APPLICATION FOR MPHIL (PHD VIA MPHIL)

Title:

"Are inexpensive surveys for maintenance management of small existing residential buildings at BIM level 2?"

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Title:

Are inexpensive surveys for maintenance Management of small existing residential buildings at BIM level 2?”

Aim:

To see if inexpensive survey techniques can be effective in creating BIM models of small existing buildings for maintenance management.

Objectives:

1. An evaluation of the various survey technologies in relation to the quality (how much details, information and level of detail are there and how much time has been spending to collect data).

2. Determination of the data format and type (how big is data and level of detail data format in meter dimensions or in coordinates and data type in measurements or photos which all of these are depend on which equipment or techniques has been used) used for constructing the virtual models from the survey data.

3. Recommendations on how to overcome the perceived barriers to BIM implementation in small scale maintenance by comparisons of level of data, time, costs, etc of different case studies or field testing by using different techniques and equipment.

Research Questions:

1. What precision and what level of detail and are adequate for a BIM model of existing residential buildings for maintenance by housing associations?

2. Can the precision of a measured building survey be achieved at a much lower cost than at present of small existing residential buildings?

Abstract:

BIM for maintenance management is still in its infancy, despite the advertised advantages it could bring. There are several barriers to overcome, mainly an understanding by those who will need to use it on a daily basis. Several issues have been identified that have prevented mainstream acceptance of the technology, especially when dealing with existing buildings.

New buildings have the advantage that a 3d virtual model exists, having been developed during the design and construction phases, but for existing buildings, surveys need to be carried out and a 3d model developed. Such techniques have seen exciting results where large corporations have had the finance to commission such a survey, but are proving too expensive for small exiting residential properties, especially those managed by local authorities and housing associations.

Some less expensive survey techniques have been tried and tested and compared to the traditional expensive techniques, such as laser scanning. Virtual 3D models of small houses and flats have been 'built' and examined to see their potential in the field of maintenance. Levels of details have also been discussed.

The requirement for 3d has been questioned, with floor plans being achieved using a 2d laser scanner (costing less than 1% of a 3d scanner), although the addition of the metadata still seems to be the major barrier in providing a useful model. Photogrammetric technics were tested but proved to still be difficult to use in confined spaces.

The conclusion is there is still a long way to go for the adoption of BIM on existing buildings. Changes to the Governments BIM standards are needed to move away from just 'new build' and quicker automatic metadata determination are required to enable BIM to be effectively used for maintenance of existing buildings.

Dedication

I delicate this thesis with love to my mother who has been through a lot as she has not been feeling well.

Forogh Moghaddam

Acknowledgement

I would like to thank you my Director of study Mr Peter Lakin and my Supervisor Professor Brimicombe and everyone whom assist me in the completion of this undertaking.

Declaration

I hereby declare that this thesis is my own work to the best of my belief, it does not contain material previously published by another party or otherwise , of any other degree at another university or institution, except where due knowledge is made in the text.

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List of Symbols and Acronyms:

BIM: BUILDING INFORMATION MODELLING

FM: FACILITY MANAGMENT

LOD: LEVEL OF DETAIL

Auto CAD: Auto COPMUTER AIDED DESIGN

UEL: UNIVERSITY OF EAST LONDON

G0, G1, G2, G3: CODE FOR CODING FOR GRAPHICAL REPRESENTATIONS FOR LEVEL OF DETAIL

2D: 2 DIMENSIONS

3D: 3 DIMENSIONS

BSI: BRITISH STANDARDS INSTITUTION

BS: BRITISH STANDARDS

BSO: INTERNATIONAL STANDARDS ORGANIZATION.

GB: GEGA BITE

TB: TRILLION BITE

Introduction:

Building Information Modelling (BIM) is the digital representation of physical and functional characteristics of a facility which allows collaboration and sharing of the information about that facility through the entire life-cycle of the building. (NBIMS), (https://buildinginformationmanagement.wordpress.com). There is a frequent misunderstanding that BIM just means 3D computer aided design. Actuality, it is much more as BIM includes the process for creating and managing all of the information on a project through the entire life-cycle of the project– before, during and after construction. (NBIMS), (https://buildinginformationmanagement.wordpress.com). Although the 3D model is the key item that links the data, it only contributes to about 17% (on average) of the whole data set that makes up the BIM. (NBIMS), (https://buildinginformationmanagement.wordpress.com).

BIM (Building Information Modelling) involves the construction or building of a digital prototype of a model and simulating it in the digital world. BIM is a new way of working made possible by advances in the technology. (NBIMS), (https://buildinginformationmanagement.wordpress.com). BIM is very helpful for providing solutions to some of the building industry failings. The main benefit and advantage of BIM is related to the saving of time, faster delivery, fast transaction cost reduction, and reduction of waste during the construction and refurbishment of buildings. (Bryde et al., 2013), (Azharet 2012)

As part of the Government initiative, a series of documents have been issued over the past few years, incorporating the various standards and protocols (see appendix 1) that everyone should be striving towards to make BIM work. Of these, PAS1192-2, the authors suggested a series of BIM Maturity levels, which have been adopted by the Government as their basis of their 2016 Mandate. From 4th April 2016, any company tendering for a Government construction contract must be able to prove they are proficient to at least BIM level 2. (BS 2013), (PAS1192-2 (2013))

The BIM process has been swamped with survey companies offering very good 3D models from point clouds collected with laser scanners. (https://thebimhub.com). The downside of this process is the cost, both in the equipment needed and the time spent in processing the data. Therefore, such technology has become the privilege of those who can afford it, such as large corporations, mainly for use in large buildings, office complexes and commercial developments where such techniques are economical due to the scale.

Alternative cheaper 3D digital models are required by many of the smaller companies who are now required to be BIM expert to level 2. (http://www.bimplus.co.uk), (NBIMS). One of these markets would be for social housing associations, which have minimal finances to invest in BIM.

BIM is an ideal tool for use by the facilities manager of a housing association, to help with the maintenance process of the massive stock of residential properties they look after. (http://www.bimplus.co.uk), (NBIMS). If there was a quick, effective and cheap method of creating 3d models of their houses and apartments, then they could use BIM to their advantage and hopefully reap the rewards by providing an improved service for their tenants.

To meet the requirements of Level 2 BIM, all data used within a building project needs to be digital, to ease movement of data between the relevant stakeholders, thus improving collaboration. (http://www.bimplus.co.uk). The techniques for implementation are available although many barriers are perceived to prevent some companies, especially facility management, from taking part. (BIFM, 2012). As mentioned earlier, the cost of collecting the data and creating the 3d digital model of an existing building for small existing residential (1 to 2 bedrooms) buildings can be prohibitive, as would be the costs involved in training the personnel to access the data once it is in the system.

One of the requirements of BIM, whether at level 2 or 3, is to have a good, accurate, reliable digital model to work from. When considering a new build, it is starting from the design models, but the approach for small existing residential buildings (1 to 2 bedrooms) is considerably different as a measured building survey is required at the offset. PAS1192-2 (2013).

The different survey techniques used in collecting data for creating 3D models of small existing residential buildings for housing associations investigated to determine usefulness and cost effectiveness and therefore inform the FM industry. As these models will be dependent upon the level of detail within the BIM because one major difference with a BIM of existing buildings with new developments is that there are issues with level of detail and metadata input, the various survey techniques of measuring buildings using different software will also need to be assessed to determine which is the most suitable for such schemes. It is hoped to provide recommendations as to how technology can be applied to help with the facilities management of existing buildings, and the guidelines arising from the work should prove beneficial in producing adequate models for use in maintenance at an attractive cost, with minimum outlay and training.

At present, there is very poor catch up of BIM within for housing associations for small existing residential buildings due to lack of engagement with the technology, the processes by the people who are involved and budget. (BIFM, 2012)

This project attempts to see if collecting survey data in inexpensive way which can save cost and time, can be used to breakdown these perceived barriers to make the process more attractive to facility managers so that the BIM process can be introduced to a sector which has so far ignored it.

Literature Review:

BIM:

BIM is the process of using computer-based technology for improved modelling and communication aiming to provide solutions to some of the building industry failings. The UK Government, among others, has recognised the advantages that BIM could bring to construction with possible cost savings on a whole project, with 20% being suggested as possible. It is recommended that if BIM is extended to every main project in the UK, it could help to save £1-2.5bn pa in the construction phase (GCCG, 2011).

BIM is very helpful for providing solutions to some of the building industry failings. It has been suggested that waste reduction, value creation and improved productivity should all be improved by using BIM, although there are only a few case studies that actually prove it (Bryde, Broquetas and Volm, 2013),(Arayici, Coates, Koskela, Kagioglou, Usher, and O'reilly, 2011) (Olatunji, 2011).

To meet this ambitious target, a mandate was set for April 4th 2016, from which time all companies bidding for Government construction projects must be able to prove a certain level of BIM proficiency before being awarded Government construction project contracts. The requirements for proving compliance are laid down in BS1192:2007 and PAS1192-2 (2013). See appendix

Level 2 BIM is effectively an enabler towards a more digital and data driven industry which is smarter and more collaborative. PAS1192-2 (2013).

The use of BIM and related technology is still in its infancy and its uses are just becoming apparent. So far, concentration has been on new build procedures but there is a gap when it comes to use with existing buildings, especially regarding their facilities management and maintenance. Furthermore, new devices and technologies for collecting survey data for use in a BIM are appearing all the time.

BIM has been around for a while now as a product (model) for some 20 years. The Government initiative is to use this model as the basis for incorporating the latest technological advances in communications, thus opening up the possibility of all project data, not just the 3D model, being accessible via computers and the internet.

It has been suggested that waste reduction, value creation and improved productivity should all be improved by using BIM, although there are only a few case studies that actually prove it (Bryde et al, Broquetas and Volm, 2013),(Arayici et al, 2011) (Olatunji, 2011).

BIM provides a common environment for all information defining a building including the building shape, design, construction time and costs, (Azhar, Khalfan, and Maqsood, 2012) which suggests that the BIM model could be an effective tool in the management of the complete building life cycle, including post-construction maintenance through to demolition.

Autodesk Revit is one of the most popular BIM software packages. (Murphy, McGovern, and Pavia, 2009)

BIM level and requirements for each level:

- Level 0 describes unmanaged CAD (Computer Aided Design) which is including 2D Drawing without common standards just dimension and measurements required.
- Level 1 describes managed CAD in 2 Dimension with the increasing introduction of spatial coordination and measurements, standardised structures and formats as it moves towards Level 2 BIM and models are shared between project team members.
- Level 2 involves developing building information in a collaborative 3 Dimension environment with data attached and models are shared between project team members with some details of the subject such as model and manufacturer details. In the UK the Government Construction Strategy published in May 2011, stated that the '...Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic)

as a minimum by 2016'. This represents a minimum requirement for Level 2 BIM on centrally-procured public projects.

- Level 3 has yet to be defined in detail

PAS1192-2 (2013), (https://thebimhub.com)

See (table 3-10) for reference for different level of BIM by referencing to LOD (see Figure 3) for applicability to this project.

Level 0 BIM: G1

Level 1 BIM: G2

Level 2 BIM: G3

- **Facility Management**

Facility management is a business that covers several disciplines to make sure functionality of the built environment by putting together people, method, place, communications infrastructure to building maintenance and technology. (Williams 2013).

Facilities management is the combination of methods and services in an organisation to provide maintenance and improve the services in a dedicated quality environment. Maintenance support and project management during the building life cycle develops the efficiency of a company's performance by optimising the requirements of the business including the fixed assets in the building. (Aouad and Arayici 2010), (Williams 2013).

Facilities management can be explained as something that will:

- Provide efficient and responsive services and make them highly cost effective;
- create competitive advantage for the organisation's core business and 'an integrated approach to operating, maintaining, improving and adapting the buildings and infrastructure of an organisation in order to create an environment that strongly supports the primary objectives of that organisation' (Barrett and Baldry, 2003).

The three key points in the improvement and development of a practical plan for facilities management are as follows:

- strategic top-level analysis;
- Solution development to find the best option.
- Applying explanations – putting the plan to work.

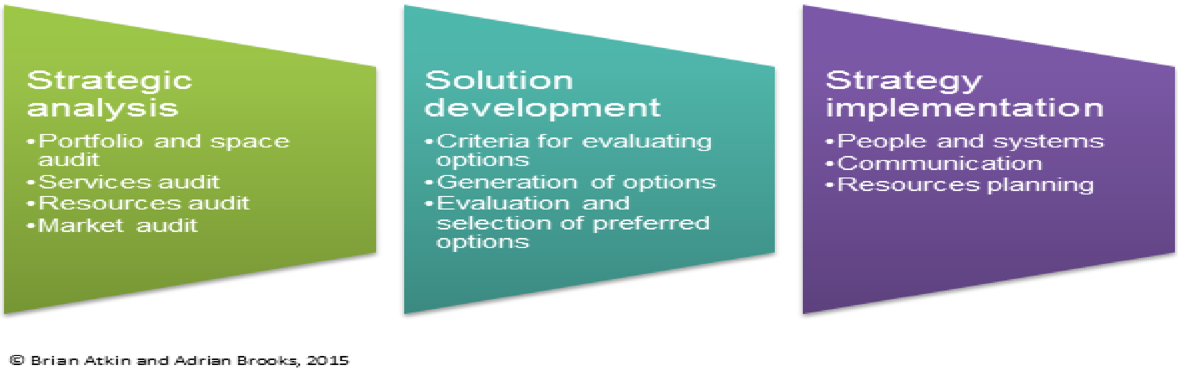


Figure 1: The three key points in the improvement and development of a practical plan for facilities management (Barrett and Baldry, 2003).

Facilities management is the combination of methods and services in an organisation to provide maintenance

• It improves project management during the building life cycle

• It brings efficient and responsive services and makes them highly cost effective

Researcher	Definition of Facilities Management (FM)
Becker (1990)	FM role is to coordinate all efforts related to planning, designing and managing the building and all services inside, including equipment and furniture to enhance organizational capabilities to compete successfully in a world rapidly changing.
Nourse (1990)	FM units are often neglected strategic planning and to emphasize the important factor.
Cotts (1992)	Practical FM is coordinating the physical work space with human capital development and the profession itself in an organization to integrate principles of business management, architectural, behavioral and engineering sciences.
Park (1994)	FM is the structuring of plant building and its contents to create the final product. It includes the systems and activities that generate profits for business.
Barrett (1995)	FM as a strategically integrated approach to maintaining, improving and adapting the buildings and supporting services of an organization in order to create an environment that strongly supports the primary objectives of that organization.
Alexander (1996)	FM is the process by which an organization ensures that its buildings, systems, ad services support core operations and processes as well as contribute to achieving its strategic objectives in changing conditions.
Then (1999)	Practical FM is concerned with the delivery of enabling to work environment and space to function optimally to support business processes and human capital development.
Grimshaw (1999)	The core of facilities management relates to managing the changes that are taking place in the relationship between organizations, their employees and their facilities, all of which are being fundamentally altered by external forces.
Hinks and Mcnay (1999)	FM is a maintenance management, space management, standards of accommodation, management of new construction and renovation projects, management of building stocks in general, and administrative support services.
Grimshaw and Cairns (2000)	Radical movement in demand side organizational structures were bringing about fundamental change in the relationship between business and their supporting infrastructure that, if facilities management were to generate an ability to enhance business performance via the effective application of infrastructure resources.
Varcoe (2000)	FM is a focus on the management and delivery of the full two entities (real estate and construction industry) that the use of productive building assets and working place.
Nutt (2000)	The basic functions of FM are resource management at the strategic level and operational support. The generic resource management of the FM function as a management of financial resources, physical resources, human capital development, and knowledge information resources
IFMA (2003)	FM is the practice of physical coordination of work between human capital development and profession in the organization. It integrates principles of business administration, architectural, behavioral and engineering sciences.
IFMA (2003)	FM goal is to create, maintenance and develop real estate and support services for the strategic and core business of the organization.
BIFM (2003)	As a practical coordinate physical work place between workers and profession in an organization.
Nordic (2003)	FM is seen as an integrated approach to operations, maintenance, improve and adapt buildings and infrastructure of an organization to aim and creating a strong supportive environment with basic objectives of an organization.
Norsila (2004)	FM is a multidisciplinary services that enable the core processes work well, smoothly and meet the business needs of an organization. Facility management to focus on the achievement of organizational goals and objectives to meet customer needs strives to continue the improvement in the quality, reduce risk and ensure profitability.
IFMA (2005)	FM is a profession that includes the integration of activities of different disciplines to ensure functionality of the environment with the integration of people, places, processes and technology.

Figure 2: Definition of Facility Management (http://digitalhighstreet.blogspot.com/2012/11/top-10-definitions-of-facilities.html)

- **BIM for Facility Management (FM)**

The on-going outlay of maintenance and operations (M&O) will be more than design and construction costs, and the lack of necessary data and information can significantly raise these costs. It is recommended that BIM for FM could be an answer to these issues as BIM can provide the rich quality data and information that can be given to owners and Facility Managers during the lifecycle of a structure which can improve M&O. (Teicholz, 2013), (Ifma 2013).

A few years ago, facility managers would have boxes full of owner's warranties and guides. The implementation of BIM gives two main advantages: (1) same significant information and data in electronic form; and (2) the facilities manager does not have to search among the boxes of paper to collect records. The facility manager can "click" on any item in a BIM model to get information about a product, their life cycle and warranties, maintenance tests, fitting, fixing, replacement fees and even place a request for a replacement online on site (Azhar, 2012). This, of course, assumes that the data has already been collected and uploaded, and is of efficient quality to be useful and can be share on cloud.

Recently, there has been great move towards the use of BIM for facility management. The model has the potential for use in facilities management and life cycle management. Though the FM sector is becoming ever more aware of BIM, there is an insight that they are not exactly certain how BIM can be helpful and used efficiently. There is a shortage of experience and best practice case studies to verify the advantages of BIM for FM of existing buildings. Facility Managers will need to speed up as the UK Government wants to implement BIM by 2016 for all Government projects. (Morrall, 2016).

Even if the facility manger is becoming more aware of BIM, there is awareness that FM has been slow to take on its development, and that Facility Managers are not exactly sure how BIM can be used for FM effectively (BIFM, 2012). It is argued that BIM is here to stay and will ideally be added to the skill set of the UK FM professional (BIFM, 2012), but there is a considerable amount to explain and many obstacles to overcome.

BIM should contain full information about a facility as it develops through preparation, design and construction. This information can be leveraged for downstream use by facility managers thereby making operations and maintenance of a facility more efficient. Research says that 85% of the lifecycle cost of a facility happens after construction is completed and approximately $10 billion are annually lost in the U.S. alone due to inadequate information access and interoperability issues during operations and maintenance phases (Newton, 2004). The use of BIM for facility management (FM) can significantly help to stop these loses.

Facility Managers are only just beginning to implement BIM for FM, and processes, software and standards are in relatively early stages of development (Teicholz, 2013).

Looking at the benefits and the overwhelming long term uses of BIM such as improved efficiency, less problems onsite, less waste, better value and quality and better buildings throughout their life-cycle, there is a great need to benefit from this revolutionary source of technology and apply its principles to Facility Management.

Standards:

PAS 1192 (BSI 2014):

The PAS1192 is a new set of standards, protocols and guidelines have been issued by the Government over the past 5 years relating to the requirements for companies to be ready for the 2016 mandate deadline. The documents present details of the standards and processes expected for BIM by providing specific assistance and guidance for the information management requests associated with projects delivered using BIM. Currently, not all information on a project is created, exchanged or managed in a suitable BIM format. The idea behind the Government's 2016 BIM initiative is to ensure all data is transferable between all the parties involved in a construction contract. (ISO 16739:2013), By considering the BIM PAS 1192 (BSI 2014) set of standards, which have basically written for new developments and building, this research will focus on different level of BIM for facilities management of small existing residential buildings as nothing written about it to give an ideas, guidance and to break some of the barriers and issues of BIM which mentioned previously for facilities management of small existing residential buildings.

The focus of the initiative, and therefore the PAS1192 set of documents, is to guide companies in the efficient, correct and accurate information exchange between systems.

Unfortunately, it appears the documentation so far including the PAS1192-2/3 standards have been written for new build developments and not for existing buildings. There are issues with level of detail and metadata input or standards for level of details written for new developments but there is one major difference of level of detail and metadata input.

Common Data Environment (CDE):

The key to efficient data exchange is the use of a common data environment, where data can be accessed seamlessly from one central database. The most obvious scenario would be to have the database in ‘the cloud’ and all the documents and models relating to the project be linked through hyperlinks, to the data itself, rather than keeping many different versions of the data circulating between the parties. The standards for this can be found in the ISO 16739:2013 (BSI 2013).

This Common Data Environment (CDE) process will guarantee that information is only produced once and also continuously improved and updated for final delivery as part of a BIM implementation. (BSI 2013).

To help achieve this Common Data Environment (CDE), several attempts at developing the necessary standards have been tried over the year

A Common Data Environment (CDE) which is for sharing data can be achieved and used for level 2 via Drobox, supplemented by a BIM viewer can be used to look at the data and these could be issued to the estate manager who could then look at the data. (Solibri. (2016)

Using Droboxes to transfer data is fundamental to BIM level 2, despite issues which make it unsuitable. Initially, there are size limitations to be considered, making it impossible to easily transfer large point data clouds. Also, being subject to storage on third party servers, there is no guarantee the data will be available for the lifetime of the building, a fundamental requirement of BIM. Thus Droboxes are limited to small short projects with low budgets. It is hoped that level 3 and the use of the cloud will overcome these issues.

COBie:

COBie is the standards for the non-graphical data used in a project and it is formats for data transfer between systems. The data is stored in a spreadsheet. This includes data and information of any electronic operations, maintenance, and asset management which is very useful for the post construction phase of the building’s life, that is, the maintenance. (BIM Task Group, 2012)

COBie helps capture and record important project data at the point of origin, including equipment lists, product data sheets, and warranties, spare parts lists, and preventive maintenance schedules and cost and can be easily access for FM as it is in Excel format, which in itself is easily transferable between spreadsheets from different software suppliers.

Levels of Detail (LOD):

Level of Detail is basically is standard of how much detail is included in the model element. LOD can be thought of as input to the element which relates to the graphical content of models, although there is scope to extend this thinking into the non-graphical data environment. It is all about the quality, quantity and accuracy of the data. (ISO 16739:2013),

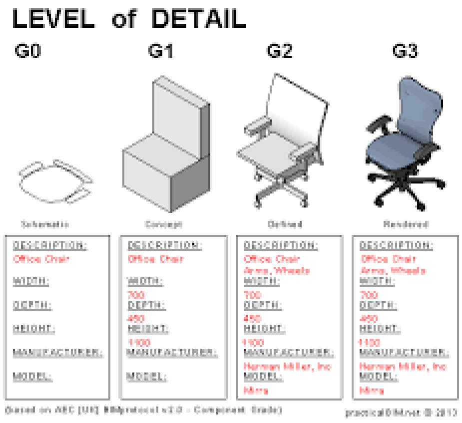


Figure 3: definition of Level of Detail (http://bimforum.org/lod/)

Level of Detail is basically how much detail is included in the model element. LOD can be thought of as input to the element which relates to the graphical content of models.

