Disjunctions and Opportunities—Architectural Science and the Design of the Interior Environments of Buildings

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INTRODUCTION

In *Architecture and the Crisis of Modern Science*, Alberto Pérez-Gómez (1983) described what he termed ''the prevalent obsession with mathematical certainty in its various forms'' and how contemporary architects found it ''difficult to reconcile mathematics' demands for invariance … with their conception of architecture as an art rather than a science''. He went on to describe the split between ''truth [as it is] demonstrable through the laws of science [and] 'reality', which is always ambiguous and accessible only through the realm of 'poetics' …'', and (more particularly) the split between architectural theory and practice, between thinking and doing. He argued that ''the conceptual framework of the sciences is not compatible with reality'' and that ''the belief in the symbolic richness of the external world [had been] replaced by the notion … of the material world as a mere collection of inanimate objects''. His extended discussion focussed on geometry, proportion and measurement, and on design efficiency and functionalism, but the underlying hypothesis has a much broader applicability that remains relevant and thought-provoking 20 years later.

However, while Pérez-Gómez was writing his book, other developments were occurring with the potential to significantly influence architectural practice. Architectural science gained momentum as a discipline and underwent a major change of focus from structural innovation to the design of the interior environment (Cowan, 1978); fuzzy theory emerged as a new division of mathematics that was able to deal with ambiguity and imprecision (Zadeh, 1973); information technology developed to the extent that high computing power accompanied by small component size not only made desk top computers possible but enabled sophisticated electronic controls to be incorporated in many pieces of equipment; and the widespread use of such control systems led to the concept of ''intelligence'' being seen to be capable of residing not only in individual equipment or the overall management system of a building but also in the fabric of the building itself (Harris and Wigginton, 2000) and its furniture and fittings.

Each of these developments will be summarised and evaluated in terms of the way it either exacerbates the disjunction of theory and practice or opens up opportunities for reuniting them. In particular, the implications for architectural research, education and practice will be explored.

COMPLEXITY AND IMPRECISION IN ARCHITECTURAL SCIENCE

Robert Venturi (1966) has made a distinction between complexity of means and complexity of goals. He has noted that many simple goals can only be achieved by considerably complex means while simple means may be sufficient (or may be all that is available) to achieve considerably complex goals. He suggests that engineering projects may fit into the former category while architectural aspects of building design are more likely to fit into the latter. Examples are easy to find. The relatively simple goal of a long structural span might be achievable only by complex and sophisticated structural analysis and technology. On the other hand, the purpose of qualitative aspects of interior environment design (such as the thermal environment, lighting and acoustics) is often complex and inherently ambiguous but the means available to achieve them are relatively simple. The trend in architectural science through the 1960s and 70s from structural innovation to the design of the interior environment of buildings might therefore be seen as one where the focus of architectural science research shifted from the development of complex means to the development of an understanding of complex goals and of ways to achieve them. Sadly, the evidence suggests that studies of people's interactions with their physical environment have either overlooked or suppressed the complexity of the real situation when setting up laboratory-based ''simulations''.

Part of the responsibility for this might be the dictum expressed by Sir William Thomson (later to become Lord Kelvin) 100 years before Pérez-Gómez's book, and frequently quoted by architectural scientists in the 1970s. Thomson (1889) said:

> ''When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *science*, whatever the matter may be'' .

This statement, or equivalent others, seems to have guided much of the research into people's interactions with the thermal, luminous and acoustic environments.

For example, Petherbridge and Hopkinson's (1950) studies of conditions influencing people's experience of glare and visual discomfort employed trained observers (eventually reduced to just six who were found to ''make consistent appraisals under constant conditions''), under idealised conditions with no specific visual tasks. This was done to keep the physical factors under control and confine the work to easily reproducible conditions. How 'subjective' the appraisals made by the observers could be, given the circumstances, can only be conjectured. The authors went on to say that the studies

> ''...were directed more towards an extended knowledge of the relationship between the various physical factors which govern discomfort from glare, rather than towards prescribing the precise values of these factors associated with any specific degree of discomfort. The results are therefore not a substitute for experience in lighting practice, but serve more to assist the quantitative interpretation of this experience.''

