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# Geometry Extraction for High Resolution Building Energy Modelling Applications from Point Cloud Data: A Case Study of a Factory Facility

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**Abstract**

The industrial sector accounts for 17% of end-use energy in the UK, and 54% globally. Therefore, there is substantial scope for simulating and assessing potential energy retrofit options for industrial buildings. Building Energy Modelling (BEM) applied to industrial buildings poses a complex but important opportunity for reducing global energy demand, due to years of renovation and expansion. Large and complex industrial buildings make modelling existing geometry for BEM difficult and time consuming. This paper presents a potential solution for quickly capturing and processing as-built geometry of a factory to be utilized in BEM. 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 were assessed to identify the potential development opportunities to automate the conversion of Point Clouds to building geometry for BEM applications. In conclusion, scope exists for increasing the speed of 3D geometry creation of an existing industrial building for application in BEM and subsequent thermal simulation.

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*Keywords:* Building Energy Modelling; Point Cloud; Manufacturing; Industrial Energy Demand; Thermal Simulation

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## 1. Introduction

In 2012 the end-use energy by industry accounted for 54% [1] of all delivered end-use energy globally; in 2015 this value was 17% [2] for the UK. This presents a significant 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.

One method of achieving these energy savings is to utilize Building Energy Modelling (BEM) software such as Integrated Environmental Solutions (IES) Virtual Environment (VE) [4]. 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 the Heating, Ventilation and Air Conditioning (HVAC) system, adjusting thermostat set points, changing solar and internal gains or altering occupant behavior. 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 [5,6] in which significant energy savings were obtained. One of the drawbacks to BEM is that model geometry usually has to be remodeled from scratch that can result in long timescales and increased project costs.

This paper aims to highlight the potential solution of quickly capturing as-built geometry that can be applied to BEM. A literature review reveals previous attempts to achieve similar results [7–13]. The methodology considered in these papers generally consider geometry that has been isolated to localized external geometry, corridors or external topography. In comparison, this project considers a full building envelope including internal room and floor layout. There are some examples of existing research where a high amount of internal detail is captured and processed [14,15] however these are not applied to industrial settings.

Development of such a solution would enable the technique to be applied to older and more complex industrial buildings where its value would be clearly demonstrated as building plans may not be kept up-to-date over, potentially, decades of renovation. Applying this technique to existing buildings has the potential to produce the geometry quicker than manually remodeling the building geometry in BEM software. As part of the University of Sheffield's Advanced Manufacturing Campus, Factory 2050 (F2050) [16] is the UK's first fully reconfigurable manufacturing facility that enables a collaborative approach to research between industry and academia, see Fig 1. A case study focusing on F2050 has been produced to showcase this geometry capture methodology.

Fig 1. 3D Visualization of Factory 2050

## 2. Materials and Methods

### 2.1. Concept

This paper presents a conceptual framework of how as-built building geometry could be successfully utilized for BEM, see Fig 2. The research gap noted by this paper is highlighted in bold in the framework that aims to increase the speed of the geometry creation phase during a BEM workflow which can typically take multiple weeks. A scan can be performed in a few days but currently requires extensive manual post-processing.

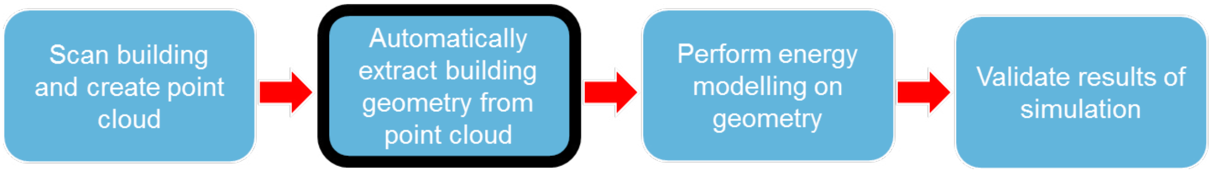


Fig 2. Conceptual framework of capturing and using as-built geometry for BEM

### 2.2. Point Cloud Data Capture & Registration

Utilizing a Leica ScanStation P20 [17], with a tripod, laser scans and photographs were captured from 85 positions internally around the F2050 building. The laser scans were captured at a resolution of 12.5 mm at 10 m from the scanner. This generated 85 individual Point Clouds such as the one shown in Fig 3.a). All of the individual scans were subsequently registered, in Leica Cyclone, as overlapping Point Clouds. The individual scans were then manually cleaned to remove erroneous points, such as reflections. Finally, the individual clouds were unified into a single Point Cloud, see Fig 3.b).

