CHADWICK GREENBIM: ADVANCING OPERATIONAL UNDERSTANDING OF HISTORICAL BUILDINGS WITH BIM TO SUPPORT SUSTAINABLE USE

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ABSTRACT

Chadwick GreenBIM is an initiative to establish a digital 3D as-built model of UCL's Chadwick Building including embedded environmental data to gain a greater understanding of its operation with the aim of developing concepts for retrofit and sustainable use. This paper investigates the above by reviewing the state of the art in reality capture to generate a parametric model using laser scanning. It also considers the challenges of managing information for simulation including complex 'big data' types (e.g. point clouds). The research in this paper was carried out through an empirical approach to create a data-rich Building Information Model (BIM) under real world conditions.

Real world measurements of environmental conditions were used to validate the effectiveness of simulations using commercial off-the-shelf (COTS) software packages. In addition, the practicalities of the integration of such data inside the BIM were investigated.

Data capture using the methods described in this paper requires extraordinary effort and is expensive in both time and cost. However, advances in BIM enabling technologies such as Indoor Mobile Mapping (IMM) seek improved savings in data collection. Technological advances will further improve the integration of data capture and extraction of information used by simulation tools.

Once complete it is envisaged that the GreenBIM model would be disseminated among a broad community of researchers to investigate various perspectives in a collaborative manner.

INTRODUCTION

GreenBIM Motivation

Building Information Modelling is a process that has been gaining global acceptance across the AEC & Operations community for improving information sharing about built assets. A key component of this is a data-rich 3D parametric model that holds both geometric and semantic information. By creating a single accessible repository of data, then other tools can be utilised to extract useful information about the asset for various purposes.

Although BIM has been extensively studied from the new build process, it is in retrofit where it is likely to provide the greatest impact. In the UK alone at least half of all construction by cost is on existing assets (Cabinet Office, 2011). With the need to achieve international environmental targets and construction being one of the largest contributors of CO_2 emissions in the UK, sustainable retrofit is only going to become more relevant. This is supported by the estimate of the UK Green Building Council that of total building stock in the UK, the majority will still exist in 2050 (UK Green Building Council, 2013). Therefore, many existing buildings will need to be made more environmentally efficient if the Government is to reach its sustainability targets.

With this in mind, GreenBIM is an ongoing project that has been established to create a full 3D digital BIM of a historical University building in order to gain a greater understanding of its use, with the aim of more sustainable building operations. A major objective is that such a BIM should serve as a backbone for multidisciplinary research across disciplines and knowledge domains. Ultimately it should be a demonstrator to encourage this method of data sharing about buildings across the University estate to provide better management.

The first step of the work presented in this paper is the development of rational workflows to accurately capture the as-built condition of a building. As the resulting model needs to support various simulation and optimisation tasks, well-defined accuracy requirements are essential in a way that can be quality controlled.

Chadwick Building

The Chadwick is a Grade I listed building and as such is subject to stringent policies and planning procedures regarding building works. For this reason, there are constraints on the physical alterations that can be made to the building. This limits the feasibility of retrofit schemes targeted at reducing energy consumption.

The building is located at the main entrance of UCL, with the north-east façade overlooking the Quadrangle and the south-west façade looking out onto Gower Street. It contains five main floors as well as two retrofitted mezzanines, housing two computer cluster rooms, three lecture theatres and six laboratories along with academic and post-graduate offices.

The Chadwick is the home of the Department of Civil, Environmental and Geomatic Engineering (CEGE). The original building was built in 1894 and was extended in the 1960s with terminating towers added in the 1980s. A ground floor mezzanine that extends the length of the building was retrofitted in 2002 to provide additional office space. There has also been a multitude of minor refurbishments carried out in the building leading to a rather ad-hoc arrangement of structural and MEP systems mixing both old and new features. Due to this, the system boundaries are not clearly defined and are sporadically documented. This arrangement is representative of many Victorian office buildings retrofitted in the UK.

Figure 1 - Chadwick Building (North-East Façade)

There are a number of sustainability issues that need to be addressed, notably the building's carbon footprint and waste generation. For example the Chadwick Building's current Energy Performance Certificate rating is the worst possible and there is no metering of energy use.

