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Oracles, draughtsmen, and agents: the nature of knowledge and creativity in design and the role of IT

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Abstract

We have been using the term 'computer-aided design' now in architecture for about four decades. But how accurate and realistic is this? Have we really managed to get computers to actually aid creative design and how effective is it? This paper discusses how we support the central creative design process itself. It does this by exploring the implications of what we know so far about the cognitive processes involved in the human design process. It outlines some of the sub-systems we will need in order to develop true comprehensive computer-aided architectural design.

We have had computer-aided design in architecture now for over four decades. During this time, the computer has been used in several quite different roles, some of which will be discussed here. However, so far, the contribution the computer has made to supporting creative design remains patchy and uncoordinated [B.R. Lawson, CAD and creativity: does the computer really help? Leonardo 35 (3) (2002) 327–331]. Why is this and what, if anything, can we do about it? One clue to this is that some four decades ago we also knew very little about the design process compared with our contemporary understanding [B.R. Lawson, How Designers Think, Oxford, Architectural Press, 1997. [2]]. Cerulli, C., C. Peng, et al. (2001). Capturing Histories of Design Processes for Collaborative Building Design Development: Field Trial of the ADS Prototype. Computer Aided Architectural Design Futures 2001. B. de Vries, J. van Leeuwen and H. Achten. Dordrecht, Kluwer Academic Publishers: 427–438.

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1. The computer as oracle

The first serious attempts at computer-aided architectural design put the computer in a far more ambitious role than we would contemplate today. Whitehead and Eldars [3] wrote a program to design single storey building layouts by optimising circulation patterns. Boyd Auger's program [4] for designing housing layouts maximised sunlight and view and privacy. Strathclyde University's programs designed layouts for schools given a timetable of classes. These programs proposed designs with the human relegated to the support role of resolving, tidying and rationalising after the computer had proposed the main ideas. This was the computer as 'oracle', or font of wisdom.

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When tested, the Whitehead and Eldars program was better at optimising circulation than human designers but the best architect beat the computer [5]. The main problem with all such software is not how good it is at doing its job, but that this job is so limited that it is not practically useful. We could conceive of a suite of programs each optimising buildings against individual criteria such as energy consumption, circulation, construction costs, lighting and so on. These programs could never usefully communicate since they have no rational way of trading off all the variables. Such a suite of programs serving a human designer would not be helpful since the task of reconciling their results is no less challenging than the original design task and there is no evidence that in any way such an outcome would be seen as better overall. Of course the human design process in architecture is not a process of sub-optimisation. So the computer as 'oracle' has not so far proved to be helpful and is not likely to do so.

2. The computer as draughtsman

These examples of the computer as 'oracle' preceded all but the most basic and crude computer graphics capabilities. We are by now all familiar with the computer as 'draughtsman'. It almost seems that once we discovered the computer could draw we have become mesmerised by this capability. We still admire computer graphics in almost the same way we that are amused by animals trained to perform human-like tricks. A study of the real use and roles of drawings in the design process rather than seeing them as ends in themselves reveals the computer versions to be rigid, inflexible and lacking in expression.

The geometric modeller is an extension of this draughting role. While this is a way of addressing such matters as consistency and reliability of production information, it has had limited impact on design. Notable exceptions include some very famous names architecturally who have recently been building constructions that would have been impossible or highly impractical without computers. Perhaps the highest profile amongst these is Frank Gehry and his work exemplified by his scheme in Bilbao. Many of Foster's recent buildings involve geometry which would have been almost impossible to resolve without computers. This sort of CAD is coming as close as we get in architecture to CAD/CAM with its ability to set out individual components for steel structures.

So we are seeing a generation of high profile and largely rather expensive buildings that depend upon computers to resolve their geometry, for example, the new opera house in Singapore by Michael Wilford. This is a series of performing spaces surrounded by their circulation that are covered by structures resembling huge glazed upturned kitchen sieves. Such geometry looks simple but is actually extremely complex. Every cell in a sieve is slightly different from its neighbours as the square grid is resolved onto a curved form. In the climate of Singapore, these cells need shading from the tropical sun. Every cell also has its own unique orientation and so is partially covered by a uniquely suitable computer designed shade. Such a task would never have been contemplated without computers.