And yet these results, with successive modifications as to how they are combined into a 'glare index', have come to be used by some as just such a substitute.

Subsequent research (Markus, 1974) has suggested that people do not have a shared concept of glare and that the perception of glare is very much context-dependent. The complexity of factors that will influence the likelihood that someone will experience discomfort glare is too high for any reliability to be attached to a glare index as a consideration in lighting design. Lighting researchers, however, seem to have forgotten (or to be determined to ignore) the comments of Petherbridge and Hopkinson. Lighting *quality* has now appeared on research agendas, and it is clearly a subjective and potentially highly complex concept — as yet, only very general definitions of lighting quality have emerged (Veitch et al., 1998). Nevertheless a technical committee has been established within the CIE to explore possible correlations between quality and photometric quantities. We are at risk of having a 'quality index' as the outcome.

Thermal comfort is another aspect of people's interaction with their environment to have been explored in laboratory-controlled conditions, in this case in a climate chamber that was distinctly unlike any real-world setting. Fanger's (1972) seminal studies in Copenhagen led to a 'comfort equation' which established the average optimum temperature for a group of people in particular circumstances. Fisk (1980) has criticised comfort theory as ''largely a pragmatic exercise aimed to reduce the term to an engineering model for the purpose of engineering design. In developing that theory, many of the finer nuances of 'comfort' have been lost''. McIntyre (1982), a former contributor to climate chamber studies, has noted that Fanger's repeated demonstration ''that the preferred temperature of a group of people does not vary, and is not affected by country, season or thermal experience'' is at variance with the analysis of field studies which suggest that people are adaptable and that thermal preferences are influenced by local culture and climate.

Quite apart from the rigid control of physical variables and the non-realistic settings in which the research was performed, a further problem with the experimental approach was the way in which the subjects' attention was unnaturally drawn to either the lighting or the thermal environment. We normally only notice these aspects of our environment when they depart from a neutral state, and yet (paradoxically) the aim of the experiments was to determine the values of physical variables which would produce just such a neutral state. (Neutrality and comfort were often assumed to refer to the same thing.) This work, and its outcomes, suggests that human interaction with the physical environment is sufficiently complex to be not amenable to traditional scientific research techniques and may instead require a new theoretical approach to complexity to be developed before real progress can be made.

This is underlined when we consider that the research has generally treated each of the environmental factors (thermal, luminous, acoustic, tactile, olfactory) as being independent of the others. The possibility of some interaction has been considered. A literature search carried out by some members of the CIE's Division 3 (Laurentin and Fontoynont, 2000) has been reported as finding that there is little or no conclusive evidence of any influence of air temperature on visual perception or preferences, or conversely of light characteristics on thermal perception. However, it turns out that the majority of the published work was carried out in climate chambers fitted out with various forms of lighting and with changeable colour schemes. Only artificial lighting was used, and the authors report that they are trying to conduct experiments in climate chambers with real windows, ''to be closer to reality''. The extent to which any climate chamber can simulate reality is debatable; and it can be argued that it is impossible for an experiment that draws an unnatural level of attention to various aspects of the environment to have retained sufficient ''reality'' for the results to have any meaningful application in design. Personal experience of the natural world suggests a thoroughly integrated experience of all aspects of the physical environment.

A further compounding factor in this dilemma is the influence of cultural factors. Hall (1969) has discussed the important role that the history of art can play as a chronicle of the development of people's perception of their world and of the cultural differences that can arise. Art reveals that some people still exist in a sense-rich environment, while for others this is no longer true. Whether this perception is shared by all people, including architects, in a given culture at any particular time has been called into question. The 19th century British architect Sir John Soane, in the eighth of a series of lectures to the Royal Academy, lamented the failure of fellow architects to employ the hidden light sources often used by French artists to light their studios. The reason he finds for this is ''that we do not sufficiently feel the importance of character in our buildings, to which the mode of admitting light contributes in no small part'' (Watkins, 1996). Earlier in the lecture, he describes the use of solar radiation to warm rooms in ancient Greece and Italy but declares ''that this mode of warming rooms might suit hot climates and ancient customs, but in England it is not sufficient that our houses are well warmed; we must see the fire, or no degree of heating will satisfy us''. Both complexity in environmental perception and the contribution of cultural factors to this complexity have been discussed in more detail elsewhere (Willey, 1999 — two references).