The thermal comfort and overall wellbeing of occupants is heavily dependent on the quality of the environment delivered by the building's heating, ventilation and air conditioning (HVAC) systems. Anecdotal evidence suggests that there are times when mechanical heating and cooling systems are on simultaneously. Building occupants have little control over their environment. Common complaints are broken ventilation systems and rooms feeling to hot or too cold are common complaints. Overheating is a particular issue in part of the building probably due to the presence of uninsulated hot water pipes and a calorifier. In summer 2012, the hot water system was changed from a centralised system to a series of individual systems distributed across the building. Optimising the operation of the MEP systems would result in greater energy efficiency and cost savings, in addition to providing a healthier working environment. It is hoped that the Chadwick GreenBIM will help with this optimisation.

SCAN-TO-BIM

Technology

Terrestrial laser scanners generally make use of a beam of laser light that is either pulsed or phase modulated and by calculating the time delay between the out and return in the former or the phase shift in the latter, a distance can be calculated (Böhler & Marbs, 2002). This laser is usually articulated on a 360° horizontal stage with a rotating mirror to provide the vertical actuation. Distances and bearings (i.e. polar measurements) allow the derivation of 3D Cartesian coordinates, which form a cloud of point measurements; commonly described as a pointcloud.

Each scan creates a volume of 3D point measurements called a pointcloud that can also be coloured if imagery is captured as part of the capture process. With static terrestrial laser scanning, multiple setups are required to capture an area by moving the instrument to mitigate shadows from obstacles in the line-of-sight of the scanner. To bring the pointclouds from different setups together, a registration is required which can either use common targets placed in the scene or prominent geometric features across the scenes.

Since the technology was commercialised, around the year 2000, terrestrial laser scanning has been the technology of choice for the 3D capture of complex structures for modelling (Budroni & Boehm, 2010). This is due to the combined features of high speed, measurement density and accuracy which compared favourably to the traditional sparse but targeted point collection provided by a total station (Sawyer, 2002). This includes architectural facades with detailed and/or historic elements (Schmittwilken & Plümer, 2010; Haala & Kada, 2010) and refineries or plant rooms (McGill, 2006) where the nature of the environment to be measured makes traditional survey workflows inefficient.

Recent years have seen increases in the accuracy and speed linked with reductions in cost and size of laser scanners as the market has matured. Since 2010, laser scanning has increasingly become an established method for initial data capture of existing buildings for BIM geometry (Huber et al., 2010; Hichri et al., 2013; Volk et al., 2014). This has been aided primarily by two drivers. The first is the technological focus of the BIM topic manifested in the endorsement of the US and UK Governments to use laser scanners for geometry capture (U.S. General Services Administration, 2009; BIM Task

Group, 2012). The second is the integration of pointcloud-handling engines by the major CAD vendors allowing native support without plugins in their BIM tools.

Process

Even with US and UK Government endorsement of laser scanning as the capture method of choice for geometry, little thought has been carried out into how to integrate this in to the BIM process. This is due to the change in the nature of the information requirements of a BIM model and uncertainty over to what extent, accuracy or level of detail of building information should be provided by a Geomatic Land Surveyor. It has been proposed that a pointcloud represents an important lowest level of detail base (stylised as LoD 0) from which more information rich abstractions can be generated representing higher levels of detail (Li et al., 2008).

Traditional surveying with scanning currently does not result in a product that is optimal for the process of BIM due to the historical use of non-parametric CAD software to create survey plans. As a result, a process shift is required in workflows and modelling procedures of the stakeholders who do this work to align themselves with this.

The shorthand name given to the survey process of data capture to parametric model is Scan-to-BIM. This probably originated from a piece of software from IMAGINiT Technologies that went by the same name and provided tools in Autodesk Revit to aid geometry creation from pointclouds semi-automatically. The phrase is now widely used without reference to this software to describe the process of parametric model creation from pointcloud data, for example by Day (2012).