But why? We are seeing a form of architecture that sets extraordinarily difficult problems which were never in the brief in the first place. Such architecture may be fun and it may create valuable urban landmarks but it is hardly mainstream. Is the computing tail wagging the architectural dog perhaps? Bill Mitchell [6] writing about Gehry's work anticipates this argument and holds out the promise of all architecture working this way in future claiming that, 'architectural practice can be liberated from its increasingly sclerotic conventions'. Whether we would want every building to look like Bilbao and whether every client, programme and site is amenable to such treatment is surely highly debatable!

In universities, we now commonly see students of architecture presenting schemes that are designed to show off their prowess on the computer. Such schemes include spectacular examples of rotations, extrusions, and all the manipulative tricks so effortlessly available in the software. This is the architectural equivalent of documents which had every available font in them which we saw a great deal of when the Apple Mac first came out. The skill of a really good designer of course is to edit out such nonsense. Recently a student in my University gained only a borderline pass for his final thesis design and then won the national CAD prize for the same work! Super-realistic computer renderings carry a sort of credibility in our televisual society which hand-drawn images lack. There is a real danger here. Before computers, the student architect had to learn to draw in order to design and also in order to see and record. It was of course possible that very poor architecture could be presented so beautifully that one was deceived. But the sensibilities needed to draw well and to design well are sufficiently similar for this to happen seldom. Not so now with computers. We are in danger of creating a generation of young architects who are highly skilled with computer software and yet have little visual sensibility.

If the computer software was really well designed and helping us, if it was really computer-aided design, then it would not be necessary to be highly skilled in it. The fact is most of this software is so enormously complex to use that those who operate it are in danger of becoming divorced from those who actually design. This then is the computer as 'draughtsman'. There is now much evidence that the computer is a faster, more reliable, potentially more consistent and more adaptable draughtsman than its human counterpart. This is especially true when graphics have to be repeated or modified or a combination of the two. Such events are so common in the design of buildings that computer-aided draughting looks here to stay for the generation of production and some presentation drawings. But the computer as draughtsman has hardly made any positive impact in creative conceptual design [1].

3. Problems developing a more creative role

What is most disappointing is that this enormous power has not yet yielded advances in thinking about buildings as integrated wholes rather than as sculptural objects. For at least four decades now, we have hoped that we could ask a computer to tell us how well a proposed design would perform in a whole variety of ways. John Landsdown [7] first pointed out that we could have software that was 'ad hoc' or 'integrated'. What he meant here was that you could have a series of stand-alone packages dealing with separate issues such as daylighting, sunlight, view, solar gain, energy consumption, acoustics, route finding, circulation efficiency and so on. Each programme would require its own input but you would only have to describe to it those features of the building necessary for it to do its limited job. On the other hand, you have an integrated suite of packages served by one single comprehensive building model. From the design process point of view, the latter is clearly more desirable. Unfortunately, it carries with it many minor and a couple of major problems we have still not yet solved.

The first problem is that the time taken to input all this information is such that you can really only afford to do it once the design is pretty well finalised. This too is one of the main obstacles to using virtual reality in design. This then is not computer-aided design but computer-checked design or computer-visualised design. The second problem is that when you are designing you need to interact with the representation you are using in a variety of mental modalities. This is in itself a complex problem that I have developed much more fully elsewhere [8] but a summary is necessary here to develop the argument.

3.1. Design modalities

Architects unselfconsciously think about their building in several ways while they are designing. It can be seen as a collection of spaces which may be indoors, outdoors or hybrids such as courtyards and atria. Next it can be seen as a collection of building elements such as walls, windows, doors and roofs. These elements are in themselves problematic to encode since some, like windows, are genuine components fully defined geometrically by their specification. However, others, like walls, may be generic surfaces with each instance geometrically unique and yet sharing a common section. Others may be junction details such as eaves or verges with each instance varying only from the others by its length. Yet again a building can be seen as a collection of systems such as circulation, structure, skin, core, services and so on. Alternatively, we also commonly think of buildings to be comprised of layers such as floor levels or sections. And so on.

