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A performance assessment ontology for the environmental and energy management of buildings

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ABSTRACT

Narrowing the performance deficit between design intent and the real-time environmental and energy performance of buildings is a complex and involved task, impacting on all building stakeholders. Buildings are designed, built and operated with increasingly complex technologies. Throughout their life-cycle, they produce vast quantities of data. However, many commercial buildings do not perform as originally intended.

This paper presents a semantic web based approach to the performance gap problem, describing how heterogeneous building data sources can be transformed into semantically enriched information. A performance assessment ontology and performance framework (software tool) are introduced, which use this heterogeneous data as a service for a structured performance analysis. The demonstrator illustrates how heterogeneous data can be published semantically and then interpreted using a life-cycle performance framework approach.

1. Introduction

Energy is a key issue in a global context and buildings account for roughly 40% of global energy use [1]. Buildings do not operate efficiently [2]. There are very strong economic [3], social [4], environmental [5] and legislative [6] mandates to improve the environmental and energy performance of the existing building stock and to ensure new construction meets more stringent performance requirements.

A recognised performance gap exists between design intent and actual performance in the architecture, engineering and construction industry (AEC) [7] and performance often deviates from design intent by a factor of 2 [8,9]. Buildings specifically designed to perform optimally regularly fail to meet expectations [10].

One of the key factors affecting building efficiency relates to information management and use throughout the building life-cycle (BLC). Building data is usually retained in domain and application specific data formats. A good way of improving building energy efficiency is to enhance the ability of applications to exchange data, and interpret that data effectively. A strong case has been made for the use of data across domains of application [11,12].

Hitchcock characterised the BLC as a long-term decision making process [13]. From the initial planning decision to the final decommissioning stage, choices are made which impact on the building. He described how a decision making process which involves diverse participants, changing objectives and a long time span, requires systematic information management. Yet, information in the AEC industry typically remains isolated in disconnected islands of information.

Increasing amounts of data are being created. More specifically, about 90% of all digital data has been produced in the past two years, mostly unstructured [14]. Many of the devices which produce this data are found in buildings or are portable in nature and used by building occupants. In terms of creating, capturing and transforming digital data, the building industry is at a tipping point, where it can now transform data in ways that were not even imagined a decade ago. Cross-domain analysis of data is beginning to emerge and new technologies and ideas such as the Semantic Web, Big Data, the Internet of Things, Cloud computing and Machine to Machine communication might allow stakeholders to deal with and transform these and other types of data in a useful manner.

This research illustrates how a greater use of the available data sources can provide enhanced understanding of building performance for building operators, and illustrates how some of the barriers to improved cross-domain data use might be overcome. Despite the many research efforts, buildings continue to consume an enormous and ever growing amount of energy. As was the case 20 years ago [13], decisions

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are still made in the absence of key information, which could be available if a life-cycle approach was adopted. As a result, the full impact of decisions is often unclear [15,11,16].

This paper describes a path to a more comprehensive building performance management structure. The path taken is based on key life-cycle analysis techniques and driven by semantic data sharing. Based on this research, life-cycle metric analysis is now possible, providing measurable key performance indicators from design to demolition. A life-cycle approach to building performance assessment includes performance assessment at all stages of the life-cycle, allowing design predictions to be more closely aligned with actual performance as the building evolves. Similarly, design predictions should more closely inform construction.

The paper is structured as follows:

- The case for semantic web technologies in building performance assessment is made in Section 2
- The publishing of AEC data using semantic web technologies is described in Section 3
- A performance assessment ontology is presented in Section 4
- A conceptual implementation is provided in Section 5.

2. The case for semantic web technologies in building performance assessment

Significant issues surround the transfer of data in the AEC industry. AEC data tends to be restricted to heterogeneous data silos and is rarely used outside its original domain [17]. The results of poor information exchange in the industry are felt throughout the building life-cycle. The problem manifests itself in different ways, including increased operating expenses [17], and ultimately poor building performance.

