Evidence-based Performance Enhancement for the Built Environment

Peter Barrett[1], Lucinda Barrett[2]

Abstract

The key role of understanding the societal impacts of the built environment, as highlighted in the CIB's Revaluing Construction initiative is highlighted and, in particular, the importance of the experience of the users. This is then contextualised in the struggles of the research community to evidence the holistic impact of spaces on human performance. Proposals are made to handle the conceptual and analytical complexity inherent in this issue. Building from these ideas a successful test of the approach is reported. This provides evidence that the built environment aspects of a sample of thirty-four UK primary schools explain around 25% of the variation in pupils' learning rates over a year.

The paper comes full circle to conclude on the systemic nature of built environment impacts, and the opportunity, if they can be better understood, to improve peoples' lives and make optimal use of the huge investments being made in the built environment. This could have radical impacts on how construction is seen – not dirty, dangerous and disruptive; but life-giving, economy-driving, a source of happiness and effectiveness. As well as raising the perception of the societal value of construction this perspective also has radical business implications for those in industry or design. By designing and building with the impact on users' health, well-being and effectiveness centrally in mind, greater value can be delivered for clients and thus the sustainability of the businesses will be enhanced.

Keywords: Industry effectiveness, user, impacts, evidence.

1. Introduction

The CIB proactive theme Revaluing Construction highlighted seven key aspects that demand comprehensive attention if sustained industry improvement is to be achieved (Barrett P S 2007; Barrett P S 2008). These are shown in Figure 1.

[1] Professor; School of the Built Environment; University of Salford; Salford, M54WT, UK; p.s.barrett@salford.ac.uk.
[2] Research Fellow; School of the Built Environment; University of Salford; Salford, M54WT, UK; l.c.barrett@salford.ac.uk..

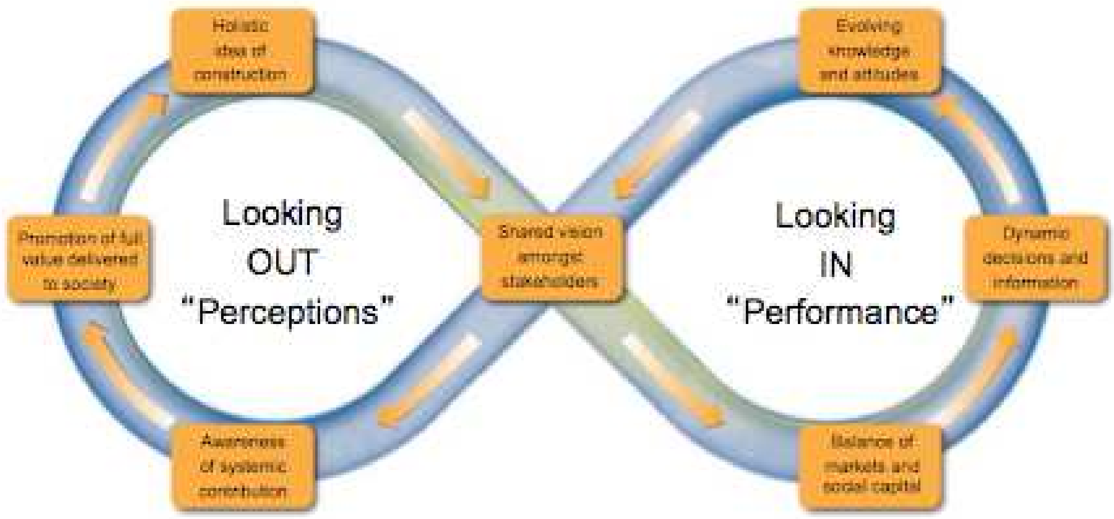

Figure 1: Revaluing Construction: Seven Linked Areas for Industry Improvement

In the UK at least significant activity around the items can be seen. For example:

(a) The multi-disciplinary / stakeholder UK Strategy Panel for Construction has adopted an *holistic idea of construction* that extends to include the whole building life cycle by taking a "built environment" perspective. Thus in their strategy document for the industry it is stated that: "the built environment industry represents some 20% of the UK's GDP … and is therefore a major national economic driver" and it is argued that beyond this it "… influence[s] all aspects of our quality of life and enable[s] the economy and society to function" (National Platform for the Built Environment 2008). This *shared vision* represents a significant shift in thinking from the group's traditional stance, which was to think about what would be good for construction in itself as 7% of GDP. This scaling of the built environment sector within the economy was based on the CIB's activity scoping of a conceptual framework for a meso-level economic analysis (Carassus J 2004). This addressed the illogicalities of the way in which the SIC economic categories work for construction as highlighted by Winch (2003), such as architects and other consultants not being counted in as part of the industry, but the meso-level analysis also factored in the use phase in terms of operating costs and property activity.

