tecnología postindustrial como lo han sido en la tecnología industrial. Las habilidades para generar conceptos originales de solución, para estructurar problemas mal planteados, para manejar contextos ricos en datos y de límites flexibles y para utilizar razonamientos abductivos y aposicionales todavía serán habilidades preciadas en la sociedad postindustrial. La utilización de medios de modelaje gráficos y otros no verbales puede tener un valor menor, debido a los cambios en la tecnología del mismo diseño, pero es probable que aún será parte de las habilidades para manejar imágenes de los «diseñadores».

Donde podríamos esperar cambios significativos, y donde deberíamos comenzar a reciclar a nuestros estudiantes de diseño, es en los movimientos que se alejan de los procedimientos individuales de diseño para acercarse a los de equipo; hacia la utilización de métodos de diseño que apoyan la incorporación de todos los que tienen un interés en el producto; y hacia una responsabilidad más amplia y colectiva de las implicaciones, efectos secundarios y otros resultados de los procesos de diseño.

Design skills: past, present and future

Design and technological change

From earliest times, people have had the creative urge to design. In pre-industrial societies, the activity of designing was closely enmeshed with the process of making. Pre-industrial artefacts were (and still are) created by a craftsperson working directly with raw materials; there was almost no separation of the activities of designing and making as there is for industrial artefacts.

We might say that the pre-industrial craft process contained virtually no «designing», in the sense that we understand the process of design in industrial society. That is, there was no creation of novel forms, no innovation, and no drawing or modelling in advance of making the artefact. Each new artefact was made as a replica of its forerunner. Each specialist craftsperson had an elaborate and very rigid set of rules for the shape of the artefact and of the procedures for making it. The craftspeople had no meta-knowledge of why these rules and procedures had to be obeyed; they only knew that any departure from the rules and procedures was highly likely to result in some failure occurring in the artefact. (This process has been explained in the case of the wheelwright, for example, by George Sturt. See Cross.[1])

Nevertheless, the craft process produced objects which were extremely well-fitted to the functions they had to perform, were complex in form and in the integration of component parts, were derived from and adapted to the available materials and manufacturing processes, and were beautiful. Design theorists such as Alexander[2] and Jones,[3] who have tried to analyse the reasons for the success of the craft process, have suggested that it worked through a process of artificial

1. N. Cross (1985), «The Changing Design Process», in R. Roy and D. Wield (eds.), *Product Design and Technological Innovation*, The Open University Press, Milton Keynes.

2. C. Alexander (1964), *Notes on the Synthesis of Form*, Harvard University Press, Cambridge, Ma.

3. J. C. Jones (1970), *Design Methods*, John Wiley & Sons Ltd., Chichester, UK.

evolution analogous to natural evolution. That is, successful, stable forms were developed over long periods of time by a process of tiny adaptations and retention of improvements.

As with natural evolution, such a process works well only as long as the environment itself remains stable over very long periods. With the Industrial Revolution, the artificial environment of artefacts began to change very rapidly. New materials were invented, new power sources were developed for driving machines, new manufaturing processes were introduced, and new social and technical requirements demanded new artefacts altogether.

To cope with these changes, a new, industrial process of design developed. In this process, designing is separated from making, and design is established as a separate occupation. This process allows and encourages the development of novel forms and new artefacts; it allows certain testing and evaluation of an artefact to be carried out before it is actually produced; it allows the whole artefact to be subdivided into constituent components which can be considered in isolation from each other; and it allows the incorporation of new, scientific knowledge into decisions on the shape, size and materials of the artefact.

Design as we know it, industrial design, is a corollary of industrial society, industrial technology and the industrial production system. The «drawing office» is integral with the factory.

The industrial design process has been relatively static for a relatively long period of time. Principally this is because its own technology has been relatively static. Its own technology is based on the drawing, a very flexible medium with a wide variety of uses in design, ranging from first exploratory sketches to final instructions for manufacture.