From a pointcloud, a 3D parametric model is derived which aids the BIM process, but is not a BIM itself. Therefore Scan-to-BIM as a phrase is wrongly formed as the result is not BIM as in the common UK definition of the “digital representation of physical and functional characteristics” (Smith, 2013) but a part of the shared knowledge resource that BIM provides.

DATA CAPTURE

Geometry

The project was carried out over the course of ten weeks with the help of four engineering undergraduates. The workflow implemented was established and tested in a series of pilot projects ahead of GreenBIM in conjunction with the construction consultancy Gleeds. This involved using a Faro Photon 120 laser scanner with camera adapter for capture of geometry and colour information. The point density of the measurements from the scanner can be varied depending upon conditions. For this project, the majority of the scans were captured at 1/5 of the maximum measurement rate, providing at least 8mm sampling density in object space. A typical scan contained about 27 million points and about 250MB in size. A Leica TS15i total station was used to provide geometric control via a network of control points allowing the registration of single scans accurately as in Figure 2.

Figure 2 - Data Capture with Faro Photon (centre) with checkerboard targets and Leica TS15i (right)

This allowed greater flexibility as the survey control was permanent but the scan targets were temporary so there was less concern about the permanence of targets after breaking from scanning to return later. Therefore scheduling and filling in missing coverage could be handled more easily. However this produced a very complex survey network consisting of over 2000 point measurements that became impractical to handle as a single network (Figure 3) and had to be divided up in sections. It also meant that a lot of survey kit was needed, requiring at least 2 people to efficiently handle the equipment.

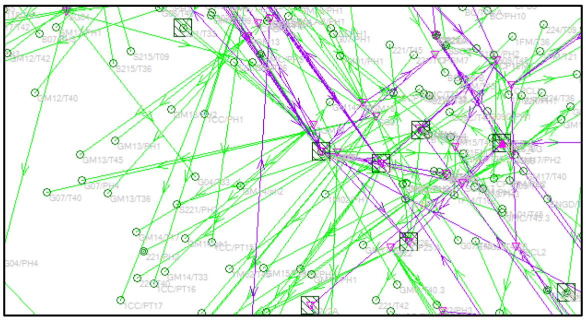


Figure 3 – Plan View extract of survey from Leica Geo Office (purple triangles: control network, green circles: observed targets and scan positions)

Another feature of the survey was the creation of a building specific datum with its origin roughly at the centre of the building's footprint. This was generated due to Revit's automatic centring of the whole modelling environment around the origin (0,0,0) point of pointclouds imported origin-to-origin. The datum was derived from the national mapping grid by preserving the building's orientation to North and translating the origin of the grid to the centre of the building. This simplified BIM coordinate grid ensured that the vast amounts of point cloud data, and by extension the parametric model, were easily manipulated for modelling and could be re-transformed into global coordinates as necessary.

Scanning all five floors, exterior and mezzanine levels of the Chadwick Building took the team four weeks and consisted of around 200 scans (~96 GB total raw data) providing in the order of 1 billion points per floor; a large amount of data overall.

Environmental Conditions

Alongside the as-built geometry, basic environmental information was captured using twenty environmental sensors with data loggers strategically distributed around the Chadwick Building.

There were three strands to this investigation:

1. Monitoring the actual environmental conditions in the building.
2. Using the captured data to inform thermal simulations on the BIM.
3. Comparing the results of the simulation with the measured data.

To measure and understand the variety of working conditions in the building, the data loggers were positioned to ensure a variety of functions were represented (office, labs etc.), and provide real world data to validate simulations of the building model in the future.

The sensors used were Onset HOBO U-12 units that were positioned at occupant height to give a more accurate reflection of the working conditions experienced by room users. They were set to record at 5-minute intervals and had enough on-board storage for about 50 days of data at this resolution. The downside of this type of logger is that the data needs to be physically retrieved rather than transmitted via a network connection.

