Design

Design is the activity of making explicit proposals for a change from some existing state to some future state which more closely approximates to mankind's concept of the ideal. As such it embraces a wide spectrum of human endeavour; the outcomes of design activity are part and parcel of our everyday life and are determinants, for better or worse, of our man-made future. In common with all complex human functions the activity of design is ill-understood; it involves the most rational and systematic process of human thought and also the most intuitive and conjectural leaps within the human mind.

The design professions are many and varied; they include the engineering professions (mechanical, civil, electrical, electronic, aeronautical, nuclear, naval architecture, chemical, environmental), the architecture profession and the industrial design profession. The educational systems from which these professionals emerge, and the institutes of which they are members are unique, disparate and, sadly, often competitive. Design then, unlike medicine, has as yet no unifying educational or professional corpus; there is a view, however, that from a developing understanding of modelling concepts within the design activity, a unifying view of design may emerge.

Modelling has a long and interesting history; to Tironowski (1975) the single most significant step in the ascent of man was the creation of cave paintings - the first bold attempt to model, for the young men of the community, a future reality as yet outside their experience. In the context of design, model development has taken place at varying rates; the classic example of the successful application of advanced modelling techniques is of course the design of lunar modules; in other fields of design endeavour, some of which are at the core of our everyday existence, the concept seems to be moribund.

It is instructive, by way of example, to consider architectural design. If the architectural historians are correct, modelling found its way into architectural design around the year 2800 BC. Prior to that time the architect or master builder stood on site and directly translated the design concept from his mind's eye into fullscale, three-dimensional reality. By dint of drawing plans and elevations in the sand with a sharp stick, the first models in architectural design, the master builder opened his concepts to critical appraisal and greatly accelerated his productivity.

Curiously, the plan and elevation - virtually undeveloped - continued to be the core model in architectural design over the next 5000 years. Only in the last decade have we seen significant development in architectural modelling; it is the progress during this decade which will be reviewed in the remaining sections of this paper.

Appraisal of design alternatives

Central to the concept of appraisal is the development of a model of the operational behaviour and formal characteristics of the
Computer aided appraisal

Developing the systems model of Figure 1, the CAD activity can be presented as in Figure 2. The designer generates a design hypothesis which is input into the computer (representation); the computer software models the behaviour of the hypothised design and outputs measures of cost and performance on a number of relevant criteria (measurements); the designer (perhaps in conjunction with the client body) exercises his (or their) value judgement (evaluation) and decides on appropriate changes to the design hypothesis (modification).

- **Representation** Representation of the design hypothesis will require to take a form appropriate to the appraisal measures which the software is designed to carry out. It may be simply alphanumerics, or, increasingly commonly, topographics (e.g., a building plan, bridge elevation, printed circuit layout, mechanical image); it is the interface between the designer's mental model and the computer based model and, as such, is the focus of the man-machine exchange.

- **Measurement** The software model of the operation and form of the design artefact
which exists within the computer must be capable of interpreting the input representation and applying known algorithms which model aspects of the design’s character and behaviour. Output measures of cost and performance may be wholly descriptive (e.g., building plan area, maximum bridge span, number of circuit modes, lengths of linkage arms), wholly predictive (e.g., capital cost of plan layout, deflection profile of the bridge span), or an appropriate mix of descriptive and predictive measures. Additionally, it may be advantageous to have the software effect a visual transformation of the input representation, to output additional views of the design hypothesis (e.g., a 3D perspective of the building plan or bridge).

- Evaluation Profiles of the cost and performance characteristics which are output by the computer, supplemented by further views from the information base on which the designer acts. Evaluation of a profile of measures on disparate or conflicting criteria can be undertaken only by the application of value judgments relating to the perceived needs of the client/user body and of society at large. Introduction of CAD models does not obviate the need for evaluative decisions. Indeed, by making the information base explicit, CAD models throw into sharp focus the subjective aspects of the design decision-making activity. In some instances, the brief for the design problem may express certain upper and lower limits of acceptability for some or all of the cost/performance characteristics, against which the profile may be judged. Increasingly, however, it is recognized that such a priori constraints cannot be set sensibly in ignorance of the casual relationships between the elements of the cost/performance profile. For example, the requirement to achieve a minimum of 2 percent daylight factor in a school plan may result in an unacceptably high energy cost for heating. In effect, if a priori cost/performance specification is a meaningful concept, agreement on its form is likely only to emerge from extensive and controlled explorations using the CAD model.

- Modification Any design hypothesis embodies a unique set of design variables. For example, a plan layout has a particular floor area, shape of envelope, topological relation of spaces, etc. Each design variable contributes, to a greater or lesser extent, to the behaviour of the design as a whole and hence to the cost/performance profile. If, from the evaluation of the profile, it is considered that, for example, the level of daylighting in some rooms is unacceptably low, the designer must decide in respect to which design variable the overall design hypothesis must be modified. Improvement in this aspect of performance may be achieved by modification of any one of several design variables; moreover, a change in any particular design variable is likely to affect not only daylighting but many (if not all) of the other cost/performance characteristics. The nature of the casual relationships between each and every design variable and each and every cost/performance variable is not, unfortunately, known a priori, but must emerge in the process of iterative use of the CAD model.