FUZZY THEORY AND THE MATHEMATICS OF IMPRECISION

The 'certainty' of mathematics, described by Pérez-Gómez, was complemented in the 1960s by the development of a mathematics of imprecision. The theory of fuzzy sets enables mathematical consideration of sets for which there can be a variable membership function, rather than an entity being either a member or not a member of a particular set. This allows for some ambiguity or imprecision in the nature of the entity. As an architectural example, the warmth of a room is subjective and so ''warm rooms'' would form a fuzzy set, rather than membership of the set being determined by a particular air temperature (as would be the case if a thermostat was effectively required to determine membership and control heating by this objective criterion). The concept of a fuzzy variable, such as *warm* can be extended mathematically to include modifiers such as *very*, *somewhat*, etc. We can therefore have sets of *rather warm* rooms or of *warm but not very warm* rooms, etc.

These fuzzy variables (in italics) can be incorporated in fuzzy algorithms which can describe human control actions; for example, ''If the room is *rather warm*, open the window *a little bit*.'' These algorithms could be included in a computer simulation of the energy and/or environmental performance of a building in which the occupants were able to adjust environmental controls to suit their preferences. The algorithms could also be use as the basis of computerised controls that were intended to simulate the actions of an experienced person who was behaving realistically (e.g. engaged in and principally focussed on a particular activity other than monitoring the environment). Since the values of a fuzzy variable will not be numbers but rather words, phrases or sentences in a natural language, it follows that the particular values and how finely grained they are, and indeed the actual variables themselves, may depend on the language and on the culture that is supported by the language. Fuzzy theory thereby provides a potentially unique approach to culturally-sensitive environmental controls.

The most successful application of fuzzy algorithms has been in industrial process control, simulating the control actions of (and achieving equivalent success to) experienced operators (King and Mamdani, 1977; Gupta, 1979). Possible applications of fuzzy theory in architectural design were explored soon after these process control successes (Willey, 1979; Gero, 1982). Fuzzy algorithms have subsequently been used in elevator control systems and in some automated domestic appliances. A more recent application has been in the development of a smoke detector with an extraordinary success rate in distinguishing hot smoke from clouds of dust, water vapour, dry ice and other light-obscuring or reflecting media (So and Chan, 1994). An attempt to provide fuzzy controls for an automated blind system, to reduce both over-heating and the experience of glare, has been less successful (Morel, et al., 1996) but the approach adopted in developing the algorithms was quite different from that employed in developing industrial process control algorithms, so the results do not preclude a better outcome being achieved by other means.

One of the most exciting prospects of fuzzy algorithms is the way in which algorithms of considerable complexity can be written. By this means, a simulation of the way people integrate various sensory inputs and respond to the overall picture will provide a counter to the simple-minded approach of physical detectors which independently monitor single variables, such as thermostats and photocells. The application of this integrated approach to the development of environmental design aids would help to overcome some of the pitfalls of entrusting aspects of design to a number of independent specialist consultants. In parallel, it may (as will be discussed shortly) promote a rethinking of the present professional specialisms and have implications for design education.

INFORMATION TECHNOLOGY, CONTROL SYSTEMS AND "INTELLIGENCE"

Recent developments in the power and miniaturisation of computer technology have enabled the widespread use of sophisticated control systems, to the point where an "intelligence" might be embodied not only in most of the items on an office desk, but also in the desk itself and, indeed, in the bounding surfaces of the room as well. In the development of smart structures and materials (Culshaw et al., 1992), the "smartness" in either a structure or material resides in its ability to react in some way to changing circumstances, such as to change shape or change colour or change transparency. As an application to building design, one or more smart materials could be selected for the outer envelope of a building that have the ability to react to changes in the external environment. This reaction requires the material to either have an inherent sensitivity or be part of a system which incorporates a sensitivity to one or more environmental variables. In the latter case, it also requires an actuator, controlled by appropriate algorithms, to respond by modifying the material's properties in an appropriate fashion.

