REVIEW ARTICLE

Applying knowledge on building performance: From evidence to intelligence

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The article examines the meaning of intelligence – or knowledge – in the context of building design and construction. The user perspective is invoked to help us understand how an intelligently designed building is expected to function better for users. The article examines how intelligence about use and users is acquired by researchers, transmitted to practitioners and then applied as knowledge to the design decision-making process. The more traditional post-occupancy evaluation approach to acquiring feedback from users about building performance is reviewed and compared with the newer approach known as evidence-based design. The results of these two traditions are examined in view of their effects on healthcare design as well as on office building design and use. The article argues that information derived from feedback collected systematically from building users is accumulating and now forms a knowledge base from which design and construction decisions are increasingly being made. As practitioners acquire this knowledge, it becomes an additional tool they can – and do – use to apply to the intelligent creation of the built environment.

Keywords: environment and behaviour; evidence-based design; healthcare design; occupants' feedback; office buildings; post-occupancy evaluation; users' needs

INTRODUCTION

In line with the idea that an intelligent building is one that has been designed and built with intelligence, this article examines the meaning of intelligence – or knowledge – in the context of building design and construction. The user perspective is invoked to help us understand how an intelligently designed building is expected to function better for users. The article examines how intelligence about use and users is acquired by researchers, transmitted to practitioners and then applied as knowledge to the design decision-making process.

An important source of at least part of the knowledge about how buildings perform has been derived from feedback studies in which buildings in use have been systematically studied and evaluated according to certain pre-established criteria. Traditionally, the link between knowledge that has accumulated about how buildings are designed and used and the practical world of design and construction decisions exists in a cluster of pre-design activities known as programming and post-occupancy evaluation (POE).

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POE has been an active area of knowledge (intelligence) gathering over the past 30 or 40 years. It is based on the presumption that studies of building use and performance shed light on the operation and management requirements of existing buildings, generate new knowledge about the human use of space, and provide feedback on key decisions made during the design and construction process. Indeed, design decisions have been characterized as a series of 'testable hypotheses' which can then be used to frame behavioural and other scientific studies (Zeisel, 2006). POE study results on how users function in the spaces a building provides, and also on how a building performs in terms of its systems and operation, create a basis for the design of new space using programming. Pre-design programming, or briefing, gathers information about users' needs from available POE studies and other research and synthesizes this information into both broad and generic, and targeted and specific, sets of design guidelines and prescriptions to which the design team refer throughout the building design process (Blyth and Worthington, 2001). The goal of the POE-programming cycle is to learn from previous projects and apply this learning to the design of new projects, in an environment of continual improvement (Marmot et al., 2005).

The currency, or operational objective, of this design decision-making cycle is information, i.e. information about how effective building decisions are in terms of eventual building operations and management, in terms of user functionality and comfort, and in terms of how close the outcome of a building delivery process adheres to initial design objectives and intentions.

Within the 'real world' of the building industry, however, the process of producing and transmitting information – or knowledge – has worked only intermittently (Preiser and Vischer, 2005). The link that exists in theory between post-occupancy research results and a new building programme is often missing in practice. Some (but far from all) projects are assessed after occupancy using a POE approach. Sometimes designers are motivated both to access research results and to apply this new knowledge to their next project. More commonly, the often voluminous results of POE studies lie unread on researchers' shelves or are published in academic journals infrequently consulted by practitioners. And new building programmes, far from integrating feedback from completed and occupied buildings, frequently take the form of a rapid summary of square footage requirements and projected growth in numbers of users, thus allowing each design team to reinvent the wheel or, more commonly, to reuse ideas they have developed on their previous projects (Vischer and Zeisel, 2008).

This is not to say that the intelligence yielded by POEs has not been valuable and has not had an effect on the way design is practised. Various forms of and approaches to generating feedback from completed projects have evolved from POE, some with more of a research emphasis to increase our knowledge of how buildings work and how users are affected by them, and some with a more applied emphasis to facilitate practitioners' direct application of results to programming and design.

