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SCAN TO BIM CAPTURING AND DATA PROCESSING TOWARDS FACILITY MANAGEMENT FRAMEWORK

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الملخص العربى :

يتم استخدام نمذجة معلومات البناء (BIM) على نطاق واسع في إدارة المرافق (FM) للمنشئات المشيدة. يوفر المسح بالليزر ثلاثي الأبعاد معلومات ثلاثية الأبعاد سريعة ودقيقة وشاملة ومفصلة فيما يتعلق بالمشاهد الممسوحة ضوئيًا. تعتبر إدارة الكميات الهائلة من بيانات السحابة النقطية التي يتم إنشاؤها من المسح بالليزر ثلاثي الأبعاد مهمة صعبة. يسعى هذا البحث إلى تحديد الأساس المنطقي لاعتماد استخدام منهجية نمذجة معلومات البناء وتقنيات المسح بالليزر في مشاريع البناء. تركز منهجية نمذجة معلومات البناء وتقنيات المسح بالليزر على المكونات الهيكلية الاساسية للمنشأ ويتطلب التحكم في المنشئات الجديدة تحديد العديد من مكونات المبنى مثل أنظمة الهندسة الكهربائية والميكانيكية. تم اقتراح مناهج مختلفة للتعرف على العناصر الرئيسية للمنشئات في السنوات القليلة الماضية. يعد التعرف على العناصر الكهربائية والميكانيكية للمنشئات في نمذجة معلومات البناء مهمة صعبة حيث انه تم إجراء ابحاث محدودة في هذا المجال حتى الآن. الهدف الرئيسي من التطبيق المقترح PCMesher هو تقييم كفاءة مفهوم منهجية نمذجة معلومات البناء وتقنيات المسح بالليزر لتتبع أعمال العناصر الكهربائية والميكانيكية للمنشئات اثناء التنفيذ والتحكم فيها. تم عرض منهجية البحث المقترحة باستخدام دراسة حالة فعلية.

Abstract:

Building information Modelling (BIM) has been widely utilized in the Facility Management (FM) of constructed facilities. 3D laser scanning provides quick, accurate, comprehensive and detailed 3D information regarding scanned scenes. Manage massive amounts of point cloud data that is generated from 3D laser scanning is considered a challenging task. This research seeks to establish the rationale for the BIM adoption and laser scanning technologies in the construction projects. Scan-to-BIM focused on structural components and the control of new facilities requires the identification of numerous building components such as MEP systems. Various approaches for the recognition of main elements of facilities have been proposed in the last few years. The recognition of MEP facilities elements in BIM models is a challenging task on which limited research has been carried out to date. The main aim of the developed PCMesher application is to assess the efficiency of the Scan-to-BIM concept to track and control the MEP ceiling works. Modelling of required facility elements includes geometric modelling that seeks to model the facility geometry

element from the laser scan obtained data, such as ceiling MEP ducts from laser scan data. The proposed research methodology is demonstrated using an actual case study.

Keywords: 3D Laser Scanning, High Density Point Cloud, Facility Management, Building information Modelling

1. Introduction

The most important implementation of the concept of Scan-to-BIM in the operation and maintenance phases is that, the documentation of the facility geometries and textures. BIM based documentation allows better preservation and centralization of historical records and guidelines to facilitate the facility maintenance and repair. As-is BIM concept is implemented for the analysis of the facilities performance including structural analysis, accessibility diagnosis and energy performance. In addition, BIM-based facility performance analysis is used to improve and study the facility performance. Also, for the existing facilities, as-is BIM models are beneficial to various facility management functionalities because of the ability of the superior of the 3D visualization and organized facility data in the BIM. The operation and maintenance of the facility elements have been improved with the BIM-based processes. BIM concept enables the efficient localization of the facility elements and real-time access to the related data, thus reducing the time and cost for maintenance phase. This research presents the methodology that has been developed in this research to address the research objectives and to provide the answers to the research questions.

