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A framework for producing gbXML building geometry from Point Clouds for accurate and efficient Building Energy Modelling

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HIGHLIGHTS

- Improved Building Energy Modelling workflow proposed for existing buildings.
- Solution proposed for rapid generation of as-built geometry from Point Clouds.
- Identification of a framework for storing the building geometry in gbXML format.
- Plans for future verification of solution outlined using industrial standards.

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ABSTRACT

The industrial sector accounts for 17% of end-use energy in the United Kingdom, and 54% globally. Therefore, there is substantial scope to accurately simulate and efficiently assess potential energy retrofit options for industrial buildings to lower end use energy. Due to potentially years of facility renovation and expansion Building Energy Modelling, also called Building Energy Simulation, applied to industrial buildings poses a complex challenge; but it is an important opportunity for reducing global energy demand especially considering the increase of readily available computational power compared with a few years ago. Large and complex industrial buildings make modelling existing geometry for Building Energy Modelling difficult and time consuming which impacts analysis workflow and assessment options available within reasonable budgets. This research presents a potential framework for quickly capturing and processing as-built geometry of a factory, or other large scale buildings, to be utilised in Building Energy Modelling by storing the geometry in a green building eXtensible Mark-up Language (gbXML) format, which is compatible with most commercially available Building Energy Modelling tools. Laser scans were captured from the interior of an industrial facility to produce a Point Cloud. The existing capabilities of a Point Cloud processing software and previous research were assessed to identify the potential development opportunities to automate the conversion of Point Clouds to building geometry for Building Energy Modelling applications. This led to the novel identification of a framework for storing the building geometry in the gbXML format and plans for verification of a future Point Cloud processing solution. This resulted in a sample Point Cloud, of a portion of a building, being converted into a gbXML model that met the validation requirements of the gbXML definition schema. In conclusion, an opportunity exists for increasing the speed of 3D geometry creation of existing industrial buildings for application in BEM and subsequent thermal simulation.

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1. Introduction

In 2012 the end-use energy by industry accounted for 54% of all delivered end-use energy globally [1]; in 2015 this value was 17% for the United Kingdom (UK) [2]. This presents a substantial opportunity for the implementation of energy saving schemes within industry that could have a dramatic effect on reducing global energy use. Not only would reducing energy use aid in the extension of dwindling global fossil fuel energy resources [3], but this would also lower the overhead costs within industry, thus allowing companies to be more adaptive and competitive in manufacturing and process industries [4].

One method of achieving these energy savings is to utilise Building Energy Modelling (BEM) software such as Integrated Environmental Solutions (IES) Virtual Environment (VE) [5], EnergyPlus [6] and DesignBuilder [7] to name a few. This type of software is capable of simulating a thermal model of a building in order to establish the energy use profile. Interventions can then be proposed to reduce energy use whilst at the same time ensuring occupant comfort. Typically, these retrofit suggestions can include changes to construction materials, glazing, the Heating, Ventilation and Air Conditioning (HVAC) system, adjusting thermostat set points, changing solar and internal gains or altering occupant behaviour via education programmes. Traditionally BEM is used to simulate residential and commercial buildings. However, in recent years there are examples of the application of BEM for manufacturing facilities [8,9] in which significant energy savings were obtained. One of the drawbacks to BEM is that model geometry usually has to be remodelled from scratch that can result in long timescales and increased project costs. If building plans are incomplete, due to expansion and refurbishment, modelling can be difficult and inaccurate. Onsite measurement of geometry for manual modelling can also be cost and time prohibitive as alluded to by Ascione et al. [10].

BEM utilises a Finite Volume Model (FVM) of buildings and room envelopes in order to simulate the thermal mass of each thermal volume relative to each other and the surrounding environment of the building. The high resolution of detail required in a typical Computer Aided Design (CAD) model for building construction is not required in BEM. This means that establishing the exact wall and room geometries is not as crucial; a wall modelled out of position by a centimetre will not have a significantly detrimental effect on the room's calculated volume and thermal mass. This provides an opportunity for rapid building geometry capture, that does not require high detail resolution, for utilisation in BEM.

