Quantity Estimation of Executed Works Using Image Analytics

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Abstract –

Progress monitoring is key to any successful project. Often this is a hectic task which involves man power in preparing Daily Project Reports (DPRs) to physically monitor the activities on site. Recent developments in the fields of photogrammetry and point cloud processing techniques have laid a new path in using point-clouds for visualization and progress monitoring of projects. However conversion of point clouds to an accessible BIM format is still a researchable topic. Present techniques include manually creating models by visualizing the point cloud which is still a time consuming task. This paper tries to provide a new methodology in using photogrammetric point clouds for progress monitoring with very little manual intervention. The proposed methodology uses Revit's Dynamo and cloud processing techniques to successfully estimate the progress and the cost of activities on site. This method effectively uses the STL file format as a key to convert models and compare the as-built and as-planned Models. Using this method, we were able to estimate the progress of concreting activities with 100% accuracy and estimate the progress of masonry wall construction with 95% accuracy.

Key words –

Point-cloud; Quantity estimation; Progress monitoring; Mesh; STL file; Dynamo; Revit.

1 Introduction

Adhering to project schedules and budgets is the performance metric that owners and contractors most highly value. Accurate data collection and efficient utilization of the data are some of the most important tasks in progress monitoring on Construction sites. This data collected is widely used to detect the progress, compare it with the actual schedule, and is also used to identify the key off-schedule activities that are affecting the progress of the whole project.

Often Progress monitoring is a difficult task, and its accuracy decreases with the increase in the size of the project. The present-day techniques involve people manually collecting data in form of DPR (Daily Progress Report) and estimating progress. Even though this process is accurate it consumes considerable time and resources. Recently the development of photogrammetric, point cloud processing techniques and the introduction of laser scanners into the construction field has opened up an advanced way of data collection using point clouds [1, 2, 3, 4]. Further development in Computer vision techniques and availability of smartphones have led to methods that use images to reconstruct a point cloud [5, 6]. Even though these methods reduce the time consumption for data acquisition on project progress, the subsequent part of using this data for understanding and computing progress is still a manual task. Often people have to import the point cloud, register it, develop a BIM model from it and compare it with the actually planned model for the progress/quantity estimation.

This paper tries to create a new method of replacing manual development of BIM models from point clouds to a semi-automated one, through the combined use of generative programming tools with BIM authoring software. This method can have any of the 2 Lidar point clouds or photogrammetric point clouds as input. These point clouds are compared with the as-Planned Mesh model and an as-built mesh model is derived. This Mesh file is accessed using Dynamo and volumetric/Areal comparison is done. This method can reduce the development phase of as-built BIM models which in turn reduces the time consumed in progress monitoring. The major objectives of this study include

1. To develop a semi-automated method of quantity estimation for any construction project which takes point cloud data as input and derives the quantity of materials that have already been placed.
2. To determine the accuracy of the proposed method using a case study.

2 Literature Review

In order to overcome the disadvantages and manual errors in the collection of data, researchers have reviewed most of the current methodologies of automated data acquisition technologies. Examples of such technologies are Radio-frequency identification

RFID and GPS (Global Positioning System), barcode and GIS (Geographical Information Systems), LIDAR **([1], [2], [3], [4])** and photogrammetry **([5], [6]**).

A laser scanner consists of a light source which emits laser beams, these reflect back from the source and the time taken for the laser to come back to the station is used to find the distance to the object. These techniques require very little manual intervention and the data is highly accurate. Lidar technology is vastly used for site data acquisition. Recognizing objects from point clouds can provide great accuracy in progress estimation. Bosche (2010) [12] developed a semi-automated system for recognizing 3D CAD model objects in site laser scans. Object detection and segmentation are used to detect cad models from Lidar point clouds and object progress can be found by as-planned point cloud retrieval rate% [13]. Bassier (2019) in [14] used laser scanned point clouds to determine progress of a structure. 5 classes such as non - existing, anchor, rebar, molding, and built, are used to determine the progress of a point in the cloud and the category to which it belongs. Mahmoud (2011) [23] concludes that laser scanning technology has additional advantages such as low training time, high resolution and quality of scanning. However its high purchasing cost and varied climatic conditions on site shifts the balance in favor of methods that use images to create point clouds and subsequently, building models.The ease of taking pictures/Images with the development of computer vision techniques opened up a path towards photogrammetry.