2. Facility Management

Facility Management (FM) for the most part is troublesome and confused work. Usually, the facility team use paper or data sheet to record the facilities maintenance tasks. Nonetheless, it is difficult for facility staff to utilize the conventional 2D CAD-based data delineation in the facilities maintenance. Additionally, the data of same facilities maintenance needs to repeat the record and cause burden for facility staff. On the other hand, the BIM approach is connected and created for overseeing and maintaining the facilities in the review as 3D information models. With the combination of the BIM model with the facilities maintenance related data, the facility stakeholders may enhance the productivity of maintenance and administration work of the facilities [1]. FM has grown in the real-estate industry and development. To maximize profit, the organizations have to comprehend that they educate customers in dealing with their facilities and properties. Nonetheless, following and overseeing facility adequately are to a great degree troublesome attributable to the different facilities.

The expected augmentation in computational cutoff points has contributed to the Architectural Engineering Construction (AEC) and FM industries for making and completing all the most compelling office and field developments. These join multi-dimensional CAD showing on the workplace side and 3D identifying advancements, for instance, the global positioning system, total stations, radio frequency identification, ultra-wide band tracking systems and 3D laser scanning. It is worth noting that the most promising and recent development is 3D laser examining [2]. The performance control tasks in many projects require the 3D as planned and as assembled data composed at the object level such as floor, wall, column, beam, and ceiling systems. These tasks incorporate:

- construction advance following;
- efficiency following;
- construction quality evaluation;
- quality control and
- lifecycle 3D wellbeing checking.

On one-part, the multi-dimensional CAD packages and more recently facilities, infrastructure, and building information models such as BIM and ISO have been produced for project and facility lifecycle management [3].

3. 3D Laser Scanning

Present day production lines, buildings and assembling lines can't be considered without various imaging frameworks for observing and controlling their mechanical procedures. These assignments must be robotized since the maximal dependability accomplished by people in the evaluation of items through dull perceptions crests at 80% [4]. Accordingly, mechanized visual examination frameworks have been generally utilized since the late 1980s [5]. From that point forward, machine vision-based examination and quality control in industry has developed strongly [6], and also handle control, parts distinguishing proof and mechanical direction and control [7]. Starting late, estimation, quality control and review in the industry benefitted from the implementation of the 3D strategies for portrayal and imaging [8]. The machine vision advancement contraptions at diminished expenses and also their scaling down and joining in modern procedures, have animated the usage of 3D imaging frameworks in industry [9].

3D data collection systems have been conventionally requested into contact and noncontact methods. Contact devices must touch the protest surface with the mechanical sensor, for instance, Coordinate Measuring Machines (CMM), rolls or computerized arms using mechanical tests. On the other hand, noncontact devices depend on attractive, acoustic or optical principles to gain the 3D required data from the scanned elements. Noncontact methods are ordinarily separated into idle and dynamic [10]. The previous methods, which use common or encompassing illuminate the scene, incorporate strategies, for instance, stereo vision and photogrammetry, among others. Instances of dynamic 3D imaging methods incorporate the laser scanning, time of flight, interferometry, shape from shadows, and photometric stereo. A momentous number of the imaging methods have shown proper implementation in a wide arrangement of the industrial projects' procedures [10].

The most regularly utilized 3D imaging frameworks in industry depend on dynamic strategies, particularly when these frameworks are required to be implemented in cruel conditions where latent techniques are contrarily influenced by surrounding or ambient light. The 3D imaging strategies for the industry quality examination give arrangements in the investigation of the surface, dimensional, basic and operational quality [11]. 3D imaging framework is a noncontact device which is used to quantify the range as well as the 3D directions of an object. 3D imaging techniques normally require the following phases to give an exact virtual portrayal of a protest which are [11]: an information catch arrange which tests the 3D world, an information enlistment organize which adjusts the different 3D views [12] and an information blend arrange which disentangles the adjusted perspectives into parametric models [13]. In industry, this portrayal is normally the contribution of strategies responsible for quality investigation and control, since it is achievable to get elements of the item under assessment.