When designing, we oscillate without noticing between these descriptions of the building. This is easy and unself-conscious when sketching. However, computer systems invariably demand that we talk to them using their own library of components. Often these are just that, components which must first be described and then positioned. While designing, one seldom thinks that way at least to begin with. So while interacting with a computer system, the designer often has to interrupt actual productive and creative thought by translating all this into the restricted uni-modal computer language. Our research has shown that a multi-modal computer building model is possible and we have written translators between the spatial, component, system and layer modes [9]. These ideas were partially implemented in an early CAD system called GABLE.

These issues turn out to be central in terms of how we think about design. The art critic Adrian Stokes used a lovely distinction between what he called 'modelling' and 'carving' [10]. In this context, I think he would have said our existing CAD systems are 'modellers', and it is interesting that we call them that. Perhaps what creative designers really need are CAD 'carvers'. A carver works with the grain, sometimes literally, but always at least metaphorically. It is a reflective process in which the nature of the material being worked on is an important influence on the final form. CAD modeling systems have none of that quality since they treat all objects as free of the constraints of any materiality. In reality, wall and roof surfaces, courtyards or rooms all have characteristics and beautiful ones are 'carved' out showing an appreciation of their natural language. Some architects are more sensitive to this than others perhaps and Eva Jiricna, who I have studied in detail, explicitly talks of a process of working up through the nature of a material to an understanding of junctions between materials and thus to a grammar of form [11].

There is yet another complexity here which we have only space to register rather than discuss in detail. It is quite clear from our studies of architects in action that they frequently employ what I have described as 'parallel lines of thought' [12]. Quite simply they maintain several more than one set of ideas about their design in parallel and in varying levels of realization and reconciliation. Not only therefore does our modeler need to multi-modal, it also must be capable of maintaining in parallel several versions with the possibility of transferring thoughts and segments of realized designs between these versions. While no existing systems do this adequately, actually developing such functionality is rather less challenging than some of the other issues under discussion here so we will leave it at that for now.

3.2. Design problems and solutions

This illustrates the fundamental theme of my paper here. If we are really to develop computer-aided design, we must first understand the human processes of designing and the methods of mental representation we are trying to support. We now know a great deal more about those processes than we did and yet that knowledge has yet to influence CAD systems significantly. The model implicitly behind much software is that design is a problem solving process that is tackled by procedural knowledge. However, it turns out that this is a very poor model and the human design process is more one of reflective practice that depends upon episodic knowledge. The designer typically works at a representation of the object being designed. Donald Schön [13] has famously described the design process as 'having a conversation with the drawing'. Quite simply we make some marks on a piece of paper and they speak back to us about possibilities and problems. If we study this human process in actual operation, then several of its features are problematic for state of the art CAD in architecture.

Firstly, the process is integrative. In his famous study of why cartwheels are dish-shaped, George Sturt [14] found one reason after another each seeming equally plausible. In fact, this one design idea simultaneously solved problems of manufacture, structural stability, manoeuvrability, and even legislation. Of course this was a vernacular process but the same essential characteristic remains true for the professional process. Take, for example, Denys Lasdun's explanation of the strong horizontal layers or 'strata' as he calls them, which dominate the appearance of his National Theatre in London [15].

'*They support the interior functions while allowing for flexible planning. They provide coherence to a large scheme which is, nonetheless, broken down to the human scale. They give visual expression to the essentially public nature of the institution: for a theatre is a place where human contact is enriched and a common experience is shared.*'

This single Lasdun design idea solves problems of radical, formal and symbolic constraints. We simply do not have theoretical structures that are capable of storing knowledge that leads us from each of these problems to this single solution.

In architecture then solutions and problems map onto each other in messy ways that so far we have been unable to describe formally. This explains why the design process can never be one of sub-optimisation. An architect in creating something as simple as a window is somehow dealing with disparate and unconnected concepts. The window significantly affects the physical dimensions of heat, light, sound and ventilation as well as the psycho-physical dimensions of comfort, glare, acoustics and the psychological factors of view, attention, relaxation and distraction. It is not meaningful to talk of optimisation in terms of many of these factors, but even if it were having a shape, location and orientation for each window which was in turn optimised for all the factors involved would not get you any nearer to a workable design and certainly not to a beautiful one.