Photogrammetry is the science of obtaining reliable information about physical objects through interpreting photographic images. These images are further used to create point clouds. Images can be collected manually using Mobile phones, on-site cameras, and using Drones. Though using drones is the most preferred method in present-day sites, smaller sites can also use other techniques.

2.1 3D reconstruction of image to a Sparse point cloud

Conversion of an image to a point cloud consists of a series of steps which can be divided into 2 parts namely sparse reconstruction and dense reconstruction. Sparse reconstruction takes images as input and tries to estimate a sparse point cloud with camera positions. SFM (Structure from Motion **[9]**) Pipeline is mostly used for sparse 3D Reconstruction. Figure 1 represents the steps included in the sparse reconstruction process.

Once the images are captured, features/interest points are extracted. The set of features extracted from this step are now compared with features from the different images and the algorithm tries to find common features between images. Verification step transforms the 2d point into a 3d point using a transformation matrix. The pair of images used to start the reconstruction play an

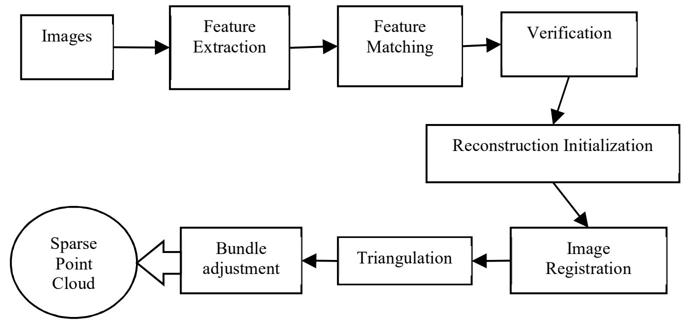

Figure 1 Sparse Reconstruction Pipeline

important role in the point cloud generated. Therefore the image pair with high common features are generally used for initialization of reconstruction. Image registration tries to stitch the remaining images to the initial image pair with high common features. A triangulation process is used to define the 3D coordinates of the new images, this takes a pair of registered images with common points and tries to estimate the camera position and adds new points to the existing cloud creating a sparse point cloud.

2.2 Dense Reconstruction

Dense reconstruction is done using a combination of PMVS and CMVS algorithms. Many multi-view stereo (MVS) algorithms do not scale well to a large number of input images. CMVS [10] takes the output of a structure-from-motion (SfM) software as input, then decomposes the input images into a set of image clusters of manageable size. A PMVS (Patch Based Multi-View Stereo) software can be used to process each cluster independently and in parallel, where the union of reconstructions from all the clusters should not miss any details that can be otherwise obtained from the whole image set. CMVS should be used in conjunction with an SFM software Bundler and an MVS software PMVS2 **[11]** (PMVS version 2). Thus a combination of CMVS/PMVS is used for a dense 3D reconstruction.

The applications of this technique to the field of construction management are many. Golparvar (2011) [15] used unordered images with SFM+ MVS pipeline to generate a point cloud, fed into a Bayesian model. SFM-MVS pipeline and SFM-CMVS-PMVS pipe lines are compared to one another by Hafizur(2019)[16]. Registration is always an important task while using point clouds, often this is done manually ensuring greater accuracies. An automated methodology of using Principal component analysis or coarse registration and Iterative Closest Point (PCA) for fine registration is employed in Bosche (2010) [17].Usage of point clouds is often followed by machine learning algorithms to detect materials or elements from the point cloud. Colour features are generally used for the detection as shown in

Kim (2011) [18] and Akash (2018) [19]. Bin clustering and height of a point are used in classifying the point cloud into structural elements such as floors, beams and columns in [20].Instead of processing point clouds there are methods in which the 3D BIM model is modified with a predetermined discrepancy. The BIM Model can be converted into a mesh and the point cloud coverage rate is used for progress estimation [21]. Bohn & Teizer have explored the advantages and challenges of camera-based progress monitoring [22].

