The creation of 3D building models using laser-scanning data for BIM modelling

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Abstract. The digital 3D models of the buildings based on laser-scanning data become a vital source of data and information repository to the Architecture, Construction, Engineering and Facilities Management (AEC & FM) sectors. A major advantage of the points cloud data captured by laser-scanning technology is its ability to the representation of the details of the three-dimensional models to exemplify the as-is conditions of buildings. However, the creation process of 3D models from the dense coloured 3D points provided by laser scanners has a significant impact on the quality of that produced models including building edges, walls, doors and windows. In particular, much uncertainty still exists about the compatibilities between the points cloud data formats and software extensions for the creation of as-is Building Information Modelling (BIM) models of the buildings. This paper presents a new framework for the creation of a 3D building model by transferring laser-scanning data into BIM software, such as Autodesk Revit. In our framework, an adopted link between software extensions was established in creating an accurate 3D building model. This framework is a road map of the required steps for investing the points cloud data relevant to BIM modelling. The promising results of the new approach illustrate to extract the 3D models of the buildings can reduce time-consuming, cost and efforts in dealing with or transferring laser-scanning data into Autodesk Revit for BIM models.

Keywords: 3D BIM Modelling, Laser scanners, Point clouds, Autodesk ReCap Pro, Revit

1. Introduction

Buildings are a key component in the different sectors, such as construction, building design and management as well as urban sustainability [1]. The dimensions of the buildings and the details of their outdoor, indoor details as well as their structures became crucial requirements to design, reconstruction, maintain and promote additional levels of building life cycle. Such required details can be exploited in the form of the two and three dimensions (2D and 3D). However, presenting a building in the form of 3D as a 3D model can aid a better understanding of building geometry which in turn can lead to more accurate specifications of the enterprise or scheme requirements [2]. The production of the 3D models of the buildings can also minimise the efforts, time and cost for the geomatics works in an efficient manner [1]. To create a precision 3D model of the building, very accurate data is required. A technology, the same as a laser scanner, provides 3D data that can depict the objects in a delicate way. Laser-scanning data is high-density coloured points which are known point clouds [3]. The high level of accuracy, cost-effective and high level details of point cloud data are essential for a wide range of engineering projects and applications. Because the point cloud data can represent the three dimensions of the objects, this feature facilitates the generation of 3D building models and their
environments. The increasing attention of point cloud data resulted from it is being able to integrate with BIM tools, such as parametric build models in Autodesk Revit. Nevertheless, the main challenge faced by many users and researchers is to identify the most suitable harmonisations of data format and software (Autodesk Revit) extensions in terms of data processing and analysis. This study is devoted to proposing a general framework for dealing with the point cloud data in BIM tools, such as Autodesk Revit software. Therefore, in the following section, we mainly consider the previous studies aimed at employing laser-scanning data in generating 3D building models and analysis approaches for BIM modelling.

2. Previous work
More recent attention has focused on the provision of 3D models of the buildings for a number of applications, such as architectural design and visualisation, construction, city modelling and urban sustainability [2, 4]. A number of authors have considered the use of laser-scanning data for generating 3D models of the buildings [5-8]. The advantages of the point cloud data captured by the laser scanner have also motivated researchers and users to develop new methods for BIM modelling. For instance, Hajian H and Becerik-Gerber B [5] reviewed the consecutive stages of generating as-built BIM using 3D laser scanning technology and determined the errors and inadequacies at every step. Their investigations concentrated on the accuracy of scanned point cloud registration and the required time for 3D modelling processes. The results of the study showed the creation of 3D models starting from the scanning to the BIM modelling processes is not semantic data and there is a need for identifying a framework as a workflow for managing building’s semantic information. The required framework, as they recommended, can connect the collected data to as-built BIMs during maintenance and various operations. Another method was suggested by Mill T et al [6] presented the workflow of creating a BIM model for data management purposes. In their method, the BIM model of a building was generated based on the point cloud data collected from surveying observations including terrestrial laser scanning (TLS) combined with data collected by the total station instrument. Although the BIM model was able to outfit the interior and exterior features of the BIM model, the creation process of the BIM model from different survey data was problematic in processing in terms of deficiency of flexibility when merging different sets of point cloud data. In point cloud computing applications the merger process between tools of BIM software and data formats should be taken into account. As a result, further editing processes of data are going to consume plenty of time and effort. This, in turn, can impact on the quality and accuracy of the produced building model. With a different method, Bosché F et al [7] introduced an automated comparison method in earning value tracking and reducing the discrepancies between as-built and as-planned BIM models of pipes depending on combining two techniques: Hough transform and Scan-to-BIM. The authors claimed that their approach has the ability to improve the recognition of the objects in both the built and planned models as well as the pipe completeness according to a metric. Nonetheless, the proposed method has deficiencies in terms of the correct recognition and identification of pipes as well as the complex integration of two techniques. In addition, their method needs to further improvements that may cause increasing the processing time. Faltýnová M et al 2016 later reviewed many methods that can be possibly used for building documentation based on transferring spatial data (e.g. laser scanning data) into BIM software. Their review work was focused on laser scanning and Photogrammetry in addition to its merits and flaws to the documented building, condition of sites and level of the renovation of the covered methods. The findings showed that both photogrammetric and laser scanning methods are convenient for the construction, project and building documentation. However, in their study, authors have used both software and algorithm for generating the 3D building models or 3D construction elements so that may be very difficult to import into the Revit software for further BIM analysis.

