have occurred as a sudden illumination in the team's design process, at a point when one of the team members, Designer J, suggests the following design concept: *'maybe it's like a little vacuum-formed tray'*. This tray idea is quite quickly taken up by the team, and the other members collaborate in developing the concept into a fully-fledged design. Their resulting design is shown in Figure 1.

Figure 1 The team's concept design

The creative leap occurs at about 1 hour 18 minutes into the 2 hour session. It is the first time that a 'tray' has been mentioned, and it seems to provide an immediate focus for the team, who begin to evaluate the concept in a constructive way, identifying the positive features that such a concept embodies relative to the required design features, and developing the concept into detailed aspects. The 'tray' concept just seems to come out of the blue, after a lengthy period of exploration and problem analysis, and provides a pivotal point in the design process, after which the team focuses on developing this concept into their design proposal.

The team's approach to the set task was a relatively rational and systematic one. Very early in the session, they plan a design strategy (Figure 2), which is a variation of a conventional model of the engineering design process. Their design process is based on a model of: 1, Explore the problem and write a performance specification; 2. Generate a range of concepts; 3. Evaluate and select the most promising concept; 4. Develop the concept into a detailed design; 5. Communicate the final proposed design. They allocated a time schedule to their process, allowing about 1 hour for stages 1 and 2, 15 minutes each for stages 3 and 4, and a final 30 minutes for presentation drawings and costings. A member of the team was appointed timekeeper/scheduler, and he made sure that they followed the plan quite closely. The creative leap, which identified a concept for detailed design, occurred right on target, between stages 3 and 4.

Figure 2 The team's design process plan

Records of their own working were kept by the team in the form of sketches on paper, and lists compiled on the whiteboard. They began by attempting to list a 'functional specification' and the problem constraints, and to this was added later a list of features that they intended their product to have. All these items were derived from the brief and related information provided in the experiment. They then developed the problem into three sub-problem areas: 1. the position of the rack device relative to the bicycle, 2. joining mechanisms between (a) the backpack and the rack and (b) the rack and the bicycle, 3. materials for making the rack device. In each case, they explored problems and solutions together, by proposing concepts (sub-solutions) for each sub-problem and evaluating/discussing the implications and possibilities of each concept. That is, they argued from form to function, rather than vice versa.

One of the significant issues that arises in this way is that the backpack's own shoulder straps become hazardous if they dangle into the bicycle wheel. After generating their random concept-lists, the team then review each list to eliminate unsatisfactory concepts and identify their preferred ones. As they go through the pack-to-rack list, the 'bag' concept is stressed as a solution for holding all the loose straps, and then the 'tray' concept suddenly appears:

> I: Bag; put it in a bag; we're gonna need some sort of thing to do something with those straps
>
> K: To get this out of the way
>
> J: So it's either a bag, or maybe it's like a little vacuum-formed tray kinda for it to sit in
>
> I: Yeah, a tray, that's right, OK
>
> J: It would be nice, I mean just from a positioning standpoint, if we've got this (backpack) frame outline and we know that they're gonna stick with that, you can vacuum-form a tray
>
> I: Right, or even just a small part of the tray...
>
> K: Something to dress this (straps) in
>
> J: Maybe the tray could have plastic snap features in it, so you just like snap your backpack down into it
>
> K: Snap in these (backpack) rails
>
> J: It's a multi-function part
>
> K: You just snap in these rails
>
> J: Yeah, snap the rails into the tray there
>
> I: OK
>
> J: It takes care of the rooster-tail problem ...

In this 1-minute segment, we see the key concept, the tray idea, being proposed, accepted, modified, developed and justified. As well as securely holding the backpack, the proposed concept solves two particular problems: the dangling straps problem and the 'rooster-tail' problem - i.e. the water/mud spray (like a rooster tail) thrown up by a mountain bicycle wheel, which would dirty the backpack unless it is protected. The conceptual strength of the tray idea seems to lie in the way it embodies a potential solution form that, once it has been expressed, recognisably satisfies certain key problems and also recognisably can be modified and refined to accommodate other problems and requirements in a satisfactory way. It is an 'apposite' proposal, as defined earlier.

But did the tray idea just come out of the blue? It was certainly the first instance of the use of the word 'tray' in the whole transcript, and from then on 'tray' is repeatedly used as the defining concept for the team's design proposal. (The word 'tray' subsequently occurs 35 times in the last 40 minutes of the transcript.) Possibly related concepts that had been mentioned earlier included references to injection-moulded plastic as a possible material, and flat plastic forms for the rack device. In fact, nearly 20 minutes earlier than the tray idea was first expressed, it's originator, Designer J, referred to a similar kind of rack idea that he recalled:

> J: It looks like everything we're looking at right now is wire-form, but actually a friend of mine suggested a product that he would do - an injection-moulded rack that would kind of like fold down - a couple of years ago...