Assessing the execution of a 3D imaging system is a hard and tedious undertaking. Gaging the presence and the repeatability of predisposition in the system involves various estimations of a similar element under similar circumstances [14]. Endeavors have been done to create the standards to assess the range errors [15], which could be characterized as a component of elements, for example, target reflectivity, distance and edge of occurrence. Execution assessment of the 3D imaging framework in view of these standards utilize surely understood elements to acquire their profile and process the contrasts between the real measurements and the virtual portrayal. The 3D laser scanning advances have been displayed in the field of surveying and can get 3D data about physical objects of diverse shapes and sizes in a cost and time compelling way. Laser scanners allow a huge number of points to be recorded in a few minutes. As a result, these scanners perhaps are broadly utilized as a part of the field of archeological, architectural, and environmental surveying [16].

3D prototyping in assembling has been done for little questions, for example, car seats. Notwithstanding, a similar idea has not yet been connected in the built environment effectively. Progressed advanced mapping instruments and innovations purported 3D laser scanner are empowering agents for powerful arranging, discussion and correspondence of clients' perspectives during the arranging, plan, development and lifecycle procedure of assembled and human situations. The recovery and change of urban areas from industrial age to knowledge age is basically a complete lifecycle prepare comprising of; arranging, advancement, operation, reuse and restoration. So as to improve the execution of construct and human condition arrangements during the recovery and change of urban areas, progressed computerized applications can have a significant effect [17].

This development is noteworthy on the grounds that it can possibly tackle the issues which dependably been related with the design and build of the current structures. It gives better quality, speedier and more exact investigation and highlight location for the facility study [17]. Within the fabricated condition, the utilization of the laser scanner empowers computerized documentation of sites, structures and physical items for recreation and reclamation including social legacy. It empowers the making of instructive assets inside the constructed condition, and in addition the remaking of the fabricated condition. Additionally, it can possibly precisely record difficult to reach and conceivably risky ranges. The laser scanner is engaged to the physical elements to be checked and the shaft is composed over the obstacle in an immovably spaced points grid. The situation in 3D space of each scanned point of the element is set up by estimating the time of laser flight. The time of the laser flight is calculated as the time of the laser go from the laser device to the physical protests and back again to the laser device. The result is a surge of centers which involves in a huge number of focuses in three dimensional spaces which are a dimensionally exact depiction of the present object. Then, this data would be able to be changed via 3D CAD show which can be controlled using CAD programming, and the arrangement of the new gear can be incorporated [18].

To calculate the coverage, the area of interest has to be separated into several small zones with horizontal and vertical grids. The zone is considered as covered if at least one scan within this zone is occurred. A small zone is deemed as covered if multiple scans are conducted and if at least one scan delivers points with the spatial resolution at this zone and required ranging accuracy. The grid size has to be designed to be close to the required spatial resolution of the scanned data. When occlusions exist among facility elements, the parameter of coverage is particularly important and the required area of interest is completely covered by the scan. So, the scanned data spatial resolution is equal to/or higher than the needed modelling accuracy. The essential coverage of the scanned data relies on the facility objects and the desired level of details. For objects with irregular shapes and numerous details such as MEP objects.

4. Research Methodology

This research has been developed to understand the concept of the role of BIM with the consideration of the economic aspects within the construction sector during the construction phase. The study queries stress principally on the understanding of the method, methodologies, related structure of data, applications on implementing the technology, and integration of tools.

4.1 3D Laser Scanning Information Requirements

The BIM applications involve different dataset that need to be mapped in the BIM models. Gathering too much data is a waste of effort and time consuming and collecting inadequate data renders the BIM model that will be useless for the required application. So, it is mandatory to specify the required data for the exact BIM application before gathering the scan data. Identification of the data requirements contains the following requirements:

- Facility components.
- Level of detail.
- Non-geometric items.

