ACCENTUATING THE POSITIVE —
SMART MATERIALS, INTELLIGENT BUILDINGS AND THE IMPLICATIONS FOR ARCHITECTURAL SCIENCE

Hayden Willey
School of Architecture
The University of Auckland
New Zealand

ABSTRACT

The advent of new technologies, such as smart glass and the control systems of intelligent buildings, provides an opportunity to enhance the quality of interior environments and enrich the environmental experience of the people who occupy them. These technologies could equally easily become locked into serving an existing and more basic objective such as reducing energy consumption. The two types of objective can be defined as positive and negative; the first focussing on enhancement and engaging with the complexity of people's interaction with their environments, with the second focussing on reduction or prevention of unwanted effects and embodying a simplifying or reductionist approach. The implications for architectural science are a need to significantly change the balance of research towards using new technologies to support positive objectives, and a need to develop appropriate research strategies and directions to achieve this.

INTRODUCTION

The rapidity of technological developments in architecture raises the possibility that some developments might be implemented before there has been time for all of their implications to have been thought through. In particular, when the motivation for a technological development has focussed on only one or a small number of factors in architectural design, then the opportunity for the evaluation of this development in terms of other factors by architects or architectural scientists may be overwhelmed or lost by the rapidity with which it is implemented. (In this context, "rapidity" needs to be judged in a relative way, to mean fast in relation to the speed with which any awareness might develop of detrimental effects of the development. This awareness might come about either through problems becoming manifest in practice or as a consequence of a mulling over or testing out of the issues in general by design professionals and scientists.)

One such situation can be seen to have arisen through the development of strategies for energy efficiency in buildings at the same time as new building materials and new consumer products were coming into use and changes in work patterns were occurring. The strategies for energy efficiency included deeper-plan buildings, more spatial and temporal uniformity in temperature and lighting, a reduction in the rate of air change in building interiors, a greater likelihood of unopenable windows and a reduction in occupant control over ambient lighting, temperatures and the opportunities for personalisation of their workplace and work patterns. At the same time, an increase in sources of volatile organic compounds and gaseous contaminants, together with a cocktail of associated odours, was being produced by new building materials (involving sealants, adhesives, particle-board, stains, fabrics, foam, carpets, etc) and consumer products and activities (from photocopiers to felt pens to wearing dry-cleaned clothes). The effects of this combination were both physiological and psychological and the lack of foresight as to its consequences has been
recognised as a principal cause of the sick building syndrome (Potter, 1988).

The potential currently exists for an analogous situation with, in many ways, strikingly similar consequences to arise from any marrying together of two areas of technological development: smart materials and the intelligent building. The two technologies could come together in the design of building facades to influence the interior environment. With forewarning, it may be possible to eliminate, or at least reduce, any undesirable outcomes, but it may require a major shift in focus for current research and practice to achieve this.

SMART MATERIALS

The development of smart materials forms one part (as yet, the smaller part) of a wider range of research activity that embraces both smart structures and smart materials (Culshaw et al, 1992; Coghlan, 1992; Stix, 1993). The "smartness" in either a structure or a material resides in its ability to react in some way to changing circumstances, such as to change shape or change colour or change transparency. The development of smart structures takes an existing material and introduces new properties or applications, while the development of smart materials starts from first principles and leads to new materials. Applications have ranged from the "stealth" technologies used to make submarines and aircraft invisible to enemy ultrasonic and radar systems (with civilian applications in neutralising noise) to technologies to damp vibrations and stabilise shape in aerospace structures.

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 that 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.

An obvious example of a smart building material is smart glass (Roche, 1997; Carmody et al, 1996). This can be any one of a range of glass types that can alter their optical and solar transmittance, activated directly by light or temperature, or indirectly by electrical control from an actuator linked to a sensor. The lack of need for a control system for light-activated and temperature-activated glazing gives them an inherent simplicity but also means a lack of flexibility in use. Their most useful applications may turn out to be vertical glazing in extreme climates and rooflighting in all climates.

