Web-Based Visualization of 3D Factory Layout from Hybrid Modeling of CAD and Point Cloud on Virtual Globe DTX Solution

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ABSTRACT

3D modeling is one of the main technologies in virtual factory. A satisfying visualization of 3D virtual factory enables workers, engineers, and managers to have a straightforward view of plant layout. It could facilitate and optimize the further planning of manufacturing facilities and systems. Traditionally, a 3D representation of manufacturing facilities and equipment is performed by utilizing CAD modeling. However, this process would be considerably time-consuming when it comes to the 3D modeling of manufacturing surroundings and the environment in the entire factory. Nowadays, with the development of 3D laser scanner, using scanning technology to obtain the digital replica of objects is becoming the new trend. The scanning result – point cloud data has been widely used in various fields for 3D- visualization, modeling, and analysis. Therefore, hybrid modeling of CAD and laser scan data provide a rapid and effective method for 3D factory layout visualization. Since visualization of 3D models is no longer limited to desktop-based solutions but has become available over the web browser powered by web graphic library (WebGL), in this paper, we proposed a systematic and sustainable workflow based on the _DTX-Solutions©_ systems engineering integrated approach to generate and visualize hybrid 3D factory layout where the point cloud model is combined with CAD objects of new manufacturing equipment on a web-based DTX-Solutions© library. _DTX-Solutions©_ systems approach supremely minimizes the visualization requirements and dependencies as well as benefits industrial companies to demonstrate and share the internal visual information with external contractors and customers. Furthermore, it provides the possibility to improve the digital factory information over the web. Additionally, one case study has been implemented as the application and demonstration of the proposed workflow associated with the detailed technical pipeline. At last, in the long term of converting the raw point cloud data to web rendering formats, a converting tool with a python-based graphic user interface (GUI) has been developed.

1   INTRODUCTION

Virtual factory plant represents a plant environment where virtual models replace reality. Virtual models enable the possibility to reduce the time of manufacturing systems planning, optimize the system design and also to verify different conflicts before implementation [10],[22]. Conventionally, visualization of virtual plant layouts is carried out by utilizing CAD representation. However, due to the time-consuming task of modeling and lack of effective understanding between persons with different fields of expertise, an improved level of visualization support is highly recommended [6],[10],[17].

In recent years, various photogrammetry, computer vision, laser scanning, light detection and ranging (LiDAR) and image-based techniques have been investigated for 3D modeling of objects because of their opportunities for fast and accurate model generation. For instance, an implementation of image-based modeling using a non-metric handheld camera has been accomplished for 3D reconstruction of heritage objects by University of Twente [12]. Besides, Akbarzadeh and Frahm et al. developed and performed an automatic geo-registered 3D modeling of urban scenes from video by means of computer vision [1]. The same topic has also been researched regarding the video segmentation, modeling, and match by Rothganger and Mijakovska [18],[21]. Additionally, in the field of Geo-information and urban planning and analysis, 3D reconstruction of buildings and landscape using LiDAR data is getting extensively used as well [2],[9]. These techniques widely broaden the horizon for researchers in exploring of a rapid, effective and accurate way of creating 3D models.

However, utilizing point cloud models from 3D laser scans in manufacturing environments is so far a relatively undeveloped area. The technology holds a potential through its simplified operation procedure, rapid capturing speed and satisfying precision of 3D scanning result. From the 3D scan data, it is possible to create a point cloud model that visualizes the as-built factory in a photo-realistic 1:1 scaled 3D model [15]. Such a model could be modified to visualize and evaluate future changes. Therefore, it is promising that hybrid modeling of CAD and laser scan data could provide a rapid and effective method for 3D factory layout visualization by placing existing CAD models into the context of point cloud [14].

Nevertheless, the visualization of hybrid models up to now is limited to desktop-based software with many requirements and dependencies of the runtime environment. The industrial companies face many challenges when they desire to provide the external contractors, project manager and customers with the real 3D view of manufacturing systems, facilities and environment of the factory plant from a hybrid model. Therefore, the research questions are aroused not only regarding how to systematically generate the hybrid model but also how to visualize them in a light, simplified and easily-accessed environment.

In recent years, powered by web graphic library (WebGL), the visualization of 3D models is no longer limited to desktop-based solutions but has become available over the web browser. Therefore, in this paper, we proposed a systematic and sustainable workflow based on the systems engineering integrated approach proposed by our previous work [22] to generate and visualize hybrid 3D factory layout where the point cloud model is combined with CAD objects of new manufacturing equipment through a web-based JavaScript library on the DTX-Solutions©. Which could be accessed conveniently by anyone through a web browser without a plugin and the downloading and installation steps would be avoided. Furthermore, in order to simplify the visualization process, a point cloud converting tool with a user-friendly GUI (Graphic User Interface) has been generated for sustainable conversion the raw point cloud data to web rendering formats.