In another recent work, Cepurnaite J et al [9] proposed a workflow method for the renovation of the existing buildings based on utilising 3D BIM models in terms of improving the assessment of energy supply, setting the architectural and structural solutions, and devising the integrated solution of different tools for data management and analysis. Unfortunately, in their method, they only mentioned the use of 3D laser scanning data and no details on how was such data integrated into the BIM environment. Another recent research presented by Adán A et al [10], a 6D-based (3D model with 3
image bands) method to process 3D dense coloured points in obtaining the small structural components in buildings, such as sockets, switches, signs, alarm devices and extinguishers on walls. The recognition of elements of buildings was detected automatically based on the fusion of the images and geometric algorithms for providing automatic BIM modelling. The method has many limitations, for instance, the position of some objects on the semantic walls of the reconstructed as-is 3D BIM model of the building was not determined as they exist on the real wall. In a new study, Sanhudo L et al [11] introduced a laser framework for the rapid and factual acquisition of the real existing building geometric data that can be used in BIM modelling. The authors modelled a BIM representation of the as-is bus station depending on employing the point clouds which were collected from scanning the station. The point cloud quality and the survey’s time and the scanning file size were tested and evaluated. However, in order to process the point cloud data (data registration and cleaning) then export it to the Autodesk Revit (as a BIM software) to create a 3D BIM model of the bus station, Leica Cyclone 9.1 was used for accomplishing that purpose. The problem is that such commercial software is not free in use for all researchers and users and this is a significant constrain to follow and adopt their work. Therefore, our current research helps to fill this knowledge gap in the scope of the study.

To date, these few studies that have investigated the association between the utilisation of the point clouds in the BIM environment are still lacking applicability in how to deal with laser scanning data by BIM software in a direct way. Moreover, the creation of 3D building models with the detailed elements of the constructions and accurate structural components for BIM modelling is technically challenging. In particular, it is an irritating issue of any project when attempting to import the different formats of the point cloud data into BIM software. Additionally, further time for delivering the engineering projects in addition to extra effort and cost will be requested when using several software extensions for processing the point cloud data to attain accurate 3D models. Hence, to mitigate these inadequacies by considering all of this evidence, it seems that further studies are required.

This paper proposes a new genuine framework to use the point cloud data in the BIM environment for creating a 3D building model. The specific aim of this work is to identify the key steps in importing the point clouds into the Autodesk Revit software (one of BIM environments) without using additional software tools or programme extensions or algorithms. There are three main parts of our contribution: (1) data collection, (2) data processing and cleaning, and (3) modelling and validating applied to the chosen case study.

The remainder of this study is presented as follows. The next section (3) is to introduce our methodology. In Section 4, the results and discussion of our approach are presented. Finally, the conclusion and suggestions for potential future works are given in Section 5.