But the technology of design is now changing rapidly; changing from paper to electronic sketchpads, from manual to computer-produced drawings, from real to virtual models. Just as the factory is changing from manual to automatic processes, from labour-intensive to capital-intensive production, so too is the «drawing office». The paperless office is already a concept that has appeared in the context of design.

What are the implications of this «automation» of design for the designer? Conventional drawings have served for centuries as the medium for design. The central, essential skill of the designer is traditionally based around the creation and manipulation of drawings as models of designs. Substantial parts of a designer's education are devoted to learning to draw. Is this now a redundant skill? Should designers throw away their paper sketchpads in favour of their electronic ones? Do students no longer need to learn the traditional drawing skills?

We are being forced to reconsider the traditional skills of the designer in the light of the changing technology of design. It is time to take stock of the whole range of traditional skills that the designer employs; not just the manipulative skill of drawing, but the cognitive skills that lie behind it. First, we should try to set out just what those cognitive skills are. We are helped here by the research in design thinking that has been conducted over the past few decades.

Core aspects of design skill

For at least thirty years there has been a slow but steady growth in our understanding of the cognitive skills of design, based on research in design thinking.[4] The research ranges from the more abstract to the more concrete types of investigation, and from the more close to the more distant study of actual design practice. The studies themselves have ranged over naïve or non-designers, through inexperienced or student designers, to experienced and expert designers, and even on to forms of non-human, artificial intelligence. They have gradually developed our understanding of the nature of design ability and design skills.

Of course, designers themselves have their own views about what constitutes design ability, and about the nature of their skills. However, like most skilled people, they do not normally reflect much upon those skills, or try to articulate them. What I would like to do is to show that the more scientific and/or reflective research studies tend to confirm the more intuitive statements that are sometimes made by designers themselves.

Let me start with a quotation which I think is quite well known in architectural circles, a comment by the architect Denys Lasdun:

4. N. Cross, C. Dorst and N. Roozenburg (1992), (eds.), *Research in Design Thinking*, Delft University Press, Delft, The Netherlands.

> Our job is to give the client, on time and on cost, not what he wants, but what he never dreamed he wanted; and when he gets it, he recognizes it as something he wanted all the time.[5]

At first sight, this seems to be a rather arrogant statement by an architect who is prepared to over-ride «what the client wants» because the architect «knows better». I prefer to see it more as reflecting a view that «the problem» («what the client wants») is ill-defined, and the designer finds it necessary to go beyond the problem statement in developing a solution that is something more than merely an adequate response to «the problem». In designing, «the solution» does not arise directly from «the problem»; the designer's attention oscillates, or commutes between the two, as Archer[6] has suggested, and an *understanding* gradually develops of both problem and solution in parallel. So a major part of the designer's skill is in generating novel perceptions of «the problem», as well as novel solution concepts.

Many research studies have confirmed that designers' cognitive strategies for problem-solving are based upon their need to resolve ill-defined problems in this commutative way. For example, Thomas and Carroll[7] carried out several observational and protocol studies of a variety of problem-solving tasks, including design tasks. One of their findings was that designers' behaviour was characterised by their treating the set problems *as though* they were ill-defined problems, even when they could also be treated as well-defined problems, for example by changing the goals and constraints.

The ill-defined nature of design problems means that they cannot be solved simply by collecting and synthesing information, as the architect Richard MacCormac has observed:

> I don't think you can design anything just by absorbing information and then hoping to synthesise it into a solution. What you need to know about the problem only becomes apparent as you're trying to solve it.[8]

This was confirmed in early observational studies of urban designers and planners by Levin[9] who realised that designers added information to the problem as given, simply in order to make a resolution of the problem possible. Levin saw this as like adding a «missing ingredient» to make possible a resolution of the problem.