Roche (1997) points out that the flexibility of electrically-controlled glazing systems means that "different control regimes can be used for different buildings so that a single type of device can be widely applied, reducing manufacturing costs". As a corollary, it can be seen that the control regime in a given building could be changed during its lifetime to match changing needs. Of the three major forms of electrically-controlled glazing, liquid crystal devices and electrophoretic (dispersed particle) glazing require a voltage that could be as high as 150 V ac, and consume energy continuously in the clear state (which is actually rather hazy).

The third form of electrically-controlled glazing, electrochromic glazing, requires low power from a 5 V source for switching only. Electrochromic glazing consists of an ion conducting solution laminated between two transparent electrodes. By applying a voltage in either direction, the ion concentration in the solution can be increased or decreased, changing the transparency and colouration of the glass. This suffers from a slow response time of several minutes and therefore cannot be used for real-time switching. When this factor is coupled with an upper limit of a few thousand switching cycles, meaning that it should sensibly be switched only a few times each day, it becomes clear that electrochromic glazing is more useful for controlling solar gain than daylighting.

Roche anticipates that the most effective form of smart glazing will turn out to be a combination of electrically-controlled glazing with a high performance blind or louvre system, to "provide good control over both solar gains and glare while using daylight effectively". If this is the case, then both the smart glass and the blind or louvre system should be linked to the same algorithm-based control system. There may also need to be provision for input from the occupants of the building to which this is applied, to reduce or avoid adverse reactions to the glass colouration and the scattering of light that is associated with some smart glass, and to the potential blockage of view and noticeability of operation inherent in adjustable blinds and louvres. Just what form this control system might take could be determined by the underlying performance objectives of an intelligent building.

INTELLIGENT BUILDINGS

The concept of an intelligent building has suffered from a range of alternative definitions and design approaches. However, it is still possible to identify common elements and to track a trend in the development of the concept and its practical realisations. The earliest phase in the development of what we would now recognise as building intelligence would be the automated building, incorporating
automation of the building's environmental, security and energy systems, automation of office activities through local area networks, and the installation of advanced information technology (at the level of such things as voice mail and video conferencing) (Gouin and Cross, 1986). This was developed to include a responsiveness to changes in information technology, the work environment and the structure and needs of the organisations that occupied the buildings (Duffy, 1988), including a growing disenchantment with the shared tenant services that had characterised many earlier automated buildings.

Duffy (1988) has identified differences that emerged between North American, Japanese and European developments in building intelligence at this time. He notes that the nature of the North American real estate market and their excellent tradition of building management has seen an emphasis on advances in office automation and information technology, rather than on building automation. In Japan, he notes an emphasis on the development of products to support building intelligence and a "willingness to extend the idea of the intelligent building beyond the isolated site, beyond the particular organisation, to a much larger scale", including a new type of city planning — the 'advanced information city'. Developments in Europe (particularly in Scandinavia, West Germany and The Netherlands) have been affected by "the enormous influence of widespread industrial democracy on the quality of working life". The effect on building automation has been to extend it from the design of an energy-efficient outer envelope to the building to allowing individual office workers to adjust the lighting, air conditioning and access to data at their own workstation to suit their personal needs and comfort.

The next phase of development has been identified as a change from responsive buildings to effective buildings, in which a supportive intelligent environment enabled an organisation to achieve its business objectives (Harrison et al, 1998). In Europe, this was seen as placing the focus on "the building's occupants and their tasks rather than on computer systems", and one of the associated design tasks was user access to environmental systems. On the basis of European thinking, Harrison et al strongly advocated a flexible HVAC system, task lighting and general user access to environmental controls. However, their study of 15 intelligent buildings in South East Asian countries (including two buildings in Australia) revealed that in the majority of cases the occupants had no direct access to HVAC controls (but in some they could send requests to the Facilities Management Department), some had accessible thermostats on each floor and some left the decision to tenant fit-out. Three of the buildings had a limited number of openable windows (two of them being low rise buildings) and two buildings had task lighting (although this could also be subject to tenant fit-out). An emphasis can be detected on the support of the business activities of the organisation as a whole, and on facilities management considerations, rather than on the performance and well-being of individual occupants. Duffy's (1988) earlier noting of a cultural factor in the provision of occupant access to control of their local environment appears to remain valid.