3. Proposed approach

A summing-up view of our developed framework is demonstrated in Figure 1. Laser scanning data were used in this work. To create a 3D building model based on employing the point clouds by exporting these dense coloured points to the Autodesk Revit software for further processing and structural analysis to the created 3D BIM model. Therefore, the following subsection presents the type of datasets that were utilised and then the following steps will be detailed in the other subsequent subsections.

3.1. Laser scanning datasets

Laser scanning is a voguish form of land surveying, capable of accurately measuring and collecting data from various surfaces, features, buildings and landscapes. Laser scanners gather data about objects in the pattern of point cloud data, consisting of millions of 3D coordinates (X, Y and Z coordinates). Present-day laser scanners can collect comprehensive and precise point clouds and thereafter these collected data points can construct digital 3D models of the detection zone with point cloud processing software. Photo detectors, laser beams, receiver electronics, advanced sensors, Inertial Measurement Units (IMU), and Global Positioning Systems (GPS) are the components of laser scanners allowing this advanced technology to compute accurate coordinates of structures and their surfaces. Capturing point clouds by modern devices of laser scanning might be through Photogrammetry, such as Light Detection and Ranging (LiDAR) or terrestrial laser scanners (e.g. the devices that are placed on the
tripod or that are carried by one hand or mobile devices). The point clouds have different file formats and extensions in Table 1 depending on the type of scanners and/or data processing software.

In our current work, we used the point cloud data of a multi-level villa as free downloadable sample data from the online sampled data © Copyright - PointCab GmbH 2019. This dataset is captured by FARO Focus 3D and it is registered and presented as the coloured point clouds. However, the dataset did not clean yet and has unwanted points’ presenting much noise to the building in addition to it is not ready to be processed as a BIM modelling. Therefore, for the aforementioned features, we have chosen it for applying our new framework. Our experiment to set up the framework procedures is demonstrated in the next subsection.

3.2. A proposed framework for creating a 3D model

Our proposed steps of the new framework are detailed as shown in Figure 2. First, after searching and collecting the point cloud dataset in a suitable and specific file format, the dataset was downloaded. As previously stated, the dataset represents the multi-level villa with its landscape. The selection of this specific point cloud dataset is to meet the need of two purposes: (1) examining our developed framework of the creation of a 3D BIM model and (2) working on more than one level of the building storeys. Free downloadable, a building geometry, the dataset file format and size were set and identified as criteria for choosing the laser scanning data. These criteria might change from work to another according to the goal of that work. Second, experimental work was conducted to explore and thereafter decide the most compatible, effective and convenient software with the BIM software to import the downloaded dataset. This step is also changeable and it depends on the type of engineering projects, enterprises and work demands. In this stage, Autodesk ReCap™ Pro © 2018 Autodesk Inc. was chosen after many attempts in which we examined some available software to accomplish the task of the generation 3D building model, Table 2. It is important to mention that the reasons behind we established the framework based on using Autodesk ReCap Pro software is because there is some evidence to show that it was possible to meet all aforementioned criteria in an efficient and feasible manner. For instance and most importantly, it is able to perfectly work with Autodesk Revit (BIM software); it deals with wide variety point clouds file formats; it is easy to install (as a software version for students); it has many tools, options and functions to process the point cloud data, and last but not least, Autodesk ReCap Pro is capable of exporting the point clouds as one united file presenting 3D building geometry with two common distinct file format extensions: (.rcp) and (.rcs), as shown in Table 3. In the second step, we managed to open, modify, merge, eliminate and finally extract the 3D model in the one combined file that can be exported to Autodesk Revit for further processing 3D BIM model.

![Figure 1. The general overview of the present study](image-url)
**Table 1.** Some popular point cloud file formats with describing their details

| The most popular point cloud file format | Data storage types | The potential representation |
|-----------------------------------------|--------------------|------------------------------|
| PCD                                     | Binary             | Surface normals (lines at right angles to given lines or surfaces) which require a constant orientation |
| LAS                                     | Binary             | The ground in addition to surface structures |
| PLY                                     | ASCII\(^a\) and Binary | Surface normals, texture, colour, transparency, data confidence value and coordinates |
| E57                                     | ASCII and Binary   | Normals, scalar density and 3D geometry, texture and colour |
| OBJ                                     | ASCII and Binary   | Normals, scalar density and 3D geometry, texture and colour |
| XYZ                                     | ASCII              | 3D geometry, texture, colour and no unit standardisations |
| PCG, RCS, RCP                           | ASCII              | Surface normals, texture, colour, transparency, data confidence value and coordinates |

\(^a\) American Standard Code for Information Interchange.