For the facility components that need to be modelled, the required level of details of each element has been identified. The level of detail term describes the degree to which the facility component is detailed and specified.

4.2 Required 3D Laser Scanning Data Quality

Recent research focused entirely on structural elements like floors, walls, beams, columns and ceilings. This research focuses also on other vital facility elements and particularly mechanical components like Mechanical, Electrical and Plumbing (MEP) ducts and pipes. MEP systems represent a huge amount of the construction costs and the facility value and therefore conjointly need to be properly managed and tracked. Knowledge of the MEP as-built current status is crucial for earned value management and for progress measurement. However, the tracking of the MEP elements has a critical and specific challenges compared to other structural works. First, the MEP elements could be delivered in packed configurations and this increase the risk of occlusions and generally produce more identification and recognition errors. Specially pipes and ducts, their installation in practice appears more flexible with respect to the positioning of the individual elements and routes compared to the structural elements.

As a result, one of the main objectives of this research is to assess throughout a real and challenging case study the efficiency of the Scan-to-BIM system to control and track the MEP systems. Although the Scan-to-BIM methodology establishes some robustness and benefits, its performance remains challenged by the MEP element installation variability. The research builds a further contribution that leverages the strengths of Scan-to-BIM techniques within a proposed framework. Reverse engineering may be used for several applications such as redesign, inspection, maintenance, verification and historical archive. There are two typical situations for the need of re-engineering:

- The first situation is when the documentations of the facility in service are unavailable, incomplete or in an incompatible form with manufacturing and CAD software and the required redesign and maintenance.
- The second is when as-built shape of the complete facility or other desired parts are required.

In general, the main aims of the 3D modelling form reverse engineering is to ensure that, the production quality control and to optimize the performances. For instance, despite the fact that the facility currently under construction are designed based on 3D data, they suffer the same lack of documentation of their accurate as-built drawings. There is always a mismatch between design and as-built data due to an inherent inaccuracy of the facility process and the tolerances of engineering techniques involved. The as-built of the facility obtained from the

3D model to the layout of internal features such as piping might not accurately reflect the design data. Therefore, the accurate implementation of reverse engineering process offers the stakeholders the way to ensure whether their facilities are built correctly from the very beginning to the end and this ultimately save time and cost. On the other hand, simulation-based facility design approach is taking a big share at early stage of the facility design process while build-and-test approach comes at the last stage. After identification of the data required for the building objects, the quality of the required scanned data that fulfils these needs has been determined. In the developed framework, the following parameters have been implemented to measure the quality of the scanned data including; accuracy, spatial resolution and coverage.

To calculate the coverage, the area of interest has been separated into several small zones with horizontal and vertical grids. The zone is considered as covered if at least one scan within this zone is occurred. A small zone is deemed as covered if multiple scans are conducted and if at least one scan delivers points with the spatial resolution at this zone and required ranging accuracy. The grid size has been designed to be close to the required spatial resolution of the scanned data. When occlusions exist among facility elements, the parameter of coverage is particularly important and the required area of interest is completely covered by the scan. So, the scanned data spatial resolution is equal to/or higher than the needed modelling accuracy. The essential coverage of the scanned data relies on the facility objects and the desired level of details. For objects with irregular shapes and numerous details such as MEP system objects such as the systems exist in the ceiling of the admin building. As presented in Figure 1, a higher coverage has been applied to obtain the desired model level of details. In general, the scan coverage should be higher to obtain more information of the facility components when the desired 3D model level of details is higher.

4.3 3D Laser Scanning Data Acquisition

The scanning factors including scanning locations, scanning instrument, the angular resolutions have been predefined before the scanning data acquisition. The scanning data coverage influence by the scanning device, the scanning locations and the angular resolutions.

