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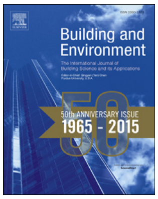

Integrated building performance simulation: Progress, prospects and requirements

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ABSTRACT

This paper is concerned with the role of Building Performance Simulation (BPS) in assisting with the creation of energy efficient habitats. It characterises achievements to date in a non-program-specific manner and in relation to the ultimate goal of providing practitioners with the means to appraise, accurately and rapidly, the multi-variate performance of built environments of arbitrary complexity. The shortcomings of the state-of-the-art, when assessed against this goal, are used to identify future development priorities.

1. Introduction

The drive towards a sustainable built environment raises challenges for practitioners. These stem from the need to reduce energy consumption, integrate clean energy supplies and mitigate environmental impacts, all while meeting expectations for human wellbeing and economic growth.

Spitler [1] has described the evolution of BPS to date: "The simulation of building thermal performance using digital computers has been an active area of investigation since the 1960s, with much of the early work (see e.g. Kusuda 1999 [2]) focusing on load calculations and energy analysis. Over time, the simulation domain has grown richer and more integrated, with available tools integrating simulation of heat and mass transfer in the building fabric, airflow in and through the building, daylighting, and a vast array of system types and components. At the same time, graphical user interfaces that facilitate use of these complex tools have become more and more powerful and more and more widely used". Hong et al. [3] provide a summary of BPS as it existed at the start of the present millennium, concluding presciently that "with the growing trend towards environmental protection and achieving sustainable development, the design of 'green' buildings will surely gain attention. Building simulation serves not only to reveal the interactions between the building and its occupants, HVAC systems, and the outdoor climate, but also to make possible environmentally-friendly design options".

While the power of simulation is widely recognised, it is not generally appreciated that the approach does not generate design solutions, optimum or otherwise. Instead, it supports user understanding of complex systems by providing (relatively) rapid feedback on the performance implications of proffered designs. This essential attribute of simulation – learning support – is well summarised by Bellinger [4]: "After having been involved in numerous modeling and simulation efforts, which produced far less than the desired results, the nagging question becomes; Why? The answer lies in two areas. First, we must admit that we simply don't understand. And, second, we must pursue understanding. Not answers but understanding".

Designing the built environment is a task made complex by the presence of interacting technical domains, diverse performance expectations and pervasive uncertainties. BPS provides a means to accommodate such complexity whilst allowing exploration of the impact of design parameters on solutions that provide the required life cycle performance at acceptable cost. The technology portends a future in which practitioners can routinely model the interacting heat,

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air, moisture, light, sound, electricity, pollutant and control signal flows and thereby nurture performance improvement by design.

The approach can be used to ensure requisite levels of comfort and indoor air quality, to devise energy efficiency and demand management solutions, to embed new and renewable energy technologies, to lessen environmental impact, to ensure conformance with legislative requirements, and to formulate energy action plans at any scale. Such functionality defines a best practice approach to design and planning because it respects temporal and spatial interactions, integrates all performance domains, supports co-operative working, and links life cycle performance to health and environmental impact. The approach is also rational from a practical viewpoint because it enables the gradual evolution of the problem description, with incremental performance outputs informing the actions to be taken at progressive design stages.

In many regions throughout the world, clean and sustainable energy solutions are being driven by legislation that mandates the BPS approach, e.g. the European Performance of Buildings Directive [5] and ASHRAE Standard 189 [6] both of which aim to bring about high performance buildings through a holistic approach to design. In addition, the collaboration activities of the International Energy Agency have accelerated developments in key areas such as energy technologies (www.iea.org/techinitiatives/end-use-buildings/buildingsandcommunities/) and solar cooling and heating (http://www.iea-shc.org/). Other organisations, such as CIBSE in the UK (www.cibse.org) and the Department of Energy in the US (www.energy.gov) are supporting BPS take-up through the development of application manuals and educational materials.