Third, the next step in the framework for generating the 3D model is to employ the 3D dense coloured points within the BIM environment. This final stage involves an essential step in terms of the integration of the generated 3D model into the BIM software and the validation of our framework. Autodesk Revit student version © 2019 Autodesk Inc. is considered one of the most powerful BIM software and its environments for producing organised, reliable and detailed model-based designs. Regarding this point, Revit® was used to obtain a 3D BIM model and conducted some fundamental structural computations and analysis for evaluating the proposed framework (in Section 4). We managed to model with accuracy and precision the point clouds sample that we chose to be a 3D building providing 3D geometry to all storeys structures and construction elements. As this paper is scheduled, the following section will present the results and discussion of the present work.

4. Results and discussion

Driving accuracy and efficiency works across the project lifecycle starting with fictional designs and ending with the real construction through visualising and analysing every single element is a core of building sustainability. The digital recording of the geometry and location...
of buildings is an essential mechanism for long-term permanence [12]. Data that is remotely collected (e.g. the devices of remote sensing technology) most often aids to provide reliable information in addition to it is considered a highly vital data source that cannot replaceable [13]. In this vein, as a matter of fact, the outputs of this current research are that laser scanners (one of the remote sensing devices) provide high-quality data with a high level of details on any surveyed object.

Table 2. The evaluation of software for processing the selected datasets including: Availability – free of use; Flexibility – the ability to deal with wide range of data format; Independency – the ability to run and execute the processing without utilising other software; and lastly, Compatibility – the ability to work with Autodesk Revit (BIM modelling)

| Software            | Availability | Flexibility | Independency | Compatibility |
|---------------------|--------------|-------------|--------------|---------------|
| ArcGIS              | No           | No          | Yes          | No            |
| Point Cap           | Yes          | No          | No           | Yes           |
| Pix4D Mapper        | No           | No          | Yes          | No            |
| Edgewise            | No           | No          | No           | Yes           |
| Autodesk ReCap Pro  | Yes¹         | Yes         | Yes          | Yes           |

¹ A software student version.

Table 3. Autodesk ReCap Pro and Revit are optimised for utilising with the exclusive legal-right file formats

| Software     | Import formats                | Export formats                |
|--------------|------------------------------|------------------------------|
| Autodesk ReCap Pro | ASC, CL3, CLR, E57, FLS, FWS, ISPROJ, LAS, PCG, PTG, PTS, PTX, RDS, TXT, XYB, XYZ, ZFS, ZFPRJ, DXF, DWG | RCS, RCP, PCG, PTS, E57, DXF, DWG |
| Autodesk Revit | DNG, DWF, DWG, DXF, IFC, SAT, SKP, RCS, RCP, | DWG, DXF, DGN, ACIS SAT, ADSK, FBX, NWC, DWF, IFC |

We were capable of employing the point clouds for the BIM modelling as a reference without problems during data processing in both Autodesk ReCap Pro and Revit. In fact, no other sources of the geometry extraction are being utilised for this purpose as same as the point clouds can do. The first step of the developed framework was to determine the suitable data for creating a 3D BIM model representing a building, as shown in Figure 3. However, the chosen point clouds contain multiple storeys of the building with its landscape. To attain that detached building, the landscape, which, however, hid the building by the surrounding trees, fence and the electric poles were removed Figure 4. Figure 4 also shows the step of data processing in Autodesk ReCap Pro.