Fundamental LOD Definitions:

Level G0: without any dimension and measurements just name of object
Level G1: with dimension and measurements of object
Level G2: G1+ simple 3Diamention with some details of the subject such as model and manufacturer details. The Model Element may be graphically represented in the Model with a symbol or other generic representation
Level G3: G2+ 3D and more details and rendered. The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element. . (http://bimforum.org/lod/)

In this project as the models will be dependent upon the level of detail (LOD) within the BIM.

Level of detail for facility management and maintenance:

If more details of level of details required by the facility management and clients for maintenance, the longer the survey and model compilation will take, often exaggerating the costs to become prohibitive. Thus, control of the level of detail in order to provide the data that is required rather than 'everything' is essential.

As the models are dependent upon the level of detail within the BIM, in this research the various survey techniques of measuring buildings are being assessed to determine which is the most suitable for such schemes for facility management for maintenance. This project looks at different level of detail through various 3D models with the aim of selecting the most appropriate level with respect to the techniques used to collect and model the data, the effective sharing of the data over the various platforms and, of course, the costs and time involved.

Collecting Survey Data of Small Existing Residential Buildings

The cost of a survey depends predominantly on the time taken to collect and process the data. If it can be proven that the Level of detail and precision can be reduced without affecting the quality of the data (how precise, how clear and has what level of detail), then BIM could become an attractive option for use in the maintenance management of small residential properties.

In the past few years, major developments and methods of computer visualization of survey data for as-built performance of a building or project have been realised. These processes and developments consist of gathering many records through photographs on site by using digital cameras and 3D remote sensing tools such as laser scanning.

This research used 3 different ways of collecting data to find the present status of a building quickly and easily which can help in making the right decision using a correct and quick evaluation of the as-built survey and status on any project gives the chance

These different survey techniques used in collecting data for creating 3D models of existing buildings will be investigated to determine usefulness and cost effectiveness and therefore be attractive to the FM industry. As these models will be dependent upon the level of detail (LOD) within the BIM, the various survey techniques of measuring buildings will also need to be assessed to determine which is the most suitable for such schemes. It is hoped to provide recommendations as to how much technology can be applied to help with facilities management of existing buildings, and the guidelines arising from the work should prove beneficial in producing adequate models for use in maintenance at an attractive cost, with minimum outlay and training.

Laser Scanning

Scanning is one option for quick data collection. 3D laser scanning is a relatively modern technique used for the rapid collection of location data which forms the basis of a BIM Model. (Golparvar-Fard et al, 2011). New scanners such as the Leica P40/P30 can collect up to 1 million points per second, up to 270m range, producing a point cloud which can only be analysed by computer.

Colour photographs can be superimposed on this “point cloud” to aid interpretation, especially useful for identifying building features at a high level of detail, (Arayici, Y. 2007) but the question rises here is this that do the facility managers need this much detail. Point clouds of laser scanners can be used to create the basis for the model, but there is still the issue of adding the metadata, especially for the hidden services, not picked up by the laser scanner.

The issue seems to be one of economies of scale. Buildings such as the RICS HQ, the Houses of Parliament and many other corporate buildings have the advantage of being large enough to justify the expense of a laser scan survey. On the other hand, small residential properties, such as those maintained by Housing Associations, are not suitable for such treatment. Many residents would find the use of a laser scanner in their homes not only intrusive but a violation of their privacy as well.

3D Modelling

Survey data provides point locations which are three dimensional, whether they are individual observations from tape measurements or total stations to the millions of points obtained by laser scanning. The data can be compiled into a 3D virtual model by a computer, which allows interrogation of the data with regards to measurement and relative positions, even quantities. Such information forms the basis from which decisions can be made regarding construction, refurbishment and facilities management. (Golparvar-Fard et al, 2011).

This project used different method and techniques of collecting data in Correct and quick evaluation of the as-built performance and status of a building quickly and easily which can help in making the right decision on facilities in cheapest and quickest way possible.

Mobile Collection Devices

Mobile collection devices are new technologies that can assist in finding out the construction details of a building through analysis of its 3D model. Clients, architects, engineers and builders can virtually walk through and take measurements from the 3D model. Mobile devices can compile 3D building models for interactive analysis, thus bringing the full range of BIM into the dynamic touch screen environment of mobile devices. (Ruwanpura et al, 2012)

Findings and conclusions in this study are maintained by data and results evidence and it can see how the author arrived at his/her findings and conclusions as they make sense however this study does not named any mobile devices which can be used, thus this project bring the full range of Building Information Models into the dynamic touch screen environment of mobile devices which can be share between everybody using cloud with an easy access on site

The latest 3D mobile devices include:

3. Pegasus (from Leica Geosystems) - a mobile mapping solution which uses laser scanners in combination with GNSS receivers, an Inertial Measurement Unit (IMU) and a Distance Measurement Instrument (DMI) on a mobile platform such as vehicle or backpack, to get accurate and precise spatial data and with software for the capture, post-processing, and storing of the gathered data. (Leica Geosystems 2016)

4. Dot Product3D is based on infra-red technology, which makes it easy for anyone to obtain accurate 3D-models and measurements in-the-field. Costing approx £4000, it is very light and can be used in conjunction with mobile devices such as i-pads and tablets. (dotproduct 2016).

5. FLIR One Infra-red temperature cameras are hand-held which can be used for thermal Figures. They are very light and handy and cost approx £239. (FLIR 2016)

6. Cubify iSense is a 3D scanner which can be attached to Ipad and it is very handy, light and its cost approx. £400 (3Dsystems, 2016).

Conclusions (from Literature Review):

Information from the published literature has highlighted many of the benefits and challenges for full participation in BIM development and application by the facilities management industry. Although facility managers are aware of BIM, few have used it, while many face barriers hindering the implementation and overall take up of the technology and the process for managing maintenance.

This research will evaluate the use of Building Information Management as a tool for use in Facilities Management. The current processes and recent advances in BIM will be reviewed to see if they can be applied to FM, and then use BIM to develop model to be easy to access and cheap, and see if the model can be used to support maintenance decisions. As the model will be dependent upon the level of detail (LOD) within the BIM, the various survey techniques of measuring buildings will also need to be assessed to determine which is the most suitable for such schemes.

The use of BIM and the related technology is still in its infancy and its uses are just becoming apparent. So far, concentration has been on “new build” projects so there is a gap when it comes to existing buildings, especially regarding their facilities management and maintenance.

All the research on surveying existing buildings so far has been based on large corporate buildings as small existing residential properties have many more barriers, economics, cost and access among them.

It seems from the available literature that there is this reluctance by facilities management to implement BIM especially with existing small buildings. As most of this is due to a lack of awareness, there is an opportunity to explore the technologies now available to see if they can be used to support the process, provide guidance that will hopefully engage the people involved and thus realise the potential benefits.

Many of the studies mentioned above tend to say the same, with similar conclusions, but they all seem to focus on the BIM aspects of new buildings and developments. It appears very little research has been carried out on developing a BIM for existing buildings, especially smaller residential properties.

Current BIM issues:

Without the relevant research, such standards such as the PAS1192 series could be unsuitable when creating BIMs of existing buildings. The key challenges of using BIM are mostly concerned with the learning of the relevant software, and the costs involved, but they do not appreciate the importance of the data management. According to the BIM Task Group (soon to become the BIM Alliance), which has been developing standards and requirements to enable BIM adoption, there are the 'Big 5 BIM issues' which need to be addressed just so BIM maturity level 2 can be achieved (BIM Task Group, 2016b).

The big 5 issues just for BIM level 2 are as follows:

1. Accuracy (or is it Precision?)

The precision of the measurements is dependent upon the equipment and the techniques used to carry out the survey. The same question arises as for LOD, how precise can the measurements be to be effective, as they too can have quite an impact on the costs.

2. Metadata

The data behind the physical model such as the text attributes, hyperlinks, costs etc. Much of this is built-in during the creation of a BIM for new build, but has to be added laboriously for existing buildings, adding substantially to the cost of the survey.

3. Interoperability

ensuring data is transferable between systems without loss or disfigurement. BIM level 2 relies on 'Drop Boxes' to transfer data between stakeholders, which add another step in the process, which is currently 'fraught with danger'. It is hoped that by level 3, the use of a single data set accessible by all will overcome these problems.

4. Level of Detail

Level of Detail is an indication of how much detail is included in the model element whether it is the graphical model or the non-graphical data attributes (metadata) linked to that aspect of the model. It is all about the quality, quantity, precision and accuracy of the data.

5. Generalisation

The representation of 2D/3D data while maintaining geometric integrity and recognisable context. The capability of the user to recognise and interpret generalised data and utilise it accordingly (BIM Task Group, 2016).

According to PAS1192, the main requirement for BIM to work is that all data, information and documentation of a project must be in electronic form to aid transfer between those involved. This is a shift away from the old traditional working in which the different parties involved in a construction project used to work on different information pools. By using BIM all the parties will be working together on common data sets.

BIM is a process that requires effective collaboration, information management and interoperability between all parties and all technologies to realise its potential. Managed BIM will reduce the information loss associated with handing a project from the design team to the construction team and to the building's owner/operator, by allowing each group to add to, and reference back to, all the information they use/create during their period of contribution to the BIM model (Bryde, et al, 2013).

One issue not considered in the studies above is the extra expense incurred when creating a digital model of an existing building. Additional problems occur when incorporating hidden items, such as electronic cables services or pipes.

The lack of necessary data and information and difficulty in locating it, can significantly raise maintenance costs as it can take more time to finish a project thus it becomes more expensive. A few years ago, facility managers would have boxes full of owner's warranties and guides; the implementation of BIM gives two main advantages to facility managers: (1) the significant information and data in electronic form; and (2) the ability to allow efficient interrogation of the data, thus the facilities manager no longer has to search among the boxes of paper to retrieve records. The facility manager can "click" on any item in a BIM model to get information about a product, their life cycle and warranties, maintenance tests, fitting, fixing, replacement fees and even place a request for a replacement online while at the location of the object (Azhar, 2012). This, of course, assumes that the data has already been collected and uploaded, and is of sufficient quality to be useful.

Having complete data sets is relatively easy with new build as the database can be built up alongside the creation of the design. Research has concentrated on this aspect and the standards developed around new building.

Thus, there are not many findings or recommendations for existing residential buildings, so there is the opportunity to review the current processes and recent advances in BIM to see if they can be applied to small existing residential buildings, and to develop models that are easy to access and cheap to produce, and still be used to support maintenance decisions. New developments in Cloud technology also seem to provide opportunities for improved sharing of the model and related data, which may have a significant impact on the process. Coupled with mobile and touch screen devices, which are now common in everyday use, this technology may be the key in a successful acceptance of BIM for maintenance by using cloud services to share and link the models and data.

Recently, there has been great move towards the use of BIM for maintenance, especially where the design model can be adapted for use in the post-construction phase. The digital model has the potential for use in facilities management, maintenance and life cycle management. It is argued that BIM is here to stay and will ideally be added to the skill set of the UK FM professional (BIFM, 2012).

Though the FM sector is becoming ever more aware of BIM, there is an insight that they are not exactly certain how BIM can be helpful and used efficiently.

The next stage of BIM 'maturity' according to Bew-Richards (2008) is the suggested use of the cloud for sharing the data. This looks as if it will form the basis of level 3 BIM.

It is obvious that an increased Level of detail will substantially add to the cost of the survey, so an investigation is required into just how much detail comprises an effective useable model. Clients are well known for over specifying and surveyors collect as much data as they can 'in case it is needed', but is this always necessary? Perhaps we should survey just what is necessary, not what is possible.

Research Design:

High quality records, information, data and cost benefit analysis over the lifecycle of a building, can simply improve the decision and approach to the maintenance of a structure. Judgments about maintenance of the buildings are mainly based on maintenance knowledge and existing information about building utilities and their technologies. Not using or capturing this information or knowledge could end with considerable costs because of unsuccessful, wrong or inefficient judgments and implementation of incorrect, sometimes damaging techniques.

This research will evaluate the use of BIM as a tool for use in Facility Management for existing small buildings. The current processes and recent advances in BIM will be reviewed to see if they can be applied to maintenance management, and then use them to develop and use 3D models to see if they can be used to support maintenance decisions effectively.

As the models will be dependent upon the level of detail within the BIM, the various survey techniques of measuring buildings will also need to be assessed to determine which is the most suitable for such schemes.

This all methods/techniques and software were chosen and done in relation to various reasons which are as follow:

1. To find an easy, inexpensive and best survey method for the data collection and following digital modelling of small existing residential buildings within BIM
2. To assess the efficiency and effectiveness of each method and techniques in relation to the quality and effectiveness of the data obtained.
3. To see the qualities, disadvantages and barriers of using each different methods and software
4. To see how these models can be used, are they sufficient to see how these models can be used in BIM by creating 3D digital models

Within this section the approach used in conducting the research will be describe, the type of methods being used to support the methodology. The methods were divided in to 4 different case studies. Explanation of each case studies will be presented as how it has been done.

Using different equipment to measure different buildings and existing utilities will enable a comparison of the 3D models which created using different software, time taken, cost and measurements with each other and then find the best, more useful, cheapest, easiest way of collecting requirement data for maintenance according to require LOD with consideration of time taken, availability, cost, and how easy to access, create and how details they need to be according to LOD requirements.

Different buildings were measured to provide data for this project, each by a different survey technique, to assess the efficiency and effectiveness of the method. Various software packages were also used to process the data in order to consider the merits and disadvantages of each. Factors such as the complexity of the equipment, the relative time taken, the ease of use, necessity for training, level of detail and therefore cost were all studied.

Autodesk 360:

It is a cloud-based platform that gives you access to storage, a collaboration workspace, and cloud services to help you dramatically improve the way you design, visualize, simulate, and share your work with others anytime, anywhere. (Autodesk)

Case Study	Aspect	Survey Method	Software
Small Flat (one bedroom)	Interior	1)Tapes and Disto (hand-held laser single measurement device) 2)RPLidar 360 Robot Laser Scanner 3) Photographs	AutoCAD / Revit Frame-grabber and Ultra-grabber software Recap 360
UEL East Building Atrium and Halls of Residence East Building	Exterior	Leica Laser scanner	Cyclone
UEL Knowledge Dock and Stairs	Interior (Stairs)	Faro Laser scanner	Recap, Context Capture Bentley
Southend 'Smart Homes'	Interior and Exterior	From drawings	Revit
Guitar	Single Object	Photographs	Recap 360

Table 1: Case Studies

To collect measurement data of various residential buildings to create 3D virtual models for analysis. Various methods of data collection have been tried with the aim of seeing which would be the most appropriate. Aspects such as the quantity, quality and accuracy of the data (LOD) are also considered in the comparison. Relative costs are also studied.

Non-graphical information can then be added to the models and data transfer investigated, as can how this can all be used to the benefit of the maintenance team.

I have been fortunate to link with another research project being carried out in UEL (I Lemon), who is looking at the sustainability and energy conservation of residential properties on a housing estate in Southend. From this project, I have been able to use the floor plans provided to create 3D Revit models, which will be investigated as their usefulness in developing a maintenance programme for the estate.

I also have the data from a small maintenance company (M2 Building Services) to see the type of work that is carried out and follow through their process to identify how BIM could be incorporated effectively, without any massive outlay for new technology or training, which they cannot afford.

- Laser Scanner and Recap software: laser scanner was used to scan some parts of UEL using cyclone and then a 3D model was created by uploading the existing scan survey data in Recap Autodesk software or using Leica Cyclone.
- 4.3 RPLidar 360 Robot Laser Scanner
  RP Lidar is a 360 robot laser scanner which is very cheap, costing about £290. It is light weight and it can scan a room in just few moments, although restricted to 2D. The software which needed for working with this scanner can be downloaded for free.

- 4.4 Frame-grabber and Ultra-grabber software
  RP Lidar Robot laser scanner was used to scan the flat and UEL's library stairs and 2D models created using 'frame-grabber' and 'ultra-grabber' software.
  The Frame-grabber software gave an Figure of the area scanned and coordinates of each point can be visible on the Figure, while 'ultra-grabber' extracted the co-ordinates in a text file for editing and transferring to AutoCAD and Revit to create a 2D plan or a 3D model. It was a very quick and easy to

use method for just a floor plan. However, the full process of creating models in 3D can be long especially when adding the metadata required.

- Disto and Tapes: A small apartment measured by using a Disto and tapes which provided a data survey set and used to help become familiar with the software (Revit) and produce a Revit 3D model.
- Revit: created full 3D models of Southend houses and flat and then a comparison of Revit and AutoCAD floor plan models
- Camera: photos were taken of a subject in a room and then a 3-D model was created by using Autodesk Recap 360 software.
- Floor Plan: Estate houses which are refurnished to smart house so using floor plans of these houses and 3D models of Pantile Avenue A and B of Southend houses were created in Revit from sets of existing drawings (on paper), to enable a comparison of using Revit and AutoCAD.
- 3D Models from Photographs: 20 photos were taken using an iPad4 of a small subject from different angles then Autodesk Recap 360 software was used to create 3D model.

Buildings were measured to provide data for this project, each by a different survey technique, to assess the efficiency and effectiveness of each method and techniques must keep the same building to measure using all techniques, which means several surveys of the same place. Moreover, various software packages were also used to process the data in order to consider the merits and disadvantages of each. Factors such as the complexity of the equipment, the relative time taken, the ease of use, necessity for training, level of detail and therefore cost were all studied.

From this the quality of measurements required and the standards used, easy access, time taken, cost was assessed. These Models can be used to provide an idea of sensitivity or precision of the details for each of equipment to see if the data collected is fit for purpose and require LOD.

Analysis of the data collected has provided an opportunity to investigate cost resolution, which is to match the level of detail (LOD) and time taken.

Model Cost can vary depending upon level of details and output required, so some modelling may be done in high details and quality to create good data and these models will cost more as they take more time.

These models also can be useful and advantage for building users as they can help with occupying and using building efficiently, improved maintenance and energy consumption.

On completion of the 3D model from the survey data, any non-graphical information was added to the models and data transfer investigated to confirm its usefulness as suggested and to identify any pitfalls and issues.

I have been fortunate to link with another research project being carried out in UEL (I Lemon), who is looking at the sustainability and energy conservation of residential properties on a housing estate in Southend. From this project, I have been able to use the floor plans provided to create 3D Revit models, which will be investigated as their usefulness in developing a maintenance programme for the estate.

I also have the data from a small maintenance company (M2 Building Services) to see the type of work that is carried out and follow through their process to identify how BIM could be incorporated effectively, without any massive outlay for new technology or training, which they cannot afford.

1. **Desk Study and Literature Review**

Firstly, an investigation and carry out a desk study and a proper literature review need to gather as much information as possible about BIM, Facility Management, specifically maintenance, life time maintenance cost, cost life of building, cost resolution/accuracy models of survey and how BIM is currently used for Maintenance/FM. The importance of standards will also need to be investigated.

There are a number of ways in which all the above information can be gathered and compiled some of which are mentioned below:

I. Through Journals, Databases, Articles and available online resources which have been published to date and previewed.

II. Compile a table of survey costs through web sites and contacting companies.

III. Contact companies to find out how they use BIM in their new developments and FM.

Information from the published literature will help develop my understanding of the subject. Existing research into the subject will also need to be looked at to influence how to proceed. Contacting companies will also help to find out about the current processes used in BIM, to see if the lessons learnt in the maintenance of the new build projects can be applied to existing buildings.

2. Case Study

Data will be collected through 4 different case studies:

- Small Flat
- KD UEL
- Small Estate Houses
- Stairs UEL

Development of the cost model will be based on analysis of case studies. The buildings of University of East London can be used to check the theories, and develop data concerning the life-cost model and maintenance requirements.

3. Experiment and Learning the BIM Software Package

Initially, a small apartment will be measured (using a Disto and tapes) to provide a data set which can be used to become familiar with the software (Revit). From this, a larger building, such as one the buildings on campus, can be considered, measured and a BIM compiled. From this the quality of measurements required and the standards used will be assessed.

4. Data Sources and Equipment:

Data Source	**Equipment**
Point Cloud	Laser Scanner
Taped Measurement	Tape/Disto
Angles/Distances/Co-ordinates/ Feature Codes	Total Station
Photographs	Cameras/IPad
3d Model/Cad Drawings	Computer with BIM Software eg Revit
Paper Plans (old)	Scanner
2d Model/Cad Drawings	AutoCAD

Table 2: Data Sources and Equipment:

Using different equipment to measure different parts of the building and existing utilities will enable a comparison of the measurements with the existing drawings. BIM can be used to provide an idea of sensitivity or precision of the details for each equipment to see if the data collected is fit for purpose.

Analysis of the data collected will provide an opportunity to investigate cost resolution, which is to match the level of detail (LOD) and time taken against the cost of the survey to determine the cost efficiency related to the output.

5. Application of Software and Comparison

Inherent in the method is the requirement to learn how to use the various software packages, such as Revit for modelling, Cost Benefit Analysis software and Matlab for cost analysis. Although existing skills such as measurement using tapes, Disto and total stations and the use of AutoCAD will be used, they will need to be supplemented by learning how to use a laser scanner and associated software (Cyclone).

Cost-benefit analysis (CBA) compares the expected financial gain derived from different set of measurement methods and equipment with the expected cost and time of providing each method to determine the most profitable option. The program must take into account the fact that the impacts of costs and the values of benefits might extend far into the future. Using the software will help support maintenance decisions and to find remaining life/age of a building to see if maintenance is cost effective or demolition would be a more economical option.

6. Cost Benefit Analysis

From the data, it is envisaged that many relationships can be formed by using graphical techniques. In addition, the BIM model can be used to help the analysis, by adding extra fields into the data base with feature codes pertaining to quality of the survey data and maintenance details. This can then be analysed to find the following:

a. The increase of cost of the survey in relation to the level of detail.
b. The increase in costs of maintenance in relation to the age of the building.
c. Other factors that need consideration would include the building type and function. (It will be assumed for purposes of this project, that the buildings considered will be office based).

By combing these data sets, the data trends should provide an indication of when it becomes too expensive to maintain and consider demolition as an alternative.

As BIM develops to become a process rather than a product, it is predicted that the further costs can be saved. Just how much impact this will have, will need to be determined. The data collected, the models created and the cost benefit analysis will be extended to consider this.

Field Testing:

Various models have been created using different survey techniques and equipment in order to assess their advantages and disadvantages.

All the case studies below covered the research areas for level 2 BIM by government. The models were analysed to assess the quality of measurements, easy access, time taken, and cost. Various important factors which are also research areas for level 3 BIM that seem to affect all of these are the level of detail that would be required, especially with regards to the cost resolution which is related to time and rapid capturing of survey data measurements and creating models, linking of models which can be done in cloud with information of life performance and also with Identification of measurement.