This curious relation and messy mapping between problems and solutions in design is one of the reasons why architecture is not only so challenging for the designer but also often so impenetrable for the client. An illustration of this the total lack of connection between the brief and the final design drawings and specifications. How can a client understand why the building is the way it is and check whether it will perform as required? Indeed how does the design team know they have solved all the problems posed by the brief? In recent years we have been trying to tackle this with software that actually records design intentions and rationale during the process and links this to the state of the design. If a CAD system is employed, then the design rationale capture system (ADS) can log the state of the computer model automatically. In our prototype, this was possible with MicroStation. This work represents an attempt to support the creative process by gathering information that is normally lost during the design phases and which frequently causes communication difficulties within the multi-disciplinary design team. With this software each member of the team is able to discover why an element of the design is currently as proposed and which other members of the team might need to be consulted if it were to be changed [16]. At the end of the process, both designers and client can check whether all the issues raised in the brief have been considered. So far of course the software is not able to advise on how well the problems have been solved.

3.3. Semantic and episodic knowledge in designing

Research shows us that expert designers are distinguishable from novices not because they know more about problems but rather because they know more about solutions. Experienced designers tend to use solution-focused rather than problem-focused cognitive strategies [17]. They understand their problems, in as much as they ever actually do, through trying out solutions rather than through abstract analysis. Such a strategy may seem odd but is in fact well adjusted to the situation since architectural problems are never fully defined and their solutions do not exist within a bounded universe of possibilities. A ‘designerly way of knowing’, to use Nigel Cross’s wonderful phrase [18], is heavily dependant on experiential rather than theoretic memory [19]. We should call these ‘episodic’ and ‘semantic’ since they are the terms more normally used in cognitive psychology [20].

Without conscious effort, we recall many events in our lives, and yet we struggle to remember theoretical material for examinations. When I was student of architecture at Oxford we were expected to be able to draw most of the famous buildings of history from memory. We got up to all sorts of clever devices for remembering particular building plans and elevations which I have largely forgotten having not needed to access them for many years. However, I can very clearly remember the pain of study. I can even recall a particular spring day sat in Christchurch Meadow rehearsing with two other students how to draw the plan of Sancta Sophia. I know it involved a clever aggregation of circles and squares but that is the extent of my recall of the actual formula. While most professions rely extensively on theoretical or semantic knowledge, architects are much more reliant on experiential or episodic knowledge. Quite how creative designers make the connections they do remains a partial mystery but surely networked computers trawling the Internet to support this process also remains a neglected potential. Perhaps in the end, the Internet will have far more impact on supporting creativity than we can ever hope for with traditional CAD.

3.4. representations during the design process

Because design solutions are integrative with respect to the problems they solve, the process combines slow reflection with intense periods of very rapid mental activity as the designer tries to keep many things in mind at once. This is why designers normally use a very rapid and flexible method of representation, sketching. Compared with the sketch pad, computer-aided design systems are like chiselling on a tablet of stone. They are just too slow to allow the creative 'conversation with the drawing'. The process of sketching itself is at once highly individual and personal and yet the sketches are often largely understandable by other designers. This implies the need for a system of sketch recognition not dissimilar in its characteristics to the natural language and speech recognition software which is now relatively advanced compared with only a few years ago. Nothing like so much progress has been made on sketching systems although Mark Gross [21] and others have demonstrated some of the kinds of things we need to put in place.

Many expert architects have described their design process as relying on surprisingly small drawings. Santiago Calatrava uses mainly A5 sketchbooks to draw in and A3 pads to paint on. Herman Hertzberger uses A3 pads to design on and communicate with his design team. Eva Jiricna draws on A4, and Ian Ritchie on A4 or A3. Michael Wilford talking of his practice with James Stirling said [11].