The remainder of the paper has the following structure: Section 2 describes the current technologies which could support to achieve our research goal. A detailed methodology with a structured and systematic pipeline has been proposed in Section 3 to elaborate how to generate

and visualize hybrid 3D factory layout on the DTX-Solutions©. virtual globe. Section 4 contains a use case implementation based on the methodological pipeline proposed in Section 3, which reflects and approves the feasibility and value of the proposed pipeline. Finally, Section 5 presents the conclusions and the future work.

2   STATE OF THE ART

2.1   3D Laser Scanning in Manufacturing Industries

3D laser scanning is used for building up a 3D digital model of existing layout or by the analysis of static constructions. 3D laser scanners operate by emitting laser beams and capturing their returned reflection to measure the traveled distance [16]. FARO Focus3D X 330 is a good example to explain how a terrestrial 3D scanner works. With such 3D laser scanners, it's possible to capture the environment in the whole spatial angle with an accuracy of ±2mm [11], which makes them very appropriate for indoor applications. The result of this procedure is a discrete capture of the environment in form of a point cloud. After the raw point cloud has been created, also the color information is being assigned to every point. This is carried out through a regular photo camera which is taking pictures in every spatial angle and then overlaps the pictures onto the point cloud data as shown in figure 1 (a). To make it possible to combine two scans into one dataset, it is recommended that corresponding reference objects are visible in both scans to combine them successfully [7]. The reference objects can, for example, be white spheres or black and white checkerboards if we use Faro 3D laser scanner, as presented in figure 1 (b).

Figure 1: Faro 3D laser scanner: (a) The functionality of terrestrial laser scanners - FARO Focus3D X 330 Fig. (b). Checkerboard reference object and spherical object.

2.2   3D Factory Plant Supported by Laser Scanning Data

As a matter of fact, the technology of laser scanning is not that new. However, the software has been drastically developed in recent years. The modern programs have become more efficient and have introduced new applications and the technology. Nowadays more and more companies use laser scanning for modern plant construction projects. Volvo Cars in Gothenburg is one of the world leading automotive companies when it comes to using and developing the concept of the digital factory with laser scanning technologies [15]. Volvo Cars Corporation uses, for example, point clouds as the main virtual representation of their factories' layouts, which enable them to ensure accurate planning when redesigning their production systems [14]. Many other companies such as Toyota, Mercedes and Ford are working actively with laser scanning today as well.

Additionally, in the work of Lindskog, et al. [14-17], they have utilized 3D laser scan data as a visual support for plant layout planning, geometry analysis, redesign of production systems, as well as develop discrete event simulation (DES) models. It enables realistic visualization of manufacturing surroundings and environment and improved accuracy including the level of detail regarding geometric representation in DES models [15]. In short, bringing this concept into the early phases of virtual manufacturing has the potential to facilitate the creation of a shared understanding of the future system within cross-functional project teams. Moreover, in the previous work [22], we have also proposed a system engineering approach for systematical, methodological and sustainable generation and application of 3D scan data in CAD simulation. This

approach provides a feasible solution for building up the digital factory context and improves the digital factory information.

2.3   Web-based 3D Model Visualization

Years ago 3D models visualization and rendering were limited to desktop-based solutions based on OpenGL (Open Graphics Library) such as Catia, Blender, Meshlab, 3ds Max, CloudCompare, etc. Some of the previous rendering solutions are very efficient in computing and processing 3D models as well as point cloud data. However, the world rotates around the web. Powered by HTML5, WebGL (Web Graphics Library) and graphic engines such as three.js, some renderers have recently become available for the visualization of 3D model and point cloud model on the web [13]. Here we introduce several projects or platforms which visualize 3D models over the web browser without a plugin.

1) Potree is a very popular free open-source WebGL based point cloud renderer which evolved from the Scanopy project at Technical University Wien. It uses a multi-resolution octree data structure to deal with large data sets. It is required to convert point cloud data locally and upload it to the server. Potree currently takes XYZ, LAS, PLY data formats and could be run on Chrome, Firefox and Opera browsers. Figure 2 (a) is an example of a point cloud model visualized in Potree.

2) Sketchfab is a platform to publish, share and discover 3D and VR content. It provides a viewer based on the WebGL and WebVR technologies that allow displaying 3D models on the web, to be viewed on any mobile browser, desktop browser or Virtual Reality headset. The main product of Sketchfab is a 3D and VR model viewer. It enables viewers to move freely around or inside the 3D scene using a mouse, touch manipulation or in Virtual Reality. Figure 2 (b) is an example of an airplane model visualized by SketchFab.