(b) The above shift in perspective has chimed with a range of practical actions to move away from lowest bid selection and towards longer term, value-orientated relationships through initiatives, such as partnering and PPP arrangements. These have not been without problems, but do represent efforts to factor in *social capital*, rather than a focus solely on market forces. However, it would seem that these initiatives are coming under pressure in the current recession as clients strive to minimise short term costs. This may look sensible, but the theory at least is that partnering arrangements should deliver better value longer term (at the end of the project and beyond) and so it will be interesting to see what the consequences are in thee medium term.

(c) The area of *dynamic decisions and information* has been building up for many years as technologies became available. The impetus for implementing Building Information Models (BIM) was given a significant boost by the NIST Report that highlighted the huge losses incurred through a lack of interoperability between the phases of design, construction and use (Gallaher M P, O'Connor A C, Dettbarn J L et al. 2004). In the UK, the Government's decision to stipulate that public sector projects "will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016" (Cabinet Office 2011). This has led to a flurry of activity amongst technology providers and users in industry. There is a danger that this will be treated as a compliance issue by industry focused on getting and using the technology. There is a wider strategy at large (HM Government 2012) and this aspires for BIM to impact very broadly on the whole supply chain, but also, hopefully, supporting the whole life cycle approach by enhancing the operation and functionality of assets. This is important as the NIST report suggested that most benefit is to be had to the client within the use phase, although most potential to act was asymmetrically located at the earlier phases of the process. The Government lead as a major client overcomes this motivational disjuncture by force, but to be entirely successful the scope and impacts of BIM need to kept broad.

(d) There has been an immediate response within educational institutions to train and educate students and practitioners around current / emergent issues and BIM has been no exception and it is to be hoped that this will impact favourably on the *evolving knowledge and attitudes* of those making up the human capital of the sector. There is no doubt that research has proactively delivered large aspects of the possibility of BIM and encouraged progress by linking those engaged in international good practice. For example academics were actively moving things from 3 to 4 to "n" dimensional CAD many years (Issa R, Flood I and O'Brien W 2003) before the industry was stung into action by public sector client demand. Even more specific is the growth of the national implementation effort in the US around the energy and expertise of a Stanford University postgraduate from their CIFE programme.

(e) Of the seven action areas two have been lagging. The *promotion of the full value delivered* by construction is a challenge, but is important if clients are to be inclined to invest and workers motivated to choose to work in this sector. The UK strategy above is an example of a strongly positive view being promoted and parallel activity has been evident elsewhere. For example an ambitious and strategic programme of activities is being instituted in Malaysia, which shows many resonances with the Revaluing Construction approach (Barrett P and Hamid Z 2011) and carries high economic and societal ambitions for that country. Within Europe the European Construction Technology Platform (ECTP) has grasped a representative role for the sector towards the EC and has produced an impressive and ambitious strategic research agenda (ECTP 2005). This led to a higher profile for the sector and it is interesting to note that, when the financial crisis first hit, construction representatives were involved from the start in high-level discussions around investments to progressively work the European economies out of the recession.

(f) This leaves the last area, which is gaining an improved *awareness of the systemic contribution* of the sector. This is implicit to the 20% GDP argument, but this just shows the built environment sector is big and important in itself, it does not show that massive benefits flow from its activities. Of course we all intuitively know, for example, that we need shelter from the elements and that certain places provide important cultural foci with deep historical connections. There is also a wealth of evidence about physiological and psychological impacts of various environmental dimensions. For example, poor air quality as indicated by high CO_2 levels are common in schools and pupils can be measured to show that this results in reduced attention and cognitive performance (Bakó-Biró, Clements-Croome, Kochhar et al. 2012). However, there is surprisingly little evidence of the holistic, combined impact of the features of spaces on general human performance / well-being. This aspect is picked up below, with a particular emphasis on the characteristics of schools and connections to pupils' learning rates.