Most studies that have used point clouds for progress monitoring have directly compared point clouds of as-built and as-planned models to give an estimate of overall progress of the project. However the individual progress of the activities are not determined. Some studies have concentrated on segmentation of point clouds in finding construction elements such as beams and columns in order to find the progress of the activities [18],[19],[20]. However these studies depend to a large extent on the accuracy of the point clouds which cannot be guaranteed under varying site conditions. The larger the size of the project, the more the number of laser scans that are required to generate accurate point clouds which in turn increase the time to capture data. With respect to photogrammetric approaches, while point clouds can be generated rapidly, using these point clouds for progress monitoring involves considerable manual intervention in creating as-built BIM Models [24]. In order to counter these drawbacks and the consequent gaps in our understanding of how to seamlessly create and use point clouds, this paper focuses on developing a framework to make the process of determining construction progress using point clouds easy, feasible, understandable, cheap and accurate.

3 Methodology

As a building contains many elements and non-linear construction schedules, it is comparatively difficult to progress monitor as compared to linear construction such as roads. Elements that are predominant in the erection of a super structure are Walls, Beams, slabs and columns. In this paper we restrict ourselves to finding out the progress of these elements by volume interpolation from their surface area. As the progress of elements are found separately, the output of the study can be further used for cost estimation and earned value analysis of the project. This study is only restricted to activities that can change the as-built point cloud of the building. Activities such as painting, tiling, and plastering are excluded in the study as they only change the colour of the point cloud but do not implement a physical change. This section describes our proposed approach in detail. The methodology proposed to be adopted for the current study has been illustrated in Figure 2.

We start by collecting images from the site. These images are to be collected with an overall overlap of atleast 20%, so that common features can be easily detected between images making image stitching and registration easy. These images are loaded into the respective software which is REGARD 3D in this study. The images are converted through a series of steps as mentioned in Figure 1 into a point cloud.

An as-planned BIM model of the project is then developed in Revit. In our approach, the as-planned model is developed and is converted into a mesh model using Dynamo. The above obtained as-built point cloud and as-planned mesh are then used for the process of registration.

Registration of point cloud is considered the key step in the process. It is the process of translating and scaling the point cloud into the global co-ordinate system. For this, an already registered model is required which in our case is the as-planned model. Both the as-planned mesh and as-built point cloud are loaded into Cloud compare a 3D point cloud processing software designed

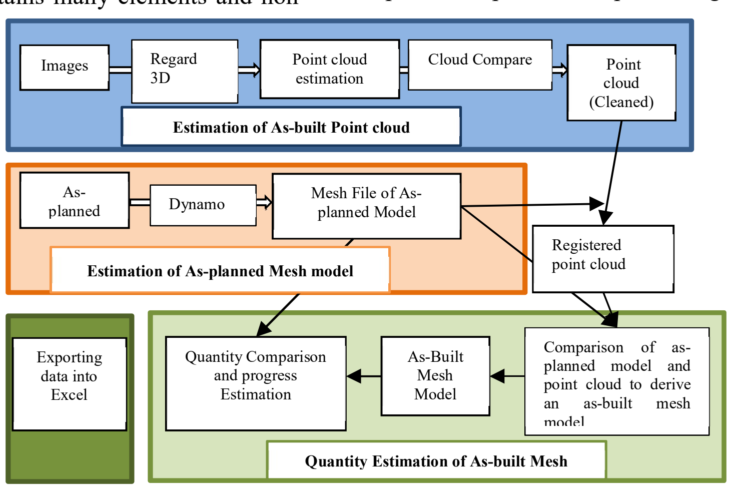

Figure 2. Proposed Methodology

to perform comparison between two models point clouds or meshes for coarse and fine registration.

Both the registered point cloud and as-planned mesh are used as inputs into a manually code developed in python to result in an as-built mesh. The code typically tries to check a preliminary condition with a point. It iterates through each point and with co-ordinates of the point, and tries to create a mesh from the as-planned model that encloses this point. Once this condition is satisfied, it counts the number of points that belong to a mesh. This number should be greater than 1 in any case. The point cloud may be erroneous which might lead to false positives. To account for this the progress of the mesh is considered. Progress of a mesh is found as the ratio of maximum height of all points of a mesh to the height of the mesh. An element is said to be constructed if the progress is greater than 0.9 or 90%. Third condition computes number of points at centre and should be greater than a minimum threshold. Threshold depends on the total number of points in the point cloud, area of the mesh. The resulting output is the as-built mesh in .ply format and is further used for quantity estimation.