Another team member, Designer I, immediately responded with recalling a similar device that he remembered:

> I: It's like the little rack that was flat, it had these panels... but these panels were solid, it had little wheels... and it would come off and then it would be like a little trailer

Designer J also suggests another kind of flat plastic panel solution a few minutes later:

> J: I think that a super simple solution - might not be strong enough though - if you can imagine just taking a piece of like propylene or something like that, and diecutting this triangle that you can fold, you know, like a cutout from a pop-up book or whatever, and it bolts on down there, and creates a flat surface... kind of acts as a mudguard too

So ideas related to the device as a flat sheet of plastic, which would also act as a mudguard, were being suggested shortly before appearance of the concept embodied in the apparent creative leap. The significant difference seems to be expressing this concept as a 'tray' - i.e. a flat surface with a raised lip around its circumference. (Proposing this as 'vacuum-formed' was also the first time this manufacturing process was mentioned, but as the concept is developed, the manufacturing process reverts to being injection-moulded.) The 'tray' concept summarises, in an envisionable form, a recognisably good solution, in a way that is significantly different from the potential concept of a 'flat', 'folded', 'panel'. The key difference seems to be related to perceiving a tray as a container (like a bag), whereas the previous concepts had only indentified a flat surface.

As the earlier transcript extract showed, the first emergence of the tray concept seems to be immediately recognised and accepted by the team as a good concept. However, they return to their discipline of checking-off the other concepts that they had generated. But Designer J is careful to insist that the new concept of 'tray' is added to the list:

> J: I think tray is sorta, a new one on the list, it's not a sub-set of bag...

Very shortly afterwards, as they conclude this stage of their design process, Designer J also makes clear his commitment to the tray concept:

> J: I really like that tray idea... I think all design eventually comes down to a popularity contest

The ways in which persuasive tactics are used by members of the team to get their own preferred concepts adopted, such as expressing emotional commitment to them, have been referred to in more depth elsewhere [6].

To summarise how this 'creative leap' emerged, we can see that it draws upon earlier notions that, in retrospect, seem very similar - a flat, folded surface in plastic material - but which lacked the apparently critical feature of 'containment' that a 'tray' has: its generation is perhaps aided by the immediately prior consideration of a more extreme form of containment, a bag; it seems to focus on one particular problem (containing the straps) as the most significant consideration; it is quickly elaborated to satisfy a range of other problems and functions; it is recognisably a bridging concept between problem and solution, which synthesizes and resolves a variety of goals and constraints; and it occurs during a 'review' period, after earlier periods of more deliberately generating concepts and ideas.

2 Descriptive Models of Creative Design

Attempts to understand and to promote creative thinking in design generally focus on a number of techniques and procedures using either free-association thinking (e.g. Brainstorming[7]) or forced associations (e.g. Synectics[8]). A number of descriptive models for creative design has also been developed through research in artificial intelligence. For example, Rosenman and Gero [9] suggested four procedures by which creative design might occur: combination, mutation, analogy and first principles (Figure 3). One other creative design procedure with similar potential has since been added to this list: emergence[10] (Figure 4). These procedures are widely accepted as useful descriptive models of creative design both within and outside the artificial intelligence community.

Figure 3 Demonstrations of the results of the procedures of combination, mutation, analogy and design from first principles, from Rosenman and Gero

Figure 4 Some emergent shapes (below) inferred from a group of three triangles (above), from Gero

2.1 Combination

Creative design can occur by combining features from existing designs into a new combination or configuration. In our example of the 'tray' idea, relevant previous concepts that had occurred in the team's discussion were that of a flat plastic panel and a bag. It seems possible that the 'creative leap' occurred by a combination in the designer's mind of 'panel' + 'bag' to give 'tray' (Figure 5). In this case, 'tray' is not a new kind of artefact (trays already exist), but the combination of 'panel' + 'bag' in the designer's mind could have triggered an association with 'tray', as suggested by Figure 5. In the context of the team's design process, at that particular point, 'tray' was a novel concept.