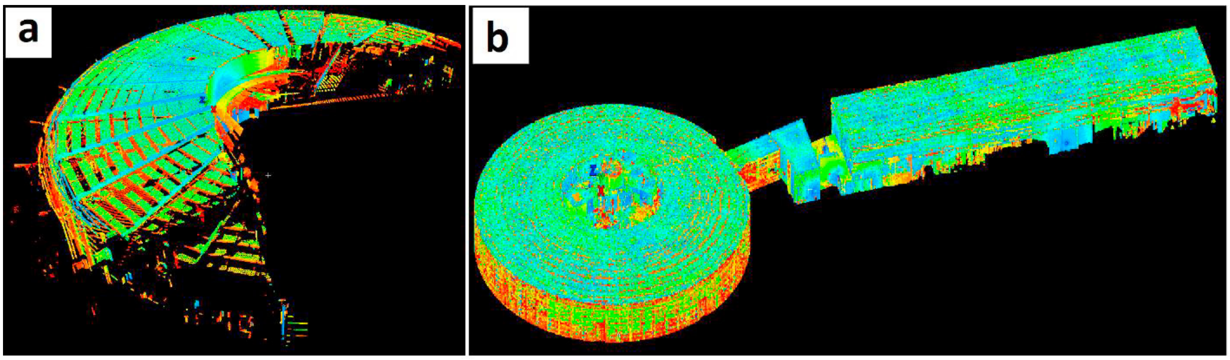


Fig 3.a) Point Cloud generated from a single scan of F2050, b) Unified and cleaned Point Cloud of entire F2050 building

Fig 3.b) illustrates a rich database of points within a 3D coordinate system that represents the internal geometry of F2050. At this stage three observations were made;

- A heavily glazed building such as F2050 creates a significant amount of noise during Point Cloud capture as glass refracts the laser radiation from the scanner. Time-of-flight instruments, such as the ScanStation P20, interpret the returned radiation from the glazing as being further away from the scanner than reality; this was observed by the large amount of erroneous points shown to be external of F2050, see Fig 3.a). The reflections within Point Clouds were observed to have low intensity. There are tools within the Leica Cyclone software that allows for removal of points in a particular intensity range however the tool operates as a blanket removal which may inadvertently remove low intensity points associated with solid surfaces. The use of multiple overlapping scans should militate against this risk.

- The sole use of internal scans has meant that some geometry, not visible to the scanner, such as spaces above suspended ceilings on the 2nd floor has not been fully captured. In addition, during the scanning process some internal areas such as locked rooms could not be accessed which again leaves geometry omitted from the unified Point Cloud. External scans may improve this situation to capture the generic building envelope however access to the roof, if required, is not always practical with a static scanner and tripod. This is likely to reduce the accuracy of a Scan to BEM workflow but this is yet to be determined.
- There is the potential for the incorporation of a Global Positioning System (GPS) to improve the speed of scan registration as well as enabling simple extraction of useful information such as wall thicknesses between rooms or the external shell of a building.

*2.3. Geometry Extraction from Point Cloud Data*

Having created a unified Point Cloud, in Leica Cyclone, patches were applied to the geometry to investigate the built-in abilities of the software to generate walls, floors and ceilings, see Fig 4.a). This was a manual operation that required points on each surface to be manually selected as seed points from which each patch was automatically grown. Then adjacent patches were manually merged where applicable to form a single surface such as a wall.

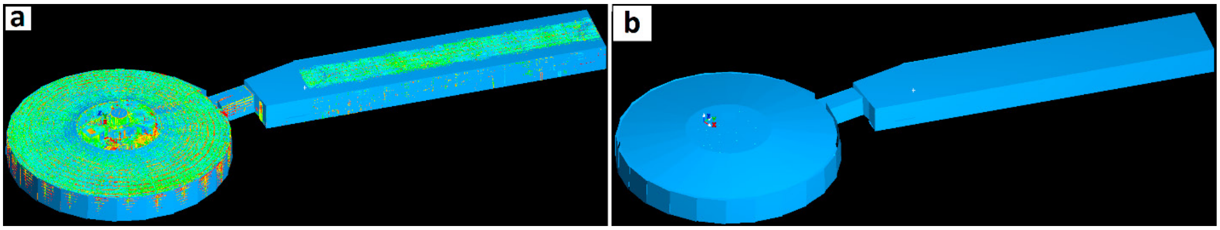

Fig 4.a) Unified Point Cloud with patches applied, b) Generated patches isolated from Point Cloud

Fig 4.b) illustrates that following the generation of patches, that have been mapped onto the Point Cloud, the patches can be isolated from the Point Cloud. These were successfully exported as a ".coe" file which could be viewed in Revit 2017 however the patches were dumb and unconnected which meant they could not be recognized as forming the boundaries of room/building boundaries in BEM.

