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Unweaving the human response in daylighting design

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ABSTRACT

Daylighting as a research topic situates itself at the interface between psycho-physiological and environmental factors, bringing together questions relevant to architectural design and building engineering, but also to human physiology and behavior. While daylighting has a strong impact on human health and well-being, and an undeniable association with (subjective) emotional delight and perceived quality of a space, it is also highly dynamic and variable in nature, based on a combination of predictable (sun course) and stochastic (weather) patterns. This makes it both a challenging and essential aspect of how "performative" a space can be considered.

This paper aims to discuss selected research developments regarding how architectural engineering and other domains of science could be more strongly bridged to address the need for meaningful decision support in daylighting design: how can we better integrate the complexity of human needs in buildings into effective design strategies for daylit spaces? As a basis for discussion and to illustrate this overview, it describes a unified goal-based approach in an attempt to address the multiplicity of perspectives from which daylighting performance can – and should – be evaluated in building design. Through five very different perspectives ranging from task-driven illumination or comfort to human-driven health and perception, it proposes a simulation and visualization framework in which one can start approaching these from an integrated approach.

1. Introduction

The ultimate impact buildings have on our lives is fundamental: buildings represent a major part of our life, with a share of over 40% of overall energy use, waste and CO_2 emissions [1], almost 50% of the population now living in cities, and 90% of time typically spent indoors. With lighting, heating and cooling being the three most energy-demanding building functions [1], it appears very clearly how efficient daylighting and solar control strategies can have a tremendous impact on energy use [2]. But any savings can only be effective if one also carefully accounts for our comfort, well-being and health criteria.

The integration of building performance criteria into the design process has received a great level of attention in the last two decades. Simulation models of increasing degree of sophistication [3] have been developed and a wide range of metrics and of tools are now available and still being developed to support our search for minimizing energy consumption or ecological footprint. One of the underlying principles for this search is that the performance of a space will typically increase with user satisfaction and decrease with energy consumption [4], the latter being used towards discomfort compensation until occupant satisfaction is reached. In today's energy crisis, minimizing this compensation becomes essential but requires a very good understanding of our comfort requirements, used as triggers for (predicted) action on our environment according to still poorly understood interaction patterns with building controls (dimming, thermostats, shading etc) [5–10]. In the contemporary context of building for sustainability, we must move beyond energy-centric approaches and consider sustainable design from a broad perspective, focusing also – or actually starting with – quality of life, occupant satisfaction and psycho-physiological human well-being.

Static comfort thresholds can only provide an incomplete picture and have led, in the 30 ies–60 ies, to an era of windowless, air-conditioned offices and classrooms as ultimate symbols of progress specifically because they adhered – under full control – to accepted standards for comfort. We have now realized that our needs far surpass these universal ones [11–13] and include a longing to bond

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with our living environment (biophilia hypothesis) as well as a need to stay connected to its ever-changing nature through windows and views [14].

While we share fundamental needs driven by evolution, it is very clear that people value things differently, and have needs far from being uniform at several levels (Fig. 1):

- *diversity*: Individual preferences about privacy, temperature swings, or architectural character e.g. depend on factors ranging from cultural background and social status to health and age.
- *variability*: The temporal variability of our needs results from our inherent attachment – at both the psychological and physiological levels – to a very variable outside environment (seasons, time of day, weather, vegetation, light–dark cycles).
- *boundaries*: In today's urge to design sustainably, we must think within an overarching reality of finite resources; to reduce our carbon footprint and use of non-renewable energy, the building sector – that accounts for a 40% share of these resources – plays a pivotal role.

The architect is thus faced with multiple, highly variable, bounded criteria that can conflict but need to be brought together to lead to a satisfying solution. Yet unlike clothing that can easily and continuously be adjusted to both user preferences and outside conditions, buildings are constrained to a somewhat limited set of materials and to basic adaptation (shading, operable windows), which prevents them from responding to individuals to the same degree of refinement as clothing: preferences have somehow to be synthesized, and the main role of the architect is to do this synthesis. On the other hand, the ultimate balance between all factors and constraints leading to a satisfying design solution cannot be solely based on measurable criteria: a design process does not reproduce conventional optimization because of its inherent non-linearity and reliance on elements that cannot always be objectified.

