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Achieving a step change in the optimal sensory design of buildings for users at all life-stages

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A B S T R A C T

A general gap in knowledge around the holistic impact of spaces on human performance is identified. It is argued that filling this gap demands that the conceptual and methodological complexity of real world users' experiences of built spaces is addressed. It is argued that a potentially productive way forward is to use multi-level modelling within a neuroscience-informed, holistic sensory approach. Published results are highlighted in support of this approach, focused particularly on primary schools.

The potential of expanding this approach to a full range of life-stages is then explored, building on a view of the brain as it evolves across the human life-span. The separation of left/right-brain cognitive processes emerges as being potentially important as an intervening variable. The schools' data is re-analysed by subject using multi-level modelling to provide, maybe for the first time, proof of concept evidence of variations in the optimal space characteristics depending on brain lateralisation.

In addition significant differences are identified in the particular types of spaces involved and the relevant measures of human performance. These range from: classrooms and learning for school pupils; to offices and productivity for workers; to housing and well-being for the elderly.

The train of argument is brought together around a vision for the development of a general model for holistic sensory space design. This would address a number of life-stages and, through a progressive meta-analysis, it is suggested that, over time, an evidenced, whole-life perspective on the holistic impact of spaces on human performance can be achieved.

1. Introduction/structure of paper

It has been estimated that people spend 90% of their entire lifetime within buildings [1–3]. Furthermore, around 5.75% of GDP in developed countries is spent on construction activity to create or improve the built environment [4]. Yet there is no real understanding of the *holistic* impacts of built spaces on human functioning, despite huge amounts of information on individual aspects, such as heat and light [5]. The potential to enhance people's well-being and effectiveness would be huge if a clearer understanding of the overall impact of spaces could be achieved. Equally the built environment sector could orientate its efforts more effectively to support building users and, in so doing, would actively address the core social and economic dimensions of sustainability.

The thrust of this paper is as follows:

- Section 2 highlights the importance of the users' perspective and the research challenge around holistic impacts is brought into focus.
- Section 3 sets out how the complexity of the research challenge can possibly be addressed, conceptually and methodologically. This is illustrated by reference to a published study that successfully utilised the approach advocated, applied to primary schools and pupils' learning rates.
- Section 4 uses a whole-life model of the development/decline of the human brain, to explore how the above approach could be extended to a number of life-stages, namely: secondary school pupils, the working population and older people. The potential role of left/right-brain activity as an intervening variable emerges from this discussion.
- Section 5 provides clear proof of concept, from a reanalysis of the primary school data, that optimal built environment conditions *do* vary depending on brain function lateralisation.
- Section 6 returns to the three life-stages covered in Section 4 and clarifies that, in each case, there is a research gap in terms of the holistic impact of spaces on users, but that the spaces and human performance measures vary in each case: classrooms and learning for school pupils; offices and productivity for workers; and housing and well-being for the elderly.
- Section 7 brings together the previous sections into a vision for the development of a general sensory space design theory,

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involving focused studies in each of the areas and meta-analysis across the studies.

- Section 8 summarises and concludes.

2. Context

2.1. Strands of development

Internal environment quality (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 [6] argue strongly that there is currently no consensus as to the relative importance of IEQ factors for overall satisfaction.

In parallel, a literature and area of practice has developed around "building performance" with a wide variety of typologies on offer [7,8]. The intelligence gained should feed forward into new designs, however, post-occupancy evaluations (POEs) are not commonplace and the lessons learnt are not generally available for use in practice [9]. The concept of Building Performance Evaluation (BPE) argues for the deployment of user performance data throughout the whole-life-cycle of the building. In a recent benchmark for BPE [10] it is made clear that BPE aspires to objectivity using *"actual performance of buildings [assessed through] established performance criteria … objective, quantifiable and measurable 'hard' data, as opposed to soft criteria … qualitative … subjective"* (p. 27–28). However, in practice this is difficult and hardly anywhere amongst the collected chapters is such evidence actually delivered, with the most common approach being occupant surveys with occasional interviews (p. 169).