The various techniques/methods and models are discussed further with mentioning the research areas related:

Leica HDS Laser Scanner and Cyclone Software:

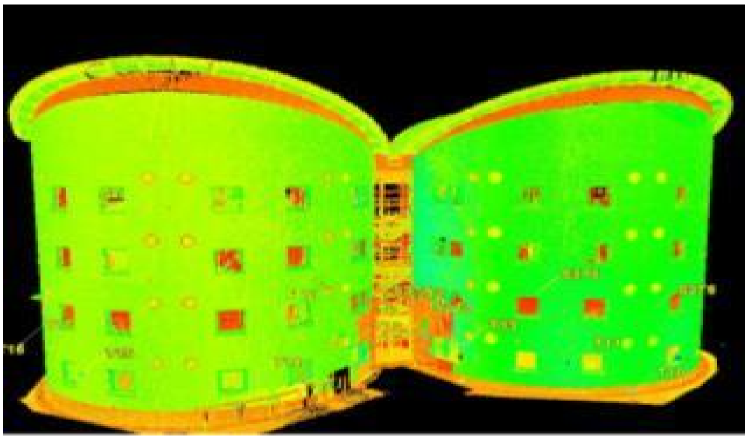


Figure 4: Halls of Residence at University of East London using Leica Scanner and Cyclone Software (also from Leica)

Figure 5: East Building Atrium at University of East London using Leica Scanner and Cyclone Software (also from Leica)

According the level of detail specification which is G3 (see Figure 4), for more precise details for a model, the laser scanning is the best option for example from above Figures the size of windows or the light locations etc. can be seen and find. From the scans taken of the University buildings using the Leica system (see Figures 4-5 above), it became clear the data created from the details was far too complex and far too large for efficient handling and analysis, and required high specification computers with details below and complex software. (English Heritage, 2011)

Due to the resolution of the laser scan, the point cloud can deliver a LOD of G3 or better, although extra analysis is needed to identify the features.

It became obvious the data formed from the details was too large and too complicated and complex so for efficient management and investigation, required high specification computers and software with details below. (English Heritage, 2011)

Smart Geomatics (2013) recommended the following specification for the interpretation of point clouds:

• RAM: For cyclone software recommended at least 32GB memory or more required. (Smart geometrics, 2015)

• Hard disk: Significant disk space and also external hard disk for backup will be required for day-to-day storage. (Smart geometrics, 2015)

Monitor: good quality display required. (Smart geometrics, 2015)

• Processor speed and type: having a fast processor may develop overall performance. (Smart geometrics, 2015)

Such computers would come at a premium price. Together with the cost of either the laser scanner (including software licenses and training) or hiring scanning services as required, it is apparent there would be financial barriers which tend to hinder this take up and use of laser scanning for use within facility management.

Thus, it is apparent there would be barriers which tend to hinder this take up and use of laser scanning for use within facility management:

1. the process and equipment (Leica laser scanner) for the initial survey is very expensive
2. for detailed analysis of the point cloud, specialised software, such as Cyclone, would be required which adds substantially to the cost and the computer power requirements, and increases the skills required by the operators
3. The times taken to laser scan larger buildings such as KD. Despite measuring 1 million points a second, the process requires considerable time to combine the data sets from many set ups into one registered model.
4. The time taken to connect point clouds, due to the huge quantity of data that is involved.
5. too much data which requires computers with a high specification (needs advanced computers with extra memory)
6. The specialised software requires customised expensive training (basic training Approx. £2395 per person). (Cices, 2015)
7. The process is far too complex and expensive for general use by facility managers.

Faro Laser Scanner and Recap software:

For this second method, a Faro laser scanner was used and the data processed using Recap (now Recap 360 Ultimate), from Autodesk, which is cloud based. The point cloud data is uploaded for processing. Once the model was completed, it was downloaded and accessed through programs such as the Recap viewer (see Figures 6-9) and AutoCAD 360, which manages and allows sharing of the information via the cloud. This idea of accessing the data from the cloud even allows the model to be viewed on smart phones and tablets. These developments will be the key in helping maintenance people to save time, see the advantages and thus drive the implementation.

Very little training is required as the software has been simplified to only include the basics. This could be seen as a disadvantage when dealing with full building surveys but could just be all that facility managers require for small existing buildings.

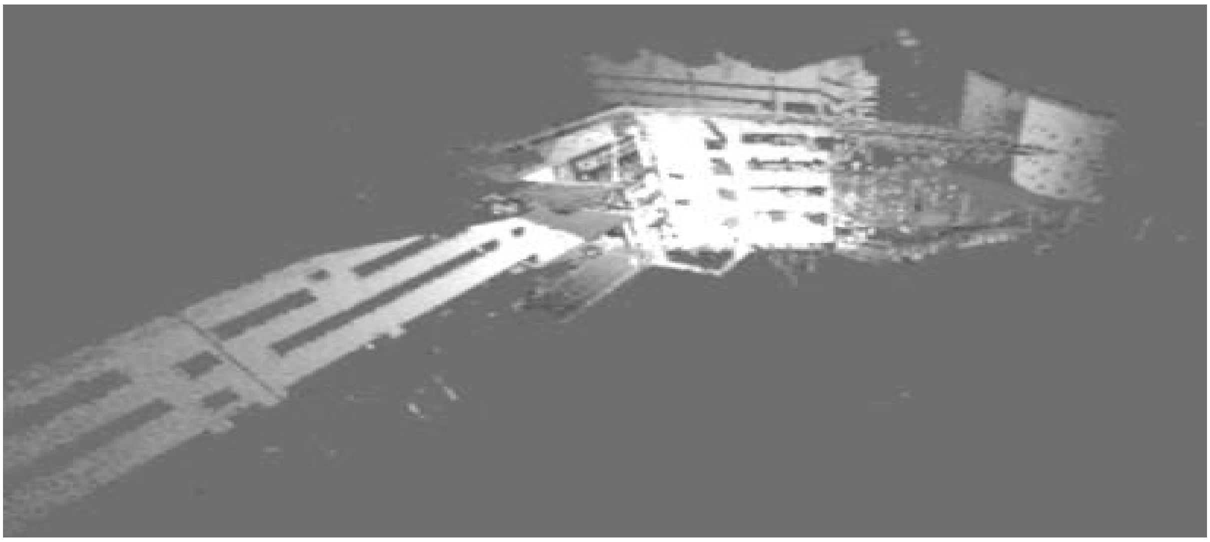


Figure 6 – Point Cloud of Knowledge Dock at University of East London created using Recap software from data collected by a Faro laser scanner.

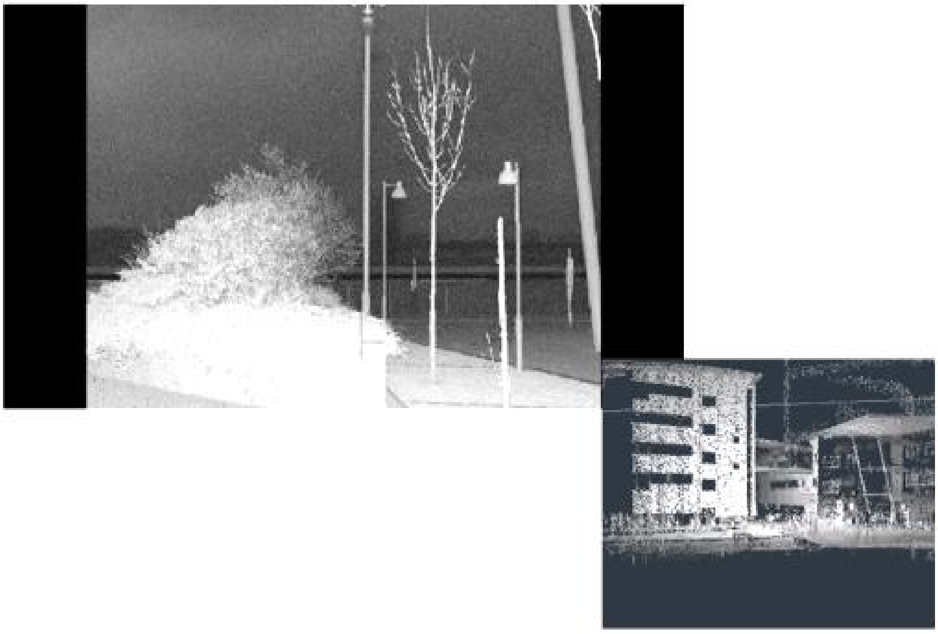


Figure 7 – view of Point Cloud of Knowledge Dock at University of East London from within model created using Recap software from data collected by a Faro laser scanner.

Figure 8 – Point Cloud video of Knowledge Dock at University of East London from Recap software

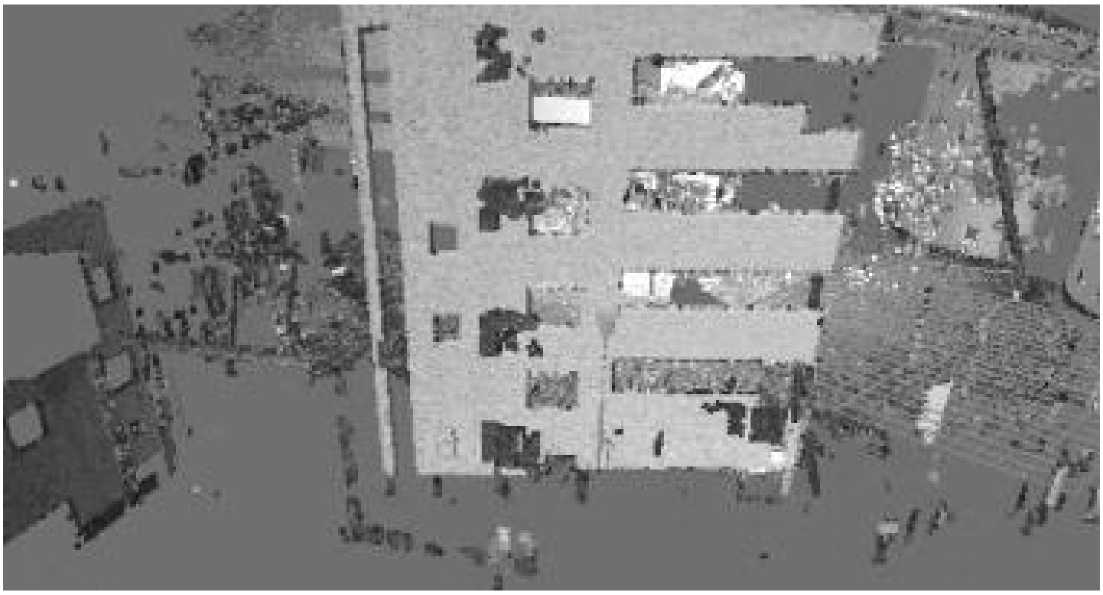


Figure 9 – Close up view of Point Cloud of Knowledge Dock at University of East London with closer view of points from Recap software

Point Cloud of Stairs (Internal stairs)

The central staircase formed the focus of the scan and highlighted the possibilities of using such technology inside a building, making it relevant for facilities management.

One issue that I did find was that of the data set became 'damaged' or rather interfered with by people walking through the area while scanning was in process (see Figure 10). Ghostly Figures were formed and would require cleaning before use, which would be possible in Cyclone but not in Recap. This would mean that the area should have restricted access during the scanning, which would also help with the health and safety issue of using lasers in public areas.

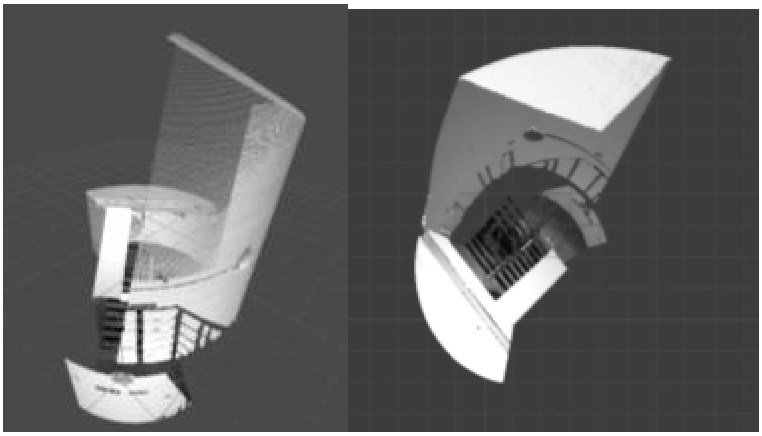


Figure 10 – Point Cloud of stairs at University of East London from side and from above using Recap software from data collected by a Faro laser scanner.

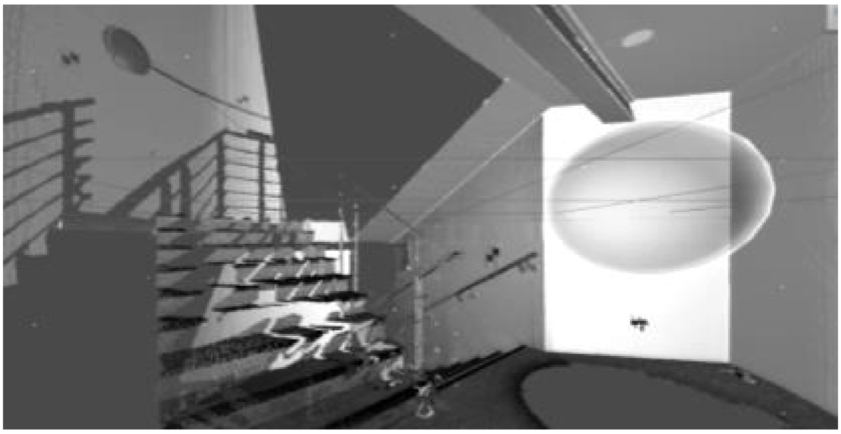


Figure 11 – Point Cloud of stairs at University of East London from inside clearly showing interference caused by people moving through the scene during scanning

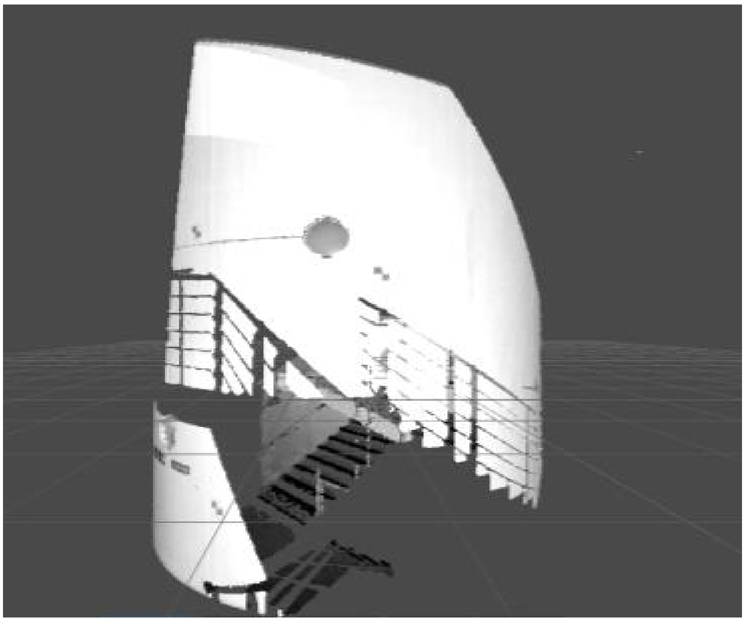


Figure 12 – Point Cloud of stairs at University of East London from outside using Recap software from data collected by a Faro laser scanner.

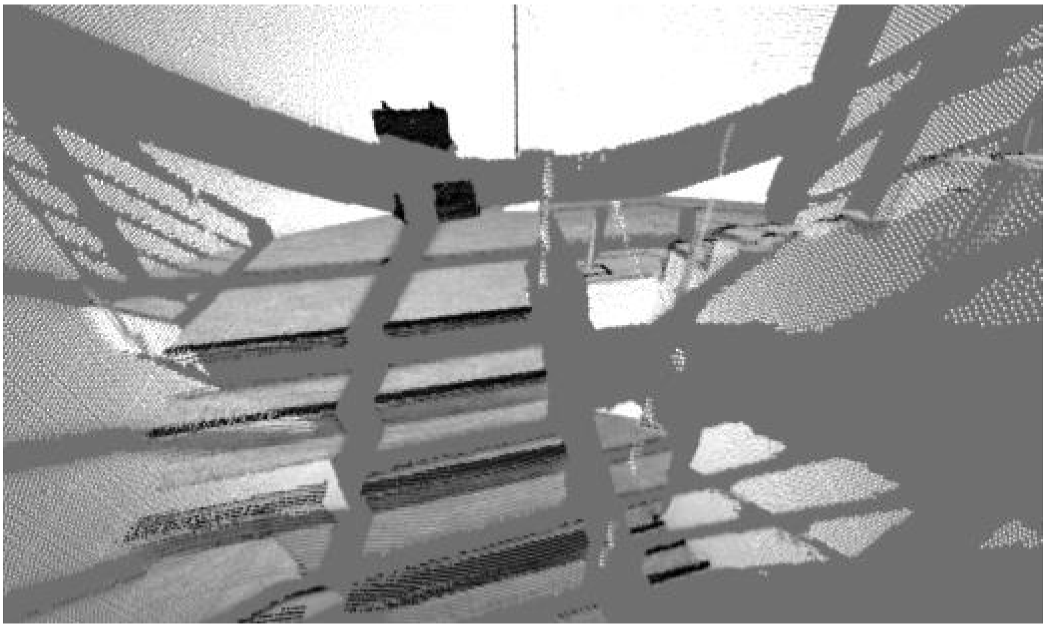


Figure 13 – Point Cloud of stairs at University of East London (close up) using Recap software from data collected by a Faro laser scanner.

From these examples, it was apparent that the use of laser scanning, although excellent at data collection, does pose some issues for the facility management of small buildings:

1. the process and equipment (Leica laser scanner) for the initial survey is very expensive
2. for detailed analysis of the point cloud, specialised software, such as Cyclone, would be required which adds substantially to the cost and the computer power requirements, and increases the skills required by the operators
3. the time taken to compile the point cloud : despite newer scanners measuring 1 million points a second, the process requires considerable time to combine the data sets from many set ups into one registered model.
4. too much data which requires computers with a high specification (needs advanced computers with extra memory)
5. the specialised software requires customised expensive training. (Leica, 2017)
6. The process is far too complex and expensive for general use by facility managers.

3D Revit Models using Disto and Tapes:

For another set of amount data which collected using tape and disto can be used for another level of LOD which requires less persists data but still some measurements require

Using these data Revit 3D model created which can be used in cloud to access, manage and share the information by using Autodesk 360 which can also use in smart phones and tablets.

This cloud can help maintenance people to save time of going to site and office as they can get information from Revit models that what product it needs to maintain and can order and then go to site to change or reinstall.

Using the disto and tape to take measurements in not very details and then created 3d models used revit software is much cheaper than laser scanning process as it takes less time as and equipment and software are cheaper

Barriers:

1: training

2: software expensive

3: standards are not sure yet

4: people do not want changes

According the level of detail specification, if a basic model with minimal details is required, then the Disto and tape are the best option. This method, when compared to using a laser scanner, produces far less data so is suitable for efficient handling and analysis using standard 'off-the-shelf' computers, available in most offices. Therefore, both the equipment and the software are cheaper, easy to obtain and much less stringent health and safety requirements need to be in place.

Such personal 'contact' may also allow collection of the qualitative data, the metadata, that is not considered when using the automated methods. This data can be included as the 3D model is created manually from the field notes.

However, there are still issues which tend to limit the use of this technology:

1. The process for the initial survey for large buildings is more expensive than small existing buildings due to the amount of time taken for a person to take measurements with a Disto or tape. Often more than one person may be required. Moreover, it is also expensive for facility management.
2. For detailed analysis of the measurements, specialised software, such as Revit, would be required which adds substantially to the cost and increases the skills required by the operators. (Autodesk 2013).
3. The specialised software requires customised expensive training.