The concept of an intelligent building has evolved from simple, automated buildings to buildings which provide a supportive intelligent environment for the activities of the building's occupants (Harrison et al., 1998). The coupling of building intelligence with smart materials to give an intelligent outer skin to a building provides a potentially sophisticated and energy-efficient means of shaping the interior environment to achieve working conditions for the occupants which not only enhance their performance but which also produce satisfaction, pleasure and delight. In a separate but parallel development, it has been suggested that the most interesting new materials (which could be used for all surfaces in a building, not just the outer skin) would be "those that are the most unstable, whose inherent characteristics and properties allow them to transform from one condition to another, to appear to be many different things and so question the very basis of material definition." (Walker, 2000) These materials could incorporate experiential properties, emitting light, heat, colour, sound or information, in response to pre-programming or to *ad hoc* environmental or building occupant input.

IMPLICATIONS FOR ARCHITECTURAL RESEARCH, EDUCATION AND PRACTICE

The principal implication for research of the preceding discussion is the need to engage with the complexity of the real world rather than to rely on grossly simplified and constrained laboratory settings in which the subjects focus unnaturally on their environment. Field studies will be important, not just for basic data on people's interactions with their environment but also for the more particular goal of deriving the "protocols" that will underpin algorithms representing human behaviour and control actions. The difficulty of getting such algorithms right, either for software that will simulate the performance of occupied buildings or for automated control systems that replicate human control behaviour, has been encountered in industrial process control. The result has been the development of "rule-modifying" algorithms (Procyk and Mamdani, 1979) which could monitor the performance of a control system and amend the fuzzy algorithms embedded in it to improve that performance when the occupants' expectations are stable, and to evolve to complement changes over time in their needs and expectations. Such rule-modification capability would allow a basic control system to have a cross-cultural applicability as it could modify itself to match culture-based differences in needs and expectations.

A parallel research development could be self-modifying hierarchical control systems where a central automated controller could respond (democratically) to requests for changes delivered linguistically from the desk-top computers of the building's occupants. Occupant input into control from desk-top computers has been explored recently for automated blind systems (Skelly and Wilkinson, 1999) and room temperature. (Perry and Raw, 1999) These studies have had a negative focus in that they sought to avoid discomfort and then to avoid any dissatisfaction as a side-effect of the automated controls. Fuzzy control systems would allow the greater complexity and imprecision associated with control that had the more positive focus of *promoting* comfort and enhancing the occupants' experience of their working environment.

Perhaps the most significant consequence of the development of such technology-focussed strategies would be the implications for the design philosophy behind their implementation and for architectural education. This design philosophy would need to be discussed and recognised as an option by architecture students, and the whole process of architectural education would need to allow this to happen. Being aware of the technological possibilities would not be sufficient; design education would need to promote a life-long gathering of the experience that would ensure the successful use of the technology and of the complementary design philosophy. Design education needs to provide the framework into which to store what Schön (1983) termed the designer's "repertoire of examples, images and understandings." Schön argued that the "artistry" of the practitioner depended on the extent and variety of this repertoire.

Design education prepares an architect for professional life, but the latter, too, may need to change as a consequence of any design engagement with the complexity of the real world. O'Sullivan (1999) made the point that an increasing proliferation of areas of expertise among building professionals has been accompanied by a clearer definition and smaller breadth of knowledge of each, and that some of the real problems in building design fall into the cracks between the different professional boundaries. This argument, and that of the preceding discussion, might be extended to proposing that the complexity of the real world and of people's interactions with it will require the separate specialisms (including architecture, lighting, acoustics, thermal design, etc) to be merged into a new professional — the *environmental* designer.

Whatever form future research, education and professional practice might take, it is clear that the disjunctions inherent in much of our present approach to design can be superseded by the opportunities that would be opened by addressing the complexity of the real world. These opportunities would address the concerns raised by Pérez-Gómez by embracing a mathematics, not of certainty but of ambiguity and imprecision, and healing the splits between scientific truth and poetic reality, and between theory and practice, thinking and doing. In order to contribute to achieving these ends, the development of an appropriate theory of complexity may be the most important and exciting challenge facing architectural science today.

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