It is possible, therefore, that in some if not most parts of the world the implementation of the technologies of smart materials and intelligent buildings will be motivated more by the reduction in energy consumption and accompanied by a similarly-focussed automation of much of the building's environmental systems, rather than by either a genuine concern for the well-being of the occupants or by any recognition of the positive effect that the latter could have on their performance and the business goals of the organisation.

"NEGATIVE" AND "POSITIVE" APPROACHES IN RESEARCH AND DESIGN

The concern that arises from this analysis is that, from an analogous set of design objectives and a similar expression of concern for the comfort and performance of the people who will occupy and work in them, it is possible that buildings will be constructed which come to reveal similar pitfalls to those displayed by "sick" buildings, and where the occupants succumb to what might become called the "intelligent building syndrome". Indeed, the effect may be even more dramatic. Not only does the typical intelligent building share the goal of energy efficiency in the design of its fabric and its electromechanical systems, it also includes a goal of optimising spatial organisation in the interests of enhancing the business performance of its occupants. While the first of these might constrain occupant participation in the control of the interior environment, the second may impose additional constraints on furniture layouts and other ways in which people might wish to personalise their working environment. While lessons learnt from investigation of the sick building syndrome may prevent a recurrence of the physiological symptoms that were largely due to inadequate ventilation, the psychological effects of behavioural constraints may be exacerbated.

To find an underlying cause which might produce such a situation, it can be helpful to adopt a broader view. It has been argued elsewhere (Willey, 1999b) that there is now a need in architectural science as well as architecture (and especially in those areas of architectural science concerned with the interior
environment of buildings) to place more emphasis on the Vitruvian element of "delight" (Wotton, 1624) rather than "firmness" and "commodity"; to undertake research into how buildings can be designed not just to support but to enrich human experience; to tackle the subjective issue of quality with equal rigour to the way in which quantitative research is undertaken; and (in order to do so) to develop ways of exploring the full complexity of design reality with the support of an appropriate theoretical framework. In the particular area of people's perception of and interaction with their environment, research and the consequent design guidance can be seen to have been restricted to physiological and physical factors related to simplified notions of comfort and performance. The omission of psychological factors from this work has prevented any offering of research-based advice on how to achieve "delight"; i.e. how to enrich people's experience of the environments that are shaped by buildings.

In more general terms, architectural science was argued to have failed to explore the complexity of the real world. Instead it has adopted a reductionist approach, simplifying the research task by dividing it into severed subsystems (a situation that is mirrored at a coarser scale by the subdivision of the design of larger buildings into a number of consultant specialisms). The complexity of the real world can be seen to be enshrined in the interconnections that are lost by this approach, but it is from these interconnections that the subtleties and finer nuances of people's interaction with their environment are derived.

The dualism of either addressing complexity or making simplifications can be complemented by another pertinent dualism which, in the context of interest here, could be called adopting either a "positive" or a "negative" approach to the design or research of the environments that are shaped by buildings and experienced by people. A "positive" approach can be associated with an objective of enhancement; for example, of enhancing the richness of people's experience of the environment. A "negative" approach can be associated with an objective of avoidance; for example, avoiding conditions that would produce thermal discomfort or glare or intrusive noise.

(The words "positive" and "negative" are being used here as the adjectives of everyday speech. In particular, "positive" implies being characterised by the presence rather than the absence of features or qualities, and has overtones of the sense of being "complete". "Negative" has implications of denial and rejection, and (through the verb "negate") of neutralisation. Any sensing that "positive" implies approval and endorsement while "negative" implies criticism of the research and design practices that fall into these categories is not intended; rather, a shift in focus is advocated. This is discussed later in the paper.)