The resulting As-built mesh is used to find the surface area which is then compared to the as-planned model's surface area, from which the progress of the project is estimated. This is done through developing code in Dynamo. To find as-built quantities of different construction elements, their technological dependencies are used. We use the surface area of each category of element in the as-planned model to estimate the as-built surface area. An example is provided below explaining the dynamo code to estimate as-built quantities of elements separately.

Example: Let the total surface area of the as-built mesh computed from the methodology be 300 m^2 irrespective of the number of elements in it. Let us assume that the total surface area planned for that day (columns – 50 m^2, slab – 100 m^2, beams – 50 m^2, walls - 300 m^2) is 500 m^2. Dynamo code first considers columns and checks if the as planned column area (50 m^2) is less than total surface area (300 m^2). If this is true it assumes that all columns that are planned are constructed amounting the columns progress as 100%. Next the code checks the next element that is technologically dependant on columns which are slabs and beams. It now checks the total area of slab and beams (150 m^2) and compares it to the effective surface area left (300 – column area (50) = 250 m^2). As the area of beam and slabs is lower than the available surface area, it assumes that all slab and beams that are planned are constructed completely making the progress of slabs and beams 100%. Next it finds the area of the next element (walls). The area of walls planned is 300 m^2 but the effective surface area is (300-column area (50) – slab and beams area (150) = 100 m^2). As the planned area is greater than the effective area, the code assumes that walls are not completed as planned. The area of constructed walls is 100 which is the as-built quantity and progress of walls is 100/300 = 33.33%. The output from the dynamo is programmed to be exported into an excel sheet which makes it easy for the end users to reuse the data for cost estimation.

4 Validation

There are 2 ways in which validation is done using a Virtual point cloud and a Real time point cloud. Validation is divided into 2 parts due to inaccessible construction sites, labs and lack of computation power for real time point cloud development.

4.1 Validation from virtual Point cloud

For a virtual point cloud, a Revit model is developed for a single storey residential building with an estimated area of 99m^2.

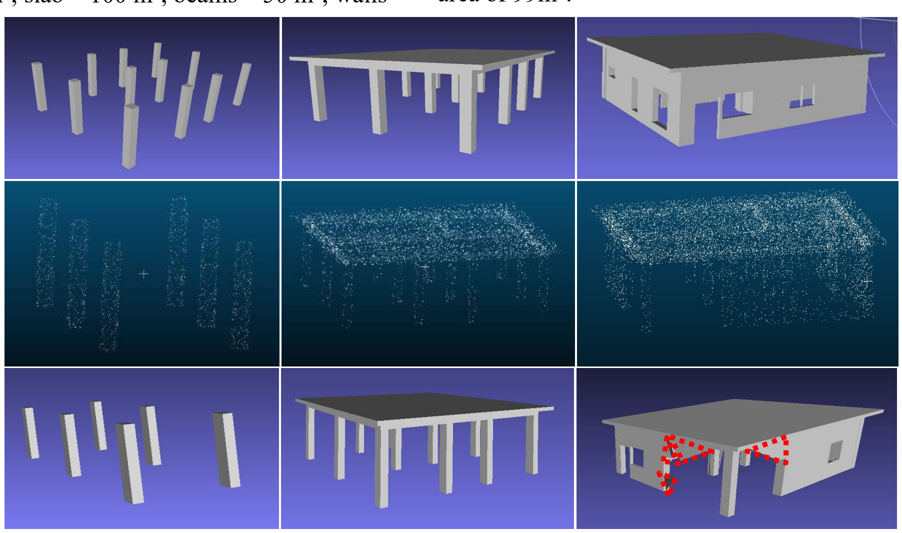

Figure 3. Row – 1 : As-planned mesh model for week 1,4,5 ; Row – 2: As-built virtual point clouds for week 1,4,5 ; Row – 3: As-built mesh model for week 1,4,5.