A relatively recent offshoot or refinement of POE-type activities is now poised to finally establish building performance feedback as a critical source of intelligence within the building industry. The term being applied to this intelligence gathering and its applications is 'evidence-based design' (EBD). As this article will show, EBD is predicated on a new relationship between research and design by basing design decisions on research results, i.e. knowledge, and thereby requiring that design decisions make a meaningful shift away from simple intuition towards empirical truth. This article will conclude with recommendations for defining the meaning of performance feedback – or knowledge of results – in the context of a building project such that the long-standing goal of using reliable feedback to improve the quality of buildings for users advances towards realization.

THE BUILDING PERFORMANCE FEEDBACK PARADIGM

The question of how building users are affected by features of the physical environments they occupy has preoccupied researchers as well as designers and other building industry professionals for many years. They are concerned not only with questions about the nature, scale and longevity of environmental effects on occupants, but also by questions of how to value the knowledge we have of such effects, so that it can be applied to decisions about space and systems design.

As this field of activity has evolved, certain theoretical frameworks have developed to guide practical and applied research on building performance and use that can be characterized as intelligence gathering. The building blocks of a theory of feedback from buildings in use are:

- human performance – how users' behaviour is enhanced and supported by the spaces designed for it;
- building performance – how specific design and construction decisions have affected mechanical and electrical performance, envelope (energy) performance and the like, and;
- social value – ultimately, a building, like any other product of concerted human social action, should be assessed in terms of the improvement it brings to users and to society at large (Vischer, 2008a).

In fact, the concept of building performance itself includes notions of use and effect on human performance, because performance is assessed in terms of how buildings and building systems affect the comfort, effectiveness and well-being of building users (Preiser and Schramm, 2002). One form it has taken is the concept of workplace performance, a term applied to workspace design whose explicit objective is to support the performance of work (Niemala et al., 2002). In order to assess building performance, measures are taken of system effectiveness that include users' perceptions of environmental comfort and satisfaction. Other measures include output quality and quantity – for example, a building's mechanical systems' performance is typically measured in terms of the amount of fresh air admitted into the building and the number and extent of contaminants in the circulated indoor air, as well as the amount of air that is distributed into the different parts of the building to serve occupants. However, this data is simply data unless research can show how users are affected.

Post-occupancy evaluation is the principal way in which the link has been forged between building design and operations (hardware) and use behaviours and user psychology. The POE typically takes the form of an applied research project in which social and behavioural data is gathered from users about their experiences in the buildings (Fischer and Vischer, 1998). Five good reasons for carrying out POEs were advanced by Friedman et al. (1978) and a practical approach to making POE effective was published by Preiser and Whyte (1988). Connecting POE results with programming for new buildings was first proposed in the 1970s, and the idea has gone through successive refinements to help practitioners understand the value of feedback on building use and apply it strategically to new building decision-making (Duerk, 1994).

One of the key components of the POE paradigm as it has been applied to research on building use has been measuring the level of satisfaction of users. Starting with surveys of residents of social housing in the 1960s and 1970s, whether or not they were 'satisfied' with aspects of their residential environment was the key measure of whether or not the housing design met their needs (Vischer, 1985). This approach to feedback from building users carried over into a wide variety of post-occupancy studies and continues to be applied to such diverse environmental questions as indoor air quality, parks and open space, and office furniture. Over the long term, however, this emphasis on measuring users' satisfaction has evolved into a weakness in the POE paradigm, being more effective at instructing researchers and practitioners in people's preferences and perceived needs than in the effectiveness of building design and operation decisions (Vischer, 2008a). What people like and dislike in a given environment depends on a variety of influences, many of which are not always related to the built environment or to the decisions that created it. From a practitioner's viewpoint, seeking out users' evaluations in terms of their personal likes and dislikes is not rewarding, teaching them little about the effects of their decisions and providing little help or guidance regarding future designs. This may be one of the reasons why POE results have failed to link in any formal way to brief-writing and programming: a new building cannot be planned on the basis of what a previous group of people did and did not like.