A more novel concept than a simple 'tray' might have arisen from the combination of 'panel' + 'bag'; for example, a bag with a normal, flexible upper part but a rigid, flat panel bottom (again, such artefacts do already exist). In fact, the team members do go on to propose developments of the tray idea which would have been more novel combinations of 'panel' + 'bag'. Immediately after the initial acceptance of the tray idea, Designer I articulates a concept of a net-like zippered container, which Designer J develops into 'a tray with a net and a drawstring', and Designer K (using analogy) further develops into the net as something like a retractable window blind:

I: What if your bag were big, or, what if your, er, if this tray were not plastic, but like a big net, you just sorta like pulled it around and zipped there, I dunno

J: Maybe it could be a part, maybe it could be a tray with a net and a drawstring on the top of it, I like that, that's a cool idea

I: a tray with sort of just hanging down net, you can pull it around and zip it closed

K: It could be like a window shade, so you can kinda, it sinks back in

I: It retracts, yeah

K: You pull down, it retracts in

J: A retracting shade

In this sequence of the team's dialogue, we see how the initial (possible) combination of 'panel' + 'bag' -> 'tray' becomes developed into a combination of 'bag' + 'tray' which leads to an original very novel concept of a tray with some form of retractable, net-bag container. (The lack of a familiar term to describe this device indicates its novelty.) This would have been perhaps a 'more creative' combination of 'panel' + 'bag' than the 'tray' concept. In the end, the team does not develop the retractable net-bag idea, but adds cross-over straps to the tray as a means of constraining the backpack.

The team seems to know how far to pursue novel combinations, before withdrawing to reconsider and start another line of reasoning. In computational systems it would be difficult to know how to set such a limit; how does a system recognise that a satisfactory, or more-than-satisfactory concept has been created from combinations of previous concepts?

Figure 5 Possible combination of 'panel' plus 'bag' to give 'tray'

2.2 Mutation

Creative design by mutation involves modifying the form of some particular feature, or features, of an existing design. In our example, a mutation procedure might conceivably have happened, transforming a flat panel into a tray (Figure 6). If Designer J was thinking of the inadequacies of a flat panel (e.g. it doesn't securely contain the backpack), he could have thought of putting a raised lip around the edges of the panel, giving rise to the concept of a tray. Designer K's earlier sketch (see Figure 9a, and the discussion of 'emergence', below) may also have been influential in suggesting such a mutation. We do not know what cognitive processes gave rise to J's 'creative leap', but it does seem that a mutation procedure could have generated 'tray' from 'flat panel'.

The difficulty for computational modelling would be identifying which structural features of the existing design to select for modification, and what kinds of modification to apply. In this case, to reproduce 'flat panel' -> 'tray', it would have been necessary to identify the panel edges as relevant features, and to modify them by thickening and/or extending them out of the surface plane of the existing design. The mutation procedure would have to have been based on recognition of the inadequate behaviour of a flat panel in relation to the function of 'containment'.

Figure 6 Possible mutation of 'flat panel' into 'tray'

2.3 Analogy

The use of analogical thinking has long been regarded and suggested as a basis for creative design. We have already seen, in the extract above, how 'window shade' is used as an analogy to help describe (if not necessarily to generate) a concept of a retractable net-bag. The 'tray' idea does seem to originate in close association with the 'bag' idea. Designer J says, 'So it's either a bag or maybe it's like a little vacuum-formed tray, kinda, for it to sit in,' which suggests that he thinks of 'tray' as an alternative to 'bag' for the backpack to 'sit in'. This strongly suggests an analogical procedure 'bag' -> 'tray' (Figure 7), based on thinking of analogues to 'bag' for something to 'sit in', to be contained and carried.

The difficulty for modelling based on analogy is in abstracting the appropriate behavioural features of an existing design. In this example, a bag's behavioural features of enclosing and carrying are apparently selected as relevant, whereas other behaviours such as flexibility are not. Furthermore, it would seem that partial-enclosure (such as in a tray) is more relevant than full-enclosure (as in a bag); about 20 minutes earlier in the session, before the 'tray' idea, J had suggested 'maybe it's a little bucket that it sits in,' but this was ignored by the rest of the team and apparently soon forgotten. 'Bucket' is more 'bag-like' than 'tray', but was apparently not deemed to be an appropriate analogy.

Figure 7 Possible analogy of 'bag' with 'tray'

2.4 First Principles

Designing 'from first principles' is often advocated as a way of generating good and/or creative designs. The difficulties for both artificial and natural design processes are in identifying what exactly the 'first principles' may be in any design situation, and how they may be used to generate design concepts. The example given by Rosenman and Gero [9] (Figure 3) is the design of the novel 'balance' chair from the 'first principles' of the ergonomics of sitting posture. But what are the 'first principles' for 'a carrying/fastening device for mounting and transporting a hiker's backpack on a mountain bicycle'?

Perhaps we see an attempt at design from first principles in the sketch produced very early in the team's session by Designer K. This is reproduced as the left-hand side of Figure 8. K makes this sketch of 'backpack + accessory + bicycle' as though it is a personal attempt to represent the design problem - she does not draw it to the attention of the rest of the team, and it plays no overt role in the design process. However, perhaps it does express the 'first principles' of the design problem, and perhaps it does embody a 'tray-like' solution concept. Designer K later sketched such a solution concept, as discussed below.