The following Figures (14 – 20) are views taken from different locations from within the 3D model of flat, created in Revit, using tape and Disto measurements. All these models created using below steps:
1: take measurement of the small flat using disto and tape measurements
2: Install free version of Revit software from Auto desk web site (student version free for 3 years) and then training using YouTube videos of Revit and Autodesk videos and at the same time applying on this models and testing and trying by using measurements of small flat

3: created a 3d model and selecting windows and doors etc. from Revit, according to measurements and types and manufacture of door and windows of the small flat

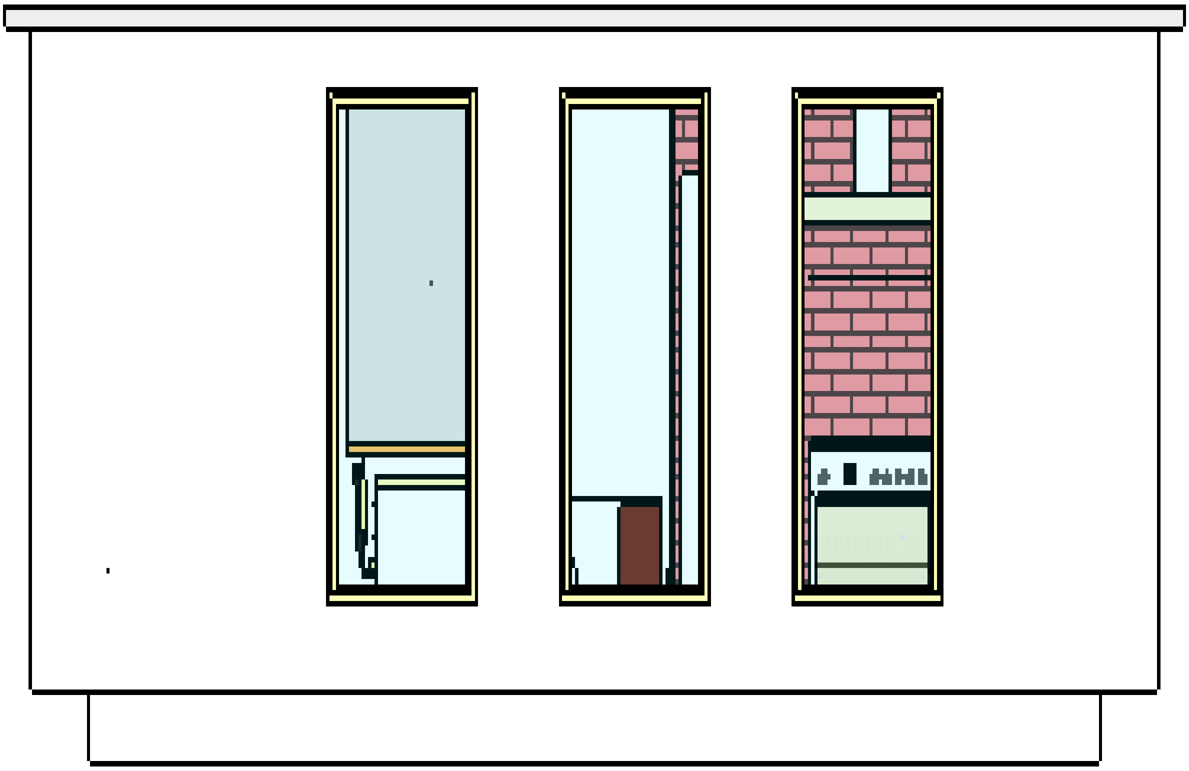


Figure 14 – North view of 3D BIM Revit Model of flat with ceiling, floor and walls

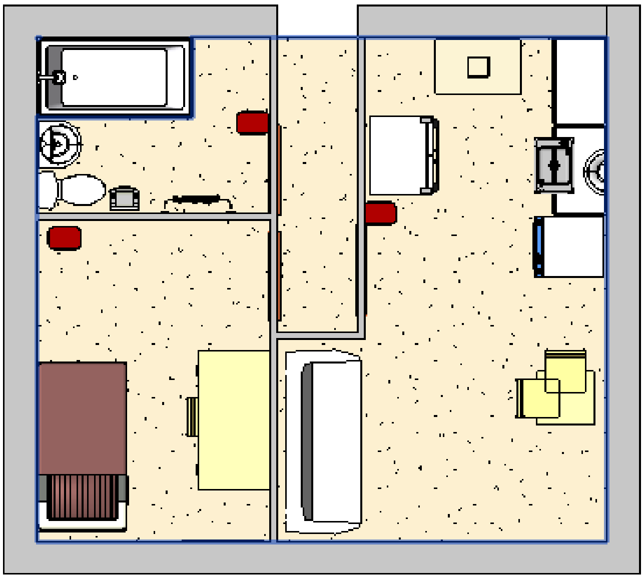


Figure 15 – plan view of 3D BIM Revit Model of flat interior

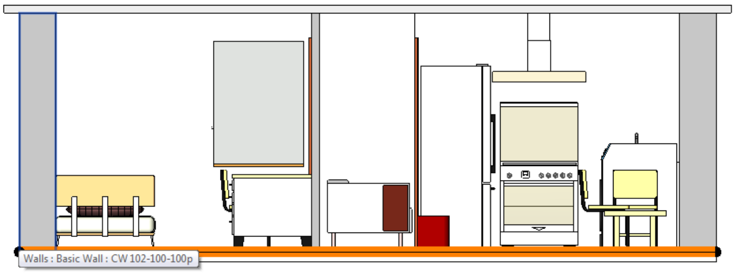


Figure 16 – North view of 3D BIM Revit Model of inside flat without wall

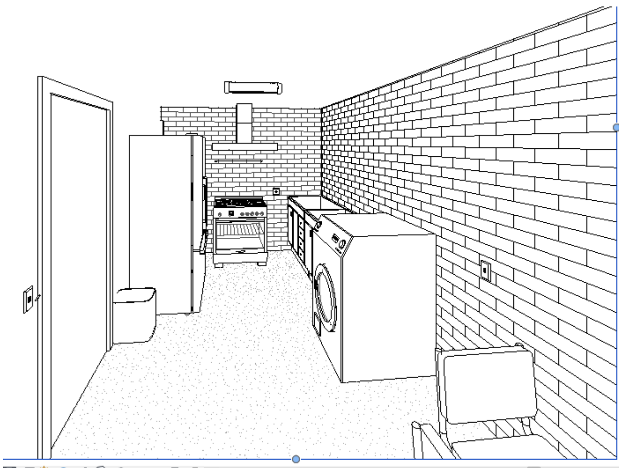


Figure 17 –camera through view of 3D BIM Revit Model of flat interior

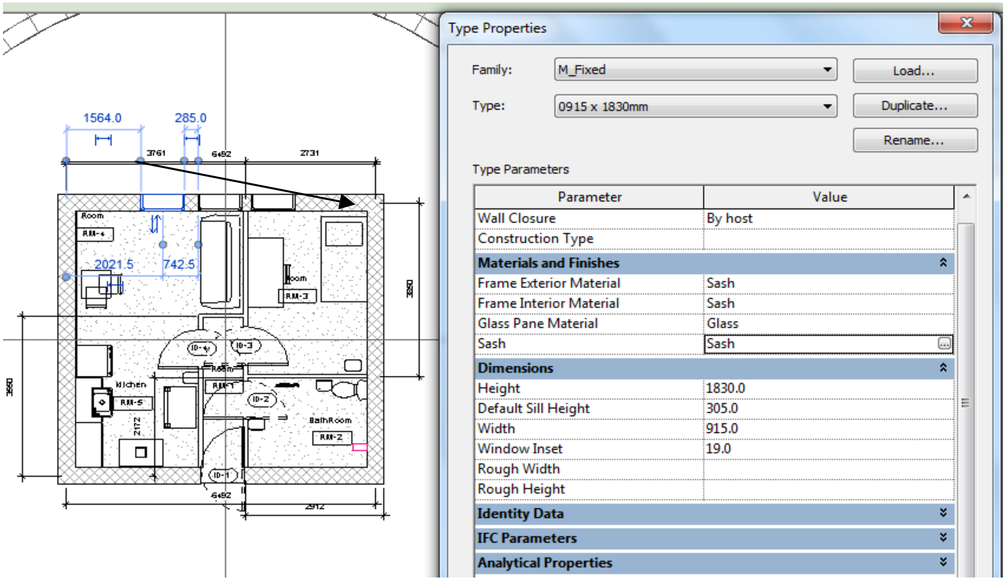


Figure 18 – 3D BIM Revit Model showing windows properties of flat with dimensions, materials and finishes details

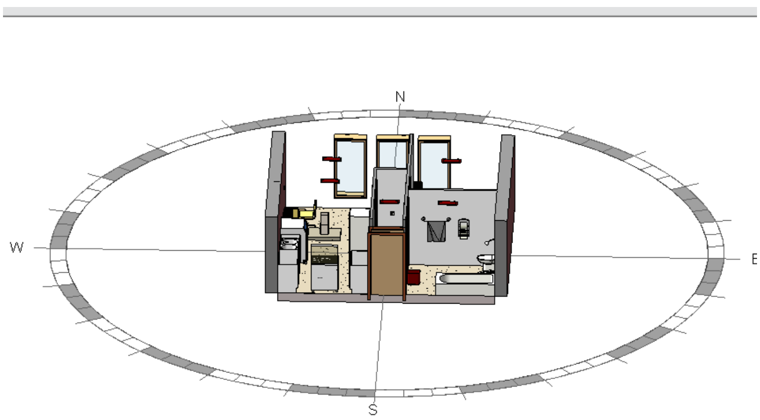


Figure 19 – 3D BIM Revit Model showing flat with services

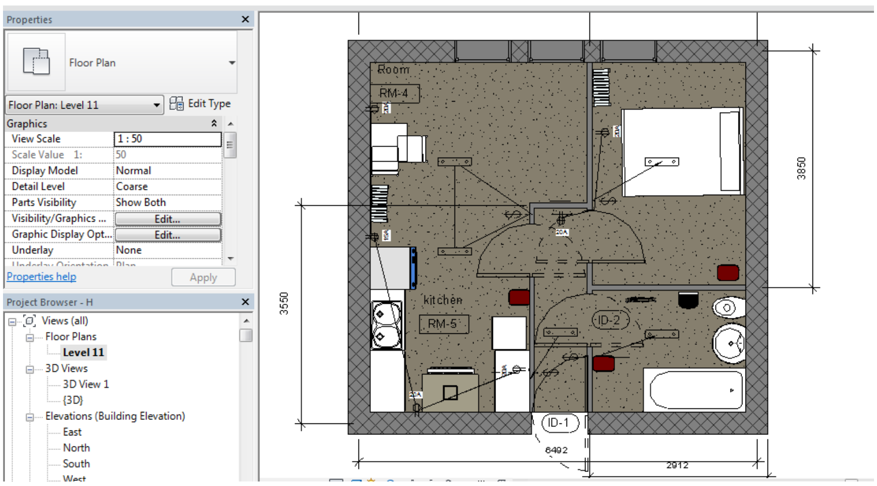


Figure 20– 3D BIM Revit Model showing flat with internal services

The following Figures (21 – 23) are views taken from different locations from within the 3D model of internal stairs at University of East London, created in Revit, using tape and Disto measurements

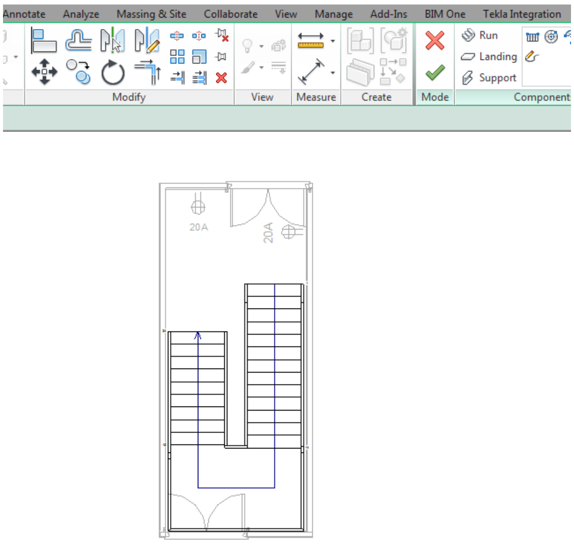


Figure 21 – 3D BIM Revit Model showing internal stairs at University of East London

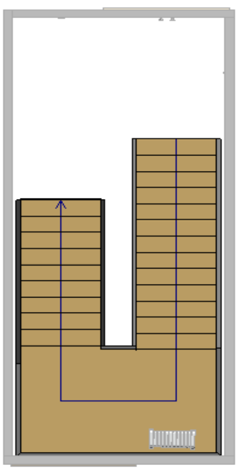


Figure 22 – 3D BIM Revit Model showing internal stairs at University of East London

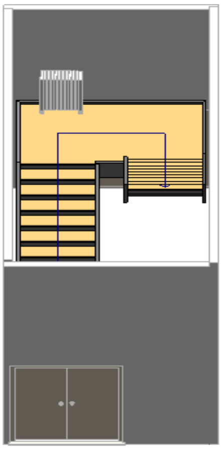


Figure 23 – 3D BIM Revit Model showing internal stairs at University of East London

Using Revit software to analyse the 3D model, any item can be selected to show all the property details e.g. dimensions, materials used and factors about the materials by giving details of materials, finishes and dimensions (see Figure 24) such as insulation properties and fire resistance which is needed to see about each equipment in flat how long can block fire in case of fire and this details can be find by looking at Heat transfer Coefficient and thermal Resistance details in drawing (see Figures 25-28).

Further details can be found through the use of hyperlinks in the model to the relevant web pages on the internet (assuming the pages are still live).

This access of the information via the cloud removes the need for the maintenance crew to visit the site to find out what is wrong, and can order replacement parts or contract a repair without leaving the office so this can save time and therefore money.

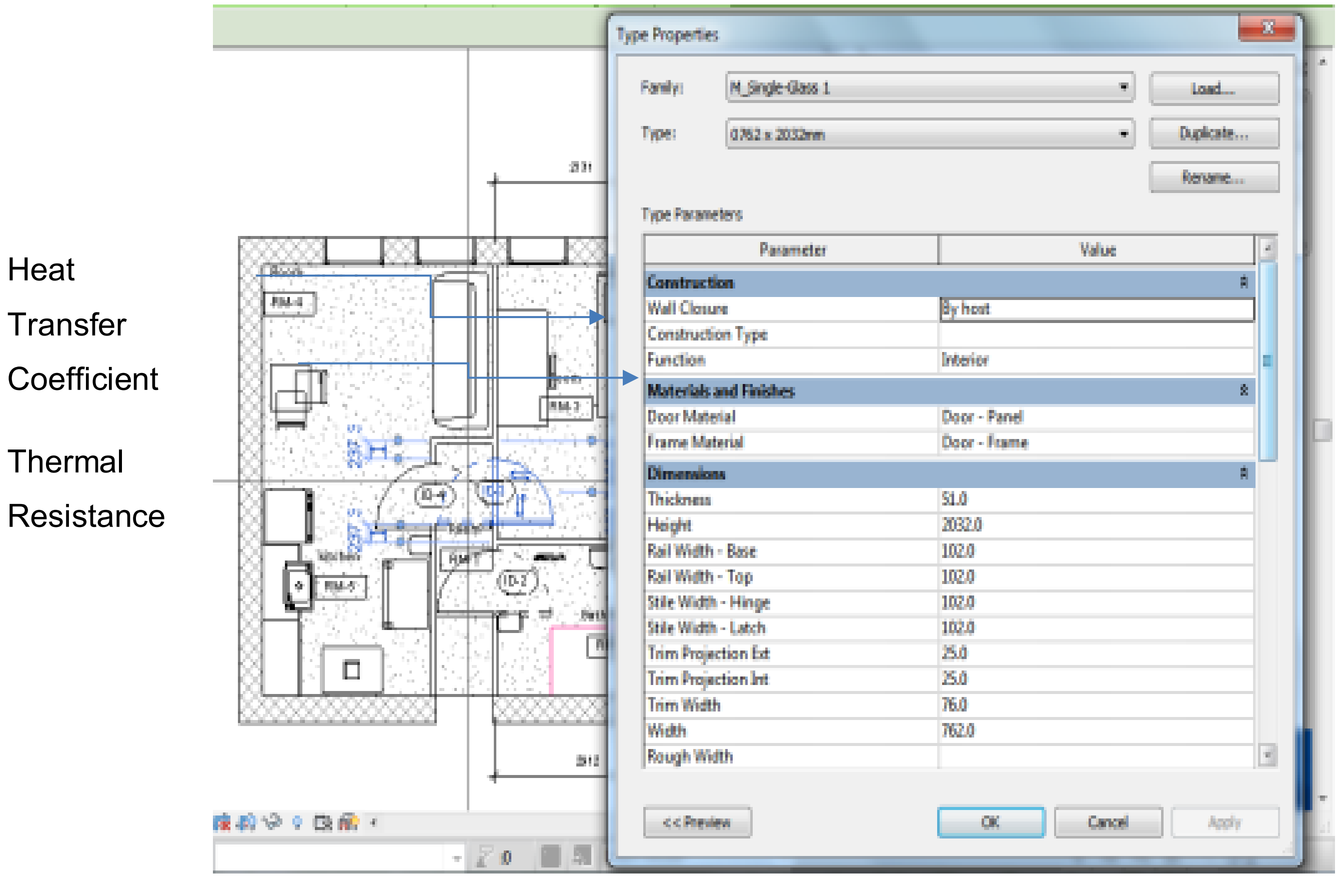


Figure 24 – 3D BIM Revit Model showing internal door properties of flat with dimension, Heat Transfer Coefficient and Thermal Resistance details

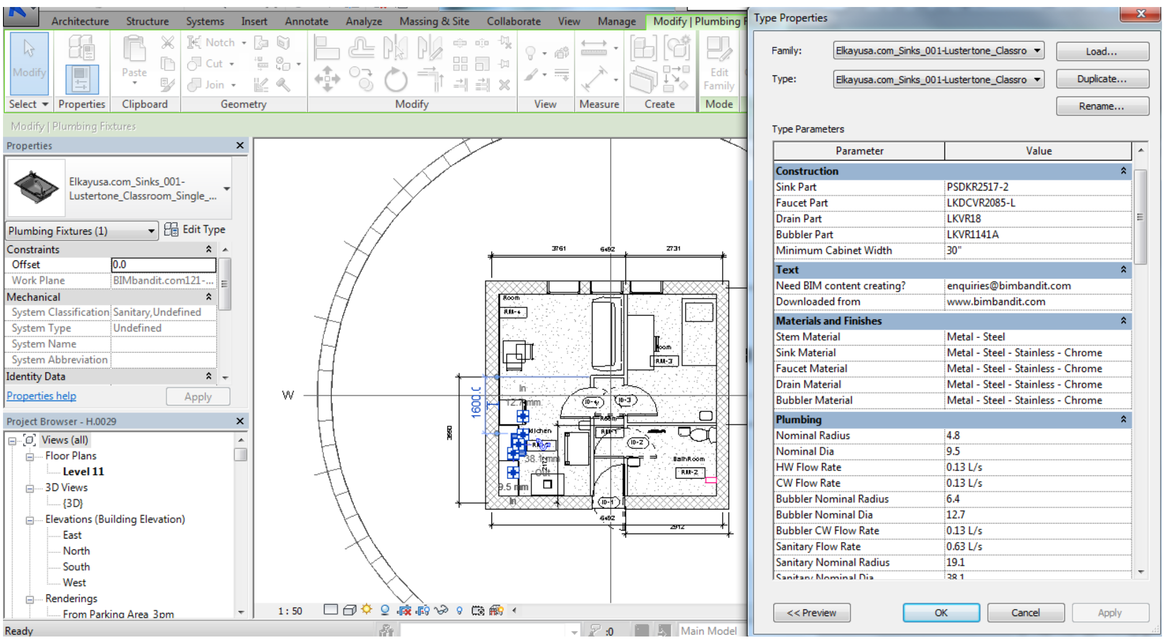


Figure 25 –3D BIM Revit Model showing bath properties with plumbing, materials, finishes and dimensions details (http://www.elkay.com)

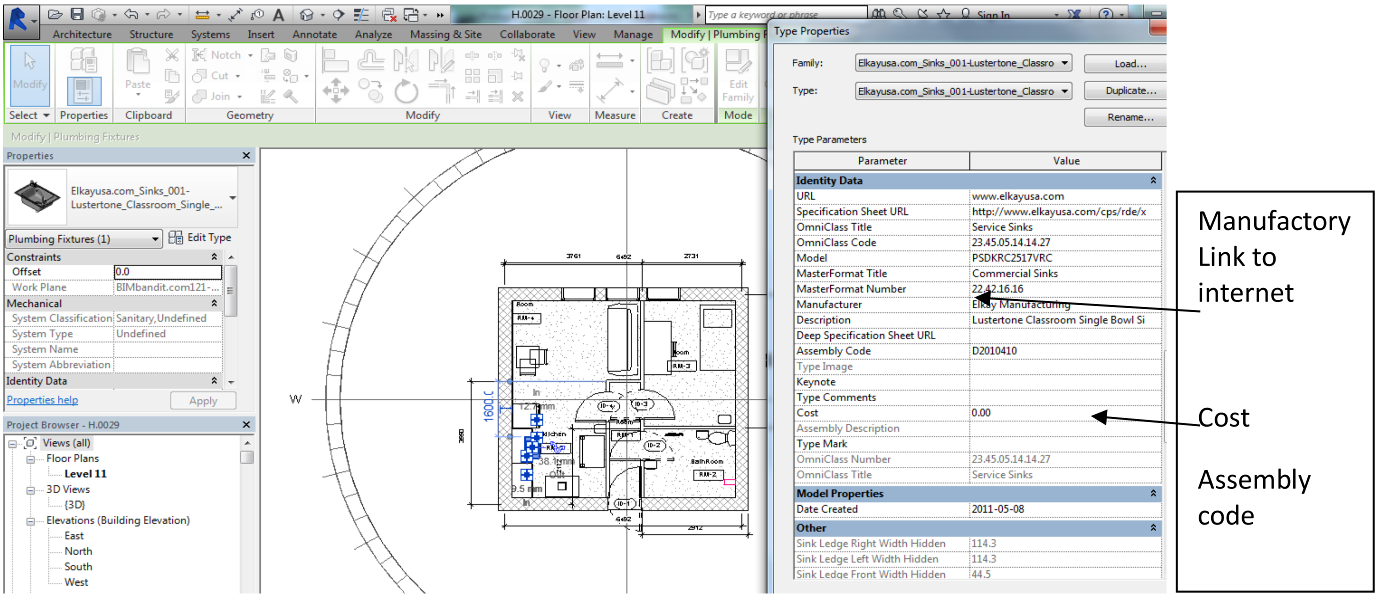


Figure 26– 3D BIM Revit Model showing bath properties with plumbing, electrical and mechanical, etc details (elkay, (2015))