Initially a schedule for the project is planned for 5 weeks, where all the external elements of the superstructure such as columns, beams, slab and walls are to be constructed completely. The mesh models are different for different weeks depending on the week's schedule. These are formulated in Table 1. As the point clouds are to be created virtually, random elements are selected for each week and are converted into a point cloud with points sampled on the mesh as mentioned in figure 3 -Row - 2. Example to construct an as-built point cloud: For week 1: out of 12 planned columns, we assumed only 6 columns are constructed completely which mean a 50% progress. Assumed Progress of the week – 4 and 5 are 100% and 45% respectively. Both as-built point cloud and as-planned mesh are used as inputs to the code which resulted in an output as shown in figure 3-Row - 3. The mesh model Obtained from the code is used as input for Dynamo code to calculate surface area which in turn estimates quantity and progress. The resultant excel output is shown in Table 1.The obtained quantities and progress are compared to the actual quantities constructed as shown in Table 2. The deviations are found minimal.

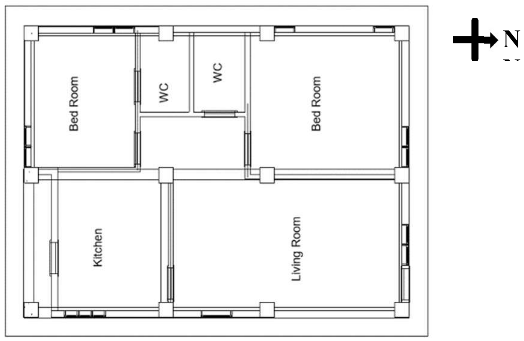

Figure 4. Plan of the residential building used for virtual point cloud

Table 1. Excel output from the proposed Methodology

Day	0	1	2			3			
Elements	Structural Columns	Structural Columns	Structural Columns	Floors	Structural Framing	Structural Columns	Floors	Structural Framing	Walls
As planned Surface Area (m2)	0	84.9	84.9	254.8	62.16	84.9	254.82	62.6	423.87
As built surface Area (m2)	0	42.45	42.45	254.8	62.16	84.9	254.82	62.16	201.8
As planned Quantity (m3)	0	8.36	8.36	24.59	4.19	8.36	24.59	4.19	32.13
Progress (%)	0	50	100	100	100	100	100	100	47.6
As built Quantity (m3)	0	4.18	8.36	24.59	4.19	8.36	24.59	4.19	15.29
Surface area lacking (m2)	80.68	42.45	0	0	0	0	0	0	222
Quantity need to be constructed (m3)	8.36	4.18	0	0	0	0	0	0	16.83

Table 2 Error estimation from the results

Weeks	**Elements**	**As-planned quantity (m^3)**	**Actual quantity constructed (m^3)**	**Actual Progress (%)**	**Quantity estimated from the proposed methodology (m^3)**	**Estimated progress from the methodology (%)**	**Error in quantity estimation (m^3)**	**% error**
1	Structural Columns	8.36	4.18	50	4.18	50	0	0
	Structural Columns	8.36	8.36	100	8.36	100	0	0
4	Floors	24.59	24.59	100	24.59	100	0	0
	Structural Framing	4.19	4.19	100	4.19	100	0	0
	Structural Columns	8.36	8.36	100	8.36	100	0	0
5	Floors	24.59	24.59	100	24.59	100	0	0
	Structural Framing	4.19	4.19	100	4.19	100	0	0
	Walls	32.13	14.65	45.6	15.29	47.6	1.12	**4.37**

4.2 Validation from actual Point cloud

We then validated our model on a real construction site. The site considered is a residential building (150 m^2) in Hyderabad. A small part of the project with an estimated area of 33 m^2 is considered. Construction has just begun and 4 columns with slab have been successfully erected. The project is being delayed due to the ongoing pandemic. Images were collected on a sunny day expecting a greater clarity of the point cloud. Images were taken using a mobile camera with a minimum overlap of approximately 20 % by picturing each element's 360° view separately. Number of images considered are 100 and are uploaded into Regard 3D and the point cloud is acquired. Images collected, Feature extraction and Image stitching are shown in the figure 5. As-built point cloud, developed as-planned mesh model and the as-built mesh model is shown in the figure 6.The area of the derived mesh model is used to interpolate the quantities which in turn estimates the progress of the project. The excel output from the methodology is shown in Table 3. Table 4 represents validation of the obtained data with the actual quantities. There are no errors in the matching process.