Designing 'from first principles' is at the core of any significant understanding of design. It assumes the theoretical position that designing proceeds by identifying requirements, or desired functions, and arguing from these to appropriate forms or structures. It is the abductive leap of reasoning from function to form that is regarded as the kernel of design [11]. But in practice, as we have seen in the extracts from the design team's protocols, and has been suggested by others [12], designers proceed by suggesting 'protomodels' of forms or structures, and evaluating these in order to amplify the requirements or desired functions.

Figure 8 Possible inference of design from first principles

2.5 Emergence

Emergence is the process by which new, previously unrecognised properties are perceived as lying within an existing design. Within the artificial intelligence community it has been discussed particularly with reference to the recognition of emergent, or extensional, shapes within the original, intentional shapes [13] (Figure 4). However, emergent behaviours and functions, as well as emergent structures

[14], are recognised by designers. For example, Designer J apparently recognises the emergent behaviour of protection from the ‘rooster tail’ spray in the tray concept, and adds that as a further validation of the concept.

In our example, it is difficult to know whether the 'tray' idea occurred as a case of emergence. In this context, it is interesting that Designer K had made a sketch quite early in the session (around 40 minutes) of what could be a design proposal which has a strong 'tray-like' resemblance (Figure 9a). As with her possible 'first principles' sketch, K does not publicly offer this sketch to the team, but makes the sketch whilst the other two team members are engaged in another activity. However, the other two certainly become aware of the sketch later, because they both use it (at around 60 minutes) to overdraw on it some different features - Designer J draws some adjustable stays onto it, and Designer I draws the wheels of his fold-down 'trailer' onto it. Designer I had just previously sketched the 'trailer' concept (Figure 9b).

Therefore it would be possible to speculate that 'tray' emerged as a structure from either Designer K's sketch or the previous concept of 'trailer' . However, there is no real evidence for this. If it did, then the emergence procedure would seem to have been one of recognising the box-like structures in the sketches and converting that to a shallow box, i.e. a tray. In anything other than flat-pattern, graphic or decorative design, emergence is not simply a matter of shape recognition. It involves recognising emergent behaviour out of structure, and/or emergent function out of behaviour.

Figure 9 Possible inference of emergent concept from previous representations

3 Discussion

Models of the engineering design process, such as that promulgated by Verein Deutscher Ingenieure (VDI) [15], the German professional engineers' association, propose that designing should proceed in a sequence of stages, like the stage-process adopted by the team studied here. They also propose that the overall problem should be decomposed into sub-problems (as the team did), and then sub-solutions found and combined into an overall solution. This is what the team attempted. However, as in this example, exploration and identification of the complex network of sub-*problems* is often pursued in practice by considering possible sub-*solutions* (i.e. considering the functional implications of form concepts).

In practice, creative designing seems to proceed by oscillating between sub-solution and sub-problem areas, as well as by decomposing the problem and combining sub-solutions. This corresponds to the explanatory model of the design process proposed by Cross [16] (Figure 10). The example considered here illustrates how creative design is manifested in the creation of an *apposite* concept. The appositional nature of design reasoning has been neglected in most descriptive models of the design process.

During the design process, partial models of the problem and of its solution solution are constructed side-by-side, as it were. But the crucial factor is the bridging of these two partial models by the articulation of an apposite concept (such as the 'tray' idea in this example) which enables the models to be mapped onto each other. The 'creative leap' is not so much a leap across the chasm between analysis and synthesis, as the throwing of a bridge across the chasm between problem and solution. Such an apposite 'bridge' concept recognisably embodies satisfactory relationships between problem and solution. It is the recognition of a satisfactory bridging concept that provides the 'illumination' of the creative 'flash of insight'.

Figure 10 Model of the symmetrical relationship between design problem and design solution