2. The systemic contribution of the Built Environment

Gaining an understanding of this aspect is a key element of how industry is perceived, but also how it performs. It is a crucial aspect for the European Construction Technology Platform's (2005) aspiration to maximise the *positive* contribution that the built environment can make by addressing value, rather than just cost considerations. Value is derived from the built environment in many forms. For example, Macmillan (2006) has suggested (and illustrated) six: exchange value, use value, image value, social value, environmental value and cultural value. It would seem logical to think that "use value" is an important concept amongst these, as if it is taken beyond the work context suggested, then impacts on users will feed many other sorts of value. For example, if a building, say a retail outlet, is effective in supporting the sales, then its exchange value will increase. Or if image value is negative, it is because it has a negative impact on those affected by the building.

Thus, it is argued that fundamentally the value delivered by the built environment is fundamentally founded on impacts on users. This leads to the question as to how these impacts occur between the built environment and individual users. The basic currency would seem to be impacts the built environment has on our senses, which are then noted and interpreted as a holistic experience by our brains. This is a simple thought experiment, but leads to some interesting possibilities.

Rolls (2005) tracks the routes from our senses to our brains and starts to dissect how they are judged and balanced through processes of primary (hard wired) and secondary (learnt) reinforcers. This is all within a context that is so information-rich that a simple calculated response is impossible and so responses to spaces are really quite implicit, or emotional in nature. So, first, as our emotional systems have evolved over the millennia in response to our natural environment, it does not seem unreasonable to suggest that our comfort is likely to be rooted in key dimensions of 'naturalness', stressing positive aspects of naturalness, such as clean air. Second, the personal way in which individuals build connections between primary reinforcers and complex representations of secondary reinforcers, situated within memories leads to the importance of 'individualization' as an additional, key, underlying design principle. Third, there is also a recurrent theme around the general level of stimulation that is appropriate for given situations. Nasar (1999) reinforces the central importance of the level of stimulation and suggests that combinations of pleasantness (or unpleasantness) and different levels of arousal yield either excitement (or boredom) or relaxation (or distress). More detailed arguments are provided for these three underpinning design principles in Barrett and Barrett (2010) and can be summarised as shown in Figure 2 – the individual at the intersection of the natural, task and personal environments.

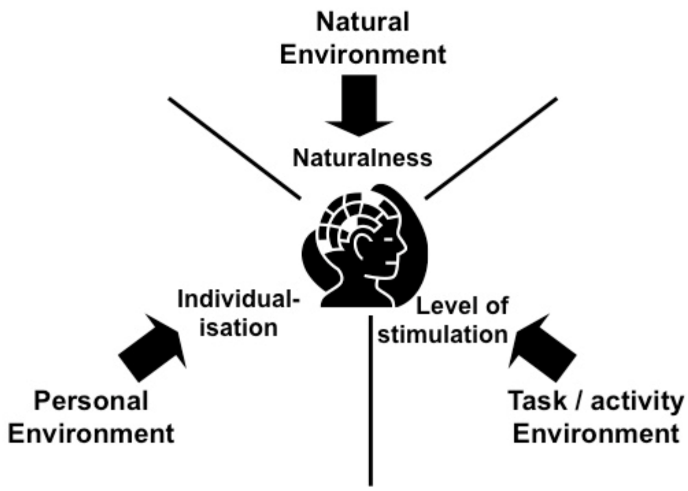

Figure 2: Neuroscience-informed analytical structure

3. Evidencing holistic impacts

Taking school design as an example, there has been a lot of research over the years. When summarised (Barrett PS and Zhang Y 2009) the overriding impression is of lots of views about good schools, some evidence of linkages between specific aspects (say layout) on pupils' learning, some evidence of impacts on users' preferences, but very little evidence of an understanding of the holistic impact of school spaces on validated learning rates. There are exceptions and Tanner (2000) is one, but this study suffers from performing a regression analysis on a multitude of factors that in many cases overlap with each other, causing problems in interpretation.

Looking more broadly, it is apparent from the internal environment quality (IEQ) literature that the analysis of the interactions of multiple sensory factors and linking these to human responses (let alone variations in performance) is a current and unresolved issue, (Bluyssen P M, Janssen S, van den Brink L H et al. 2011). IEQ research has primarily focused on the readily measurable aspects of: heat, light, sound and air quality, and although impressive individual sense impacts have been identified, it has been a struggle to explain variations in overall human performance with these variables. Indeed Kim and de Dear (2012) argue strongly that there is currently no consensus as to the relative importance of IEQ factors for overall satisfaction.