Clearly, a more diverse, sensitive and wide-ranging number of outcome measures is in order than simple occupant satisfaction. The practice of assessing design outcomes in terms of users' satisfaction ratings has been criticized and is increasingly replaced by other, more targeted and realistic outcome measures of a built environment's effectiveness (Vischer, 2007). These include a sense of belonging and community, appropriation behaviour and territoriality, functional comfort and task support, managing stress, and effects on rates of illness and accidents.

EVIDENCE-BASED DESIGN: A PARADIGM SHIFT

One of the useful innovations of the EBD approach to measuring building performance feedback is the variety of behavioural outcomes that serve as measures of building performance and building effectiveness. EBD has evolved out of the precedent set by evidence-based medicine, i.e. relying on published research results for evidence on which to base diagnostic and treatment decisions. The application of evidence to design decisions means that the results of research – whether these are POE studies or other feedback studies, field research in specific sites or buildings, or laboratory research designed to study human behaviour in relation to specific features – are needed to make 'good' and 'right' design and construction decisions. The paradigm shift means that building industry professionals, including designers, managers, builders and investors now have a knowledge base of evidence on which to base their decisions. This knowledge base is the intelligence derived from systematic research on occupant needs and behaviour rather than the idiosyncratic mix of intuition, project experience and short-term cost considerations that has tended to guide building industry professionals in the past. When fully implemented, EBD effectively closes the loop linking feedback derived from building research to programming and design decision-making for new projects.

Definitions of evidence-based design include:

> Evidence-based design … is the conscientious and judicious use of current best evidence related to the physical environment's effects on well-being, and its critical interpretation, to make significant design decisions based on sound hypotheses (concepts) related to measurable outcomes, for each unique project. (Salvatore, 2006)

And, more simply:

> The use of scientific method to guide design decisions based on empirical knowledge. (Stickler, 2006)

In addition, attempts have been made to set priorities on what 'evidence' means. Not all research results in equally convincing 'evidence'. It is suggested that:

> 1. strong evidence [is] based on independently verified data; 2. evidence [can also be] based on weaker data; and 3. evidence from respected authorities based on available data [is also admissible]. (Patience, 2006)

These definitions, and indeed the whole notion of using evidence based on research, have evolved from evidence-based medicine, in which the decision-making burden on medical professionals is reduced in part by being able to refer to published research to inform medical decisions. Studies of medical and surgical procedures, their difficulties and their likely outcomes, of treatments such as pharmaceutical products and doses, and of new medical technology and tools, help practitioners select the right procedure for the right diagnosis. By referring to the ongoing accumulation of published evidence, a medical professional treats a patient's condition by using up-to-date objective facts rather than relying only on previously acquired knowledge and their hunches and convictions resulting from experience. For example, although it may seem obvious that inserting feeding tubes into elderly patients prolongs life, evidence from studies has shown that feeding tubes increase infection and do not in fact prolong life. In theory, the same evidence is available to others involved in treating the patient and even to the patients themselves. Increasingly, doctors choose to explain to their patients the evidential basis for their decisions, which is something that immediate access to electronic databases makes possible. Responsibility for an important medical decision is thereby shared between provider and consumer of medical treatments. Moreover, it has been demonstrated that the opportunity for patients to participate in their own care increases the likelihood of a positive medical outcome.

Giving design and building professionals the opportunity to access published evidence to guide their decisions provides an opportunity to building users, clients and other consumers of building industry services to understand and comment on why certain decisions are made and even to participate in decision-making. And studies have indicated that in buildings, as in medicine, informed and engaged users have a more positive experience of the built environment they occupy (Preiser and Vischer, 2005).

In addition to accessing evidence from published research, another advantage of the EBD approach is that building industry professionals have an opportunity to focus and direct data gathering to the issues that they have identified as needing evidence. In other words, each design team has an opportunity to identify project-related research topics or needs that will provide intelligence they can apply to the process. Also, designers need access to databanks of research results that cover issues likely to arise during project design and construction, much as the medical professional will review published evidence on their current patients' conditions. These data repositories are not limited to feedback from building occupants, but ideally include information about materials selection and performance, construction technology and management, cost containment and risk control, and other areas of knowledge that are key to constructing successful buildings and have not always been included in POE studies.