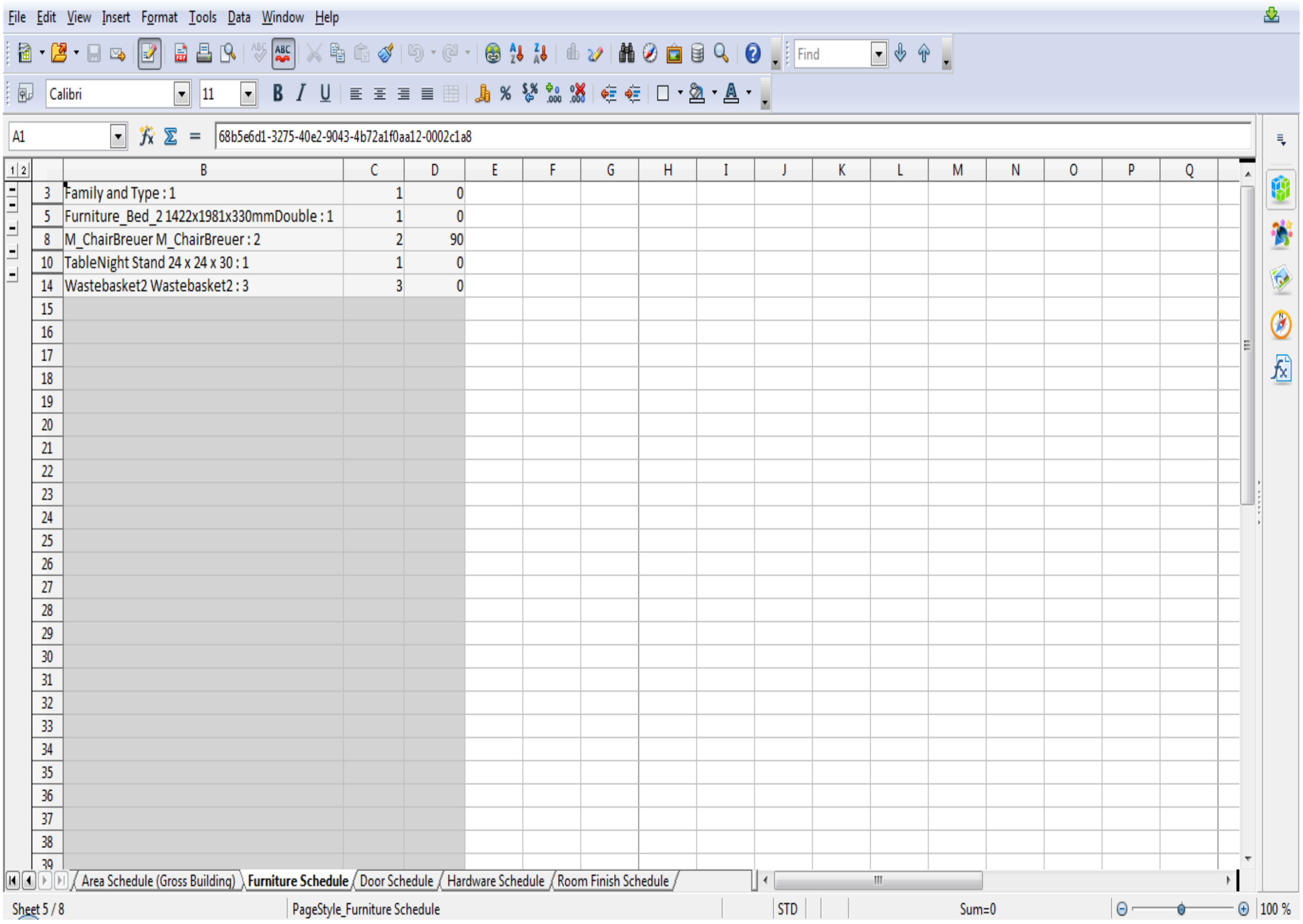
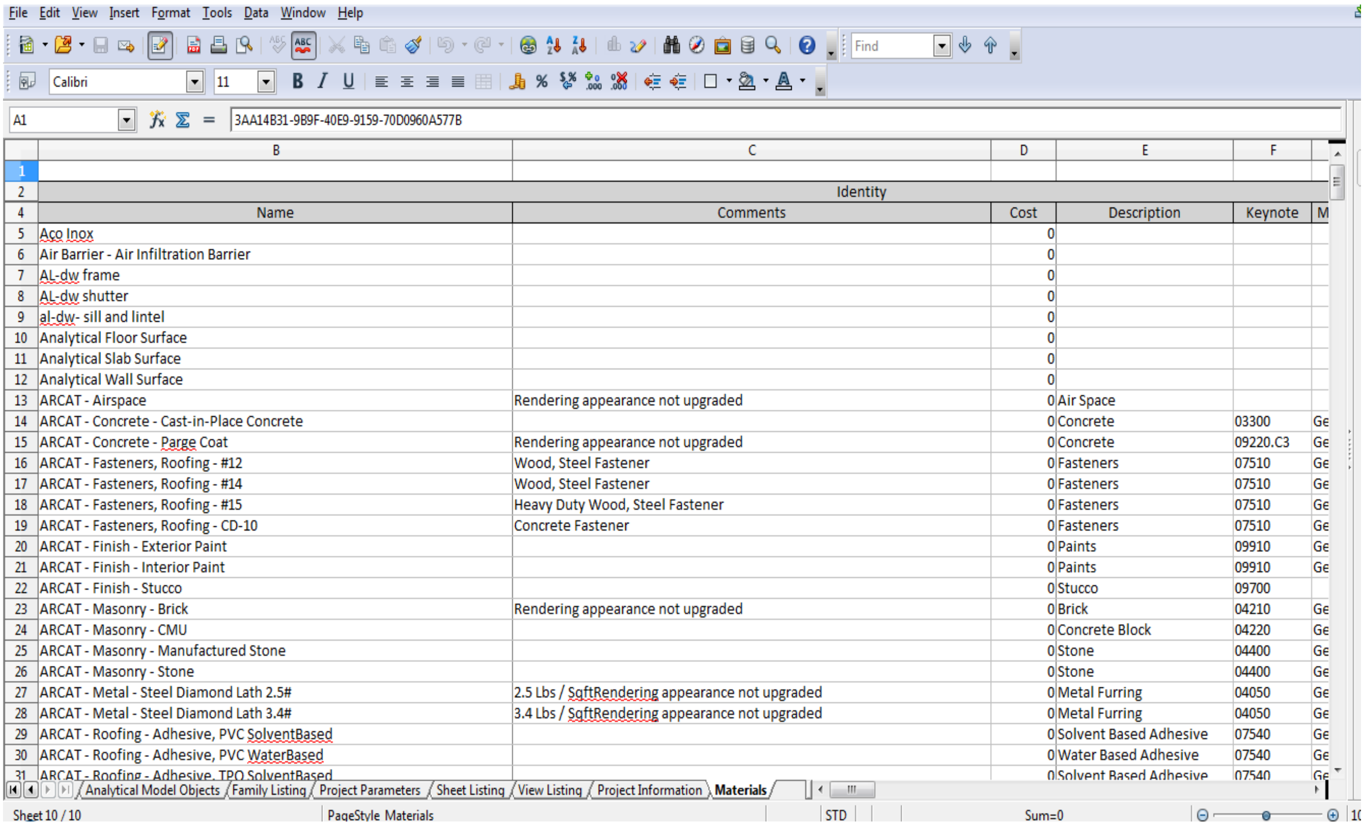


Figure 27 – showing different metadata and schedules information of 3D BIM Revit Model of flat



	Name	Comments	Cost	Description	Keynote	M
5	Aco Inox		0			
6	Air Barrier - Air Infiltration Barrier		0			
7	AL-dw frame		0			
8	AL-dw shutter		0			
9	al-dw- sill and lintel		0			
10	Analytical Floor Surface		0			
11	Analytical Slab Surface		0			
12	Analytical Wall Surface		0			
13	ARCAT - Airspace	Rendering appearance not upgraded	0	Air Space		
14	ARCAT - Concrete - Cast-in-Place Concrete		0	Concrete	03300	Ge
15	ARCAT - Concrete - Parge Coat	Rendering appearance not upgraded	0	Concrete	09220.C3	Ge
16	ARCAT - Fasteners, Roofing - #12	Wood, Steel Fastener	0	Fasteners	07510	Ge
17	ARCAT - Fasteners, Roofing - #14	Wood, Steel Fastener	0	Fasteners	07510	Ge
18	ARCAT - Fasteners, Roofing - #15	Heavy Duty Wood, Steel Fastener	0	Fasteners	07510	Ge
19	ARCAT - Fasteners, Roofing - CD-10	Concrete Fastener	0	Fasteners	07510	Ge
20	ARCAT - Finish - Exterior Paint		0	Paints	09910	Ge
21	ARCAT - Finish - Interior Paint		0	Paints	09910	Ge
22	ARCAT - Finish - Stucco		0	Stucco	09700	
23	ARCAT - Masonry - Brick	Rendering appearance not upgraded	0	Brick	04210	Ge
24	ARCAT - Masonry - CMU		0	Concrete Block	04220	Ge
25	ARCAT - Masonry - Manufactured Stone		0	Stone	04400	Ge
26	ARCAT - Masonry - Stone		0	Stone	04400	Ge
27	ARCAT - Metal - Steel Diamond Lath 2.5#	2.5 Lbs / SqftRendering appearance not upgraded	0	Metal Furring	04050	Ge
28	ARCAT - Metal - Steel Diamond Lath 3.4#	3.4 Lbs / SqftRendering appearance not upgraded	0	Metal Furring	04050	Ge
29	ARCAT - Roofing - Adhesive, PVC SolventBased		0	Solvent Based Adhesive	07540	Ge
30	ARCAT - Roofing - Adhesive, PVC WaterBased		0	Water Based Adhesive	07540	Ge
31	ARCAT - Roofing - Adhesive, TPO SolventBased		0	Solvent Based Adhesive	07540	Ge

Figure 28– showing different metadata and schedules information of 3D BIM Revit Model of flat

2D AutoCAD Models using Disto and Tapes:

Figure 29 – 2D AutoCAD Model of flat using Disto and Tapes

According the level of detail specification, if a basic model with minimal details (2D) is required, then the Disto and tape are the best option and using AutoCAD to draw models which is a traditional process and most of companies and facilities management using it.

However, there are still issues which tend to limit the use of this technology as seen in the example:

1. Due to the amount of time taken for a person to take measurements with a Disto or tape for the initial survey for large buildings is more expensive than small existing buildings due to the amount of time taken.
2. For detailed analysis of the measurements, specialised software, such as AutoCAD, would be required which adds substantially to the cost and increases the skills required by the operators.

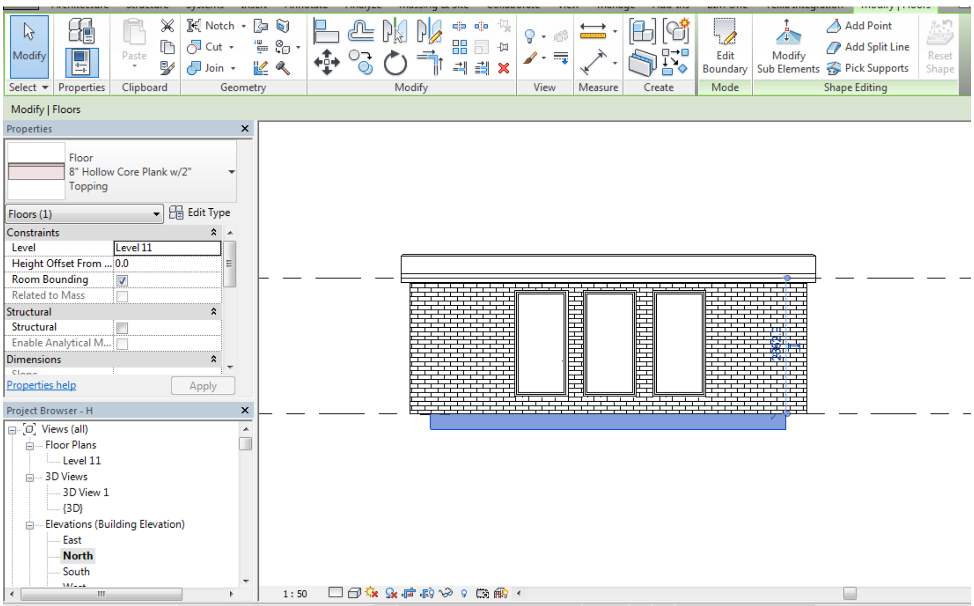


Figure 30– showing 3D BIM Revit Model of flat

3D photogrammetric models from photographs and created using Recap 360 software and Bentley context capture:

According the level of detail requirements, for basic details for a model, it appears the camera is the best option. From 20 photos were taken of a guitar using an Ipad, this has been done to get familiar with recap software (see Figure 31-32), how does it work and to find out best way and angles for taking photos, and then 90 photos taken of a room of the flat using a standard compact cannon camera sx210 IS pc1468 14.1mega pixels although only 68 were suitable to be used for processing using Bentley ContextCapture (see Figure 33), then again same 90 photos were used to create a 3D model of a room of the flat although only 83 were suitable to be used for processing using Recap 360 (see Figure 34-36), which is accessed through cloud, it became clear the amount of data created from the details was not excessive for efficient handling and analysis especially when compared to laser scanning because it does not given the measurements data so it less information can be found in this process.

The photographs were processed using Recap 360 from Autodesk and context capture from Bentley, which are cloud based to check the validity of the findings from the 3D photogrammetry model using different software. The photos were uploaded for processing. Once the 3D photogrammetry model was completed after an hour or so, it was downloaded and accessed using AutoCAD 360.

Minimal training is required as the software ism intuitive. One issue that I did find was that the models produced were not of a good quality because there were not enough photos for the required 60% overlap in each case, not taken at right angles or not enough intersection between each of the photographs (Autodesk 2014).

If photos not taken in right angles and not enough intersection between each photos then so 3D photogrammetry model will not be with good quality so these points need to make note of it when taking the photos to get better 3D photogrammetry model with good quality. Also not interfered by people, this would mean that the area should have restricted access during the scanning,

The advantages of using this technique are that the details are stored within the Figures rather than the model, although they may not have any intelligence attached to them. A point cloud is generated and the photographs draped around it to give the Figure of realism.

The models produced still require considerable editing to create a reasonable model. Cropping extraneous details from the background improve the appearance of the 3D model, especially of individual objects. In both these models, the bed stands out as basically complete, while the rest of the room is, at best, incomplete. Trials of the system have been published with excellent models of specific objects achieved (Pix4D 20155)

Figure 31 – view 3D models from photographs using Recap 360 from different angles

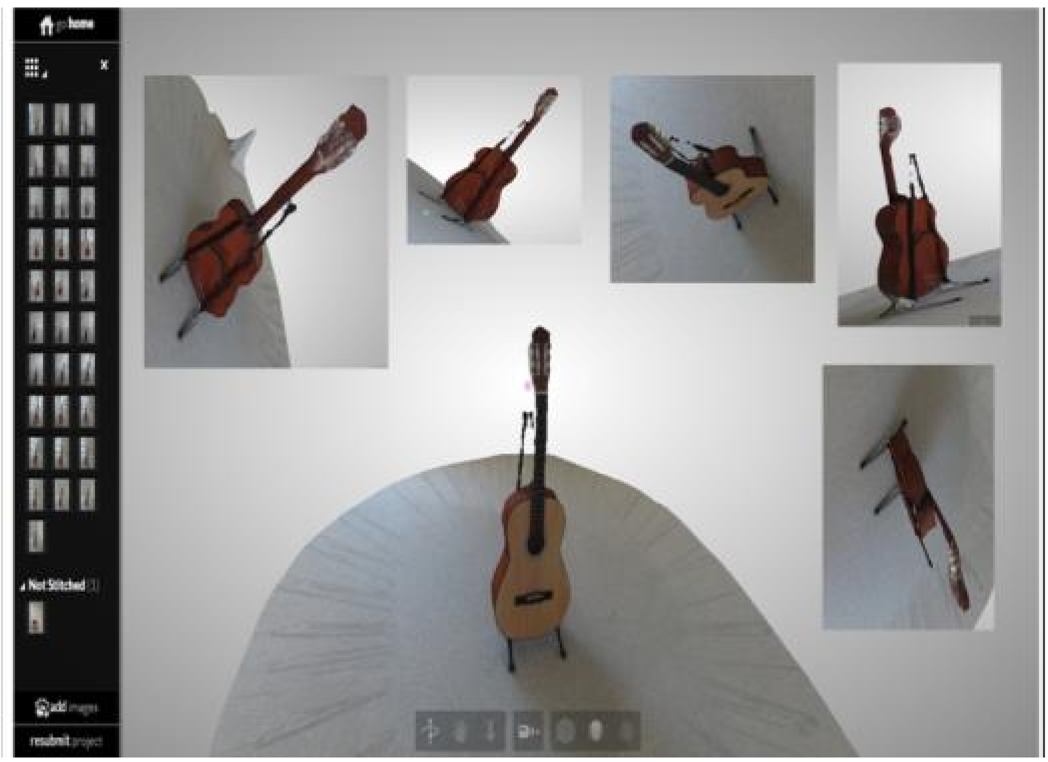


Figure 32 – view 3D models from photographs using Recap 360

Figure 33– view 3D models from photographs of flat using Bentley Context Capture

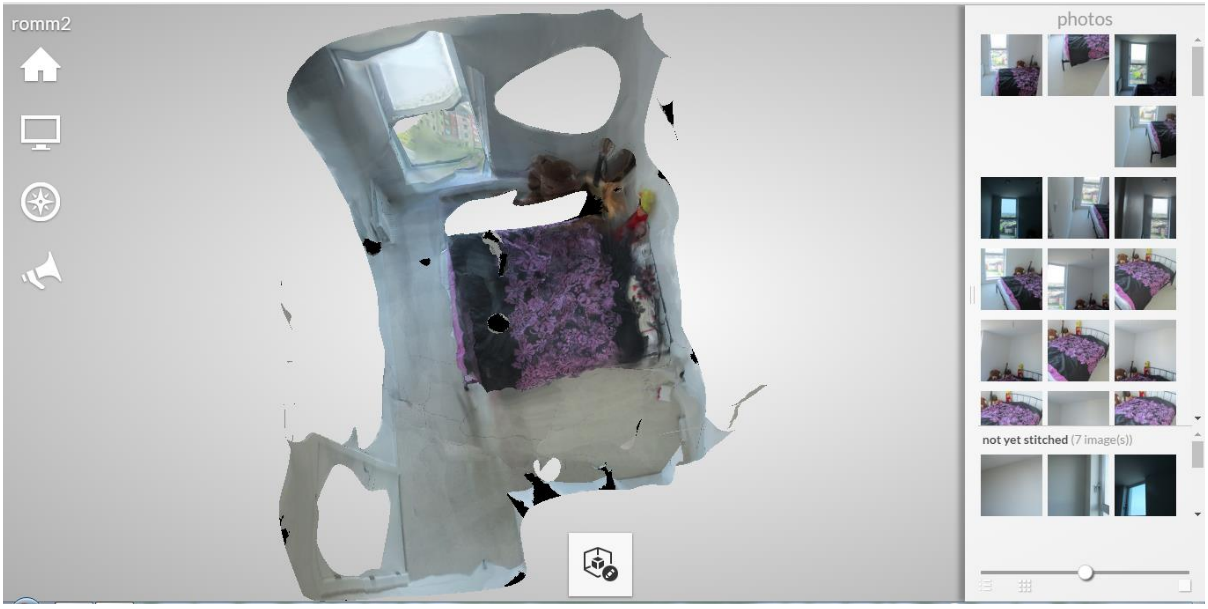


Figure 34– up view 3D models from photographs of flat using Recap 360

Figure 35– side view 3D models from photographs of flat using Recap 360

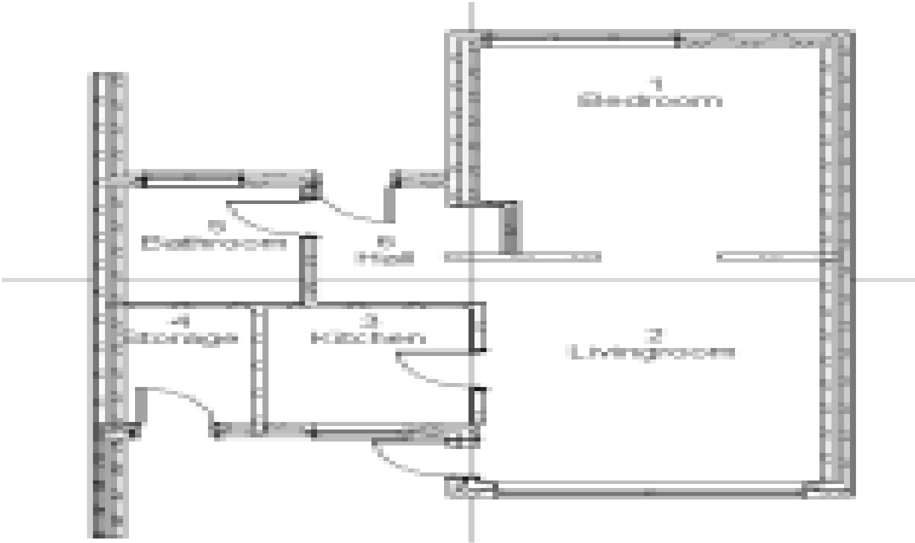
Figure 36– front view 3D models from photographs of flat using Recap 360

One issue was with the accuracy of the measurements taken from the models. Although it is possible to scale the model and then determine the distances between points, as can be seen from the Figures above, the model is not always perfect as the process is dependent upon good sharp definition of the edges of the object being photographed. As a result, background features may interfere with the model.

Revit models from Existing Paper-based Floor Plans: Real Smart House Project (Southend)

From existing 2D floor plans and sections (Figure 39) of bungalows from an estate in Southend 3D Revit models were created (Figure 40), which will be investigated as their usefulness in developing a maintenance programme for the estate.

Figure 37– example 1 original 2d floor plan of Smart House Project (Southend)


1
Bedroom
5
Bathroom
6
Hall
4
Storage
3
Kitchen
2
Livingroom

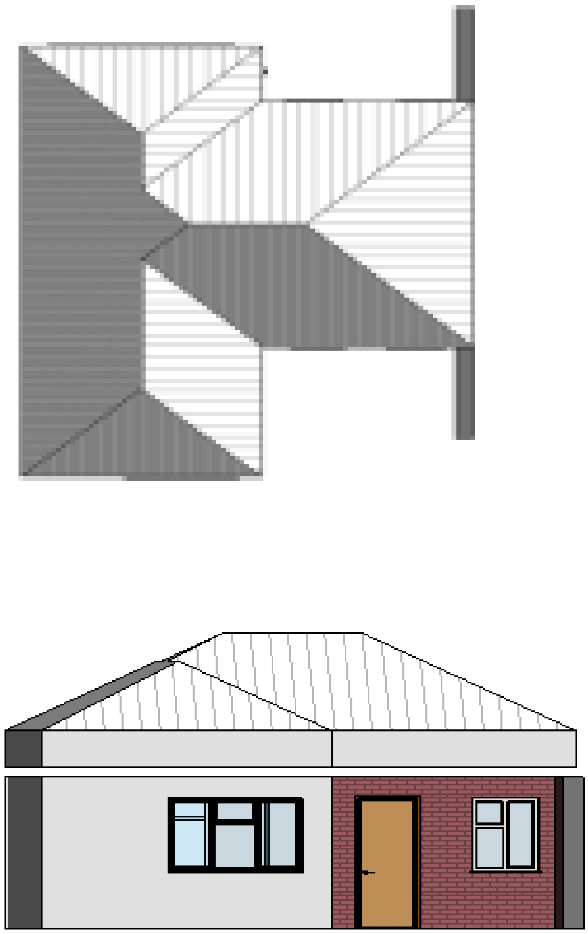


Figure 38 – views of 3D Model created in Revit of Smart House Project (Southend)

Non-graphical data was added to the model in the form of hyperlinks to external web pages:

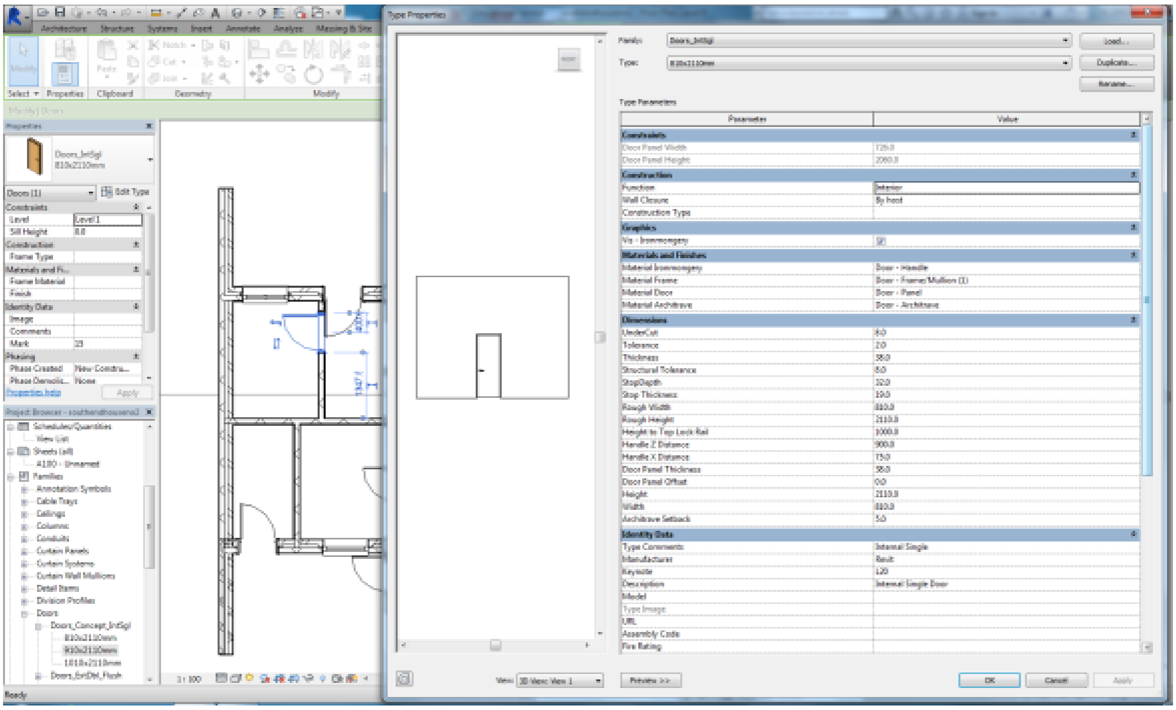


Figure 39 – 3D Model from Revit showing internal door properties with dimensions

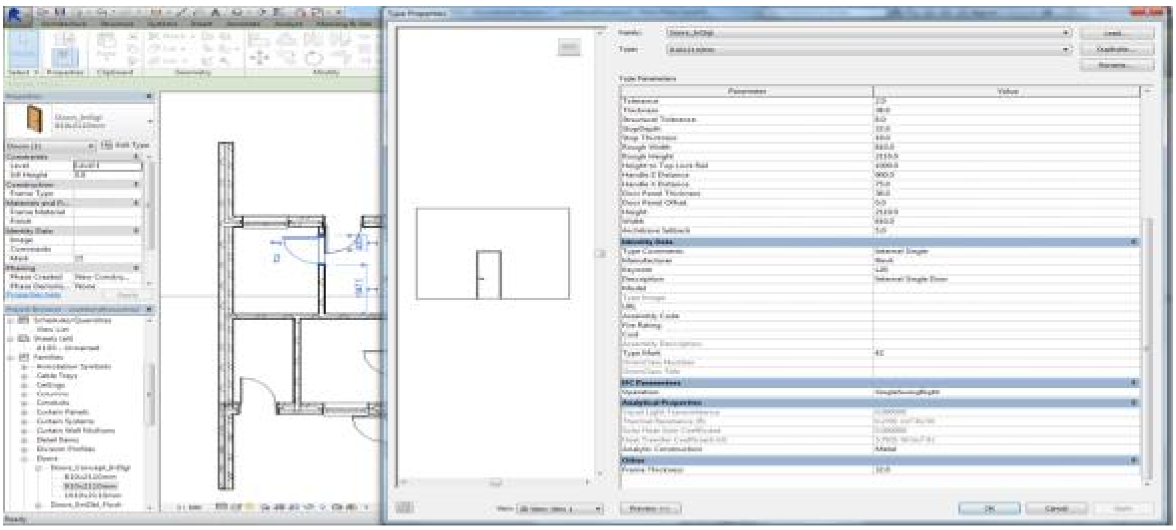


Figure 40 – the same door indicating Heat Transfer Coefficient and Thermal Resistance and other useful information for planning an energy saving strategy.