In the field of BEM there are two key file schemas that are used to structure data depending on its application. These include Industry Foundation Classes (IFC) [18] that uses a STEP file structure and gbXML [19] that uses an eXtensible Markup Language (XML). Both are used for securely transferring Building Information Modelling (BIM) data between different software depending on the required applications such as BEM. Through development of an automated Point Cloud processing algorithm, any geometry created from scan data should be able to be stored in one or both of these formats as this then increases the wider application of creating 3D geometry from scan data.

## 3. Results

The work presented illustrates that existing software, namely Leica Cyclone, has the potential to be developed for the purposes of extracting as-built geometry that can be fed into a BEM software. The current software is able to produce patches via a manual process however this could be automated by feeding the point cloud through a processing algorithm. It is anticipated that such an algorithm would distinguish other features useful for BEM such as holes, windows and doors in walls. In addition, the ability to join the patches together as intersecting surfaces will also be extremely beneficial in creating thermal volumes as part of the BEM workflow.

If BEM geometry generation from scan data is successful, it is important that the accuracy of the thermal simulation can be adequately guaranteed. For this purpose, in parallel with the work outlined previously, a building energy model of F2050 has been created manually using Sketchup, with the aid of floor plans, to create geometry which can then be validated. The geometry was processed by the Sketchup IES VE Plugin and imported into IES VE [4] for thermal simulation of the building envelope to be conducted, see Fig 5a). It was noted during this process that geometry creation was the most time consuming aspect, taking several weeks, thus reinforcing the potential benefits of an automated process using Point Clouds for BEM, especially considering the novel geometry of F2050.

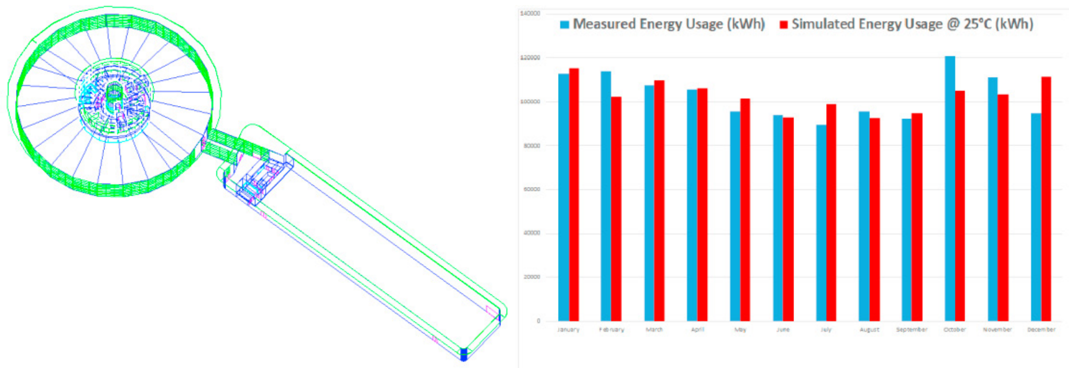


Fig 5.a) F2050 Manual Building Energy Model in IES VE [4], b) Validation of the simulated total energy use in F2050 for 2016

Appropriate boundary conditions such as thermostat set point, HVAC system, building location and orientation etc. were applied to the F2050 manual building energy model using data from site and guidance in CIBSE Guide A [20]. A localized weather file for 2016 using data sourced from the UK MET Office [21] was applied to the model. These will be the same conditions applied to any thermal models generated from scan data. It should be noted that the manual model's results see Fig 5.b) have been validated separately thus providing a validation benchmark against annual energy bills for a consecutive 12 month period from F2050 in 2016. In accordance with ASHRAE Guideline 14 [22] validation maximum limits for the Normalized Mean Bias Error (NMBE) and the Coefficient of Variation of the Root Mean Square Error (CVRMSE) are 5% and 15% respectively for a well calibrated building energy model. The illustrated results achieve a NMBE of 0.02% and a CVRMSE of 0.06%.

## 4. Conclusions

A potential solution has been identified, following further development, for increasing the speed of 3D geometry creation of an existing industrial building for application in BEM. A suitable method of validation has also been identified by comparing the results with that of a manually created building energy model. This will enable result discrepancies to be identified to enable iterative improvements to the automated process. In addition, this comparison will highlight the advantages and disadvantages of using an automated process over the manual process. Such information can then feed into a best practice workflow and guidance for industry. This will support smarter and more cost effective decisions to be made prior to carrying out BEM on existing industrial facilities.