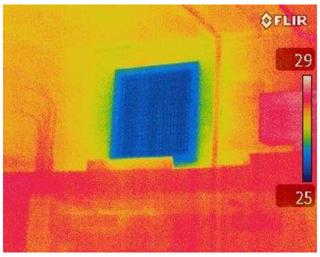


Figure 4 - Thermal image of operating vent

The status of the ventilation system of each room was recorded including the location of vents and their working order. For vents that were active, the airflow rate and temperature were monitored using an anemometer. Thermal images were captured in each of the rooms using a FLIR E60x thermal imaging camera (Figure 4). The results were compared with the thermal logger values to validate them as well as to identify hot and cold spots within a room.

CREATING THE MODEL

Geometry Modelling

Once captured the scans needed to be post-processed to register them to each other and reference the solution to survey control as in Figure 5.

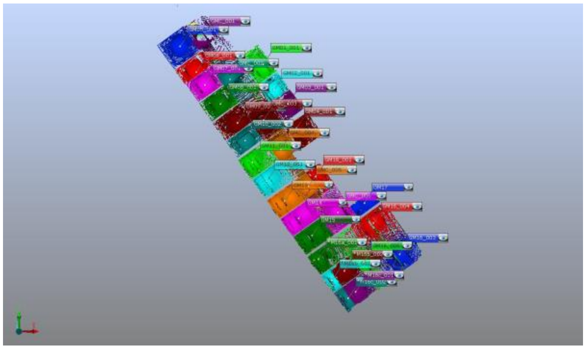


Figure 5 - Registered pointclouds referenced to survey, coloured by scan

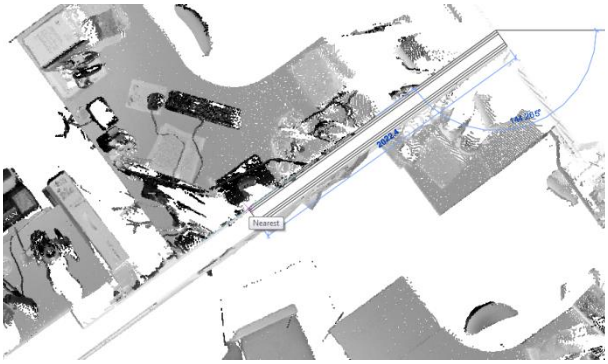


Figure 6 - Plan of registered pointclouds with wall being modelled in Revit

Then they could be converted from Faro's pointcloud format into Autodesk's "pcg" format. This was performed in Autodesk Revit Architecture 2012, utilising the pointcloud engine that had been integrated into the software. The process involved loading in the pointclouds to the software and using them as a guide to create the geometric elements of the building.

A 'Chadwick BIM' project file was created in Revit. The central copy was saved on network storage. Local copies of the project were made and linked to the central copy. This meant that two or more operators could collaborate on different parts of the model at the same time. Changes made in the local copies update in the central copy when the 'collaboration – synchronise' command was used. Not only does this save time but also encourages the collaborative working ethos that BIM is hoped to help provide.

In the initial phase of the project the modelling specification for the geometry was kept to a low level of detail. The second floor was modelled in detail (Figure 10B) with the walls, floor and ceilings generated in the rest of the building.

Walls were assumed to be the blank space between scans of adjacent rooms and corridors as can be seen in Figure 6. Whilst pointclouds provide shape and dimensions, they do not give definitive information about the building materials used because they are only measurements of surfaces visible to the scanner.

A basic internal building survey was carried out to estimate building materials. Some walls were identified as partitions, whilst solid walls were assigned the material properties of ‘brick’. Brick walls were given a thickness typical of walls for the part of the building in which they were located. For example, the majority of the exterior walls were a similar thickness, so one wall type called ‘exterior brick’ was created with a material property of brick and a set thickness of 500mm. Internally, where paper surveys indicated that the walls were partitions, the nearest standard partition size was used from the default standard UK model libraries within Revit.

Environmental Data Analysis

Thermal monitoring results were compared with the Chartered Institution of Building Services Engineers (CIBSE) standards for acceptable conditions in offices. A comfortable temperature range is defined as between 20 and 25°C; around 50% is considered to be an acceptable humidity level; the optimum light intensity range is 200 to 600 Lux (CIBSE, 2006). For the majority of the rooms monitored, the maximum room temperature recorded exceeded the comfortable range several hours a day as shown for a room in Figure 7.