Figure 41– example 2 original 2d floor plan of Smart House Project (Southend)

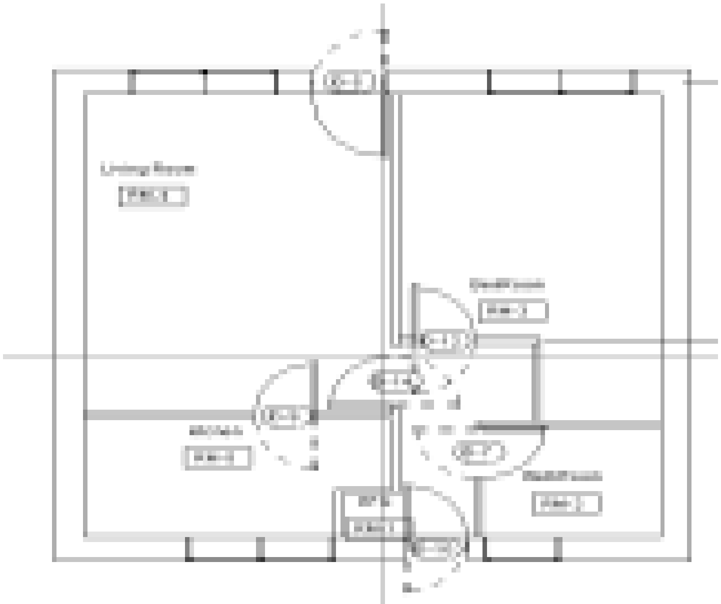


Figure 42– elevation and floor plan created in Revit of example 2 of Smart House Project (Southend)

This process can be used for addition of the refurbishment details of the Southend houses (to the SmartHome specification) to determine the suitability of such models in assessing sustainability.

RP Lidar 360 Robot Laser Scanner:

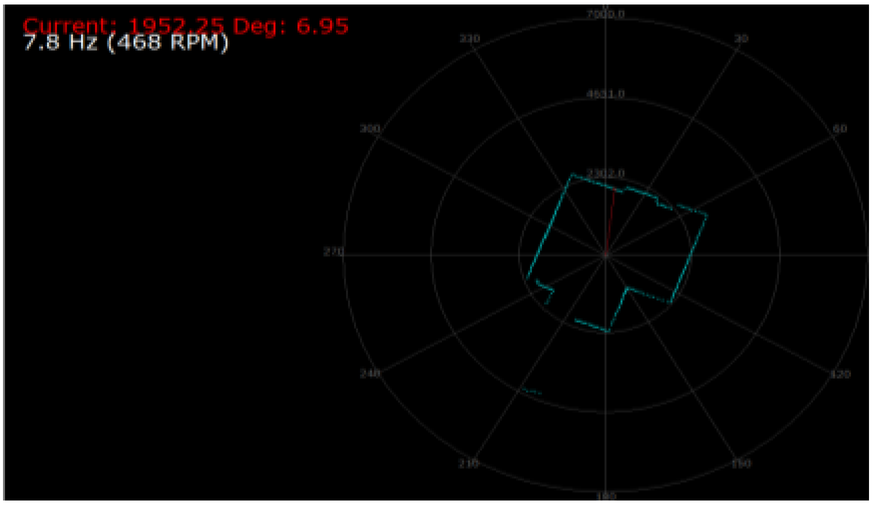


Figure 43 – Point Cloud of dining room and kitchen of flat using frame grabber software collected by RP Lidar 360 Robot Laser Scanner

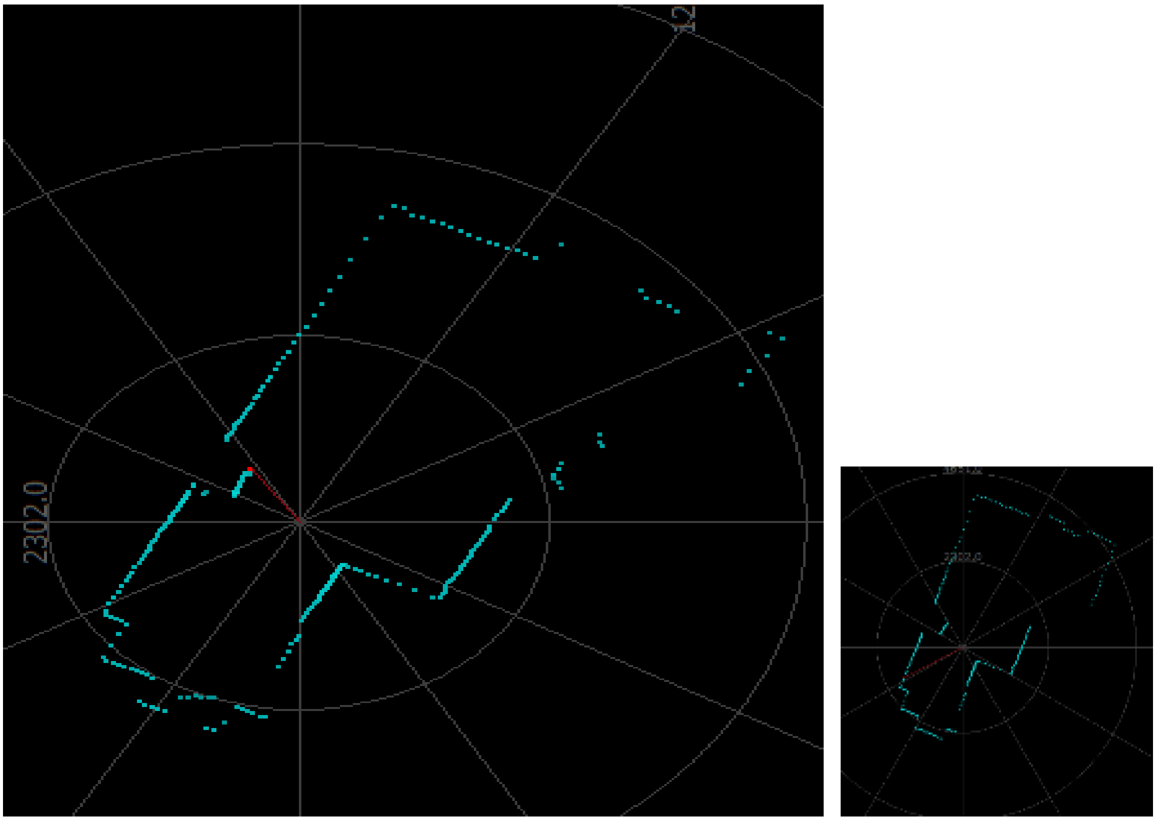


Figure 44 – Point Cloud of dining room and kitchen of flat using frame grabber software collected by RP Lidar 360 Robot Laser Scanner

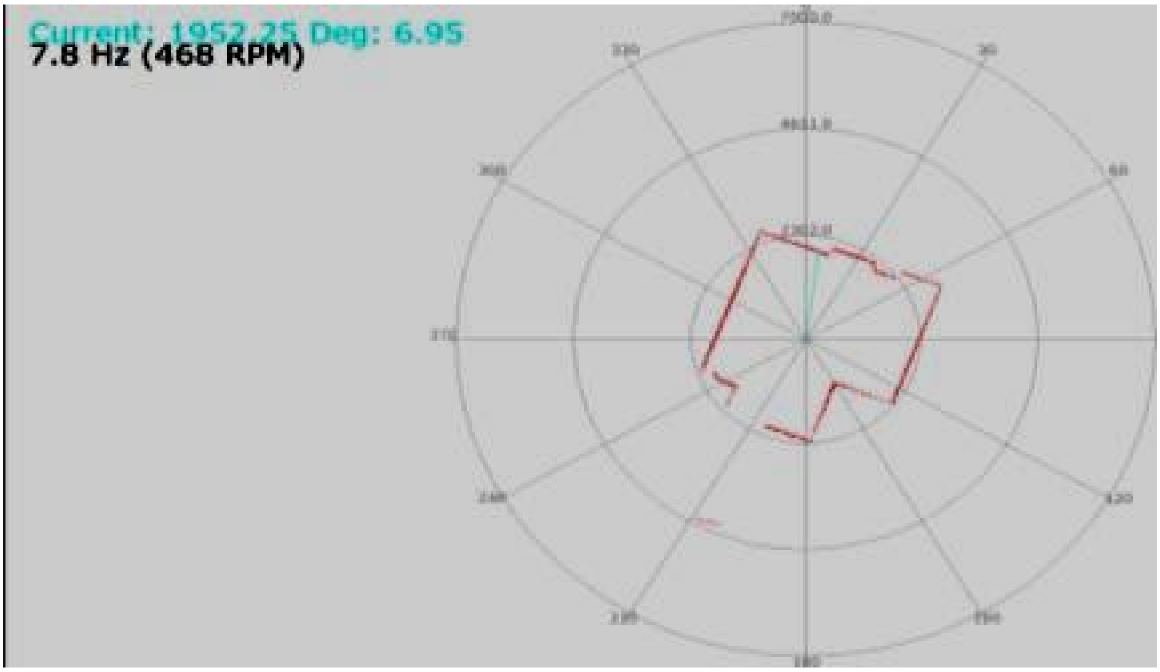


Image 45 – Output from frame grabber software collected by RP Lidar 360 Robot Laser Scanner (flat)

Figure 46– Point Cloud data dining room and kitchen of flat in excel using ultra grabber software collected by RP Lidar 360 Robot Laser Scanner

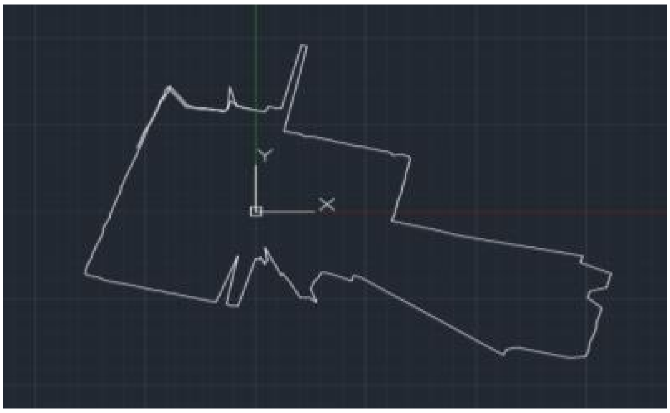


Figure 47– 2D AutoCAD model dining room and kitchen of flat using point cloud data from excel using collected by RP Lidar 360 Robot Laser Scanner

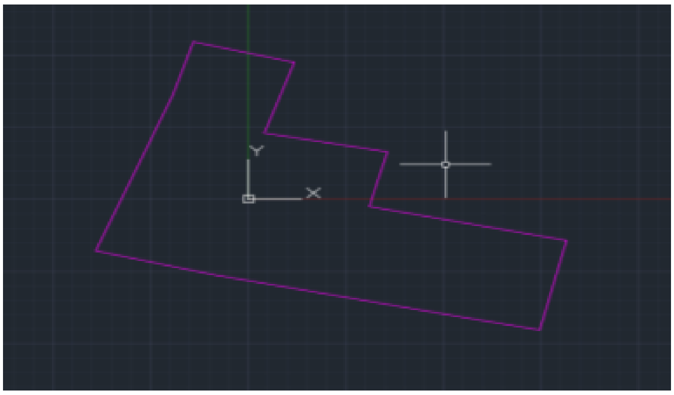


Figure 48 – Edited 2D AutoCAD model dining room and kitchen of flat using point cloud data from excel using collected by RP Lidar 360 Robot Laser Scanner

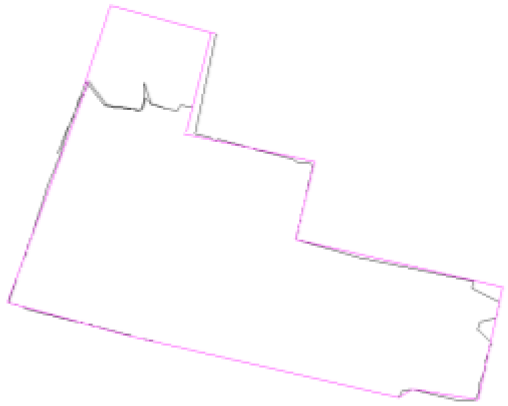


Figure 49– 3D Revit model dining room and kitchen of flat using point cloud data from excel using collected by RP Lidar 360 Robot Laser Scanner

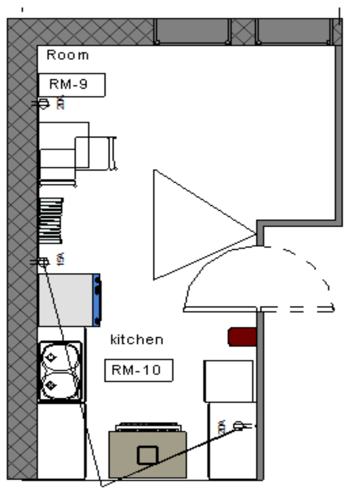


Figure 50 – 3D Revit model dining room and kitchen of flat with extra information

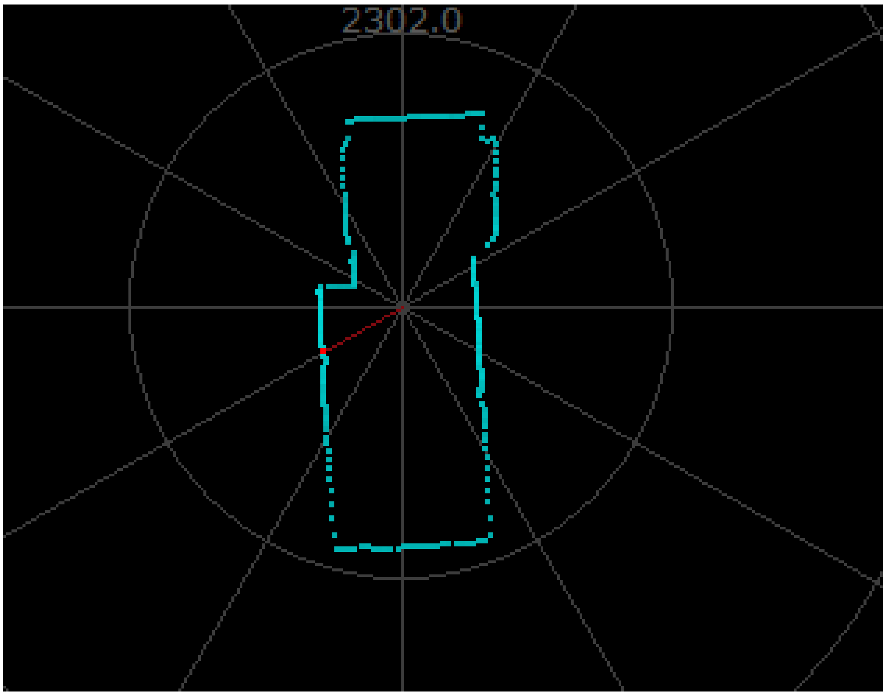


Figure 51 – Point Cloud of corridor of flat using frame grabber software collected by RP Lidar 360 Robot Laser Scanner

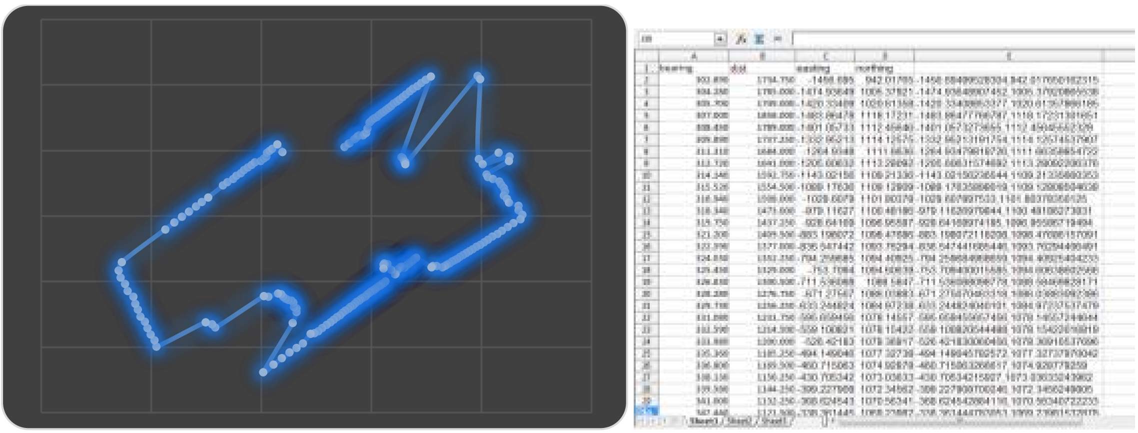


Figure 52 – Point Cloud data corridor and kitchen of flat in excel using ultra grabber software collected by RP Lidar 360 Robot Laser Scanner

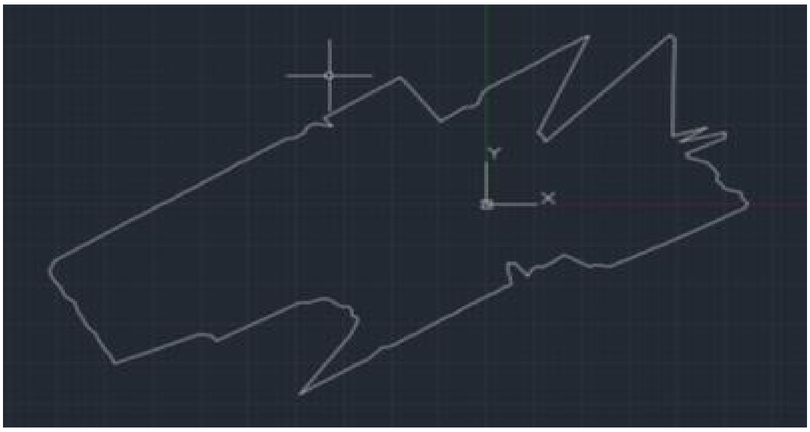


Figure 53 – 2D AutoCAD model corridor of flat using point cloud data from excel using collected by RP Lidar 360 Robot Laser Scanner

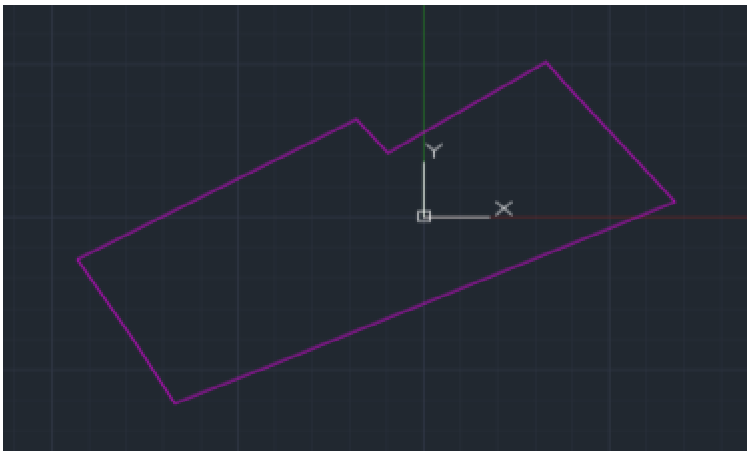


Figure 54 – Edited 2D AutoCAD model dining room and kitchen of flat using point cloud data from excel using collected by RPLidar 360 Robot Laser Scanner

Figure 55– Original and Edited 2D AutoCAD model dining room and kitchen of flat using point cloud data from excel using collected by RP Lidar 360 Robot Laser Scanner

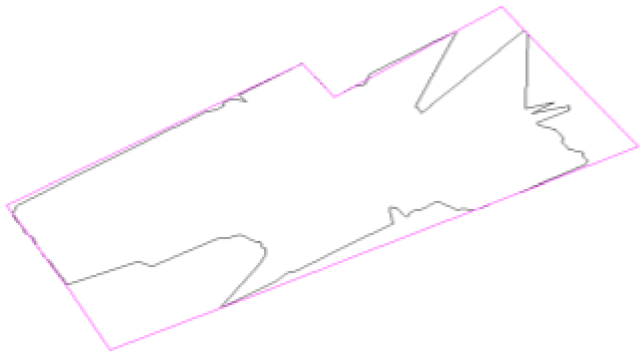


Figure 56 – 3D Revit model corridor of flat using point cloud data from excel using collected by RP Lidar 360 Robot Laser Scanner