Another strand of development in recent years has been the rise in polemical works arguing for "inside-out design" [11] that builds from a focus on user needs and challenges the visual dominance of much design effort [12]. This is twinned by those arguing specifically for aspects of sensory-sensitive design [13,14]. Whilst Mallgrave [15] takes in a broad historical sweep and calls for the "'re-assertion of the human body as the locus of experience' (quoting Holl et al. [16]) … [that has] been shunted aside by high-minded abstractions and abject formalism." (p. 205).

2.2. The emerging challenge

These complementary efforts stress that the evidence of building users' needs should be taken more fully into account and provide copious case study examples of potential *elements* of "good" design solutions. However, there remains a big gap between these putative elements and effectively achieving the desired *holistic* effects for users. Some specific aspects linked to "real" impacts have gained traction, for example Ulrich's [17] classic evidence of the positive healing effects of views of nature. There has been progress from this promising start, for example around individual control of thermal conditions in hospitals [18], but this still falls a long way short of comprehensively addressing the complexity of the design challenge. The difficulty of studying multiple dimensions is illustrated by the problems encountered when the impressive Heschong Mahone [19,20] daylighting studies extended to include other issues. It is also evident in Tanner's [21] struggle to analyse the multiple aspects impacting on learning rates in schools.

So there exists an important research challenge around the issue of better understanding, and evidencing, the holistic impacts of spaces on users.

3. Addressing the challenge

This research challenge has two dimensions. First, a way has to be found to address the *conceptual* complexity of the real world factors to be considered (and the wealth of state-of-the-art knowledge, from a range of disciplines). Secondly, the *practical* complexity of the analysis needs to be addressed.

3.1. Addressing the conceptual complexity

An over-arching conceptual perspective is essential to synthesise the alternative design factors into a form that can generate hypotheses for optimal design, which can be tested. An interesting possible way forward is to use the simple notion that the effect of the built environment on users is experienced via multiple sensory inputs in particular spaces, which are resolved in the users' brains. These mental mechanisms can provide a basis for understanding the combined effects of sensory inputs on users of buildings at a level of resolution where "emergent properties" [22] may be evident. This is the approach being promoted by the Academy of Neuroscience for Architecture (ANFA), based in San Diego, and stimulated by, eg Eberhard's [23] work. Arbib [24] makes an interesting distinction between, what he terms "neuromorphic architecture" and Eberhard's "neuroscience of the architectural experience". In simple terms, the former addresses analogies of brain functioning for designed spaces and the latter the impact of spaces on the brain.

The approach taken here is neither of these and is not concerned with the brain per se. Rather it employs the broad characteristics of brain functioning to structure the sensory factors to be considered with a view to better understanding the holistic impacts of spaces on human performance and well-being [25]. It could be said to focus on neuro-informed architecture. Until recently the only exemplar study using this sort of thinking was focused on Alzheimer's care facilities [26], which successfully demonstrated how characteristics of the built environment, viewed through a neuroscience lens, can have medically convincing impacts on symptoms such as aggression and depression.

The implication is that the structuring of the brain's functioning can be used to drive the selection and organisation of the environmental factors to be considered, not just their inherent measurability. This approach to postulating "generative mechanisms" underlying the complexity observed, has been termed "retroduction" [27]. Thus, drawing especially from Roll's [28] detailed description of the brain's implicit systems, a novel organising model has been proposed [25]. This structures the factors to be considered into:

- Naturalness: eg, light, sound, temperature and air quality.
- Individualisation: eg, choice, flexibility and connection.
- Appropriate level of stimulation: eg, complexity, colour and texture.

The rationale for the choice of these themes [28] can be summarised as follows. 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'. This is encoded via the action of hard-wired 'primary reinforcers' operating in the orbitofrontal cortex of our brain where the value of the environmental stimulus is assessed. Examples would be our attraction towards fresh air and daylight. Second, over time individuals build connections between 'primary reinforcers' and complex representations of 'secondary reinforcers'. Taken together with the situated nature of memory, these personal value profiles lead to highly