So it is interesting to note that since Ulrich's (Ulrich R 1984) ground-breaking work on views of nature and healing (one dimension of the environment) and Heschong Mahone’s (1999; 2003) studies on daylighting in schools there seems to have been very little development in linking the impact of the holistic, multiple aspects of the environment on human performance. There appears to exist an important research challenge around the issue of better understanding, and evidencing, the holistic impacts of spaces on users. To address this challenge it is argued that, first the *conceptual* complexity of the real world factors to be considered needed to be prioritised and structured. Secondly, the *practical* complexity of the analysis needs to be addressed.

The struggle that the IEQ researchers are having to address the interactive impacts of combinations pairs of factors argues for the need for a complementary effort, working from the other end of the telescope, by adopting a top-down selection and structuring of the factors to be considered. This is where the neuroscience-informed model described above may have utility. This over-arching conceptual perspective could be a route to synthesise the alternative design factors into a form that generates hypotheses for optimal design that can provide a basis for understanding the combined effects of sensory inputs on users of buildings at a level of resolution where “emergent properties” (Checkland 1993) may be evident. Until recently the only exemplar study using this sort of thinking was focused on Alzheimer’s care facilities (Zeisel J, Silverstein N, Hyde J et al. 2003), which successfully demonstrated how characteristics of the built environment can have medically convincing impacts on symptoms such as aggression and depression. The implication is that the structuring of the brain’s functioning could be used to drive the selection and organisation of the environmental factors to be considered, not just their inherent measurability. Thus, the three neuroscience-derived design principles could be used to choose and order the factors to be included, covering the usual four IEQ factors (heat, light, sound and air quality) but also others, such as aspects linked to “appropriate level of stimulation”, for example, colour and visual complexity.

The second aspect concerned the analysis of the data. As the focus is on people in spaces it will tend to be inherently nested (e.g. pupil in class in school), thus to avoid misleading results due to the overestimation of significance, a multi-level analysis approach can be adopted (Goldstein H 1995; Peugh J 2010). This provides a rigorous way of dealing with unmeasured effects by allowing the residuals to be partitioned at each level. Multilevel modelling is well tested in educational research, a specialist support centre exists at Bristol University (Rasbash J, Steele F, Browne WJ et al. 2009; MLwiN 2012) and this approach was used with success in Zeisel’s study.

4. Testing the proposition in the context of schools

Using these two approaches together to address the issue of holistic built environment effects on humans in spaces is novel and a project on primary schools has been carried out with funding from industry and the UK's Engineering and Physical Sciences Research Council. The HEAD (Holistic Evidence and Design) project research model, built on the above ideas, is given in Figure 3.