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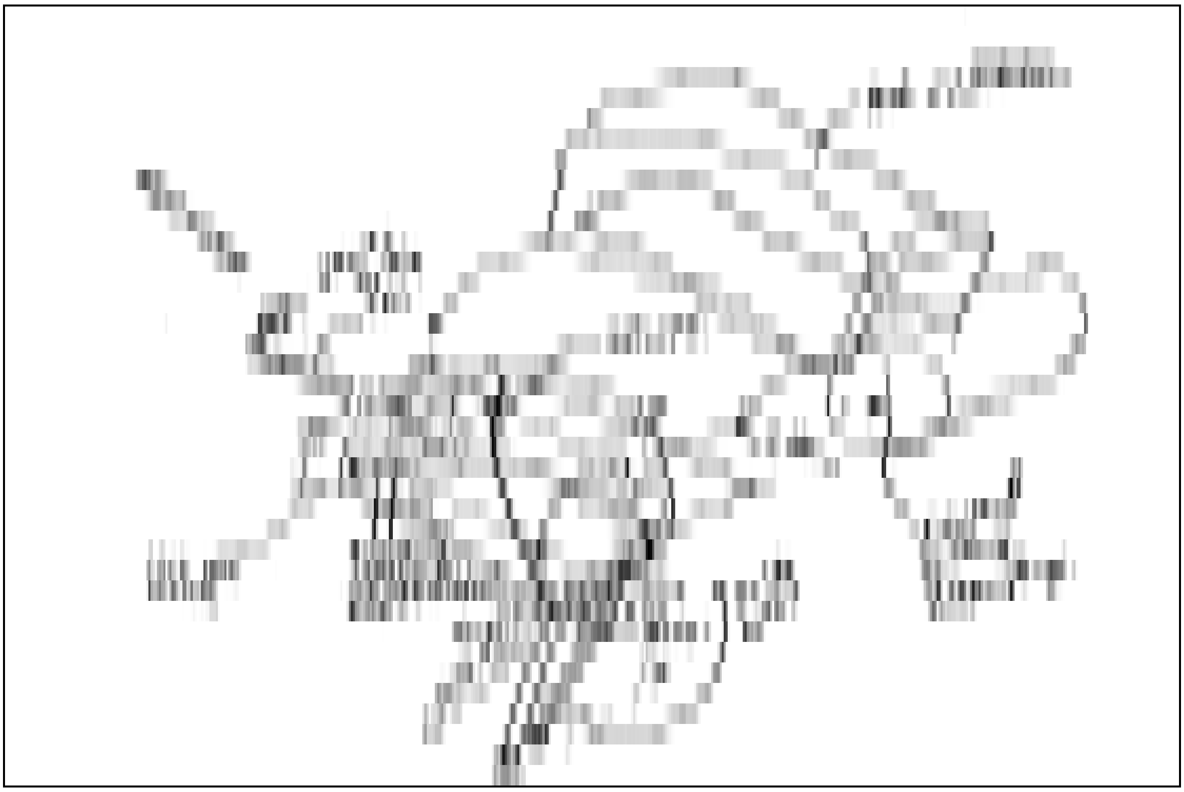