The unified Point Cloud presented in this paper has not been reduced in size and consists of approximately 676 million individual points. In order to improve the efficiency of any geometry creation algorithm research will be conducted into the optimum downsizing of a Point Cloud such as increasing the average spacing between individual points to reduce requirements on computing power as well as the optimum level of detail required for BEM. For example, increasing the average point spacing to 1,000 mm in the F2050 unified Point Cloud reduces the number of data points to 135,177. This has the potential to reduce processing times with smaller data files.

Applying BEM for a manufacturing environment is useful, however, the incorporation of a Manufacturing Process Simulation (MPS) would further improve the methodology through a holistic approach to energy modelling within a factory. This improvement would be achieved by considering the energy use of machines and manufacturing processes as well as building systems. Such an approach could provide even greater opportunity for reducing the energy demand of manufacturing facilities via retrofit projects. Following a review of previous attempts at combining BEM & MPS promising opportunities have been identified for developing a holistic manufacturing energy simulation. There is the potential for the work presented in this paper to be expanded into a "Scan to BEM&MPS" best practice workflow and guidance.

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## References

[1] U.S Energy Information Administration (U.S. EIA). International Energy Outlook 2016. Washington D.C.: 2016.

[2] Department for Business Energy & Industrial Stratergy. Energy Consumption in the UK. 2016.

[3] Wang Q, Zhou K. A framework for evaluating global national energy security. Appl Energy 2017;188:19–31. doi:10.1016/j.apenergy.2016.11.116.

[4] IES. Integrated Environmental Solutions Virtual Environment (IES VE) n.d. https://www.iesve.com/ (accessed November 2, 2016).

[5] Bawaneh K, Overcash M, Twomey J. Analysis techniques to estimate the overhead energy for industrial facilities and case studies. Adv Build Energy Res 2016;10:191–212. doi:10.1080/17512549.2015.1079241.

[6] Wright AJ, Oates MR, Greenough R. Concepts for dynamic modelling of energy-related flows in manufacturing. Appl Energy 2013;112:1342–8. doi:10.1016/j.apenergy.2013.01.056.

[7] Ochmann S, Vock R, Wessel R, Klein R. Automatic reconstruction of parametric building models from indoor point clouds. Comput Graph 2016;54:94–103. doi:10.1016/j.cag.2015.07.008.

[8] Wang C, Cho YK. Application of As-built Data in Building Retrofit Decision Making Process. Procedia Eng 2015;118:902–8. doi:10.1016/j.proeng.2015.08.529.

[9] Cho YK, Ham Y, Golpavar-Fard M. 3D as-is building energy modeling and diagnostics: A review of the state-of-the-art. Adv Eng Informatics 2015;29:184–95. doi:10.1016/j.aei.2015.03.004.

[10] Thomson C, Boehm J. Automatic Geometry Generation from Point Clouds for BIM. Remote Sens 2015;7:11753–75. doi:10.3390/rs70911753.

[11] Previtali M, Barazzetti L, Brumana R, Cuca B, Oreni D, Roncoroni F, et al. Automatic façade modelling using point cloud data for energy-efficient retrofitting. Appl Geomatics 2014;6:95–113. doi:10.1007/s12518-014-0129-9.

[12] Volk R, Stengel J, Schultmann F. Building Information Modeling (BIM) for existing buildings - Literature review and future needs. Autom Constr 2014;38:109–27. doi:10.1016/j.autcon.2013.10.023.

[13] Poullis C. A Framework for Automatic Modeling from Point Cloud Data. IEEE Trans Pattern Anal Mach Intell 2013;35:2563–75. doi:10.1109/TPAMI.2013.64.

[14] Xiong X, Adan A, Akinci B, Huber D. Automatic creation of semantically rich 3D building models from laser scanner data. Autom Constr 2013;31:325–37. doi:10.1016/j.autcon.2012.10.006.

[15] Wang C, Cho YK. Automatic 3D Thermal Zones Creation for Building Energy Simulation of Existing Residential Buildings. Constr. Res. Congr., 2014, p. 1014–22.

[16] University of Sheffield. Factory 2050 - Current Projects - Estates Development - Estates & Facilities Management - 2016. https://www.sheffield.ac.uk/efm/estatesdevelopment/projects/factory2050 (accessed January 31, 2017).

[17] Leica. Leica ScanStation P20 Industry's Best Performing Ultra-High Speed Scanner n.d.

[18] British Standards Institution. BS ISO 16739:2016 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries. 2016.

[19] About gbXML Green Building XML Schema n.d. http://www.gbxml.org/About_GreenBuildingXML_gbXML (accessed March 8, 2017).

[20] CIBSE. Guide A - Environmental Design. 2016.

[21] Weather and climate change - Met Office n.d. http://www.metoffice.gov.uk/ (accessed February 14, 2017).

[22] ASHRAE. Guideline 14-2002 Measurement of Energy and Demand Savings. 2002.