Since «the problem» cannot be fully understood in isolation from consideration of «the solution», it is natural that solution conjectures should be used as a means of helping to explore and understand the problem *formulation*. Designers tend to move rapidly to early solution conjectures, and use these conjectures as a way of exploring and defining problem-and-solution together. For example, the engineering designer Kenneth Waldron, in comments on an engineering design case study, reflected on the necessity of having some starting point, even though it may later prove to be inadequate.

> The premises that were used in initial concept generation often proved, on subsequent investigation, to be wholly or partly fallacious. Nevertheless, they provided a necessary starting point. The process can be viewed as inherently self-correcting, since later work tends to clarify and correct earlier work.[10]

This is not a strategy employed by all problem-solvers, many of whom attempt to define or understand the problem fully before making solution attempts. This difference in cognitive strategies was observed by Lawson,[11] in his controlled tests of problem-solving behaviour in which he compared scientists with architects, and concluded that the scientists operated a «problem-focused» strategy, whereas the architects operated a «solution-focused» strategy.

The slipperiness of the relationship between problem and solution in designing is also conveyed in the

5. D. Lasdun (1972), in T. Birks (ed.), *Building our New Universities*, David and Charles, Exeter, UK.
6. L. B. Archer (1979), Whatever became of Design Methodology?, *Design Studies*, 1, n. 1, pp. 17-20.
7. J. C. Thomas and J. M. Carroll (1979), The Psychological Study of Design, *Design Studies*, 1, n. 1, pp. 5-11.
8. R. MacCormac (1976), Interview with N. Cross, TV Broadcast *Design Is...*, BBC/Open University.
9. P. H. Levin (1966), «Decision Making in Urban Design», *En 51/66*, Building Research Establishment, Watford, UK (republished in N. Cross, [ed.], *Developments in Design Methodology*, Wiley, Chichester, 1984).
10. M. B. Waldron and K. J. Waldron (1988), «A Time Sequence Study of a Complex Mechanical System Design», *Design Studies*, 9, n. 2, April, pp. 95-106.
11. B. Lawson (1979), «Cognitive Strategies in Architectural Design», *Ergonomics*, 22, n. 1, pp. 59-68.

comments of the furniture designer Geoffrey Harcourt, interviewed by Davies,[12] discussing how a particular design emerged:

> As a matter of fact, the solution that I came up with wasn't a solution to the problem at all. I never saw it as that. [...] But when the chair was actually put together (it) in a way quite well solved the problem, but from a completely different angle, a completely different point of view.[13]

Designers do not, therefore, work by a method of «conjectures and refutations»; their solution conjectures are studied to see if they can be confirmed, rather than refuted. Solution concepts are inspected for their positive features, rather than their negative ones. This behaviour was observed, for example, in early protocol studies of architects by Eastman.[14]

In order to cope with the uncertainty of ill-defined problems, the designer needs substantial self-confidence. It is not surprising, therefore, that this is a central feature of design ability identified by the structural engineering designer, Ted Happold:

> I have perhaps one real talent, which is that I don't mind at all living in the area of total uncertainty.[15]

Designers have to define, redefine and change the problem as given, in the light of the solutions that emerge in the very process of designing. Problem goals and constraints are not sacrosanct, and designers exercise the freedom to change goals and constraints during solution generation, as understanding of the problem develops and definition of the solution proceeds. Where do these new task goals come from? Frequently they come from the designer's own thinking processes —from their experience and from their intuition. When talking about design and design processes, designers often refer to the role of «intuition» in their reasoning processes. The engineering designer Jack Howe commented:

> I believe in intuition. I think that's the difference between a designer and an engineer. [...] I make a distinction between engineers and engineering designers. [...] An engineering designer is just as creative as any other sort of designer.[16]

Similarly, the industrial designer Richard Stevens has commented on the role of intuition in engineering design and industrial design:

> A lot of engineering design is intuitive, based on subjective thinking. But an engineer is unhappy doing this. An engineer wants to test; test and measure. He's been brought up this way and he's unhappy if he can't prove something. Whereas an industrial designer, with his Art School training, is entirely happy making judgements which are intuitive.[17]