In terms of this positive/negative dualism, an objective of energy efficiency in the design of the fabric and the services systems in a building may be seen as positive in its own terms (that is, in terms of the performance of the fabric and building services) but negative in a wider frame of reference (such as the shaping of the internal environment of the building) where it would be seen as the avoidance of the wastage of energy (or, equivalently, a reduction in the cost of energy consumed by the building). If any potential disadvantages are foreseen for the occupants in terms of the quality of the environment and the occupants' experiencing of it, there might initially be seen to be a positive aspect to efforts made to address this. However, if we take as an example the situation mentioned earlier where the occupants could be given some input into the control system to reduce or avoid adverse reactions to changes in the colouration or light-scattering with smart glass and to any view blockage or distraction associated with the operation of automatically adjusting blinds or louvres, then the remedial action can still be seen as essentially negative in approach; it is an avoiding action rather than an enhancing one. A number of systems are being developed and tested for occupant input (usually from their desk-top computer) into such things as room temperature (Perry and Raw, 1999) and the control of automated blinds (Skelly and Wilkinson, 1999). While the intention is to improve worker satisfaction (and therefore productivity and workplace efficiency), the approach essentially involves two negative objectives — initially avoiding discomfort and then avoiding any dissatisfaction as a side effect of the automated controls.

The source of the problem, and the origin of the labelling of the objective as being negative, lies in the way in which energy efficiency is conventionally defined and evaluated — as the efficiency with which the energy is used to establish and maintain environmental variables within pre-set bounds. It has been argued elsewhere (Willey, 1997) that energy-eficiency in lighting should not be considered in terms of the mere production of light but rather in terms of the support it provided for people and their activities. The first way of evaluating energy efficiency assumes that the outcome that is sought from the energy investment that is made is simply the production of light in a way that meets illuminance recommendations and avoids glare. The alternative form of evaluation takes a more positive provision of support for the people occupying a building as its outcome. This more extensive concept of energy efficiency clearly embraces the energy efficiency of...
the production of light but couples this with the effectiveness with which that light supports people and their activities. This support extends from task performance to include the enhancement of people's experience of the lit environment (which, if it is necessary to do so, may also be measurable in terms of longer-term enhancement of productivity from the satisfaction and pleasure that people get from their environment; and the argument could no doubt be widened further). If people and their activities are not well supported, then the energy consumed by the lighting has been used wastefully, however energy-efficient the lamps and luminaires might be in their own terms.

This way of evaluating energy efficiency can clearly be extended to other aspects of the interior environment as well. A positive approach to energy efficiency, and to the use of new technologies such as smart materials and building intelligence towards this end, must clearly be focussed on the appropriate enhancing of the richness of people's experience of their environment. This, in turn, requires the associated strategies to address the complexity of this experience and of the interaction of people with their environment. This complexity of interaction will include not only complexity within each aspect of the environment but also the complexity of the interconnections between these aspects and the way in which the thermal environment, lighting and acoustics (and perhaps even olfactory and tactile stimulation) become integrated in people's experiencing of their environment. (One contributing factor in the psychological aspects of the sick building syndrome is arguably the failure of design professionals and researchers to recognise the integrative character of this interaction, and to thereby significantly reduce or confuse the sensory stimulation provided by the interior environment of such buildings.) The question that must therefore be addressed is how to achieve such a positive objective.

ACCENTUATING THE POSITIVE

There is an economic justification for providing a healthy and productive indoor environment for the individual occupants of a building that is enhanced to support their activities and the richness of their environmental experience, together with the corresponding refocussing of the definition of energy efficiency. This has been discussed in detail elsewhere (Willey, 1997). In summary, studies in New Zealand, the USA and the UK have shown similar results, to the effect that personnel costs (principally staff salaries and wages) constitute 80—92% of the annual running costs of an office building while energy costs constitute up to 2.5%, a striking disparity in size. And yet great effort is put into the effective use of the energy investment in running the building or the individual organisations housed in it and much less effort into maximising the return on the investment in "human resources". A very strong economic argument can be made for overturning this situation.