Figure 1 The team's concept design

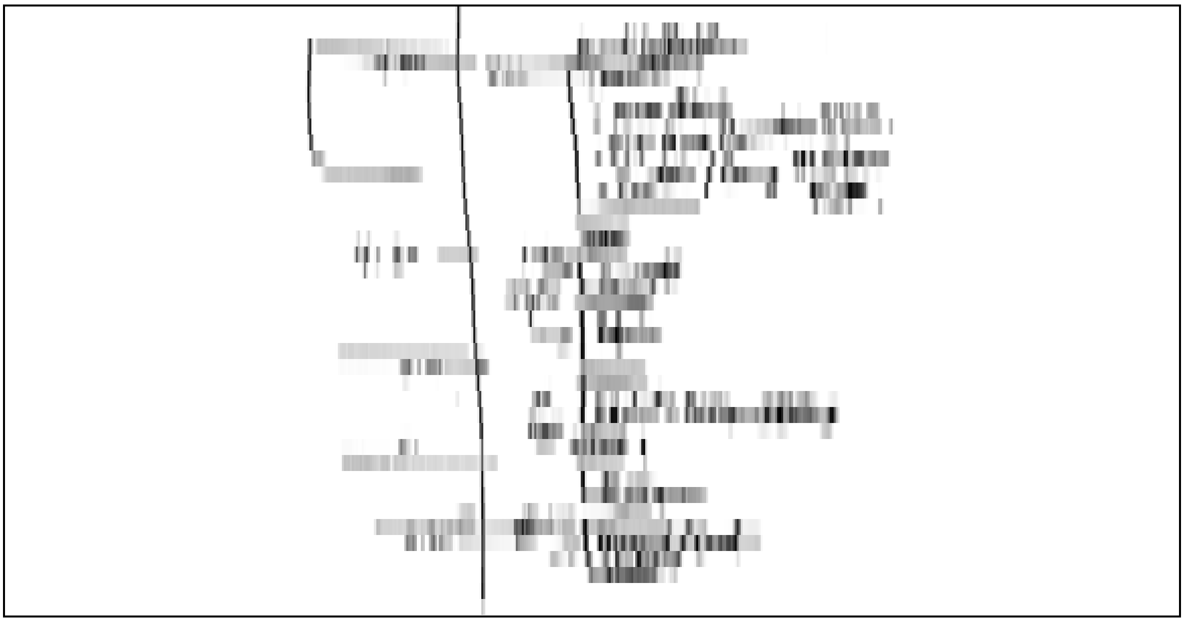


Figure 2 The team's design process plan

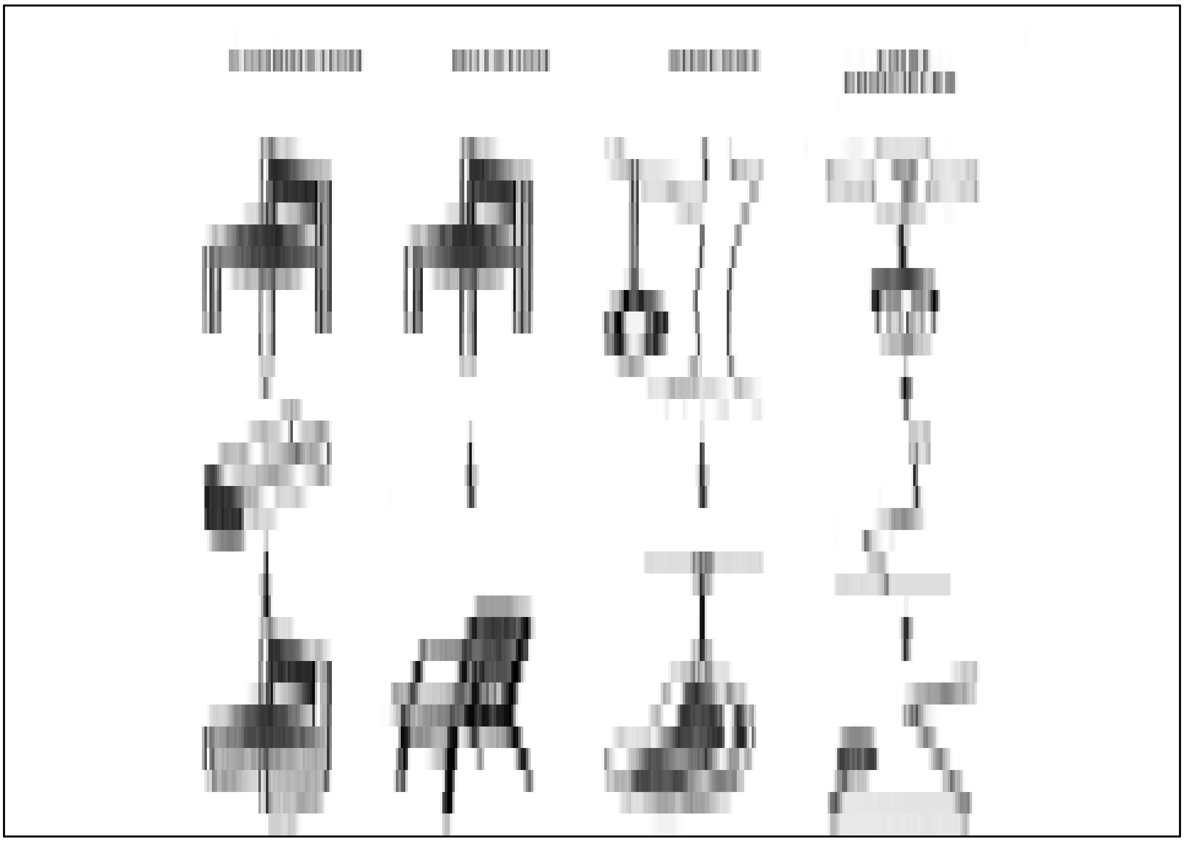


Figure 3 Demonstrations of the results of the procedures of combination, mutation, analogy and design from first principles, from Rosenman and Gero