This paper investigates a selection of research perspectives aiming to reinforce links between building science and architecture through trans-disciplinary approaches reaching out to other fields such as photobiology and psychophysics regarding perceptual, visual (comfort-based) and non-visual (health-based) daylighting design. It proposes a goal-based strategy to address design decision support, and discusses five interpretations of "good daylighting" performance objectives, brought together in a unified visualization framework for daylighting simulation centered around human needs.

2. Dynamic daylighting for variable and diverse humans

Although basic physiological needs can be considered similar enough for most humans, leading to somewhat predictable ranges of acceptability regarding comfort and well-being in buildings, some degree of diversity and variability is inevitable regarding building occupants' preferences and perceived needs, particularly marked as they relate to daylighting penetration [5].

As far as illumination is concerned, these needs typically get translated into target illuminance values or ratios [4,6,15,16] – with the earliest "daylight factor" recommendations dating back to the end of the 19th century. Established metrics relevant to daylight penetration have indeed been focusing on finding benchmarks for task illuminance and visual comfort (glare avoidance) [4,6,7,15] yet with varying degrees of applicability beyond the conditions in which they were measured, and with results that are often difficult to compare [6]. More recently, climate-based modeling has become a widespread approach – at least in research but also to some extent in practice – so as to consider daylighting on an annual basis [4,10,17–20]. Other studies have looked at individual preferences [5], or at "light quality" indicators typically derived from luminance averages or ratios [21]. Different daylight metrics concepts have been proposed, such as associated to entire space areas [18] or viewed scenes [22] rather than individual detection points, and based on relative approaches for more complex systems [23]. The latter helped to shift the focus back on daylight variability, not only its spatial distribution [18,19,22].

How well a given space is daylit is by essence a multifaceted question: it is a key factor in how well any visual task will be performed, a main driver of occupant satisfaction regarding visual and thermal comfort (and hence energy consumption resulting from trying to meet comfort requirements), has a strong impact on human health and well-being, a close association with the perceptual quality of a space, and is highly dynamic in nature as a result of daily and seasonal variations.

The multiplicity and variability of our needs regarding (day)light exposure have thus clearly been a topic of investigation for years. To more deeply embed the diversity and variability of human needs as foundational elements of daylighting design and put human occupants back at the core of the question, we now also need to reach out to other research fields, so as to bring new insights and a deeper understanding of how we interact with our environment.

This requires first to uncover – unweave – essential relationships between human occupants and a daylit environment with a focus on their dynamics, and to establish cross-disciplinary

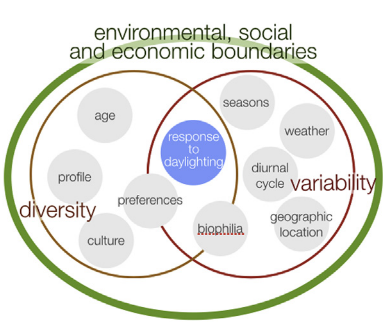

Fig. 1. Ingredients of human-driven design.

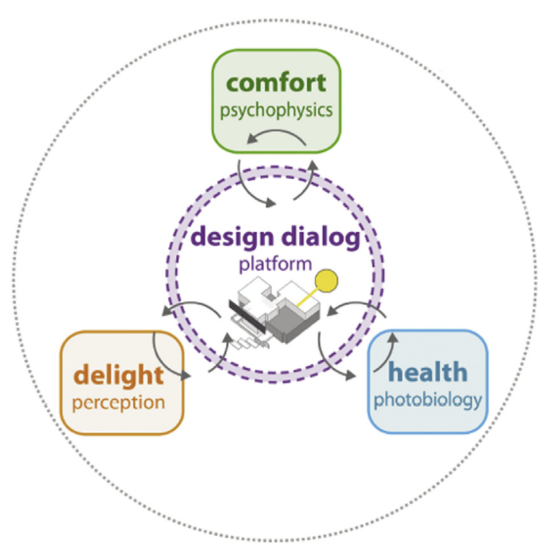

Fig. 2. Inter-related aspects of human-responsive (day)lighting design reaching out to other fields of research.