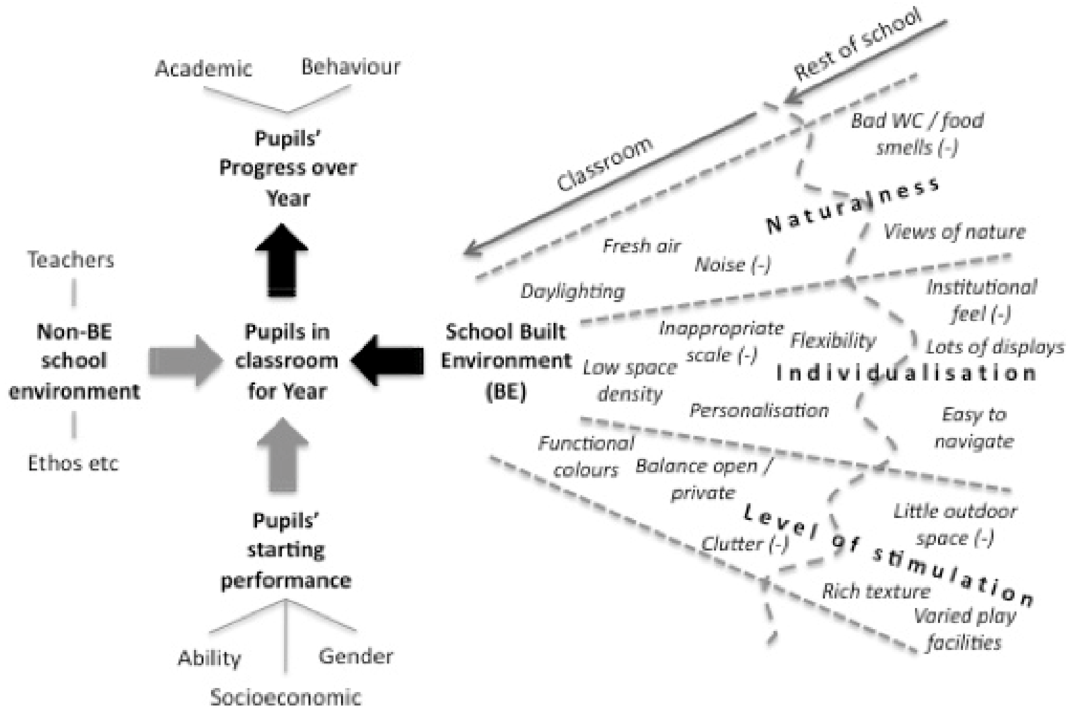

Figure 3: Research Model for Schools study

Blackpool Council supplied access to seven primary schools. All of the schools studied had their own unique features in terms of school site and buildings. They displayed a good level of variety across the sample, which facilitated meaningful analysis. Similarly SATs results for the pupils in the chosen classrooms were obtained so the improvement in "learning" over the preceding year could be assessed. Primary schools provided an ideal test environment for the ideas in play here, as young pupils of this age spend almost all their time in the same room, so any influence of the characteristics of that room should be at a maximum. The study design and results have been described fully in Barrett et al (2013).

The results of this study of schools have provided strong *proof of concept* for the efficacy of this approach to both the conceptual and practical complexity inherent in "natural" data of the sort studied. At the "class" level, 73% of the variation in learning rates of 751 pupils, based on exam their results, was explained by six built environment design parameters, which together contribute at an estimated 25% of the overall influences on learning rates. Thus, it is apparent that the holistic impacts of spaces on people can be identified and are potentially very large. The six environmental aspects that were found to be significant are summarised in Table 1.

Table 1: Summary Results from Schools' Project

Design Principle	Design parameter		Good classroom features
Naturalness	Light	◆	Classroom receives natural light from more than one orientation. And (or) natural light can penetrate into the south windows.
		◆	Classroom has high quality and quantity of the electrical lightings.
		■	The space adjacent to the window is clear without obstruction.
Individualisation	Choice	◆	Classroom has a high-quality and purpose-designed FF&E
		◆	Interesting (shape and colour) and ergonomic tables and chairs are welcomed.
	Flexibility	◆■	More zones can allow varied learning activities at the same time.
		◆■	The teacher can easily change the space configuration.
	Connection	◆	Wide corridor can ease the movement.
		■☛	The pathway has clear way-finding characteristics.
Stimulation,	Complexity	◆	Big building area can provide diverse opportunities for alternative learning activities.
appropriate level of		■	With regard to the display and decoration, classroom needs to be designed with a quiet visual environment, balanced with a certain level of complexity.
	Colour	■	Warm colour is welcomed in senior grade's classrooms while cool colour in junior grades, as long as it is bright.
		■◆	Colour of the wall, carpet, furniture and display can all contribute to the colour scheme of a classroom. However, it's the room colour (wall and floor) that plays the most important role.

◆ design-related classroom features
■ usage-related classroom features
☛ future study is needed to pursue its positive characteristics.

5. Conclusions

This paper started with the Revaluing Construction perspective on industry improvement. This led to the identification of the importance of making progress on the "awareness of the systemic contribution" of the built environment within society. The focus was then targeted down on the impact of spaces on users via their senses and mediated by their brains. The problem with studying the complexity of human performance in "natural" settings was illustrated and strategies proposed for dealing with this conceptually and analytically. The results were reported of a study that successfully took this approach.

This brings us full circle. If the holistic effects of the built environment can be more fully understood for all users of spaces there is tremendous potential to improve peoples' lives and make optimal use of the huge investments being made in the built environment. In addition it will provide a meta-structure with potential to sweep in a lot of very rigorous laboratory studies of single dimensions, such as the light work by the Lighting Lab at the Rensselaer Polytechnic Institute. Finally, it will provide a way forward for the development of functional, holistic, standards for *spaces*.

The approach and initial test described above have taken several years, but offers real hope that the issue of the value of the built environment within society can be understood and evidenced. This should have radical impacts on how construction is seen – not dirty, dangerous and disruptive; but life-giving, economy-driving, a source of happiness and effectiveness. For the industry the challenge will be to work with clients to accommodate new knowledge about user impacts within an already congested briefing space.