The minimum temperature recorded never fell below the acceptable range. This is to be expected because the monitoring was carried out in the summer months; for a complete comfort analysis, monitoring will need to be continued throughout the winter months. Then it will be possible to determine whether overheating is more of an issue than rooms being too cold. On occasion, the first mezzanine computer cluster and the second floor cluster were outside the acceptable humidity range, though not repeatedly. For a number of rooms the maximum light intensity recorded was below the acceptable minimum light intensity.

The second strand of the thermal comfort analysis involved running simulations using Autodesk’s Ecotect thermal modelling software. In the initial stage of this project the thermal modelling extended to exporting one room from Revit into Ecotect in the data interchange format gbXML. This task was undertaken in order to assess the capabilities of Ecotect and to determine whether the software is appropriate for thermal modelling in later stages of the project. Two levels of detail were simulated, one model with walls, doors and windows, the other with lighting in addition to these. The main structure of the room was exported from the central copy of the Revit model and basic library elements (e.g. windows and doors) were added. Ecotect does not recognise lighting elements added in Revit and replaces them with voids as shown in Figure 8.

In Ecotect, pre-defined building elements along with their material properties were selected to match the building properties of the Chadwick building. A number of parameters were set with regards to occupants (number of people, activities, etc.) and internal conditions (humidity only). The humidity values were taken from the sensor data and input into the model.

It was found that Ecotect provided a reasonable simulation of the building for our purposes. The simulated temperature results for the room were found to be slightly lower than the values recorded by the thermal sensor in that room. This inaccuracy might be related to the fact that the simulation of the room was run in isolation, as neighbouring rooms were not considered. This was confirmed when neighbouring rooms were added to the G08 model and the simulation re-run, with the calculated temperature found to be closer to what was measured (Figure 9).