Several theoretical arguments have been advanced in support of the view that design reasoning is different from the conventionally-acknowledged forms of inductive and deductive reasoning. For example, March[18] distinguished design's particular mode of reasoning from those of logic and science, and drew upon the work of the philosopher Peirce in identifying the design mode of reasoning as «abductive» in character. March himself preferred to use the term «productive» reasoning for that type of thinking which *produces* a design proposal, but several other authors have taken up and developed the idea of «abductive» thinking as being a key elements of design reasoning (e.g. Roozenburg).[19] Other authors (e.g. Cross)[20] have referred to parallel modes of reasoning, such as «appositional» (in contrast to propositional). The important point is that design reasoning is understood as characteristic to itself, and that inappropriate modes of reasoning should not be forced upon it.

12. R. Davies (1985), *A Psychological Enquiry into the Origination and Implementation of Ideas*, M. Sc. Thesis, UMIST, University of Manchester.
13. G. Harcourt (1985), quoted by Davies, *op. cit.*
14. C. M. Eastman (1970), «On the Analysis of Intuitive Design Processes», in G. T. Moore (ed.), *Emerging Methods in Environmental Design and Planning*, MIT Press, Cambridge, Ma.
15. E. Happold (1985), quoted by Davies, *op. cit.*
16. J. Howe (1985), quoted by Davies, *op. cit.*
17. R. Stevens (1985), quoted by Davies, *op. cit.*
18. L. J. March (1976), «The Logic of Design», in L. J. March (ed.), *The Architecture of Form*, Cambridge University Press, Cambridge, UK.
19. N. Roozenburg (1993), «On the Pattern of Reasoning in Innovative Design», *Design Studies*, 14, n. 1, pp. 4-18.
20. A. Cross (1984), Towards an Understanding of the Intrinsic Values of Design Education, *Design Studies*, 5, n. 1, pp. 31-39.

Finally, let me return to the basic skill I referred to at the beginning —that of drawing. The principal working method that designers use in their work is, of course, the drawing. They use this method early in the design process in a form of simultaneous drawing-and-thinking. For example, the engineering designer Jack Howe said that, when his design thinking gets «stuck»,

> I draw *something*. Even if it's «potty», I draw it. The act of drawing seems to clarify my thoughts.[21]

Schön's[22] studies of designers have reinforced the central role of drawing as a modelling language of design, and of the way solution-and-problem are explored together through this medium. According to Schön, this exploration is almost a «conversational» exchange between the external representation and the designer's internal cognitive model of the problem-and-solution.

Of course, many forms of modelling besides drawing are used by designers, ranging from symbolic, mathematical models to concrete, three-dimensional models. But it is graphic modelling that still forms the core of design skill.

Summary

From this discussion and comparison of designers' own observations with those of design researchers, we can conclude that essential and characteristic features of design ability include the following:

- Proposing novel solutions.
- Structuring ill-defined problems.
- Managing data-rich, open-boundary contexts.
- Employing abductive, appositional reasoning.
- Using graphic and other non-verbal modelling media.

These skills are not exclusive to designers; they are used in varying degrees by most people in many situation. Of course this is inevitable and natural; if they were skills exclusive to designers then designers would be genetic freaks, able to do things that fall outside the scope of most human beings. But designing is not outside the scope of most human beings; design ability is shared by everyone to some degree, even though there may be some people who are recognised as having their design ability more highly developed than most other people.

The end of industrial design?

Design as we know it —industrial design— is relatively young discipline, certainly not more than two hundred years old. The question we face is how industrial design will be transformed as society and technology are transformed from industrial to post-industrial forms. Can we rely on the traditional design skills, or will new aspects of design ability emerge or be developed as new demands are made on designers and the design process?