Figure 1: Admin building Ceiling MEP system elements

The required areas in the admin building have been covered with the spatial resolution and required accuracy by scan data. The scanning device contains the necessary instruments such as a camera to capture red, green and blue colors in order to capture other properties. In addition, the locations of scanning have enabled a sight line from the scanning device to the target required to be captured these properties. The option to enable or disable a sensor by setting scanning parameters has been determined according to the system components priorities. Having more scanning locations with shorter distances, higher angular resolutions and lower incident angles satisfy the desired scanning data coverage, accuracy, and spatial resolution. However, this scanning process causes more efforts, time consuming and produces redundant scanning data. So, based on Construction Engineering Technology Lab (CETL) team expert judgment, site study has been conducted to find the near optimum scanning parameters with the minimum number of scans and also satisfying the required scanning data quality. For a specific scanner position, the amount of horizontal and vertical repetitions which determine the laser scanner positions is considered to be from range 2 to 20 repetitions. The constraint of the max spacing is utilized to range between 4 and 6 millimeters and 60° is the max used incidence angle and the scanning resolution is considered to be the final optimization parameter [19].

4.4 As-Is BIM Reconstruction

The as-is BIM model is reconstructed from the scanned data after scanning data acquisition. The reconstructed as-is BIM addresses all the required data that has been identified in the pre-scanning phase. As-is BIM reconstruction phase includes facility element geometric modelling and non-geometric modelling characteristics such as:

- The spatial relationships for the facility components.
- The required materials.
- The facility components surface characteristics.

The surface characteristics of the facility objects have been associated with each laser scan point. Automated as-is BIM reconstruction application has been developed to replace the process of traditional as-is BIM reconstruction. The automated methods of as-is BIM reconstruction are discussed with respect to the developed framework in the following section.

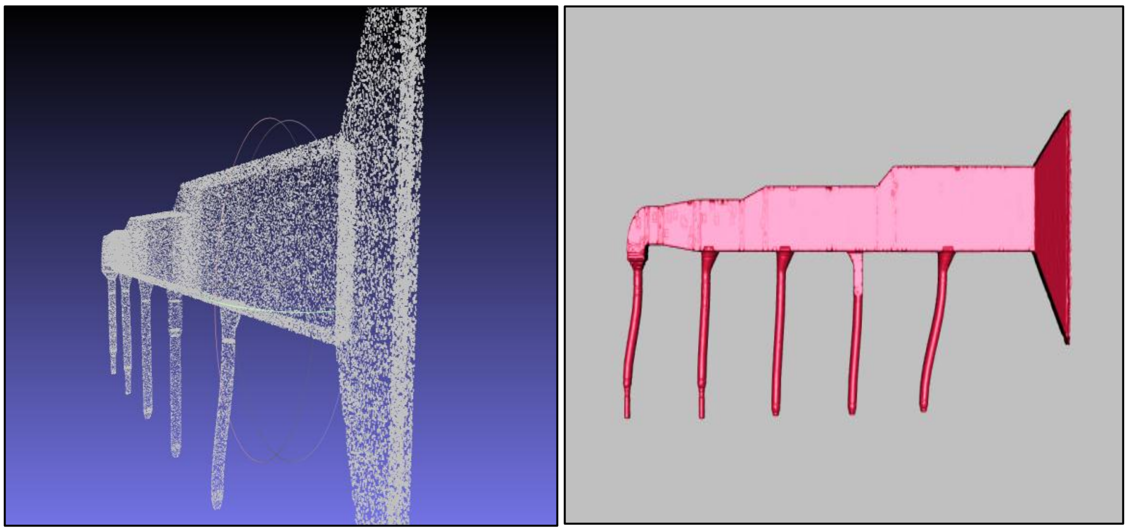
5. Results and Discussion

BIM is rapidly penetrating the Architecture, Construction, Engineering (ACE) and Facilities Management (FM) sectors. However, this increase in use has been predominantly for new builds, as well as on the design stage of those new constructions. Yet, it has been argued that, the most significant value of BIM will be delivered during Facilities Management stage. The efforts made for Scan-to-BIM modelling, to date, been focused on large architectural and structural components. It is clearly necessary to extend automatic Scan-to-BIM beyond these large components to other smaller ones, such as MEP systems components. MEP systems constitute a large portion of construction costs and asset value, and thus these systems need to be appropriately tracked and controlled. Knowledge of their as-built status is critical for control and earned value measurement. Tracking MEP components presents specific challenges compared to structural works. The strategies and developed code to model facility elements illustrated clearly in the next sections.