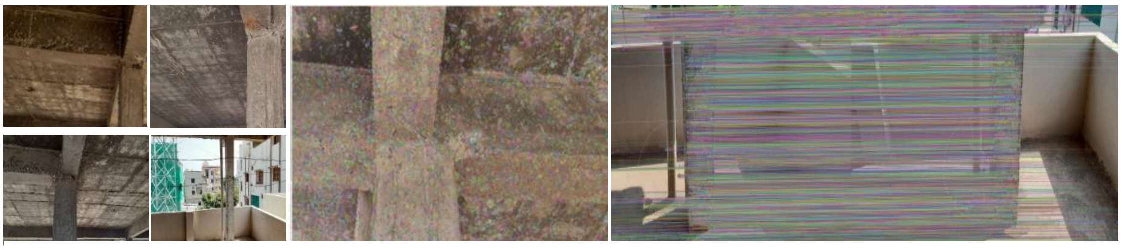

Figure 5. Site Images (left), Features detected (Middle), Feature matching and image stitching (right)

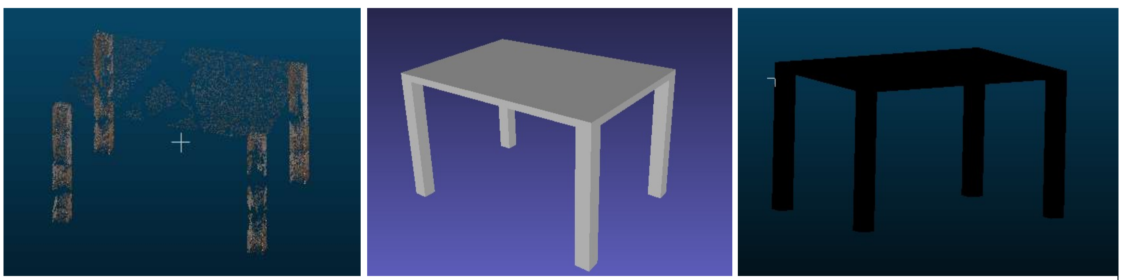

Figure 6. As-built point cloud (left), as-planned Mesh model (Middle), as-built Mesh model (right)

Table 3. Excel output from the proposed methodology

Day	1	2	
Elements	Structural Columns	Structural Columns	Floors
As planned Surface Area (m2)	0	28.3	135.78
As built surface Area (m2)	0	28.3	135.78
As planned Quantity (m3)	0	2.94	6.624
Progress (%)	0	100	100
As built Quantity (m3)	0	2.94	6.624
Surface area lacking (m2)	28.3	0	0
Quantity need to be constructed (m3)	2.94	0	0

Table 4. Error estimation from the results

Weeks	Elements	Actual quantity constructed (m^3)	Actual Progress (%)	Quantity estimated from (m^3)	Estimated progress (%)	Error in quantity(m^3)	% error
1	Structural Columns	2.94	100	2.94	100	0	0
2	Floors	6.63	100	6.63	100	0	0

5 Results and discussion

The performance of the proposed framework was tested on virtual and actual point clouds. Results from the methodology are 100% accurate in case of concrete structures as seen in the table 2 and 4 and for walls the accuracy is estimated to be 95%. Accuracy in the methodology majorly depends on the stage of construction of the element and the distance between point clouds of that element to the nearest point cloud of other constructed elements. Moreover, actual data considered is too small, so the results need to be improved using larger point clouds. We have also assumed a simplistic construction sequence and this assumption must be revisited as we extend this method to more complex structures with different dependencies between members.

This study has presented a semi-automatic system for progress and cost estimation, with a goal to improve the process of progress monitoring using point clouds and Mesh models. The proposed method describes the usage of Dynamo to automate the progress monitoring, reducing time and computation power making the process easy and cheap. The combination of a generative programming tool such as Dynamo with existing photogrammetry techniques to analyse project progress is the main innovation and contribution of this paper. However this paper only represents a start. Our methodology must be extended to more complex structures and building elements and also to activities such as sub-structures, connections, joinery, finishes and so on. RGB values of the point cloud can also be incorporated for quantity estimation of activities such as tiling, plastering etc.

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