ACCESSING BUILDING INTELLIGENCE THROUGH EVIDENCE

In part because the roots of the EBD approach are in medicine, evidence-based design has found favour among healthcare designers and architects, especially in North America. It was recently pointed out that: 'A growing body of research is demonstrating that improved physical design can help bring about dramatic increases in safety and quality – particularly reductions in infection, falls, errors, transfers, nurse turnover and stress, and increases in satisfaction' (Zimring and Bosch, 2008). It is important to note the range of outcome variables identified in this list, of which user satisfaction is only one. In a recent book reviewing the research available to be applied to a wide range of design decisions in healthcare facilities, the outcomes measured include elevator access and convenience, type and location of art displays, and numbers of patient beds in a room (Malkin, 2008). Current research in the UK indicates that EBD has applications that extend beyond healthcare facilities and can be applied to housing and new community planning, to crime prevention through environmental design, and to schools and offices (CABE, 2006).

As well as being informed about and guiding decisions based on published research results, another way of defining evidence-based design is to locate the research problem in the context of the design problem and construct the study specifically to yield results that will solve the problem. In one recent example, researchers placed hand-washing basins in various locations on a hospital ward and compared their access and utilization in terms of how frequently staff washed their hands at each location. The result showed unequivocally where best to locate the hand-washing facilities in order to make it easy and convenient for staff to wash their hands after each patient visit (Stickler, 2006). The problem presented was a behavioural one: how to increase and also how to ensure that staff washed their hands. The solution was a design one: the best location for facilities to ensure that hand-washing would occur. But without the results of the study, the design decision would have been based on precedent, or cost, or left to chance.

New thinking about EBD is focusing on mechanisms and strategies that enable and facilitate this intimate relationship between research and design, obviating the need for what was formerly a burden on the POE researcher to find a way of dressing up research results and making them attractive to, and usable by, design professionals. This was always called 'bridging the gap' – the gap that exists between design and research (e.g. EDRA Proceedings). The EBD approach requires building practitioners to define the evidence they need in terms that are relevant to the building project. So although they may not want to design the research – this is the researcher's area of expertise – their priorities drive the type and style of applied research projects that seem likely to yield useful new knowledge – or intelligence – in a form that makes it relevant to the decisions that are facing them.

As the building design professions shift to a more rational and research-based approach to design, professionals will likely be less prone to avoid acquiring knowledge that could inform design decisions than they have been in the past. Architects in particular have tended to express concern that taking a rational approach to design may limit their creativity and ability to have new ideas, that having 'too much information' could reduce or even eliminate their ability to find 'artistic' solutions to design problems. One of the positive impacts of the EBD approach is that it is based on the assumption that more and better information and knowledge will *ipso facto* improve the design of buildings. Another positive effect is that the value of informed design decision-making is not only supportive of design creativity but with so much more information available, trying to do without it is both foolish and dangerous. It is no longer considered the action of a responsible professional to embark on a building design project without paying attention to what is known about the impact of previous, related design decisions on human behaviour. As building-related research expands, design professionals are increasingly expected to access the growing multidisciplinary knowledge base not only on how building users are affected by features of their environment, but also how to combine what we know about building user psychology and behaviour with the innovative features of LEED, GreenStar and BREEAM certified buildings (Brown and Cole, 2009).

One of the ways that distinguishes the European approach from the North American approach to EBD is the definition of 'evidence'. Depending on the perspective, evidence has a different meaning in terms of how it is sought and how it can be applied. Design professionals may seek evidence in a variety of ways, ranging from studying examples published in architectural magazines, to visiting a recently completed project for a walkthrough, to systematically interviewing building users and applying the results to an architectural programme or brief, to performing or commissioning a full-scale POE using social science research (Preiser and Whyte, 1988). 'Evidence' in the real estate finance and construction industry pertains to cost impacts, return-on-investment scenarios and market conditions. A whole new field of 'evidence' is emerging as certified green buildings are designed, constructed and occupied. In terms of building performance, evidence is derived from research results that demonstrate how specific building conditions and spaces affect occupants and occupants' behaviour.