Point Clouds are datasets that consist of multiple points stored within a three-dimensional (3D) coordinate system; usually a Cartesian coordinate system (i.e. X, Y and Z). This type of dataset can be useful to virtually represent the surface geometry of objects within the coordinate system. These datasets can represent landscape topography, building features (e.g. floors, walls, roofs, windows and doors) and equipment. Point Clouds can be acquired through the implementation of sophisticated laser scanning equipment that can record data points in a 3D volume down to a resolution of a few millimetres. A high resolution Point Cloud of a building, for example, could have millions of data points in the dataset. Most commercial laser scanners are supplied with software allowing the 3D coordinates to be mapped into a CAD software package.

The benefits of Point Clouds for mapping real-world objects as-built are numerous. For example, the ability to inspect manufacturing or construction tolerances, rapid geometry mapping of large objects or land areas, use as-built information to inform future design decisions and further enhancements such as virtual reality plug-ins.

The ability to accurately measure and capture geometric information for the purposes of BEM is highly beneficial in order to inform effective sustainable retrofit decisions. Point Clouds offer one method to rapidly generate as-built building geometry in a VE that can include possible renovations that have taken place since the building was first constructed.

The broad aim of this research is to identify a potential solution of quickly capturing as-built geometry of large scale and complex buildings that can be applied to BEM. A review of previous related works, in Section 1.1, summarises previous attempts to achieve similar results and the research gaps that will be addressed in this work. The novelty in this paper is the outlining of a gbXML framework that will allow the generation of a valid gbXML format from a set of internal building Point Clouds.

For clarification, Building Information Modelling (BIM) is used across a range of engineering disciplines to store building data centrally however interoperability between the disciplines is a growing concern as every engineering application requires individual modelling capabilities [11–19]. This can lead BIM files to become unwieldy unless correctly planned and implemented at all levels on a project. BEM can be considered as a specific BIM application subset.

1.1. Previous related works

This work focuses on the use of BEM at an individual building level however it should be noted that some work has previously been conducted in using Point Clouds for BEM applications over larger urban areas [20,21], this differs from efforts of other researchers that have primarily used GIS data for BEM applications [22].

Volk et al. [23] conducted a review of BIM implementation within existing buildings including data capture techniques and subsequent attempts of model reconstruction. The authors concluded that a major challenge is the automation of data capture and BIM creation as the existing efforts struggle with capturing concealed structural geometry or semantic building information in challenging environmental conditions. However, the inclusion of monitored values such as energy use, resource use and maintenance costs into a BIM will provide considerable advantages in a building's lifecycle.

Cho et al. [24] reviewed state-of-the-art technology to automatically create as-built geometry and thermal models for BEM and retrofit assessments from external Point Clouds of a building shell into the green building eXtensible Mark-up Language (gbXML) format for BEM purposes [25,26]. Subsequently, Wang and Cho [27,28] introduced a method of automatic as-built BIM model creation and automated thermal zone creation to create a building zone and room zones through a case study. An external laser scan and thermography of a residential building were captured which were mapped onto each other and 2D floor plans were used to determine location and size of each thermal zone (interior rooms/features), see Fig. 1. The authors demonstrated a framework for automatic model generation of a building envelope using the gbXML [25,26] schema format from external Point Clouds and thermography.

Thomson and Boehm [29] aimed to automate generation of 3D geometry from Point Cloud data rather than a labour-intensive manual operation. The proposed method only concentrates on major room boundaries; doors, windows and similar objects are ignored. The authors concluded that there has been partial success towards the aim of fully automatic reconstruction, especially where the environment is simple and not cluttered. It was identified that clutter in the environment obscured the building features that need to be constructed.

Previtali et al. [30] presented an automated methodology to derive highly detailed 3D vector models of existing building façades starting from terrestrial laser scanning data. The final product is a semantically enriched 3D model of the building façade that can be integrated in BIM for planned maintenance. The integration between derived façade models and infrared thermography is presented for energy efficiency evaluation of buildings and detection of thermal anomalies. It is noted that the integration does not extend into a more holistic full lifecycle BEM.

Poullis [31] presented a framework for automatically modelling from Point Cloud data for large urban areas, up to 16 km^2, resulting in a set of non-overlapping, vastly simplified, watertight, polygonal 3D