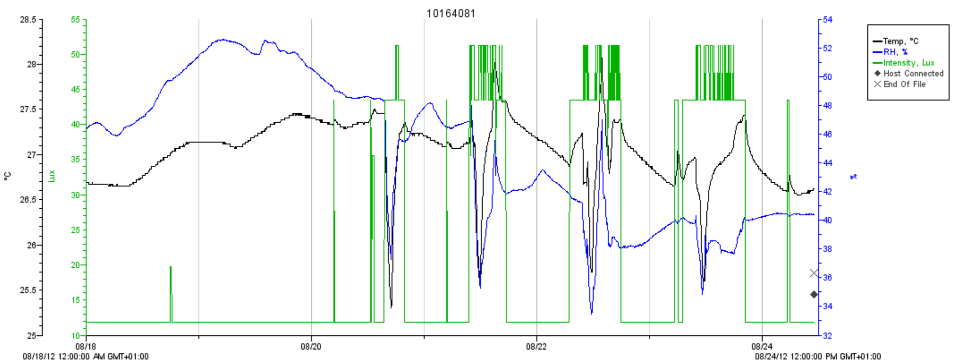


Figure 7 – One week HOBO data plot from G08 sensor

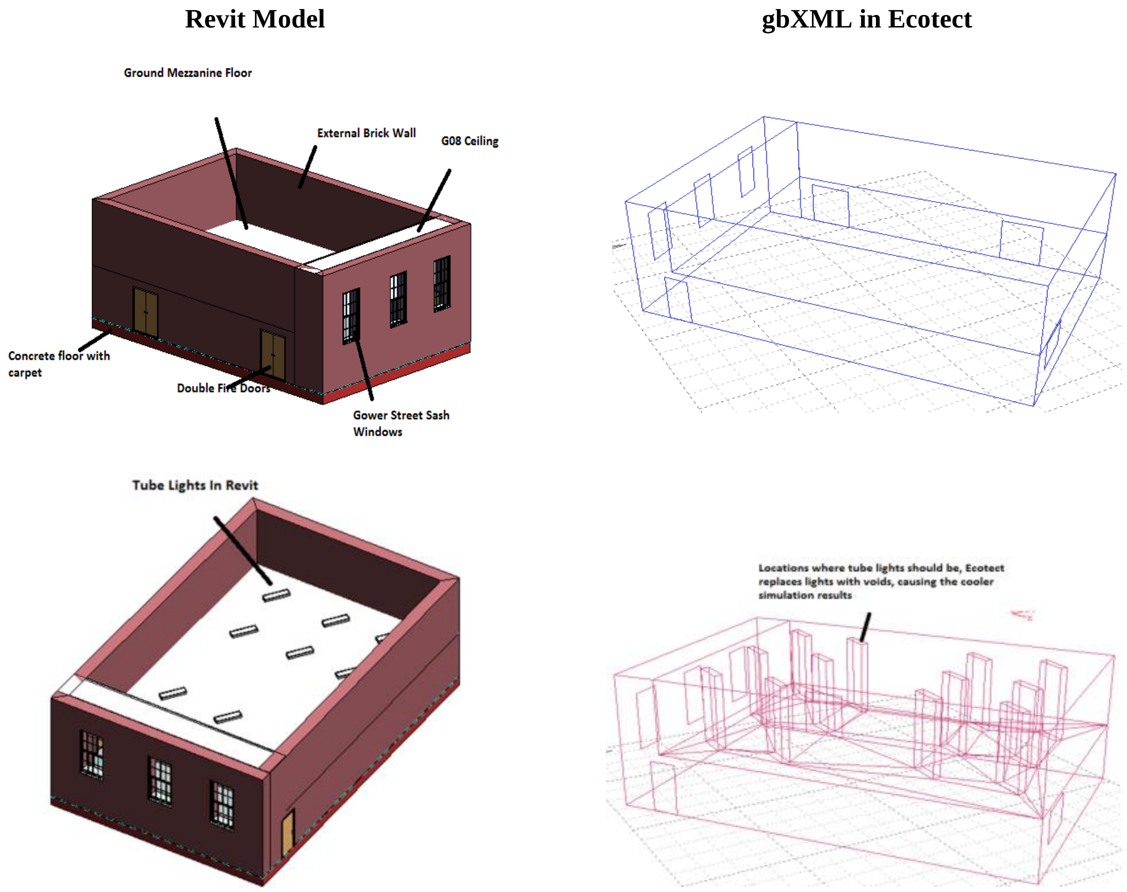


Figure 8 - Basic (top) and more detailed (bottom) room models and their gbXML representations in Ecotect