Figure 3. A sample of the selected point cloud dataset (Mulit-level villa with its landscape)
Figure 4. The procedures of point clouds processing in Autodesk ReCap Pro 2018: (a) import, open and zoom in the datasets; (b) modify and eliminate unwanted points and the landscape; (c) save the merged and complete model of as-built 3D laser scanned data

Figure 5. Open the imported file of the pre-final 3D model in Autodesk Revit 2019 by applying the centre-to-centre method after exporting it from Autodesk ReCap Pro with the file format (.rcp or .rcs)

The pre-final merged model has been exported in both extensions (.rcp) and/or (.rcs), this, in turn, facilitated the merged 3D point clouds be processed in Autodesk Revit, as seen in Figure 5. Thereafter, in the Revit environment, the 3D BIM model was created in Figure 6. In this step of the proposed framework, the creation process of the 3D building model was based on a new technique in combining the merged dataset with the created BIM model for matching and marking the axes of the building, aligning the building boundaries and edges of the walls, and the floor heights, Figure 6 and 7. The assessment step of how much the 3D BIM model matches the 3D building model captured by the point clouds was also achieved within the former procedure. The façade surface was modelled entirely utilising cloud data from the laser scanning stage. Because Revit does not automatically detect the best fit for the façade surface position, the modeller manually selected the position. As a result, it can be very strenuous to manually pick the right position for the surface, particularly if the surface is irregular surface. The various structural and architectural parts of the building were built by applying Revit’s commands, such as walls, stairs, doors, windows, roof and slabs, Figure 7.
Figure 6. The creation of the 3D building model by adjusting and conveying the elevations of the building floors between the ReCap Pro outcome (the 3D geometric model of the point clouds) and a BIM model which was being created.

Figure 7. The procedures of modelling, alignment and fitting different structural and architectural parts processes: the ReCap Pro output (left) and the Revit output (right).

This variety of the structural and architectural parts of the selected building in this work was a reason for choosing the building design to model it. In addition, this building design can be seen in the north part of Iraq as well as some contemporary built-up areas in the capital of Iraq - Baghdad. Our developed framework remarkably shows the consistency and compatibility between ReCap Pro and Revit and their processing tools in turning the point clouds into a 3D BIM model in an accurate manner, as shown in 8. The final and complete model includes all structural components, such as windows and doors in addition to underground building structures (e.g. the basement). Although the 3D BIM model was built using the 3D model of point clouds, structural elements were designed by modeller according to their locations within the point clouds model. This last step of the creation framework illustrates the minimal efforts and time-saving in case the building has a complicated geometry to be modelled. Being modelling in Revit, the implementation of structural calculations can provide direct presentations of information for accomplishing further advanced BIM structural engineering analysis, Figure 8. However, it was found that not all building parts possibly can be drawn in a BIM environment without going back and check the accurate position of that part or element.
within the 3D point cloud model. Further, the final version of the 3D BIM model was having a geometry discrepancy in some parts of the building. One possible explanation can give is that the elimination of the additional point clouds which display greater details on the specific object may cause losing the accurate representation of its geometry.

![Figure 8](image-url)

**Figure 8.** The final 3D BIM model after modelling all structural and architectural parts comparing to the 3D model of the building using the laser scanning data with a sample of the basic constructional calculations and structural analysis for the succeeding BIM applications

5. Modelling time
All processing work and modelling were performed on a laptop computer (Lenovo W520) with a CPU Intel Core i7-2720QM processor with 2.20 GHz and 4 GB RAM. We used NVIDIA Quadro 1000M graphic card. Although the point cloud file size was 1.1 GB, the estimated total performance time was eight hours.

6. Conclusion
This article presented the creation framework of a 3D model of a building using laser scanning point clouds for BIM modelling. The framework is considered as workflow steps of a prompt and accurate acquisition of the 3D geometric information of any building that can help users and researchers to be used in the BIM environment. Three key stages were included in this work. First, the point cloud data
was collected based on the purpose of the engineering project, file format and its availability. Second, Autodesk ReCap Pro was used to open, cleaning and processing data to obtain the 3D building model composed of the point clouds. Third, the final 3D model and the structural computations applied to the model were attained using Autodesk Revit functions. The method can mitigate the problem of dealing with the different data file format and extensions. However, there is still a need to do further work in determining the compatibilities of various software that deal with laser scanning data to avoid the complex processes and reduce the time, efforts and cost. In the future, two goals are planned to achieve which are the use of different formats of the point cloud data that will be surveyed and captured by the laser scanner device for a particular building. Additionally, we are decided to experiment with a different design and shape of the building that prevails in the region.

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