Visualization Toolkit (VTK) is an open-source scientific visualization and computational geometry algorithms library. It is stable, reliable and widely used. It has been developed by Kitware and other parties like Los Alamos Labs and has been used in many commercial and open-source applications like ParaView. Point Cloud Library (PCL) is an open-source library specialized in 3D surface construction from a point cloud in addition to pre and post processing of point clouds including noise elimination and refinement. The following sections discuss the detailed proposed framework components. VTK has been built on Windows using Visual Studio and the developed code has the following components:

- VTK Module.
- *.stl* file exportation.
- Graphics stuff creation.
- Setting the background and size.
- Generation of an interesting view.
- Model Viewer.
- Visualization.

The main aim of PCMesher application is to assess the efficiency of the Scan-to-BIM concept to track and control the MEP ceiling works of the admin building in the case study. Automated modelling of required facility elements includes geometric modelling that seeks to model the facility geometry element from the laser scan obtained data, such as ceiling MEP ducts from laser scan data. The application is not limited to MEP work and has been implemented for generating 3D model for the duct as in Figure 2.



a) Point cloud of the Duct b) Generated 3D model of the Duct

Figure 2: Generating 3D model for the Duct

The code implements the iso-surface extraction in the context of mesh simplification. The Euclidean Distance Transform (EDT) of the input mesh has been calculated and the octree has been adapted to the data and sampling the transform more finely near the surface of the mesh. The input mesh is watertight with the accurately oriented triangles. The output of this process is a polygonal representation and a triangulation has been obtained as well by enabling the flag that computes the minimal area triangulation. The 3D model has been created from the raw point cloud through the framework developed PCMesher application. The generated 3D model is used for creating as built shop drawings during operations and maintenance stages. The expected input is a point cloud file and the output will be *.stl* 3D model. The programming language used for this application is C++ and Windows Platform.

PCMesher application simply use a console terminal and run the command that identifies the path to input point cloud file and the path to output 3D file as follows:

PCMesher.exe duct.obj duct.stl.

The Mesher generates the surface mesh and invokes a window to visualize the generated model. PCMesher is able to compute the vertex normals defining the orientation and topology of the geometry, and if the input file has normals data, the PCMesher reads the normals data from the input point cloud file. To visualize the model after generating it, the end user can use the model viewer separately using a minimal model viewer. The end user can also use a model viewer to visualize the model like MeshLab or simply import *.stl* file to AutoCAD. As presented in Figure 3, PCMesher use the command prompt terminal to run the viewer using the following command:

VTKModelViewer.exe (path to 3D file). Ex: VTKModelViewer.exe ducts.stl

Figure 3: Generated 3D model for All ceiling ducts

Conclusion

The critical task to perform the facility management is the lack of availability of the as-built drawings and related documents. The investigation of multiple cases, the use of BIM facilitates the required maintenance work order and the faults that leads to decreasing the costs of the facilities management by removing the extra labor costs. Therefore, BIM supports bridging gap by permitting the ongoing process of transferring the data from project progress time to hand over phase. BIM is considered a powerful tool to manage accurate facility data over the engineering phase and it is adequate to support the maintenance and deconstruction phases data. The operational phase of the facility has been considered as the major contributor to its lifecycle cost. The facility management is complete in nature that covering everything from the preliminary study, financial management, maintenance till deconstruction. This research presented the PCMesher application to generate 3D model from a raw point cloud input. The generated 3D model is used for creating as-built shop drawings during operation and maintenance stages. The proposed method has been applied on a case study to illustrate the benefits of using laser scanning and BIM technologies in the facility management.

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