There have been different interpretation of the concept of post-industrialism, since the mid-1970s. The differences tended to polarise between the «high-tech» vision and the «eco-tech» vision. In the former, post-industrialism meant a form of hyper-industrial technology, based on the information revolution, automation and highly advanced technology. In the latter, it meant a more small-scale, resource-conserving, «convivial» technology. In the former, technology was a virtually autonomous, science-driven force; in the latter, technology was brought under the influence and control of people and communities.

There is no doubt a new paradigm of technology is emerging as we move towards the next millenium. Some features of the new technology are continuations of the old, but we will also see some discontinuities. Some features are generated by the possibilities of technological development itself, whereas others are responses to the problems created by that same technological development.

We have learned that the products and processes of a technology are linked with each other. Pre-industrial technology had its own particular types of products and processes, just as industrial technology can now be seen to have had its own particular types of products and processes. In turn, post-industrial technology will have its particularities which will affect its design processes and the products that stem from it. I have contrasted industrial with post-industrial products and processes in the next comparison table.

21. J. Howe (1985), quoted by Davies, *op. cit.*

22. D. A. Schön (1983), *The Reflective Practitioner*, Temple-Smith, London.

The products of industrial technology tend to be mass produced, standardized goods, whereas in post-industrial technology we can expect products to be flexibly produced and capable of being customized. Industrial products are short-lived, intended to be thrown away after use, and frequently highly resource consuming. In contrast, post-industrial products will be long-lived, designed to be recyclable and resource conserving as far as possible. Industrial products are fragile, whereas post-industrial products will be more robust. Finally, having very limited built-in artificial intelligence and being designed with little understanding of human-machine interface design, industrial products are characteristically stupid and alien, but we should expect post-industrial products to be clever and friendly.

Turning from products to their design processes, in industrial technology the design process is dominated by the individual designer and therefore tends to be individualistic, autocratic and secretive. In post-industrial design we might expect to see this change more towards teamwork and therefore become more democratic and collaborative. In industrial design the process tends to be kept internalized and exclusive to a select few, whereas the post-industrial design process will tend to be externalized so that many more people can be included in it. The industrial design process is rigid, and seeks revolutionary outcomes, but post-industrial designing will be more relaxed and looking for more consistent, evolutionary development. Finally, the traditional design process of industrial technology is already criticized for its «sequential» nature; we can expect post-industrial design to be based on newer, simultaneous procedures.

Comparison of products and processes for industrial and post-industrial design

Industrial design	*Post-industrial design*
Products are:	*Products are:*
mass produced	flexibly produced
standardized	customized
short-lived	long-lived
throw-away	recyclable
resource consuming	resource conserving
fragile	robust
stupid	clever
alien	friendly

Industrial design	*Post-industrial design*
Process is:	*Process is:*
autocratic	democratic
secretive	collaborative
individualistic	team-based
internalized	externalized
exclusive	inclusive
rigid	relaxed
revolutionary	evolutionary
sequential	simultaneous

Conclusion

We have looked at how industrial design as we know it is an inherent feature of industrial technology as we know it; if that technology is going to transform into a post-industrial version, then we should expect design to transform along with it.

It would be simple to dismiss traditional industrial designers as themselves products of industrial technology. However, from analysis of their underlying, core intellectual skills, we have seen that their abilities are as likely to be relevant to post-industrial technology as they have been to industrial technology. Abilities to generate novel solution concepts, to structure ill-defined problems, to manage data-rich, open-boundary contexts and to employ abductive, appositional reasoning will still be valuable abilities in post-industrial society. Using graphic and other non-verbal modelling media may be of reduced value, due to changes in the technology of design itself, but is still likely to remain as part of the image-handling abilities of «designers».

Where we should expect significant changes, and where we should start reskilling our design students, is in moves away from individualistic towards team design procedures, towards open-ness rather than secretiveness; towards the use of design methods that support the inclusion of everyone who has a stake in the product; and towards a wider, collective accountability for the implications, side-effects and other results of design processes.