This is only a small start, but hopefully it will help researchers and practitioners crab-wise sneak up on the issue of how to create better spaces in real situations to the benefit of users and so society.

References

Bakó-Biró, Z., D. J. Clements-Croome, N. Kochhar, et al. (2012). "Ventilation rates in schools and pupils' performance." Building and Environment **48**(0): 215-223.

Barrett P and Barrett L (2010). "The Potential of Positive Places: Senses, Brain and Spaces." Intelligent Buildings International **2**: 218-228.

Barrett P and Hamid Z (2011). Malaysian Revaluing Construction Workshop Report. Kuala Lumpur, Malaysian CIDB / CREAM.

Barrett P S (2007). "Revaluing Construction: An Holistic Model." Building Research and Information **35**(3): 268-286.

Barrett P S (2008). Revaluing Construction. Oxford, Blackwell Science.

Barrett PS and Zhang Y (2009). Optimal Learning Spaces: Design Implications for Primary Schools. Salford, UK, SCRI.

Barrett PS, Zhang Y, Moffat J, et al. (2013). "An holistic, multi-level analysis identifying the impact of classroom design on pupils' learning." Building and Environment **59**: 678-689.

Bluyssen P M, Janssen S, van den Brink L H, et al. (2011). "Assessment of wellbeing in an indoor office environment." Building and Environment **46**: 2632-2640.

Cabinet Office (2011). Government Construction Strategy. London, UK Government.

Carassus J, Ed. (2004). The Construction Sector System Approach: An International Framework. Rotterdam, International Council for Research and Innovation in Building and Construction.

Checkland, P. (1993). Systems Thinking, Systems Practice, John Wiley and Sons, Chichester.

ECTP (2005). Strategic Research Agenda for the European Construction Sector: Achieving a sustainable and competitive construction sector by 2030. Paris, ECTP.

Gallaher M P, O'Connor A C, Dettbarn J L, et al. (2004). Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry, National Institute of Standards and Technology.

Goldstein H (1995). Multilevel statistical models London, Edward Arnold.

Heschong Mahone Group (1999). Daylighting in Schools. Fair Oaks CA, Pacific Gas and Electric Company.

Heschong Mahone Group (2003). Windows and Classrooms: A Study of Student Performance and the Indoor Environment. Fair Oaks CA, Californian Energy Commission.

HM Government (2012). Building Information Modelling - Industrial strategy: government and industry in partnership. London, UK Government.

Issa R, Flood I and O'Brien W, Eds. (2003). 4DCAD and Visualization in Construction. Lisse, The Netherlands, Swets & Zeitlinger Publishers.

Kim J and de Dear R (2012). "Nonlinear relationships between individual IEQ factors and overall workspace satisfaction." Building and Environment **49**: 33-44.

Macmillan S (2006). The Value Handbook: Getting the Most From Your Buildings and Spaces. London, The Commission for Architecture and the Built Environment.

MLwiN (2012). "MLwiN software package." Retrieved 5 November, 2012, from http://www.bristol.ac.uk/cmm/software/mlwin/.

Nasar J (1999). Design by Competition: Making Design Competition Work. Cambridge, Cambridge University Press.

National Platform for the Built Environment (2008). Research Priorities for the UK Built Environment. London, Constructing Excellence.

Peugh J (2010). "A practical guide to multilevel modelling Journal of School Psychology." Journal of School Psychology **48**: 85-112.

Rasbash J, Steele F, Browne WJ, et al. (2009). A User's Guide to MLwiN. Bristol, University of Bristol.

Rolls ET (2005). Emotion Explained. Oxford, OUP.

Tanner C (2000). "The Influence of School Architecture on Academic Achievement." Journal of Educational Administration **38**(4): 309-330.

Ulrich R (1984). "View Through a Window May Influence Recovery from Surgery." Science **224**: 420-421.

Winch, G. M. (2003). "How innovative is construction? Comparing aggregated data on construction innovation and other sectors–a case of apples and pears." Construction Management and Economics **21**(6): 651-654.

Zeisel J, Silverstein N, Hyde J, et al. (2003). "Environmental Correlates to Behavioral Health Outcomes in Alzheimer's Special Care Units." The Gerontologist **43**(5): 697-711.