In terms of accessing evidence that is already available, reviews and summaries of relevant research are more desirable than the outcome of one or some targeted studies. At a recent seminar in the UK, specific initiatives, such as government incentive programmes and investment in innovation to increase urban regeneration and sustainability, a framework for acquiring, assessing and various ways of using (applying) evidence in the workplace and schools, and managing building-related pathology such as offgassing materials that cause asthma, were all described as examples of evidence-based design research (CABE, 2006). On both sides of the Atlantic, the EBD approach emphasizes that researched evidence must be reliable and acquired using rigour, certainty and validity.

Evidence is not knowledge: design professionals need a reflective practice to turn information into knowledge (Schön, 1983). But evidence from research goes beyond informed opinion, it is predicated on proof. Therefore, hypotheses must be identified and tested in order for designers to claim they are using an EBD approach. The conventional POE provides information but not necessarily evidence. The two terms should not be confused: collecting feedback from users on whether or not they like or are satisfied with the physical environment is not a substitute for systematically validating a hypothesized relationship between users and built space. And although users' subjective experiences are often the basis for the 'proof' that is being collected, the EBD approach depends on a more scientific paradigm than that traditionally applied by POE.

Once the information acquired has been transformed into evidence that can support a commitment such as a design decision, then it is on its way to becoming knowledge. Studies of how knowledge is produced, stored, transmitted and dispersed in organizations as human capital are shedding increasing light on the subtlety and complexity of this process (Burton-Jones and Spender, 2009). When then does knowledge become intelligence? According to the intelligence industry, when it is explicitly applied in a given situation by those who have the knowledge to those who are going to use it – that is, the owners, occupants and managers of built space.

Basing building decisions on research evidence lends a scientific caste to design and construction activities, potentially increasing the positive opinions clients have of their project team professionals, and therefore their willingness to pay for evidence-supported recommendations. As research-based proof – or evidence – accumulates, it must be stored and maintained for easy access and retrieval in the context of project applications, much as legal decisions and opinions are stored for legal practice and as medical practitioners in clinical practice now have EBM data electronically available. EBD alters the definition of design from a function of individual creativity (which clients may or may not feel like paying for) to a process of creatively applying evidence to building decision-making. This increase in respectability goes hand in hand with greater responsibility – for example, to demonstrate conclusively that the physical environment of hospitals and seniors' residences is a form of treatment in healthcare and the treatment of dementia, that the physical environment of the workplace is a tool for performing work, that environmental design affects sales in stores and supermarkets, and supports better and faster learning in schools.

USING EVIDENCE-BASED DESIGN FOR MORE INTELLIGENT BUILDINGS

At a recent conference in North America, the range of research reported includes a study of patient safety and looks at systemic problems in how emergency healthcare facilities are designed and operated in order to identify ways of enabling hospital staff to avoid mistakes and of increasing the effectiveness and efficiency of their time (Vaughan, 2006). In another example, studies of the impact of improperly performing ventilation systems on illness, discomfort and stress are summarized to indicate ways of improving indoor air quality in a wide variety of building types (Hamilton, 2006). And a third example examines a range of methodological approaches in order to demonstrate the close relationship between the way a research hypothesis is formulated and the selection of the appropriate data collection method to test it (Stickler, 2006). In another example, a study of the distance of room doors from patient beds in an emergency department was found to have an effect on how quickly emergency patients received care, and collaboration with both emergency room staff and patients was recommended in order to optimize door placement in future designs (Hall et al., 2008).