'*I like to see things encapsulated in one small image. We have a rule never to draw at a size larger than necessary to convey the information intended...we always use the smallest possible image.*'

If we take the A4 drawing and hold it at arms length as if drawing on it, then the whole of the image remains projected on the foveal area of the retina. This means that the whole drawing is in clear focus without moving the head. Herman Hertzberger gave a clue to the importance of this for him when he said [11]:

'*It's a sort of imperative for me, you know. I insist upon having my concentration on quite a small area, like a chess player. I could not imagine playing chess in an open place with big chequers.*'

Anyone who has tried playing chess this way knows that it is frighteningly easy to 'lose sight' as it were of one of your own or your opponents pieces. This also links with the work of the psychologist De Groot [22], who studied expert chess players. De Groot's work showed that a key distinguishing factor between the chess master and the less expert player was as much in perception as in action. Chess masters, he found, recognised rather than analysed board situations. We are familiar with this in design, the use of known precedents that have been studied by the expert. The expert designer's knowledge is thus of precedents in the form of solutions or parts of solutions that have the potential for solving problems.

Other work on advanced expertise adds to the picture here. Research on the way experts solve problems in physics reveals that they recognise problem situations not in terms of their superficial features but in terms of deep underlying structures [23]. Those of us who did mathematics or physics will recognise this skill. It is the ability to see past the superficial features of problems and recognise their fundamental characteristic which then enables us to use well known theory to solve the problem. In the case of architectural design, however, we have relatively little theory, but rather a store of knowledge that is more based on episodic memory and is more solution-oriented. This may mean not being restricted to building typological knowledge but being able to access useful ideas from other types and even from forms and patterns that lie beyond architecture. A librarian colleague recently expressed surprise that when some architects started to talk to him about ideas for a new university library they showed him pictures of Selfridge's food hall. I told him this was not at all surprising and to prove the point showed him pictures of a British Airways Business class lounge. Both were useful in understanding how a modern library might look and function. As a result of both conversations, he began to become more able to understand the problem and to write his brief.

This then is what expert creative designers do. They make what may look like creative cognitive leaps but are actually normal design thinking. They somehow recognise the deep underlying structures of a design situation in such a way that they are able to use ideas from apparently unconnected sources of knowledge. This is the precious core of creative designing. Drawing is not the end in designing it is the means to the end. Concentrating on drawing will not enable us to make real progress with computer-aided design.

3.5. Design conversations

In fact, while designing looks as if it is done through drawings, much of the thinking is really done through conversations between members of the design team. We have begun to study design conversations which turn out often to give us far more insight into the process than looking at the drawings. At one of our research seminars, a colleague who specializes in computer graphics dismissed this as being irrelevant. "Go into any architects' office", he claimed, "and 90% of what you see will be drawings". "Yes", I replied, "but 99% of what you hear will be words". It is just that those conversations do not get recorded in the way the drawings do. When conducting research on the British architect and ex-president of the RIBA, Richard MacCormac I listened to conversations in his office. In the space of 1 day, three different members of the practice used the word 'belvedere'. Now while this is a perfectly acceptable word, it is hardly in such common usage even in architectural circles. This tells us that the members of this practice were in fact exchanging a hugely complex set of conceptual ideas through a single word. These ideas are of course about design precedents, how they work, are constructed and the potential they have for solving problems. It is only because such complex arrays of knowledge can be summarized and shared so efficiently that creative design in possible in a team. To discuss design creatively with a computer then will require a similarly sophisticated form of conversation.