Although a large number of BPS tools exist (www.buildingenergysoftwaretools.com), there is a significant overlap in functionality [7], and while most tools aspire to encapsulate the interactions between a building's constructions, systems, user behaviour and weather, not all do this in a fully dynamic manner. Through iterative evaluation of design variants, simulation supports strategic decisions that recognise new potential directions in the development process. What-if analyses may also be performed to evaluate the robustness of a new technology under different usage scenarios and operating conditions. Moreover, BPS can act as a virtual test bed to assess the potential of hypothesized (as yet non-existing) materials, components and systems intended to create competitive advantage by improving performance in a cost-effective way.

Moving beyond the design phase, there is the potential to apply simulation to building commissioning and operation. There are two reasons why growth in these regards may be expected: first, it will address the present discrepancy between predicted and actual performance; second, new business models are emerging that are driven by whole life performance.

In common with other technology fields, BPS is subject to the so-called ‘hype cycle’ [8]: while BPS has in general supported an upward slope of productivity improvement over the last two decades, specific aspects such as systems simulation, building information modelling and life cycle assessment are often the subject of hyperbole.

The present challenge is to ensure that BPS tools evolve to adequately represent the built environment and its myriad supply technologies in terms of their performance, impact and cost. Attaining multi-functional tools, and embedding these within the design process, is a non-trivial task. This challenge is being addressed by the International Building Performance Simulation Association (IBPSA; www.ibpsa.org), which provides a forum for researchers, tool developers and practitioners to review modelling methods, share evaluation outcomes, influence technical developments, address standardisation needs, and share application best practice. A major activity of IBPSA is the delivery of bi-annual international conferences – Vancouver, Canada (1989), Nice, France (1991), Adelaide, Australia (1993), Madison, USA (1995), Prague, Czech Republic (1997), Kyoto, Japan (1999), Rio de Janeiro, Brazil (2001), Eindhoven, Netherlands (2003), Montreal, Canada (2005), Beijing, China (2007), Glasgow, Scotland (2009), Sydney, Australia (2011), Chambéry, France (2013) and Hyderabad, India (2015) – with all proceedings open-access. The existence of two peer-reviewed journals – *Building Performance Simulation* (ISSN: 1940-1507) and *Building Simulation* (ISSN: 1996-8744) – is a clear indication of maturity within the field.

2. BPS aims and achievements

A need for innovation is at the heart of many technology roadmaps for sustainable buildings and cities, such as those recently issued by the International Energy Agency [9] and the European Commission [10]. To cite but one example here, it is expected that breakthrough developments in new facade constructions [11] will make substantial contributions in the transition towards cost-effective, nearly-zero energy buildings with high indoor environmental quality.

The ultimate aim of BPS is to support such innovation by providing a high integrity representation of the dynamic, connected and non-linear physical processes that govern the disparate performance aspects that dictate the overall acceptability of buildings and their related energy supply systems. While there has been good progress with fundamental process representation, this has been achieved with much duplication of effort and significant deficiencies remain. No formal research has yet been undertaken into acceptable levels of problem abstraction to service the myriad possible performance appraisal tasks. Indeed, there remains confusion about the difference between modelling and simulation. Becker and Parker [12] have stated that it is “common to see the words *simulation* and *modeling* used as synonyms, but they are not really the same thing; at least, not to those in the field bearing those words in its name. To be precise in terminology, a simulation enacts, or implements, or instantiates, a model. A model is a description of some system that is to be simulated, and that model is often a mathematical one. A system contains objects of some sort that interact with each other. A model describes the system in such a way that it can be understood by anyone who can read the description and it describes a system at a particular level of abstraction to be used”.

BPS must also couple different domain models in order to represent the interactions and conflicts that occur between problem parts and give rise to the need for designers and clients to accept performance trade-offs. While there has been some progress with principal coupled domains (e.g. thermal and lighting), many domains are still missing or inadequately represented (e.g. occupant behaviour and integrated renewable energy systems). There is therefore a need for formal research into domain impacts and interactions.

Finally, design process integration is required to embed high fidelity tools within design practice in a manner that adds value and, in the long term, supports virtual design through the interactive manipulation of a design hypothesis against performance feedback given in real time. While some promising integrative mechanisms have emerging, in the form of data and process models, these offer only partial solutions at the present time. Further research is required to significantly extend these models and to understand the business process adaptations necessary to accommodate a fully computational approach to design.

These three issues – high integrity representation, domain coupling, and design process integration – are now considered in turn.