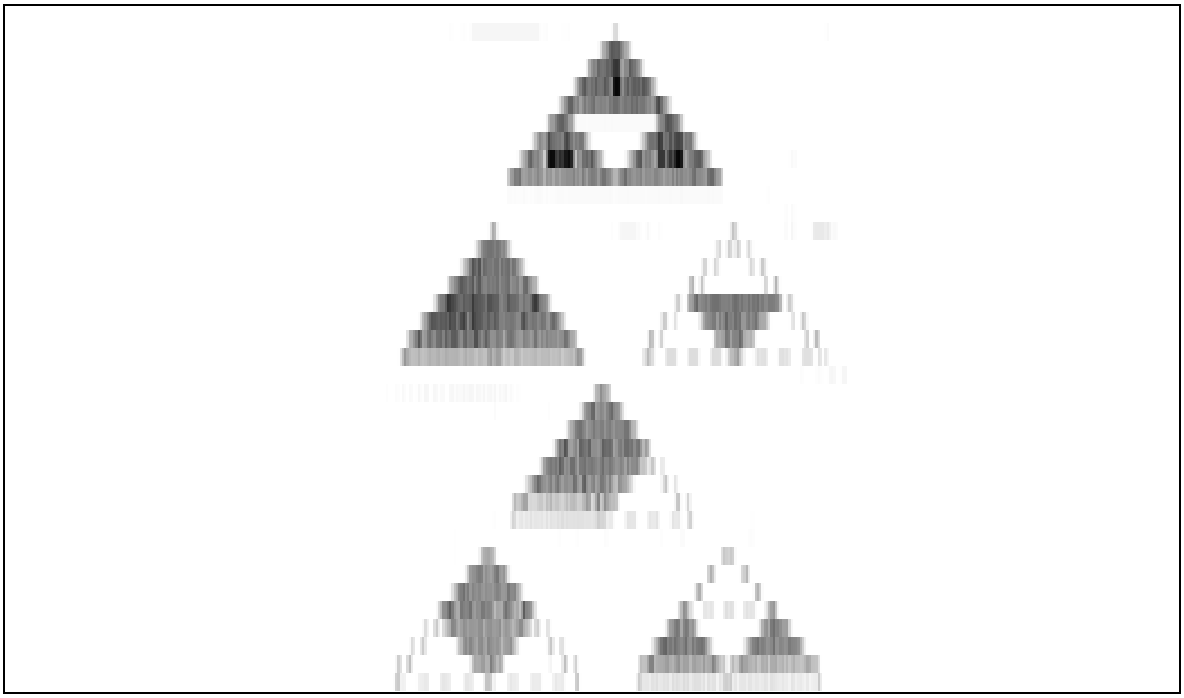


Figure 4 Some emergent shapes (below) inferred from a group of three triangles (above), from Gero

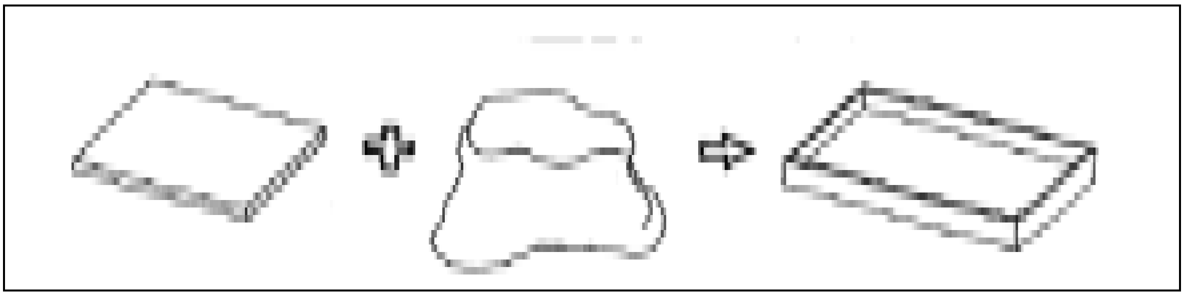


Figure 5 Possible combination of 'panel' plus 'bag' to give 'tray'

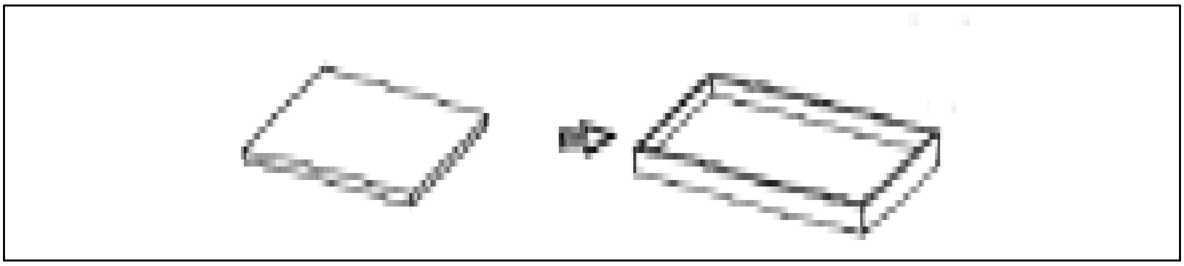


Figure 6 Possible mutation of 'flat panel' into 'tray'

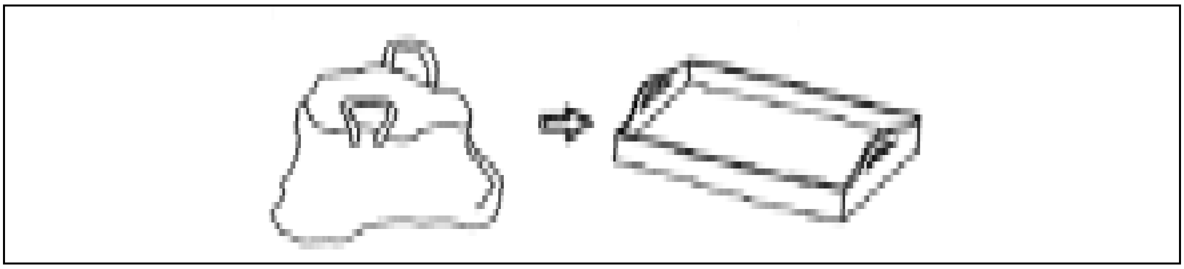


Figure 7 Possible analogy of 'bag' with 'tray'