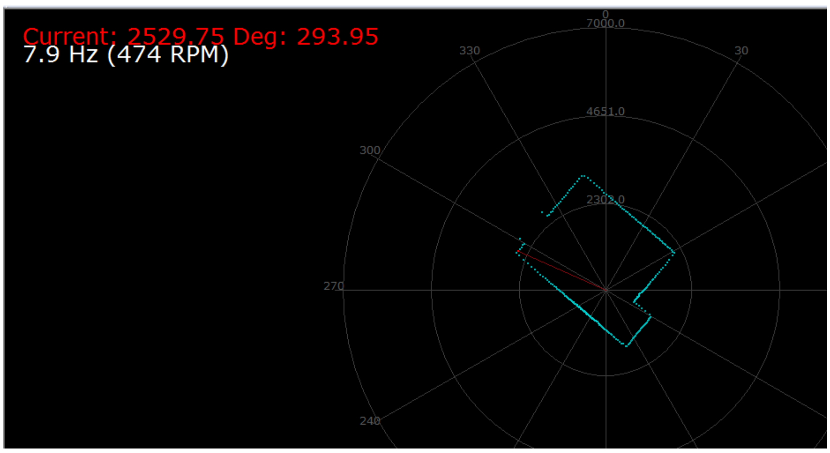
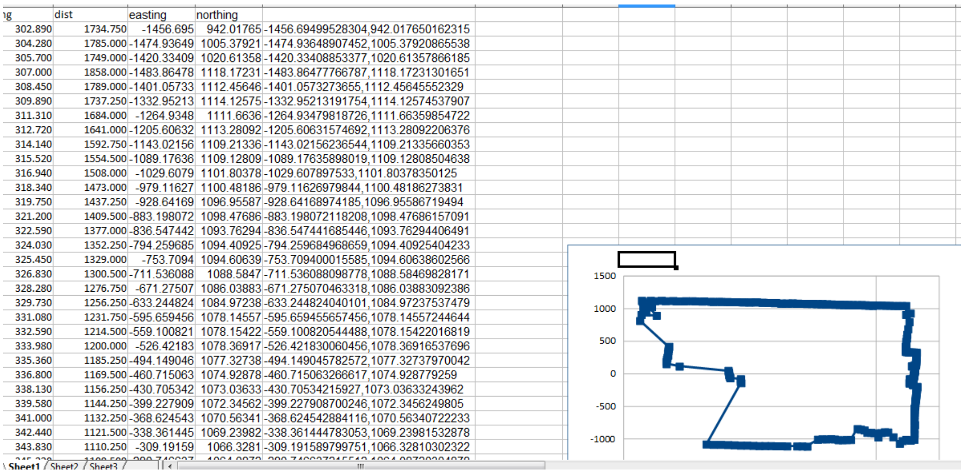


Figure 57 – Point Cloud of bedroom of flat using frame grabber software collected by RPLidar 360 Robot Laser Scanner



ng	dist	easting	northing	
302.890	1734.750	-1456.695	942.01765	-1456.69499528304,942.017650162315
304.280	1785.000	-1474.93649	1005.37921	-1474.93648907452,1005.37920865538
305.700	1749.000	-1420.33409	1020.61358	-1420.33408853377,1020.61357866185
307.000	1858.000	-1483.86478	1118.17231	-1483.86477766787,1118.17231301651
308.450	1789.000	-1401.05733	1112.45646	-1401.0573273655,1112.45645552329
309.890	1737.250	-1332.95213	1114.12575	-1332.95213191754,1114.12574537907
311.310	1684.000	-1264.9348	1111.6636	-1264.93479818726,1111.66359854722
312.720	1641.000	-1205.60632	1113.28092	-1205.60631574692,1113.28092206376
314.140	1592.750	-1143.02156	1109.21336	-1143.02156236544,1109.21335660353
315.520	1554.500	-1089.17636	1109.12809	-1089.17635898019,1109.12808504638
316.940	1508.000	-1029.6079	1101.80378	-1029.607897533,1101.80378350125
318.340	1473.000	-979.11627	1100.48186	-979.11626979844,1100.48186273831
319.750	1437.250	-928.64169	1096.95587	-928.64168974185,1096.95586719494
321.200	1409.500	-883.198072	1098.47686	-883.198072118208,1098.47686157091
322.590	1377.000	-836.547442	1093.76294	-836.547441685446,1093.76294406491
324.030	1352.250	-794.259685	1094.40925	-794.259684968659,1094.40925404233
325.450	1329.000	-753.7094	1094.60639	-753.709400015585,1094.60638602566
326.830	1300.500	-711.536088	1088.5847	-711.536088098778,1088.58469828171
328.280	1276.750	-671.27507	1086.03883	-671.275070463318,1086.03883092386
329.730	1256.250	-633.244824	1084.97238	-633.244824040101,1084.97237537479
331.080	1231.750	-595.659456	1078.14557	-595.659455657456,1078.14557244644
332.590	1214.500	-559.100821	1078.15422	-559.100820544488,1078.15422016819
333.980	1200.000	-526.42183	1078.36917	-526.421830060456,1078.36916537696
335.360	1185.250	-494.149046	1077.32738	-494.149045782572,1077.32737970042
336.800	1169.500	-460.715063	1074.92878	-460.715063266617,1074.928779259
338.130	1156.250	-430.705342	1073.03633	-430.70534215927,1073.03633243962
339.580	1144.250	-399.227909	1072.34562	-399.227908700246,1072.3456249805
341.000	1132.250	-368.624543	1070.56341	-368.624542884116,1070.56340722233
342.440	1121.500	-338.361445	1069.23982	-338.361444783053,1069.23981532878
343.830	1110.250	-309.19159	1066.3281	-309.191589799751,1066.32810302322

Figure 58 – Point Cloud data bathroom of flat in excel using ultra grabber software collected by RP Lidar 360 Robot Laser Scanner

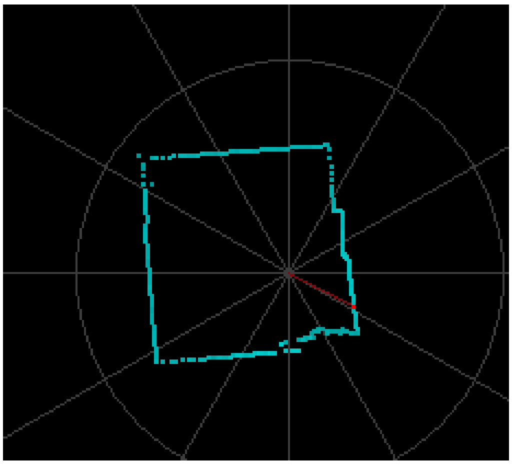


Figure 59 – Point Cloud of bathroom of flat using frame grabber software collected by RPLidar 360 Robot Laser Scanner

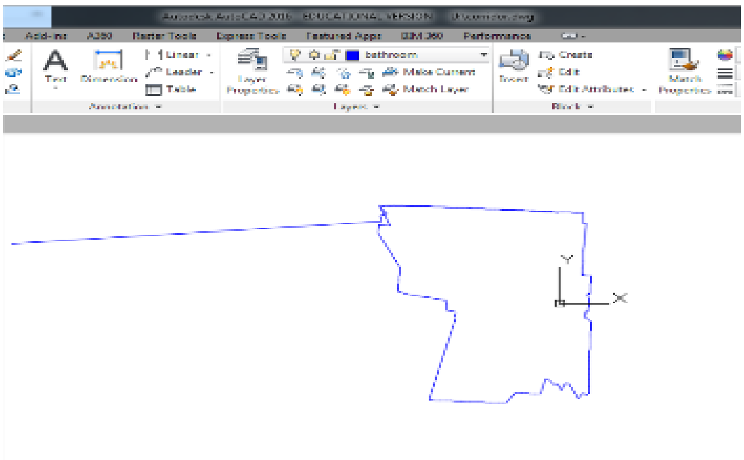
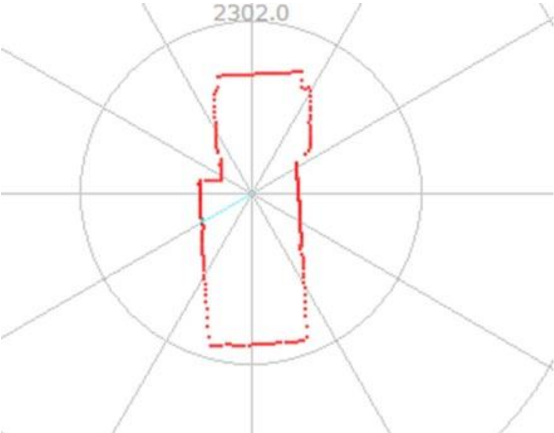


Figure 60 – original 2D AutoCAD model bathroom of flat using point cloud data from excel using collected by RP Lidar 360 Robot Laser Scanner



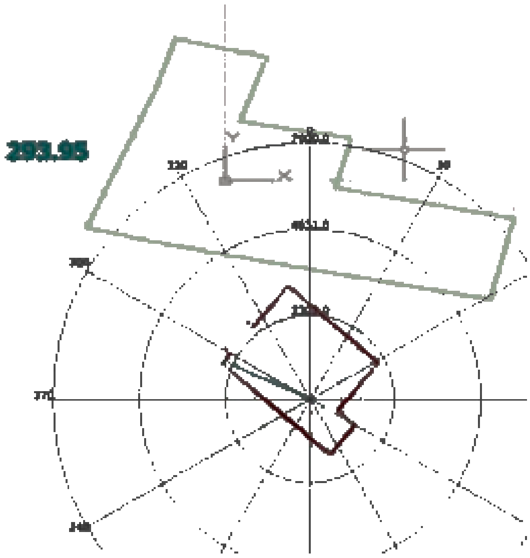
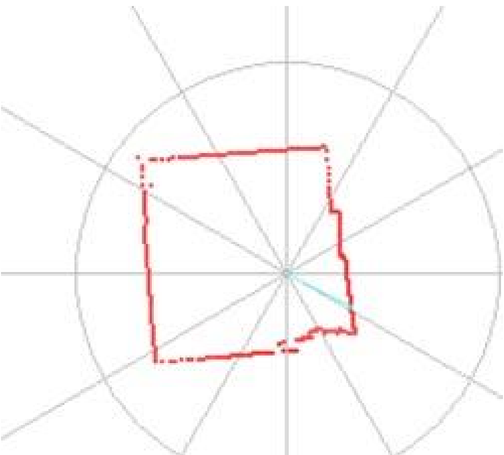


Figure 61 – Point Cloud of corridor and bedroom



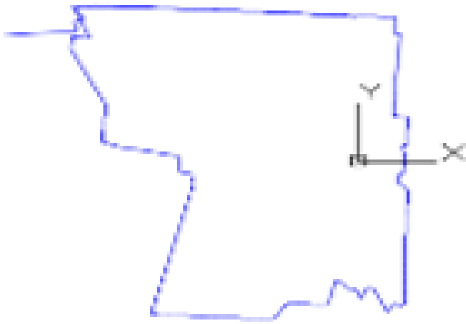


Figure 62 – Point Cloud of bathroom of flat using frame grabber software suggesting an inherent error in the data collection process

According the level of detail specification, for fewer and basic details (G1 (see Figure 1)) for a model, the robot laser scanning is one option. From the scans taken of the University buildings stairs and flat using the Leica system (see Figures 40-57 above), it became clear the data created from the details was not complex and not large for efficient handling and analysis, and not required high specification computers with details below and complex software when compared to using a laser scanner.

Therefore, both the equipment and the software are cheaper, easy to obtain, less time taken and much less stringent health and safety requirements need to be in place and less training required. By using this process for the initial survey for small buildings is not expensive due to the amount of time taken for a person to take measurements with robot laser scanner.

However, there are still issues which tend to limit the use of this technology:

1. The main problem is what it produces is only 2D then it needed append more time on it to convert to 3D with data.

2. The robot laser scanner does not correspond to the actual finished floor plan when putted on floor where the room is not clear with staff so it needs to hold it up to make it useful as the robot will scan staff on floor (see Figure56). to give a good definition of the fixed features, such as the walls
3. Targets need to be considered and included so that the outlines can be linked together to form a complete model of the building in question.
4. Other features not caught by the laser will need to be added manually. Although this is common with any laser scanning, and also where objects create areas of shadow as the room was not clear and objects were on the way of RPLidar 360 Robot Laser Scanner in time of scanning the room the need editing the point cloud data collected by RPLidar 360 Robot Laser Scanner using Auto CAD.

Analysis:

Laser Scanning:

According the LOD specification if we do look at the more precise details of our project the laser scanning is the best option as it scanned the buildings in too much details and it is very persistent compare to other technology and techniques available for getting information for existing buildings.

Using these models created using recap software, can be used in cloud to access, manage and share the information by using Autodesk 360 which can also used in smart phones and tablets which can help maintenance people to save time of going to site and office as they can get information from recap models.

The Barriers of using this technique are as follows:

1. It is very expensive and also the software which come with it cyclone is very expensive too
2. Take time for laser the big buildings
3. Take time also to connect point clouds
4. There is too much amount of data which requires huge memory (needs advanced computers)
5. Too complex
6. It requires another set of software to create the models which also need to pay for it
7. Training issues

Leica Laser Scanner and Cyclone:

A Leica ScanStation2 was used to scan the East Building Atrium (internal) and Halls of Residence (external) at the Docklands Campus of the University of East London (UEL). 3D models created using Leica Cyclone and Autodesk Recap software.

Faro Laser Scanner and Recap software:

A Faro laser scanner was used to scan south side of UEL Knowledge Dock in front of library and Library Stairs of UEL and then 3D models created using Cyclone and Recap software.

Some surveyors are producing laser scanned models of buildings but these tend to be very expensive, the point cloud produced is huge (many gigabytes) and unwieldy requiring top of the range computing to deal with it and laser scanners are heavy.

The area should have restricted access during the scanning, due to the health and safety issue of using lasers in public areas and getting better results which can save time in analysis.

This research used two different laser scanners with different software which mentioned in the table 1, because they are different in cost, time taken of collecting data and weight and also each of the laser scanner used different software which are different in cost, time taken of analysing data and training cost. The differences of costs benefit analysis of each laser scanner can be seen in the table below:

Survey Method, equipment and cost	**Software cost and training cost**	**Level of Details (see Figure1)**
Leica Scan Station 2 Cost when new: Approx. £45,000+.	Cyclone (from Approx. £15,000 per licence and basic training Approx. £2395 per person)	G3
Faro Laser scanner Cost when new: Approx. £40,000	Recap annually cost Approx. £1595	G3

Table3: Costs of different laser scanners and software

RPLidar 360 Robot Laser Scanner

RP Lidar is a 360 robot laser scanner which is very cheap, costing about £290. It is light weight and it can scan a room in just few moments, although restricted to 2D. The software which needed for working with this scanner can be downloaded for free.

Frame-grabber and Ultra-grabber software

RP Lidar Robot laser scanner was used to scan the flat and UEL's library stairs and 2D models created using 'frame-grabber' and 'ultra-grabber' software.

The Frame-grabber software gave an Figure of the area scanned and coordinates of each point can be visible on the Figure, while 'ultra-grabber' extracted the co-ordinates in a text file for editing and transferring to AutoCAD and Revit to create a 2D plan or a 3D model which it depends on the amount of data actually captured not the software used. It was a very quick and easy to use method for just a floor plan. However, the full process of creating models in 3D in this field can be long because it is a long process starting from collecting survey data by using the RP Lidar robot with using frame grabber software and creating 2D AutoCAD model using collected data and then convert 2D to 3D models in Revit which depends on the amount of data actually captured not the software used and adding the extra information required such as services.

Survey Method, equipment and cost	Software and Costs	Level of Details (see Figure 1)
RPLidar 360 Robot Laser Scanner	Frame-grabber and Ultra-grabber software is free to download and easy to use	*G1* *G1*
Approx £290	AutoCAD Approx. £118.80 rental for 3 months Revit Approx £1,575.00/ per year	*G3* (which depends on the amount of data actually captured not the software used)

Table4: Costs of different software and RPLidar 360 Robot Laser Scanner

Disto and Tapes:

A small apartment measured by using a Disto and tapes which provided a data survey set and used to help become familiar with the software (Revit) and produce a Revit 3D model which depends on the amount of data actually captured not the software used. Also, 2D models created in AutoCAD.

Survey Method, equipment and costs	**Software and Costs**	**Level of Details**
Tapes from £1 Leica Disto from Approx. £80 (hand-held laser single measurement device)	AutoCAD **(**approx £118.80 rental for 3 months) Revit Approx £1,800 per year	G1 G3 (which depends on the amount of data actually captured not the software used)

Table5: Costs of tapes/Disto and different software

Existing Drawings:

3D models of Pantile Avenue A and B of Southend houses created in Revit and to enable a comparison of using Revit and AutoCAD to produce models.

Survey Method	Software and costs		Level of Details
From existing CAD drawings (PDF versions, non-editable)	Revit	Approx £1,575.00/ per year	G3(which depends on the amount of data actually captured not the software used)

Table6: Cost of software

Photogrammetry:

Camera:

90 photos were taken to create a 3D model of a room using a cannon camera sx210 IS pc1468 14.1mega pixels, although only 68 were suitable to be used for processing using Bentley Context Capture. Again the same 90 photos were used to create a 3D model of a room using a cannon camera sx210 IS pc1468 14.1mega pixels although only 83 were suitable to be used for processing using Recap 360. These techniques can be extended to model a whole flat which require more photos so it can takes more time as there are more rooms so it needs more photo to be taken to create the 3D model. This software is accessed through ‘the cloud’ so can be easily used and view anywhere there is an internet connection using cloud service such as Autodesk 360.

Survey Method, equipment and cost	Software cost and training cost	Level of Details
Cannon camera sx210 IS pc1468 14.1mega pixels	Bentley Context Capture, Approx £26453 for permanent licence	G3
	Recap 360 , Approx £30 per month/ easy to use	G3

Table7: Costs of different equipment and software for photogrammetry using camera

IPad:

20 photos were taken using an iPad4 of a small subject from different angles then Autodesk Recap 360 software was used to create 3D model. This software is accessed through 'the cloud' so can be easily used anywhere there is an internet connection.

Survey Method, equipment and cost	Software cost and training cost	Level of Details
IPad	Recap 360 software, Approx £30 / per month/ easy to use	G3

Table8: Cost of different equipment and software for photogrammetry using IPad

As all the models above were dependent upon the level of detail within the BIM, the various survey techniques of measuring buildings assessed to determine which is the most suitable for existing buildings.

Buildings were measured to provide data for this project, each by a different survey technique, to assess the efficiency and effectiveness of each method and techniques must keep the same building to measure using all techniques, which means several surveys of the same place. Only then can it be see which method is best. This is the key item to a comparative study like this.

Moreover, various software packages were also used to process the data in order to consider the merits and disadvantages of each. Factors such as the complexity of the equipment, the relative time taken, the ease of use, necessity for training, level of detail and therefore cost were all studied.

Tables of Comparison Stairs:

Survey Method and equipment	**Time Taken**	**Software cost and training cost**	**Time Taken**	**Level of Details (see Figure1)**
Leica Laser Scanner C10, Approx: £ 37834	1hour 30 min	Cyclone (from Approx. £60000 per licence and basic training Approx. £2395 per person)	1 hour	G3
Faro Laser scanner, Approx: £40000	1hour 30 min	Recap, annually cost Approx. £1595	1.30 min	G3
RPLidar 360 Robot Laser Scanner, Approx £290		Frame-grabber software free to download and easy to use	5 min	G1
		Ultra-grabber software free to download and easy to use	5 min	G1
Tapes from £1 and Disto from Approx. £80 (hand-held laser single measurement device)	20 min	Revit, Approx £1,800 per year	45 min	G3

Table 9: Table of comparison for stairs

Flat:

Survey Method and equipment	Time Taken	Software cost and training cost	Time Taken	Level of Details (see Figure1)
RPLidar 360 Robot Laser Scanner, Approx. £290		Frame-grabber software free to download and easy to use	5 min	G1
		Ultra-grabber software free to download and easy to use	5 min	G1
		AutoCAD Approx. £118.80 rental for 3 months	15 min	G1
		Revit, Approx. £1,575.00/ per year	45 min	G3 (which depends on the amount of data actually captured not the software used)
Tapes from £1 and Disto from Approx. £80 (hand-held laser single measurement device)	20 min	Revit, Approx. £1,800 per year	45 min	G1
		AutoCAD, Approx. £118.80 rental for 3 months	45 min	G3 (which depends on the amount of data actually captured not the

				software used)
Cannon camera sx210 IS pc1468 14.1mega pixels Approx £200	5 min	Bentley Context Capture, Approx £26453 for permanent licence	15 min	G1
		Recap 360, Approx £30 per month	15 min	G3

Table 10: Table of comparison for flat

Discussion:

The idea of this research project is to find ways of overcoming some of these barriers. Various survey techniques were employed to survey small residential and parts of other buildings in an effort to investigate simpler, easier methods of data collection. Different software packages were also used to process the data in order to consider the merits and disadvantages of each. Factors such as the complexity of the equipment, the relative time taken, the ease of use, necessity for training, level of detail and therefore cost were all studied. This study will be able to suggest an easy, inexpensive and optimum survey method for the data collection for the digital modelling of small existing residential buildings, without losing the quality of the data required; that is up to the standards as laid down by the various bodies.

As the result, by using the comparison of the different survey techniques in this research and has agreed that laser-scanning, while an excellent method of collecting and analysing data with high level of details, is inappropriate for creating BIM models for maintenance and for facility management, due to the sheer expense, time taken, amounts of data and specialist software. It is suggested that recent developments in photogrammetry could be the answer for best model if the low level of LOD needed by facility management for maintenance but if facility management require higher LOD like G3 then the robot scanner can be used which is a lot cheaper than laser scanning and take less time.

The use of BIM and related technology is still in its infancy and its uses are just becoming apparent. So far, concentration has been on new build but there is a gap when it comes to existing buildings, especially regarding their facilities management and maintenance. Furthermore, new devices and technologies for collecting survey data for use in a BIM are appearing all the time.

It is envisaged that this research will be able to assess the data collected by the different methods, and analyse it using a BIM, to determine information as to the cost implications of maintenance. It is hoped to provide recommendations as to how much technology can be applied to help with facilities management of existing buildings.

Through discussions at the facility management (FM) Conference 2015 (Excel), it seems apparent that there has been very little research being carried out in applying BIM for existing buildings and then only for large corporate buildings, not small domestic properties. Using BIM for new buildings is well documented, as most of the processes are built into the overall plan from the start of the design phase. For existing buildings, there is a lack of interest, maybe caused by certain barriers perceived by those who would be using the technology for small residential refurbishments. These barriers include the cost and time of creating the digital model to start with. The costs of the technology and the necessary training are also seen as barriers, as is the issue of having too much data requiring high spec (expensive) computers.

At a presentation given by Bentley/CrossRail (2015), it was pointed out that the biggest barrier to adoption of BIM were the scepticisms of the people themselves. People in general do not like change. The costs of the technology and the necessary training are enough to put people off.

