Integrating sensor data with building information models: towards the design of more effective building interactions

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Abstract
Our position in this paper is that a more holistic view of building interactions, that links digital data from design, construction, operation, and experience of buildings, can provide more valuable insight than any of these in isolation. We present some preliminary considerations of the nature of this design task, and outline our methodology for carrying this out.

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BIM; Building Information Models; Internet of Things; Building Performance; Pervasive Sensors; Feedback

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

Introduction
Buildings are becoming increasingly digitised and 'connected'. This might be through the provision of services or added functionality for consumers (for example, NEST, smart lighting, security, and IoT appliances), and through metering and billing by utility providers (smart meters and monitoring). It also includes the wider supply chain's use of Building Information Models (BIM) and pursuit of ever more

detailed performance (e.g., air-tightness) and condition (e.g., rising damp) monitoring and management.

These digital services and artefacts are siloed in their design and use: they might be vertically integrated applications like the NEST thermostat for home heating control, or designed for domain-specific purposes, like the use of BIMs by architects and the construction industry. Our position in this paper is that a more holistic view of building interactions that links design, construction, and operation and experience of buildings can provide valuable insight for 1) closing the loop on how building performance relates to design and construction, but also 2) better informing how buildings are controlled, used, and modified over time by occupants and digital services working on their behalf.

BIMs with integrated sensor data that captures, for example, indoor temperature, air quality, noise, light, building interactions, and occupant experience, provide the context required for both of these; for understanding design-in-use (i.e. how design specifications actually perform in everyday use), and for understanding use-in-design (how properties of the indoor climate and building use relate to building design, construction, and infrastructure). This holistic view can help us design better buildings, as well as design smarter digital services for the people living in them. In this paper, we present some preliminary considerations of the nature of this design task, and outline our methodology for carrying this out.

Background: Building Information Modelling

Information models are widely used throughout the design, construction and operational phases of buildings. BIM refers to a standardised approach to delivering information throughout the project information lifecycle of a building. Standards, roadmaps, and manuals provide a framework for collaborative teams to manage the process of developing information requirements and maintaining and validating data [1,2,3,4,5,6,7].

BIM involves the creation and sharing of data electronically, integrating 3D data with semantic data about the building, in an agreed file format. The file format commonly used is the Industry Foundation Classes (IFC) format. In April 2016 the UK Government mandated that all publicly procured construction projects should utilise BIM level 2 methods of working [8]. BIM level 2 represents the current state of the art in BIM adoption. It supports the integration and sharing of models in a central repository known as a collaborative data environment (CDE). Despite the mandate many organisations have still not adopted BIM citing a lack of need, training, and cultural awareness as barriers to adoption [9, 10].

In February 2015 the UK government released the Digital Built Britain (DBB) strategy which outlines the programme for BIM level 3 [11]. The aim of the programme is to integrate further data into BIMs to create a more holistic view of models to improve organisational performance. BIM level 3 aims to create a standard approach to using data about building operation and usage to better manage maintainable building assets **(**e.g., furnishings and infrastructure**)** and improve the efficiency of their usage. The future of BIM is to go beyond the traditional construction sector to building performance and operation through the integration of sensor data and systems to develop smart services. The future vision of the DBB strategy is to direct the focus of such digital data and services towards support for improving social outcomes and citizen wellbeing in a level 4 programme. Our position in this paper sits at levels 3 and 4 of BIM. It concerns the design and development of a platform that connects sensor data and occupant data from buildings to BIMs.

Designing an integrated platform

What we are proposing is the concept of a central open platform that can interpret and provide feedback and actionable advice from the wide range of data generated in the design, construction and, most importantly, use of buildings. Some characteristics of this are as follows:

Multi-stakeholder: 'users' of the platform include domestic and non-domestic building owners, building landlords and facilities managers, supply chain stakeholders such as architects and the construction industry. Each of these will have different needs and requirements for the insight that the platform provides.

Multi-dimensional, 'connected' data: Data sources will include existing BIM data such as building asset registers, 3D models that capture structural, mechanical, engineering services and predicted performance data. As well as these, data will include measures of building performance and operation in use (i.e., via real-time environmental sensors), and occupant comfort and wellbeing. While some of the insight from linking these data will be anticipated in advance through stakeholder requirements gathering, further value and scenarios may be unanticipated and require an exploratory approach.

Social considerations: Although the technical characteristics of the platform are clear, its ultimate realisation as new 'building interactions' will involve investigating important social issues. These include 'ownership of data'. For example, does a building model as a whole belong to the property owner or the architect/construction company, or might ownership be different for different data sources? Might this data travel with occupant/owner or would it stay with the building? Who has access to the data and how is this decided? Are there privacy and security concerns for the various stakeholders and how might this be managed? Might value or insight be traded to different stakeholders (e.g. owners/landlords, new owners, owners of similar buildings, other stakeholders)? Answering these questions requires dealing with the tension between the potential value of big data and the value and potential harm for the individual.

To address these preliminary design factors, we propose the following mix of methods:

- Carry out stakeholder focus groups to understand the data and service needs for portfolio managers and landlords; (non)domestic building occupants and owners; architects and the construction industry.
- Build and develop a software platform enabling sensor data to be linked to BIM data and occupant experience data, and populated with data from a longitudinal deployment of sensors (incl. CO_2, temperature) in a real-world deployment.
- To explore unanticipated use cases of the platform we will run hackathon events, and

develop interactive visual tools for exploring the data with stakeholders.

- To investigate broader social factors, such as data ownership and privacy, we will run participatory design fiction workshops with all identified stakeholders. These will allow the co-creation of multiple perspectives, as well as a medium for communicating and negotiating these between the various stakeholders.

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