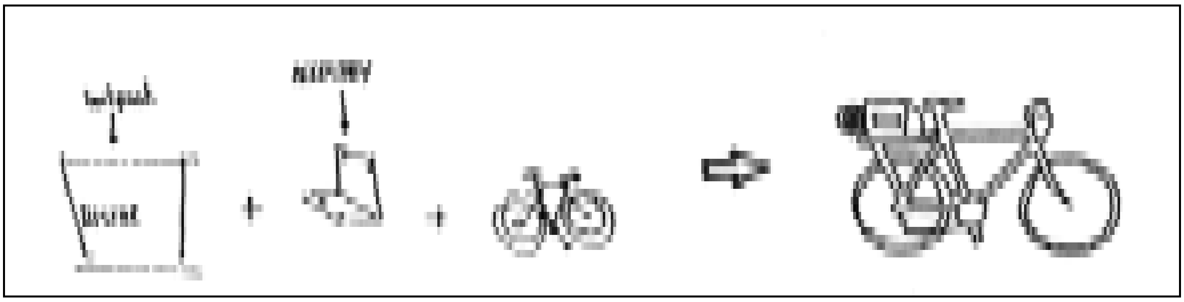
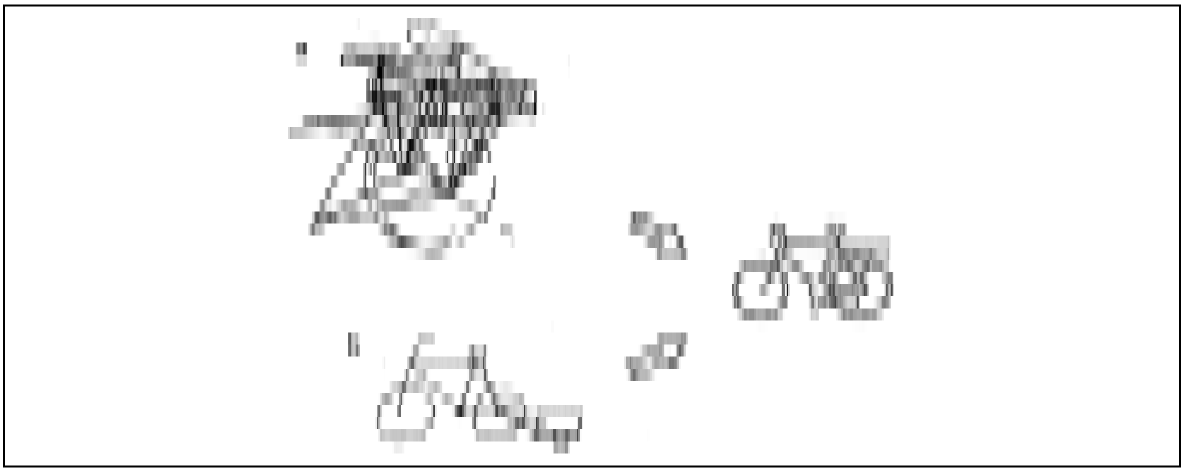


Figure 8 Possible inference of design from first principles



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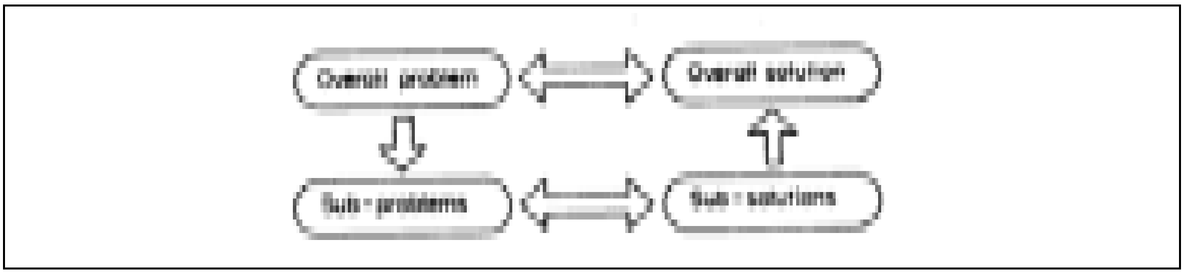

Figure 10 Model of the symmetrical relationship between design problem and design solution