Without the necessary ‘buy-in’ from the users, setting standards is purely academic, with no perceived advantages being obvious. Nowadays, for new buildings, the use of BIM will make it possible for the process to become accepted by the construction industry, as the base model will set up from the start. Large existing corporate buildings can be modelled to some extent using a laser scanner, but for small existing residential buildings, such models are not that easy to create, and such a task, and the expense incurred, is putting off clients from adopting the BIM process. Some surveyors are producing laser scanned models of buildings but these tend to be very expensive, the point cloud produced is huge (many gigabytes) and unwieldy and requires top of the range computing to deal with it and restricting their usefulness to large corporate buildings as they have enough finance to deal with it.

Therefore, it is this Level of Detail (LOD) which needs to be specified and incorporated into any guidelines for using BIM. The Government has risen to the challenge and through their BIM Task Force have produced a set of Publicly Available Standards/British Standards (PAS/BS 1192) to give guidance to designers so that models can be easily exchanged between the stakeholders. Unfortunately, the guidelines produced are for new buildings being constructed from nothing, so that the metadata at the correct Level of Detail (LOD) can be added to the model from the start.

All the attempts at creating formats for data exchange, such as COBie, do not have the facility to incorporate data from existing surveys, whether they be topographical or measured building surveys – the BIM can only start when the architect starts.

BIM cannot be adopted overnight. The process has to be developed slowly, almost drip-fed, like Health and Safety, Word Processing and GIS were back in the 1980s, to become used as everyday tools, taking 25 years to reach the current level of acceptance.

Recent innovations in mobile technology, with many 'apps' becoming available might be able to speed up the process of adoption, as 'people' are more likely to 'play' and learn 'by trial and error' in their own time rather than expensive. Structured training courses, thus becoming 'au fait' with the technology at their own pace.

The increased use of 'the cloud' is a key element of BIM level 3, the proposed new set of standards for 2020 and beyond (BSI 2015). Using 'the cloud' as a central storage device has opened up opportunities in sharing data thus reducing, maybe even eliminating, the problems caused by some parties using out-of-date data from old drawings, as has been often the case in construction over the years. Maintenance work is still taking too much time, with too much risk, at too much cost, and often does not meet customer expectations. It is time for a fundamental overhaul of the facilities industry to optimize the use of digitally based information. Building Information Modelling (BIM) provides an opportunity to change business processes. BIM implies a team approach to developing facilities which means that Standards must be in place before collaboration can take place – all members of the team must be able to access the same data sets.

Model Cost can vary depending upon level of details and output required, so some modelling may be done in high details and quality to create good data and these models will cost more as they take more time.

These models also can be useful and advantage for building users as they can help with occupying and using building efficiently, improved maintenance and energy consumption.

New buildings have the advantage that a 3d virtual model exists, having been developed during the design and construction phases, but for existing buildings, surveys need to be carried out and a 3d model developed. Such techniques have seen exciting results where large corporations have had the finance to commission such a survey, but are proving too expensive for small exiting residential properties, especially those managed by local authorities and housing associations.

Some less expensive survey techniques have been tried and tested and compared to the traditional expensive techniques, such as laser scanning. Virtual 3D models of small houses and flats have been 'built' and examined to see their potential in the field of maintenance. Levels of details have also been discussed. So All methods/techniques and software in this research were chosen and carried out in relation to various reasons which are to assess the quality of each of the techniques in relation to the effectiveness of the data obtained to find an easy, inexpensive and optimum survey method for data collection and compilation of the digital model.

The findings which arising from table of compression of each tourniquet in this project should prove beneficial in producing adequate models for use in maintenance at an attractive cost, with minimum outlay and training.

Conclusions:

The different survey techniques used in collecting data for creating 3D models of small existing residential buildings for housing associations investigated to determine usefulness and cost effectiveness and therefore inform the FM industry. As these models will be dependent upon the level of detail within the BIM because one major difference with a BIM of existing buildings with new developments is that there are issues with level of detail and metadata input, the various survey techniques of measuring buildings using different software will also need to be assessed to determine which is the most suitable for such schemes. It is hoped to provide recommendations as to how technology can be applied to help with the facilities management of existing buildings, and the guidelines arising from the work should prove beneficial in producing adequate models for use in maintenance at an attractive cost, with minimum outlay and training.

This research has focused on the different levels of BIM for maintenance of small existing residential buildings in order to understand how the requirements of using BIM for maintenance differ from BIM for Design. The issues with Level of Detail (LOD) and metadata input for existing buildings when compared with new developments have highlighted the inadequacies of the published standards.

This research is evaluating the use of BIM as a tool for use for small existing residential buildings. The current standards, processes and recent advances in BIM have been reviewed to see if they can be applied to small existing buildings. Models are being developed to see how easy the information can be accessed.

New developments in Cloud technology also seem to provide opportunities for improved sharing of the model and related data, which may have a significant impact on the whole BIM process. Coupled with mobile and touch screen devices, which are now common in everyday use, this technology is the key in a successful acceptance of BIM for small existing residential buildings because Autodesk 360 and Revit viewer, etc with information can be access through mobile and can be edited and make comment and share.

As the models are dependent upon the level of detail within BIM, the various survey techniques of measuring buildings are being assessed to determine which is the most suitable for such schemes and if they meet the standards as set out in the Government's 'level 2'. This project looks at level 2 BIM through different levels of detail, various 3D models to the required standards and by selecting the most appropriate techniques used to collect and model the data, the effective sharing of the data over the various platforms and, of course, the costs, time, measurements and the techniques of capturing data involved.

It has been shown in the previous studies that BIM can help save time, resulting in more effective maintenance. The information is more readily available and being 'on computer' is easy to transfer. Therefore, arranging repairs or ordering replacement parts is much more efficient. Such information is just as useful for reactive repairs as well as organising schedules for preventative maintenance.

There are still many perceived barriers preventing industry wide acceptance of BIM, mainly due to the cost of producing the initial 3D model. Hopefully, the methods of data collection as discussed above may go some way in helping to minimise the costs and the barriers. Certainly, it is always difficult to make changes to established processes, even if they are more efficient. Perhaps if the training is kept to a minimum to start with, then the process may become accessible to more people. To achieve this, less complex software is needed with clear guidelines, which are accessible to everyone involved.

The aim of my project is to see if these developments can be used to break down these perceived barriers to make the process more attractive to small existing residential building so that the BIM process can be introduced to a sector which has so far ignored it for small existing residential building.

Another aspect considered is the perceived need for all digital modules to be 3D – is so much detail really needed? Would a 2D plan suffice provided it had the metadata added to it? This is where the RP Lidar 360 Robot Laser Scanner came in, a quick, low-cost 2D laser scanner producing quick easy to handle floor plans.

Therefore, this project will provide alternatives for the creation of a BIM for an existing small building (to meet the Government's mandate), to clarify that what should be included in the BIM level 2 standards for data collection of existing buildings and how BIM can be used for maintenance management.

Limitation:

- People disturbance during collection of data using laser scanner
- Too much data (coordinates) and point clouds when using laser scanner
- Data collected using Robot 360 needing editing as there was furniture in the room so it should clear before collecting data

Future Work:

Saving and accessing data to and from ‘the Cloud’ needs to be investigated, as does its use with mobile devices. The ‘internet of things’ where linked sensors are incorporated into the model for external control is also of interest.

Thermal Figures need to be incorporated into the 3D models to aid interpretation.

The models can also be useful from a sustainability viewpoint as one advantage for the building users is the management of energy levels, temperature, heating, lighting and many other aspects of the environmental control.

References:

10. Abmayr, T., Hortl, F., Reinkoster, M. and Frohlich, C. (2005) 'Terrestrial laser scanning applications in cultural heritage conservation and civil engineering. International Archives of the Photogrammetry', *Remote Sensing and Spatial Information Sciences* 36 (Part 5/W17) (*on CD-ROM).*

11. Allen, P.K., Troccoli, A., Smith, B., Murray, S., Stamos, I. and Leordeanu, M. (2003) 'New methods for digital modelling of historic sites', *IEEE Computer Graphics and Applications* 23 (6), 32–41.

12. Anumba, C. and Wang, X. (2012) 'Mobile and Pervasive Computing in Construction'*, John Wiley & Sons*. Available at: http://onlinelibrary.wiley.com/book/10.1002/9781118422281

13. Arayici, Y. (2007) 'An approach for real world data modelling with the 3D terrestrial laser scanner for built environment', *Automation in Construction*, *16* (6), 816-829.

14. Arayici, Y, Onyenobi, TC and Egbu, CO. (2012) 'Building information modelling (BIM) for facilities management (FM): The MediaCity case study approach', *International Journal of 3D Information Modelling*, **1** (1), pp. 55-73.

15. Aranda mena, G., Crawford, J., Chevez, A. and Froese, T. (2009) 'Building information modelling demystified: does it make business sense to adopt BIM?' *International Journal of Managing Projects in Business,* 2 (3), pp. 419-434.

16. Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. and O'reilly, K. (2011) ' BIM adoption and implementation for architectural practices', *Structural Survey,* 29 (1), pp. 7-25

17. Arayici, Y. (2008) 'Towards building information modelling for existing structures', *Structural Survey,* 26 (3), pp. 210-222.

18. Atkins B. and Brooks A. (2015) 'Total Facility Management', fourth edition, Wiley-Blackwell 2015, p48

19. Atrick, R. Munir, M. and Jeffrey, H. (2012) ‘Building Information Modeling (BIM), Utilized During the Design and Construction Phase of a Project Has the Potential to Create a Valuable Asset in Its Own Right ('BIMASSET') at Handover that in Turn Enhances the Value of the Development’, *Energy Systems Laboratory* and *Texas A&M University,* ESL-IC-12-10-20

20. Autodesk. (2013) ‘Revit’, Available at: www.autodesk.com’. (Accessed 10.01.15).

21. Azhar, S. Khalfan, M. and Maqsood, T. (2012) ‘Building information modelling (BIM): now and beyond’, *Australasian Journal of Construction Economics and Building*, 12 (4), pp. 15-28

22. Bakker, J. D., Van Der Graaf, H. J., & Van Noortwijk, J. M. (1999) ‘Model of lifetime-extending maintenance’, *In Proceedings of the 8th international conference on structural faults and repair, London, United Kingdom*.

23. Bentley. (2011) ‘Bentley Engineering’, Available at: www.bentley.com. (Accessed 10.01.15).

24. Bergin, M. (2012) ‘A brief history of BIM’, [Online], Available at: http://www.archdaily.com/302490/a-brief-history-of-bim/

25. Bert, R. (2008) ‘BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors’, *Civil Engineering,* 78 (7), pp. 78.

26. BIM Task Group, (2012) ‘COBie UK 2012’, Available at: http://www.bimtaskgroup.org/cobie-uk-2012/, (accessed on 4/4/2015)

27. BIM Task Group, (2016a) ‘white papers’, (accessed on: 23/7/2016)

28. BIM Task Group, (2016b) ‘resources’, available at: http://www.bimtaskgroup.org/resources/, (accessed on: 23/7/2016)

29. Boeykens, S., Santana Quintero, M. and Neuckermans, H., (2008) ‘Improving architectural design analysis using 3D modelling and visualization techniques’, *In: Ioannides*.

30. Bryde, D. Broquetas, M. and Volm, J. (2013) ‘The project benefits of Building Information Modelling (BIM)’, *International Journal of Project Management,* 31 (7), pp. 971.

31. BSI (2013) 'ISO 16739:2013: Industry Foundation Classes (IFC) for data sharing in the construction and facilities management industries', BSI, 2013.

32. BSI (2014) 'PAS 1192-3:2014 Specification for information management for the operational phase of assets using building information modelling', available at: http://shop.bsigroup.com/forms/PASs/PAS-1192-3/, (accessed on 7/4/2014).

33. BSI (2015) 'Bis-15-155-digital-built-britain-level-3-strategy', available at http://shop.bsigroup.com/forms/ Bis-15-155/ , (accessed on 7/12/2015).

34. Bucher, C. and Frangopol, D. M. (2006) 'Optimization of lifetime maintenance strategies for deteriorating structures considering probabilities of violating safety, condition, and cost thresholds', *Probabilistic engineering mechanics*, *21* (1), pp. 1-8.

35. Building smart (2015) 'building smart tech' Available at: http://www.buildingsmart-tech.org/specifications/ifc-overview

36. Campbell, D T & Stanley, J C. (1966) 'Experimental and quasi experimental designs for research', *Skokie: Rand-McNally*

37. Cheng, X.J. and Jin, W.S. (2006) 'Study on reverse engineering of historical architecture based on 3D laser scanner', *Institute of Physics Publishing International*

38. Chevrier, C., Maillard, Y. and Perrin, J.P. (2009) 'a method for the 3D modelling of historic monuments: the case of a gothic abbey. In: International Archives of Photogrammetry', *Remote Sensing and Spatial Information Sciences 38* (Part 5/W1), (On CDROM).

39. Clarke A (1999) 'Evaluation Research: An Introduction to Principles, Methods & Practice', *Sage.*

40. Davidson, E J. (2005) '*Evaluation Methodology Basics:* Sage.

41. DeLacey, M. (2012) 'Why BIM will become even more important in 2012', *Engineering News Record*. Available at: http://enr.construction.com/technology/bim/2012/0111-why-bim-will-become-even-more-important-in-2012.asp

42. dotproduct3d (2016) 'We make tablets see the world in 3D', available from : http://www.dotproduct3d.com/ , accessed 29/08/16

43. Eastman, C. (2007) ‘BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors’*, first ed. Wiley, NewJersey.*

44. elkay, (2015) ‘elkayusa sink’, available at: http://www.elkay.com/, (accessed on: 30/11/2015)

45. English Heritage. (2011) ‘3D Laser Scanning for Heritage (second edition): Advice and guidance to users on laser scanning in archaeology and architecture. Edited and brought to press by David M’. Jones. *Swindon, UK: English Heritage Publishing*, 2011.

46. FARO. Faro Focus3D Features, Benefits & Technical Specifications. Available at: FARO: www2.faro.com/site/resources/share/944 (http://www.smartgeometrics.com/laser-scanning-software/leica-cyclone-suite/leica-cyclone-hardware-and-system-requirements/) (accessed on: 22 April 2014.)

47. FLIR (2016) ‘Turn your Smart Phone into a Brilliant Phone’, available at : http://www.flir.co.uk/flirone/ios-android/ , accessed 29/08/16

48. Frangopol, D. M. (2002) ‘Reliability deterioration and lifetime maintenance cost optimization’, In *Keynote lecture in proceedings of the first international ASRANet colloquium on integrating structural reliability analysis with advanced structural analysis*.

49. Frangopol, D.M. and Furuta, H. eds. (2001) ‘Life-Cycle Cost Analysis and Design of Civil *Infrastructure Systems,* ASCE, Reston, Virginia, 336 pages.

50. Gliner, J.A, Morgan, G.A. & Leech, N. (2009) ‘Research methods in applied settings’, *London:Routledge*.

51. Golparvar-Fard, M. Bohn, J. Teizer, J. Savarese, S. and Pena-Mora, F. (2011) ‘Evaluation of Figure-based modeling and laser scanning accuracy for emerging automated performance monitoring techniques’, *Automation in Construction*, *20* (8), 1143-1155.

52. Graphisoft. (2011) ‘ArchiCAD’, available at: http://www.graphisoft.com/’ (accessed on: 10.07.15).

53. Guidi, G., Frischer, B. and Lucenti, I. (2007) ‘Rome Reborn – Virtualising the ancient imperial Rome. In: International Archives of the Photogrammetry’, *Remote Sensing and Spatial Information Sciences* 36 (Part 5/W47), (on CD-ROM).

54. Hichri, N. Stefani, C. De Luca, L. Veron, P. and Hamon, G. (2013) ‘from point cloud to bim: a survey of existing approaches’, *int. arch. Photogram. Remote Sens. Spatial Inf*. Sci., XL-5/W2, 343-348, doi: 10.5194/isprsarchives-XL-5-W2-343-2013.

55. HM Government (2015), ‘Digital Built Britain - Level 3 Building Information Modelling - Strategic Plan’ p.32, available from : https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/410096/bis-15-155-digital-built-britain-level-3-strategy.pdf, accessed 29/08/16

56. Ibrahim, M. and Krawczyk, R. (2004) ‘The level of knowledge of cad objects within the building information model’, *CAADRIA 2004 Conference, Seoul, South Korea,* pp.73–177.

57. Ifma. (2013) BIM for Facility Managers*. John Wiley & Sons Inc* . Available at: https://www.dawsonera.com/abstract/9781118420676

58. Jacobs, G.L. (2000) ‘New large-scale 3D laser scanning, modelling & visualization technology provides advanced capabilities for scene reconstruction & interpretation’, *Proceedings of SPIE* 3905, 92–101.

59. Jim, B., Yong K, C. and Li, H. (2010) ‘Expanding BIM to Meet the Grand Challenges in Buildings – What is needed?’ *HVAC&R Research*, 16 (5), pp543.

60. Khosrowshahi, F. and Arayici, Y. (2012) ‘Roadmap for implementation of BIM in the UK construction industry’, *Engineering, Construction and Architectural Management,* 19 (6), pp. 610-635.

61. Kong, J. S. and Frangopol, D. M. (2003) ‘Life-cycle reliability-based maintenance cost optimization of deteriorating structures with emphasis on bridges’, *Journal of Structural Engineering*, *129* (6), pp. 818-828.

62. Leica Geosystems (2016). Leica Pegasus:Two, http://www.leica-geosystems.co.uk/en/Leica-PegasusTwo_105371.htm accessed 29/08/2016.

63. Maurice, M. Eugene, M. and S. Pavía (2009) 'Historic building information modelling (HBIM)', *article in structural survey,* Available at: http://www.researchgate.net/publication/241582141

64. McAdam, B. (2010) 'Building information modelling: the UK legal context', *International Journal of Law in the Built Environment,* 2 (3), pp. 246-259

65. McPhee, A. (2013) 'What is this thing called BIM?' Practical BIM. Available at: http://practicalbim.blogspot.co.uk/2013/03/what-is-this-thing-called-Level of Detail .html (Accessed on: 5/3/2013).

66. Murphy, M. McGovern, E. and Pavia, S. (2009) 'Historic building information modelling (HBIM)', *Structural Survey*, 27 (4), pp.311 – 327.

67. Murphy, M. (2013) 'ISPRS Journal of Photogrammetry and Remote Sensing 76' 89–102 101

68. Muller, P., Wonka, P., Haegler, S., Ulmer, A. and Van Gool, L. (2006) 'Procedural modelling of buildings', *ACM Transactions on Graphics* 25 (3), 614–623.

69. NIST. (2004) 'Cosy analysis of inadequate interoperability in the U.S capital and facilities industry', [Online], Available at: http://fire.nist.gov/bfrlpubs/build04/art022.html

70. Neves, L.C. and Frangopol, D.M. (2002) 'Lifetime maintenance cost models for deteriorating structures', in progress

71. Okasha, N. M., & Frangopol, D. M. (2009) 'Lifetime-oriented multi-objective optimization of structural maintenance considering system reliability redundancy and life-cycle cost using GA', *Structural Safety*, *31* (6), pp. 460-474.

72. Oluwole, A.O. (2011) 'Modelling the costs of corporate implementation of building information modelling', *Journal of Financial Management of Property and Construction,* 16 (3), pp. 211-231

73. Pektas, S.T. (2009) 'Building Information Modelling Technology in Architecture', *Mimarlik Dergisi,* (346), pp. 81-84

74. RP Lidar Robot laser scanner. (2016). ‘RP Lidar Robot laser scanner ‘ Available at: http://www.robotshop.com/uk/rplidar-360-laser-scanner.html (accessed on: 20/04/2016)

75. Ruwanpura, j., Hewage, K. and Silva, L. (2012) ‘Evolution of the I-Booth© onsite information management kiosk’, *Automation in Construction*, 21, pp. 52-63.

76. Sebastian, R. (2011) ‘Changing roles of the clients, architects and contractors through BIM’, *Engineering, Construction and Architectural Management,* 18 (2), pp. 176-187

77. Smart geo metrics. (2013). ‘Smart geo metrics’, Available at: http://www.smartgeometrics.com/laser-scanning-software/leica-cyclone-suite/leica-cyclone-hardware-and-system-requirements/

78. Solibri. (2016) ‘Solibri’, Available at: https://www.solibri.com/products/solibri-model-viewer/ (accessed on: 21/07/2016)

79. Suermann, P. (2009) ‘Evaluating the impact of Building Information Modelling (BIM) on construction’, *7th International Conference on Construction Applications of Virtual Reality,* PP.1-234

80. Symposium on Instrumentation Science and Technology. Journal of Physics: Conference Series 48 (1), 843–849.

81. Tekla Bimsight. (2016) ‘Tekla Bimsight’, Available at: https://www.teklabimsight.com/. (accessed on: 22/07/2016)

82. Tse, T.K., Wong, K.A. and Wong, K.F. (2005) ‘the utilisation of building information models in modelling: a study of data interfacing and adoption barriers. Journal of Information Technology in Construction’, *ITcon 10, Special Issue From 3D to nD modelling, pp*. 85–110, Available at: <http://www.itcon.org/2005/8>, (accessed on: 20.05.15).

83. Underwood, J. and Isikdag, U. (2011) ‘Editorial: Emerging technologies for BIM 2.0’, *Construction Innovation,* 11 (3), pp. 252-258

84. Wong, A.K.D. Wong, F.K.W. and Nadeem, A. (2011) 'Government roles in implementing building information modelling systems: Comparison between Hong Kong and the United States', *Construction Innovation,* 11 (1), pp. 61-76

85. Wexler, N. (2010) 'The Powerhouse-BIM to the Future', *Modern Steel Construction Magazine*, pp. 24-27

86. Williams, R. (2013) 'utilising building information modelling for facilities management', *The Bartlett School of Graduate studies,* pp.1 – 98.

87. 3DSystems (2016) Available at: http://www.3dsystems.com/shop/isense/techspecs (accessed on: 29.08.16).

88. Definition of Facility Management (2016) Available at: (http://digitalhighstreet.blogspot.com/2012/11/top-10-definitions-of-facilities.html)

89. National BIM Standard - United States". Nationalbimstandard.org. Archived from the original on 16 October 2014. NBIMS – National BIM Standard – United States.

90. Building information management, Definition of BIM available at: https://buildinginformationmanagement.wordpress.com/2013/01/12/definition-of-bim-building-information-modeling-nibs-agc/

91. The BIM Hub, available at https://thebimhub.com

92. The BIM Plus available at: http://www.bimplus.co.uk

93. Autodesk , available at https://www.autodesk.co.uk/

Table to Appendices:

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• BS 1192:2007

• BS 7000-4:1996A

• BS 8541-1:2012

• BS 8541-2:2011

• BS 8541-3:2012

• BS 8541-4:2012

• PAS 1192-2:2013

• PAS 91:2012

To be developed:

• PAS 1192-3

• BS 119