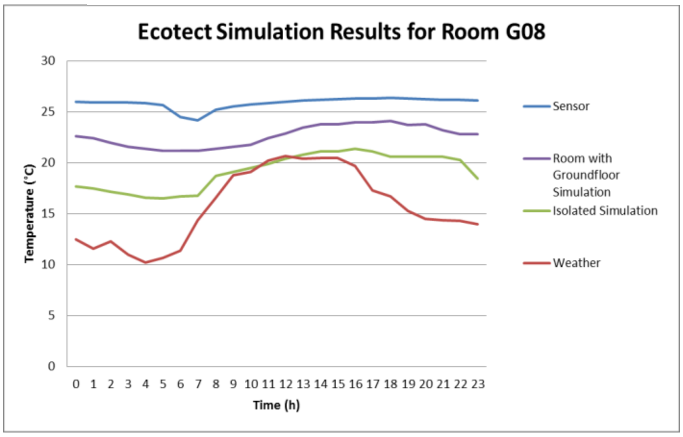


Figure 9 - Temperature graph of real sensor and Ecotect simulated data

DISCUSSION

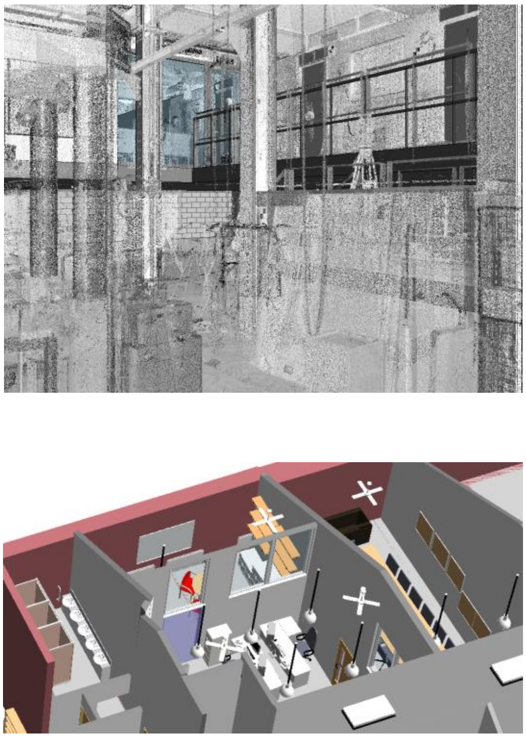
The team set out to create a rich BIM which should allow the investigation of building improvements on one hand and foster cross disciplinary research ideas on the other hand. In its initial phase students have been given the opportunity to start the project through its initial data collection and gain valuable work experience.

A comprehensive data set has been collected which consists of heterogeneous data types and sources including pointclouds, image data, paper surveys, archive data and environmental sensor networks. To make use of the full value of the information, well designed database management systems are required which will consolidate various sources and ease the accessibility of information. Data interfaces between user groups and requirements of different applications need be defined in order to design an adequate data collection strategy. It is believed that the availability of a very detailed model and real sensor data will aid the development of specifications for the model in detail and accuracy.

A geometrically consistent pointcloud covering the entire building is suited to act as full documentation to serve as a source of information to be used for any building related simulations, retrofit planning and building management. However data collection of the pointcloud for the as-built model using the current technologies is expensive and laborious. Static scanning requires time, and a data collection strategy needs to be kept in mind paying attention to the purpose and requirements of the applications. The currency of the data will also be an issue as the resulting model will need frequent updates.

Forthcoming enabling technologies will speed up the process of data capture. The next generation of Indoor Mobile Mapping Systems (IMMS) will ease this process and allow rapid data capture in the near future (Thomson et al., 2013).

Thermal modelling can assist in future space utilisation decisions. Changing the function and occupancy of a room can be modelled and the effect on the whole building can be analysed. This will be particularly relevant for planning retrofit and space optimisations. It is envisaged that upon completion, the Chadwick BIM will be used for more advanced simulations, for example to simulate air flow and temperature throughout the whole building. In so doing it will provide a basis for recommendations for improvements for the HVAC systems serving it.



A.

B.

Figure 10 - Combined low level of detail model and pointcloud (A) and pure parametric model to high level of detail (B)

For some regions in the building, simplified models would be best used for CFD simulations. However the fully detailed parametric building model will be invaluable where further geometric detail is desired including furniture and occupants.

CONCLUSIONS

A number of lessons have been learned, during the initial stage of the project. Data collection, modelling and management all require a dedicated skillset. Computer literacy as well as knowledge of geomatic technologies and the built environment are crucial. A dedicated and well designed IT infrastructure is required which allow comfortable data handling and management for the expert user as well as its dissemination to the stake holders.

At this initial stage in the project the early findings show a strong need to define the basic data quality needs for retrofit. This encompasses definitions of what level of detail is required for different simulations – a multi-modal model is desirable but needs thought as to how this is best proscribed for use downstream. The requirement for accuracies and detail of GreenBIM are defined by the most dedicated application or use cases. Figure 10 depicts two representations of the data rich 3D model showing a high level of detail. It remains to be investigated how the data rich model would support more accurate simulations.

Data capture requires extraordinary effort and is expensive in both time and cost currently. However advances in BIM enabling technologies such as indoor mobile mapping look to provide great savings in initial data collection.

In the future, having a good dataset of environmental variables to compare with will be crucial for the successful simulations of the building environment and will allow identifications of areas where the simulations are not good enough or do not capture the real environment with its occupants.

Future work

The team's aims going forward in the next phase are directed towards the consolidation of the collected information in a structured way embedded in an adequate IT infrastructure. Once complete it is envisaged that the GreenBIM model would be disseminated among researchers to investigate various perspectives, including structural and environmental simulation, making the building both a virtual and physical 'living lab', with the ultimate aim of rolling out the concept across the whole University campus.

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