Studies like these, which have informed or could inform critical healthcare design decisions, illuminate the enormous potential for implementing a programme of environment-behaviour studies that can and should inform hospital design decisions. A similar richness of research questions and studies awaits design researchers in other areas, for example, workspace design. Much of the research in this rapidly growing field of study has responded to critical issues that have arisen in the commercial real estate industry. These may include, but are not limited to, sick building syndrome and indoor air pollution in the 1970s and 1980s, thermal comfort and temperature control as well as ergonomic workspace and management of repetitive strain injuries in the 1990s, broadening out in the current decade to managing noise and distractions in workspace, studying the impact of increased workstation density, measuring the effects of different types of lighting on task performance, and producing knowledge about how employee performance is affected by the overall and interactive effects of environmental conditions at work (Vischer, 2008b). Studies of building occupants' 'functional comfort' have generated a large amount of evidence on both supportive and non-supportive elements of workspace design. Space planners, designers and facilities managers now can access knowledge about how worker behaviour – task performance, communication with co-workers and employee retention – is affected by various combinations of environmental influences, including lighting and daylight, furniture and spatial layout, noise levels, and thermal and ventilation conditions. Moreover, studies of worker mood – well-being, satisfaction and engagement – also show important connections to environmental features (Vischer, 2005). Evidence is accumulating on the optimal balance between individual workspace (offices or workstations, concentration rooms, places to work alone) and shared or communal facilities (meeting rooms, work rooms, lounges, places that facilitate collaboration). There is no simple directive for establishing this balance, but studies to date indicate that systematic analysis of the tasks people are performing and the environmental requirements for the types of work they are doing may offer a formula that can be applied to these key design decisions (Vischer, 2008b).

In another example, criteria for designing accommodation for older people with Alzheimer's disease are also based on data from multi-site studies in which specific design characteristics and behavioural health outcomes were measured (Zeisel, 2006). Outcome behaviours or symptoms measured in residents of Alzheimer's units include agitation, aggression, social withdrawal, depression and psychotic symptoms such as hallucinations (Zeisel et al., 2003). The research findings clearly indicate fewer symptoms in more appropriately planned and designed environments. Anxiety and aggression are reduced where there is greater bedroom privacy and more personalization of bedrooms. Social withdrawal is reduced in settings with not more than four communal spaces, each of which needs to have a unique design character to help residents orient themselves and make choices. There is a lower incidence of depression in residents when exits are camouflaged using less visible electronic locks instead of alarms (Zeisel, 2008).

It is not unrelated that the combined field of neuroscience and architecture is a fast-growing area of research in which links can be identified between the physical features of a building and the mental, emotional and behavioural effects on users, and it is likely to have important implications for EBD research (Eberhard, 2007).

As more of this type of knowledge is generated and made accessible to various building industry professions, both professional practice and buildings themselves are changing. Healthcare facilities in North America and Europe are now routinely planned using intelligence derived from EBD. And in becoming aware of and familiar with the new intelligence means that members of building-related professions have taken on the responsibility not to look the other way when evidence relevant to a design decision is presented, and not to make subjective decisions when EBD data is available. Basing important decisions on research results rather than on experience, intuition and creativity – whether in medicine or in design – has an effect on the political role of the professional and on the balance of power during a building project. Employing an evidence-based approach to design decision-making equalizes an unequal relationship in the building industry much as it does in modern medicine. Just as the patient has a more important role to play in a medical situation where the doctor shares 'evidence' in order to engage the patient in decisions, the architect has an opportunity by using evidence-based design to empower the client, to enlarge the role of the building user and to incorporate the users' perspective (experience and comfort) into key design decisions.

As the EBD approach expands its reach, more knowledge will find its way into building performance decisions, and be applied as intelligence to specific design, construction and operation procedures. Transforming the evidence from research into intelligence that informs and enlightens building performance is a new opportunity for delivering intelligent buildings. The intelligent building is a reality in the foreseeable future based on the informed and rational way in which it is produced. No professional in any field can easily defend a reliance on research results in order to continue doing things the same old way. Just as doctors take the Hippocratic oath to do no harm, the designers and builders that create our environment have an important new opportunity not only to protect building users and to do them no harm, but in fact to improve and enhance their environmental experience and the environmental future of our planet.

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