While not contributing directly to work performance, an enriching of the environmental experience and satisfaction of building occupants can indirectly enhance the investment in them through improvements in work attitudes and reduction or elimination of absenteeism caused by dislike of the work environment. Recent studies and recommendations for new approaches to the design of offices and the environmental systems that support them continue to use the language of the economists and make direct reference to ensuring the effective use of human resources. A study by Duffy et al (1993) noted changing user expectations, including that "new workplaces and systems of managing the working environment will have to be designed which constrain users much less, and which enhance the quality of working life as well as productivity". With respect to changes in building performance, they noted that "there will no longer be such sharp divergences between the design of long term shells and short term scenery; nor between natural external environments and artificial interiors. Building services will be more accessible to end users and will be used in a more sophisticated way, complementing and assisting natural systems."

Their recommended initiatives included a comment that "building skins and particularly windows, the interface of buildings with the natural environment, will take on more significance in maximising building performance while meeting changing needs. Building skins will become more independent of structure to facilitate change and more operable by users at the same time as being capable of environmentally higher performance." They also recommended that building intelligence should be used to provide "more distributed and more controllable building management systems, a shift from prescriptive to responsive building management, and the development of such novel building products as adaptive facades."

In a more recent study by Laing et al (1998), the authors anticipate that individual clients or users in new or refurbished buildings "will increasingly ask for environmental systems that provide a higher degree of personalised individual and group control than is available at present, with the control interface being simpler and more accessible" and "much more consideration in the design of environmental systems to facilitate a transition from work patterns that are continuous and low in interaction to patterns of work which are certain to be quite the opposite." As an
example of the implications, a trend is seen towards greater reliance on local occupant control of lighting, to allow for unpredictable and diverse occupancy patterns as well as increasing diversity in the tasks undertaken and the characteristics of the individuals or groups undertaking them.

Unfortunately, only outlines are given of possible control systems to implement such flexible and localised environmental systems. As one example of a possible development in control strategies, fuzzy-logic controllers have the ability to simulate or interact with the inherent imprecision of human perception of the environment and of human behavioural control actions. This has been discussed (repeatedly) elsewhere (e.g. Willey, 1979, 1982, 1985, 1987, 1996b, 1997, 1999a) and the arguments will not be further repeated here. However, it should be noted that, quite apart from applications to industrial process control (simulating expert human operators), to building equipment (from heat pumps to elevator control systems) and to household appliances (from dishwashers to rice cookers), fuzzy-logic control has also been applied already to smart materials and structures (Matsuzaki et al, 1992).

It is clear that both the technology and the fundamentals of an appropriate control system exist already to enable adaptive facades to meet the complex needs of people in modern work environments and to enrich their experience of that environment. What is required is a new and sharper focus to both research and design, which may demand, to some extent, an overturning of existing ways of thinking and acting. As Johnny Mercer (1909—76) wrote, in the lyrics of his 1944 song, "You've got to ac-cent-tchu-ate the positive".

IMPLICATIONS FOR ARCHITECTURAL SCIENCE

The implications for architectural science need to be seen in an equally positive way. An opportunity is provided to complement existing strands of architectural science endeavour with research that will support designers in providing interior environments that are more stimulating and enriching than those that are merely comfortable; and that invigorate people in the performance of their activities rather than simply enable a satisfactory level of performance to be achieved as measured by ergonomic criteria.

Designers do espouse such goals and can write lyrically about them (Heschong, 1979). One research approach would be to examine environments (including historical ones) that do in some way go beyond the norm, to find out how this was (perhaps unselfconsciously) achieved and express it in terms of contemporary knowledge of the mechanisms of human perception of the environment (Willey, 1996a). Another is to develop fuzzy algorithms, both for basic automatic controls that simulate occupant control actions and for more advanced controls that, say, learn how to provide environmental variation in a way that computer-based feedback from occupants shows that they respond most favourable towards.

Mercer's lyrics, however, go on to say "Elim-my-nate the negative". On the contrary, there is still a role for research that reveals economical ways of avoiding discomfort and adverse effects on performance. What architectural science needs to do is to strike a better balance now than has been achieved in the past between "positively" and "negatively" focussed research. The advent of a combination of smart materials and intelligent buildings provides both an opportunity and an imperative to achieve this.

REFERENCES