In fact, we have begun to design computer programs that can hold design conversations as another way of understanding their role in the process [24]. To hold intelligent conversations, the participants need to understand and play a variety of roles. We have identified five roles necessary for a design conversation system which we call; learner, informer, critic, collaborator and initiator. Had he the benefit of our system, Le Corbusier might have told it that 'a house is a machine for living in'. He would have expected the computer in 'learner' role to record this association and to request explanation of any words it did not understand. As a 'critic', the computer might have reminded him of the differences between a house and a machine, perhaps replying "a house has rooms and furniture but a machine does not". In its 'collaborator' role, the computer might have tried to extend or elaborate the metaphor of the house as machine by suggesting that "a house performs functions" or perhaps "a house uses fuel". The computer acting as an 'initiator' might have given a new direction to the discussion by suggesting that "a family lives in a house" thus focusing attention on the occupants rather than the building. In fact, real creative thinking in design takes place in these sorts of conversations, which are very frequently connected to drawings as linguists who have begun to study architects' conversation have established [25]. Kvan and others have shown that graphical images may not always assist design as much as we have previously assumed. Kvan studied architecture students with a control group taught in the normal face to face tutorials compared with a group supported by a text-based web-board. Assessments of the designs produced showed the better work was associated with more use of text to re-describe the design situation. Other evidence suggested that students without graphical communication focussed more on the central issues and less on superficial detail [26].

Understanding design conversation roles and selecting appropriately is part of creative and productive team working and each team has its own style. Clearly our system will require a role manager that is able to learn about this. There are also a whole series of other such reasoning agents needed to make such a system useful such as those to parse and analyse sentences and so on, but these are generally parts of natural language systems that are already being developed elsewhere and which we have no space to discuss here.

4. The computer as agent

So how can we imagine computers helping in this process? Real computer-aided design will support the thinking of designers rather than the superficiality of their drawing actions. It will be more like an 'agent' than an 'oracle' or a 'draughtsman'. In fact, it will need to have a number of key capabilities. It will need to be web-based, intelligent, and capable of learning and being pro-active. It will need to be able to converse with designers in a way that they find helpful. It will need to be able to access a pool of design precedent including that which the designer who it supports has already designed but we envisage it will be connected to the Internet and able to search more widely and therein will eventually be its huge strength and advantage. Again, we see here that it will employ a series of agent-based routines that also are being developed for crawling around the Internet. However, the really difficult part of such a system will be that which allows it to analyse and recognise the deep underlying structures of designs and forms in such a way that they are relevant to the current problem or situation. So far, everything I have discussed here either exists or has at least had feasibility tests on rough development models. It is here however that we have to leap into the future and have some faith in what we will be able to achieve in time.

Imagine the scene. I am sitting at my computer drawing ideas directly into it. As I do so, the sketch interpreter is making graphical sense of the marks I make. The multi-modal interpreter is trying to understand what this means in terms of architecture. This allows me to make changes, for example, either by moving components or by moving spaces. The interpreter will understand all modes and keep building and maintaining a multi-modal model as it goes. The design rationale capturing system is keeping a record of my reasons for making these changes and relating them to the state of the model at the time. The agent-based software is analysing this and looking for patterns. In fact, it is comparing these with huge banks of other projects, some done by me, some by others and many I was not myself aware of. It sifts this information and suggests that I may find some of it interesting. Of course, it has also been working with me for some time and by now has knowledge of the kinds of ideas I find useful and the kinds I do not. It has also learned to know when in the process I am open to interventions and suggestions and when I am not. It knows what conversational modes to use and when. In fact, it behaves like a colleague. But this is a colleague who not only shares and understands ideas that we can name and describe about architecture but has the whole world-wide web in which to search for inspiration.

This would be real computer-aided architectural design. This is the computer as 'Agent'. Perhaps it is part oracle and part draughtsman but it would really assist in creative designing. It deals not so much in the superficialities of drawings and pictures but in the very essence of creative design which is the ideas and meanings that lie behind those images. Eventually this agent may, as it crawls around the Internet, meet other agents also looking after their master's interests. They may exchange information and introduce their masters to each other. They may also help clients or developers to find architects or architects to find new members of their practices.

Of course, this is fanciful right now, but we are building this system piece by piece. So far we have developed prototypical demonstrators of the multi-modal interpreter, the design rationale capturing system, and the conversational system. Much else of what we need is being developed much more generically in terms of Internet agents and natural language systems. Even so, this is an ambitious research agenda. As these pieces gradually become usable, we are finding something else that is perhaps the most important reason of all for trying to develop real computer-aided design. Such systems when put into use enable us to explore and learn far more about what is really going on the heads of creative designers. In fact, they are rapidly becoming amongst the most powerful research tools we have for understanding design.

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