It will be seen, then, that if the representation and measurement modules of the design system can be set up and made available, the processes of evaluation and modification take place dynamically within the design activity as determinants of, and in response to, the pattern of exploratory search. This mode of
The current state of the art

Despite the complexity of the design decision-making process the emerging new generation of computer-based models is already having an impact on how design is performed and, hence, on the quality of design. The impact stems from the fact that the new models, as opposed to paper-based plans and elevations or other conventional forms, are predictive rather than descriptive; dynamic rather than static; explicit rather than implicit; and, above all, permit a more-or-less quantitative and instructive assessment of the effects of a developing design on cost and performance.

Evidence is growing of the advantages offered by the application of computers to design, and these can be summarised as follows:

* Widening the search for solutions

Access to programs which dynamically predict the cost and performances characteristics of optional design proposals can increase the scope of search for good solutions by as much as ten-fold. Not only is the search coverage extended, it is also more purposefully directed because designers are able to compare the quality of any one tentative solution against the quality of all previous solutions.

* Greater integration in design-making

In conventional working, a great deal of design time is lost as proposals are passed to and fro between the architect (who tends to be the originator) and the other specialist members of the design team (who tend to be the "checkers"). Quite frequently, the scheme on which the architect has lavished time and effort is found by one or other of the specialists to be infeasible. With access to appropriate appraisal techniques embodied in computer programs, it is possible to check a proposal against a wide range of criteria from the outset of the design activity. Moreover, it is entirely practical (though not yet a widespread working method) for all members of the design team to have access to, and operate on, the common design model whether or not they share a design office. The models, then, can provide a strong integrating force in design team working.

Improving design insights

Apart from the use of appraisal programs to search for better designs, the program can be used in a research and development context to provide insights into the way in which particular design decisions affect cost and performance. Typically, a designer working in this mode would select an existing building for study, then, keeping all other design variables constant (so far as this is possible), systematically vary one factor while recording the cost/performance output from the program. In this manner, the architect can establish sets of causal relationships which provide powerful insights into the structure of design decision-making.

Differentiation of objective and subjective judgements

Contrary to the early fears of many architectural practitioners, the use of CAAD techniques focuses increased attention on objective value judgements rather than less. As measurable attributes of optional design are made more explicit, the necessary value judgements are forced to the surface of design activity and thereby, by themselves become more explicit. The effect of this is to make it clear to designers and their clients, which...
judgements are based on quantifiable criteria and which on subjective and intuitive concepts. If we are to identify the contribution of CAAD to the achievement of sustainable environments we need to have some view of what sustainability in the context of the built environment actually means. For the authors, the necessary and sufficient conditions are:

- Fitness for Purpose(s)
  Over the life span of the building the needs of the client/users may change significantly. It is important, if a building is to be sustainable over its life it must be sufficiently adaptable to fit these changing requirements.

- Cost-Beneficial
  The benefits which the client/users get from the building must justify the initial capital cost of the building plus the very considerable set of running costs over its life span.

- Culturally Significant
  Those which survive longer than the typical life span often do so because they have become an icon of the culture of the period in which they were built.

- Environmentally Friendly
  As indicated above, buildings are major consumers of energy and, therefore, major contributors to environmental pollution.

Specific contribution to modelling of the energy behaviour of buildings

If we look at the energy delivered in Western Europe in any year we see that 9% is attributed to iron and steel production, 21% to transportation, 16% to agriculture, 16% to the manufacturing industries and 52% - more than all the other demands put together - is consumed to maintain acceptable environmental conditions within our building stock. The quadrupling of fossil fuel prices since 1978 has brought the recurring expenditure on energy in buildings in the UK to a staggering £12 billion Euro per annum.

Estimates by the UK Department of Energy suggest that better design of new building could result in a 50% reduction in energy consumption and that appropriate design intervention in the existing stock of building could yield energy reductions of 25%; take together, and universally applied, these initiatives could reduce the UK energy bill by up to £3 billion Euro per annum.

In response to this imperative, research and development took place in a number of leading academic institutions around the world. Shavit at the Technion initiated a highly productive programme of research and development since then, producing application software for use both in the design studio and in practice. Building progressively on earlier work she had by the late 1980s developed an integrated knowledge-based CAA system for the design of solar and low energy buildings (Shavit, 1991) in which it knowledge base, which contains heuristic rules, in conjunction with a simulation model, guides the (student) designer through the decision-making process.

Milne (Milne, 1990) at UCLA, has also maintained a major effort in the development of computer-based “design tools” for energy efficient buildings. He defined a design tool as “a piece of computer software that has an easy-to-use interface that allows the manipulation of the buildings three-dimensional representation and that shows the potential of the architect something useful about the performance of the building...” His signal contribution was two-fold:

1. Integration of both heating and lighting (both natural and artificial) into the energy appraisal.
In 1988 the launch of a spin-out company, originally known as ABACUS Simulations Limited and now known as Integrated Environmental Solutions (IES). IES has an international client base of progressive architectural and engineering practices engaged in the design of some of the most innovative and sustainable buildings worldwide.

In conclusion

Sustainability is, the authors believe, the most important current paradigm in architecture; it encompasses fairness, commodity and delight. It is easy to recognise – in the buildings which remain from previous times and which still fulfil a purpose or delight us – but seriously difficult to deliver to future generations.

Delivery of sustainability will, we believe, depend on our ability to represent, simulate, visualise, and experience our future environments.

References