The Building Information Modelling (BIM) approach has somewhat improved information exchange in the design and construction phases. In the operational phase however, this exchange is still a challenge. BIM can be seen as a central repository of building data, for use by all project stakeholders, across the project life-cycle. However, within the wider context of the organisation BIM is only one silo of information and other relevant information must also be utilised to optimise both the building and organisation itself [18]. The performance gap is a significant issue which in part emerges from poor data integration.

2.1. Performance gap

A number of studies illustrate the multi-faceted nature of the performance gap problem. The PROBE studies describe how predictions can be unrealistically low [19], due to inaccurate design assumptions and modelling tools, while issues surrounding management and controls, occupancy behaviour and build quality can lead to poor actual performance levels.

The CarbonTrust [20] have listed some of the common faults experienced as inadequate predictions at design time; poor communication of performance intent from the design team; inadequate testing of design; overly complex building systems and controls; poor construction practice; inadequate commissioning; a poor measurement approach and incorrectly operated buildings. These issues span the entire building life-cycle.

The ZeroCarbonHub [21] identified similar issues in the area of new low carbon home construction. Acknowledging a lack of study in the area, an undeniable issue existed, caused by insufficient technological understanding, industry culture, poor integration of energy and carbon performance in the design phase and poor feedback mechanisms amongst others. Bordass [22] points to the gap resulting from slippage occurring throughout the development life-cycle from initial design assumptions, ending in a poorly performing building a distance away from the original assumptions. De Wilde, in the most recent review of this area, suggested the performance gap was evident throughout the BLC [7]. ARUP also say that the performance gap exists throughout the building life-cycle. They indicate that solutions should take the form of a feedback loop, so that design and operational information can be compared [23].

A key observation from these studies is the absence of a life-cycle performance assessment approach in the AEC industry. The Performance Framework (PF) has been proposed as a holistic approach to building performance assessment and is discussed in the following section.

A range of proprietary and open-source software solutions exist which provide building simulation capabilities to designers [24–27]. The level of data exchange between energy simulation tools and other general modelling tools is usually limited. Comparing functional design intent with actual performance is by definition, the essence of narrowing the performance gap. Some research has taken place into the effective comparison of design intent and actual performance. It is true that user behaviour plays a significant role in the deviation of actual performance from design intent. Identifying this deviation accurately is a key goal of this work.

The Energy Performance Comparison Methodology (EPCM) [28] described the process of comparing simulated and measured performance data to evaluate resulting differences in detail. The holistic energy efficiency simulation and life-cycle management of public use facilities (HESMOS) project [29] developed a cloud-based service to generate simulation results and compare them to measured data. Although the HESMOS project illustrates the benefits of effectively comparing measured and simulated performance data throughout the life-cycle, the tool limited user interaction capabilities to define and modify HVAC systems and component details.

ecoDomus is a life-cycle data management software and service that recently participated in a pilot project to integrate energy simulation into their software suite [30]. The EnRiMa project adopted a simplified modelling approach [31]. The Cascade project produced process based solutions for airports [32].

The Performance Framework approach is different in that it does not provide simulation capabilities, but is concerned with initially publishing simulation and other building related information semantically, and then analysing the homogeneous data sets that emerge. In taking this semantic approach, we move away from approaches that use the more traditional monolithic data model. The monolithic approach requires significant up-front investment and commitment from stakeholders [33], whereas the semantic approach offers a more light-weight solution to the exchange of data. Augenbroe describes how a rigorous, system-theoretic definition of performance indicators is necessary to prepare a rational decision process [34], and he advocates a rigorous use of performance indicators to ensure compliance between project specification and performance. Using the performance framework approach, building function is maintained within specified parameters and the minimum energy needed to satisfy this functional intent is described. The performance framework solution will follow the appropriate semantic web standards which govern the development of ontologies.

2.2. The performance framework

The effective management and maintenance of facilities affects different stakeholders in different ways [18]. It is a multi-domain problem encompassing financial accounting, building maintenance, facility management, human resources, asset management and code compliance. Breaking performance down into a series of measurable components and employing a comprehensive continuous commissioning strategy has been shown to improve building performance drastically [35,36].

The performance framework is an approach which describes a clear relationship between a specific building performance objective, an associated metric and relevant data stream. Hitchcock uses the