3) Cesium is an open-source JavaScript library for world-class 3D globes and maps which use WebGL for hardware-accelerated graphics, and is cross-platform, cross-browser, and tuned for dynamic-data visualization. Cesium is developed by an open-source community, with the support of different kinds of 3D tiles which will be used to stream 3D content, including buildings, trees, point clouds, and vector data. Figure 2 (c) is an example offered by Cesium team which shows a point cloud model been visualized on top of the background map. Figure 2 (d) shows the 3D truck models on DTX-Solutions© virtual globe.

| (a) | (b) | (c) | (d) |

Figure 2: Examples of web-based visualization of 3D models a) A point cloud model in Potree: Westend Palais, Frankfurt, Germany, (b) An airplane model in SketchFab [25], (c) A point cloud in Cesium: Church of St Marie at Chappes, France [3], (d) A truck model in Cesium [3].

3   METHODOLOGY

From the previous research work, we have proposed a systems engineering integrated approach based on the adapted V-Model to improve the digital factory information as shown in figure 3. The whole process has been divided into 3 phases: system design (on the left side of V-model), system implementation (on the bottom of V-model) and system integration (on the right side of V-model). For each of them, 2 sub-phases has been elaborated including requirement analysis phase, laser scanning phase, data handling phase, process simulation phase, result analysis phase and

integration in digital factory phase. Based on this framework, in this paper, the new workflow consisted of 6 steps has been proposed to generate and visualize the data from 3D laser scanning and CAD modeling over the web-based platform.
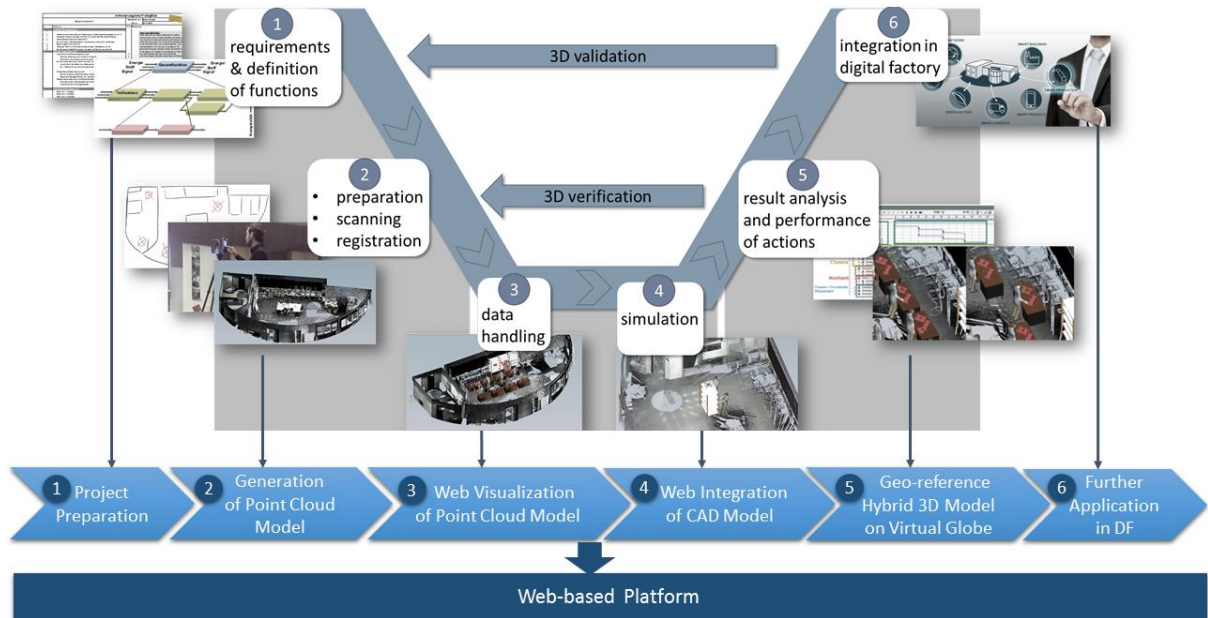

Figure 3: Workflow for web-based visualization of hybrid 3D models from adapted V-Model framework [22].

Each step in the workflow corresponds with the each phase in the V-model based framework. The first step 'project preparation' addressed the preparation work in terms of project preparation and requirement analysis. The second step 'generation of point cloud model' includes scan strategy preparation and planning based on factory 2D layout, scan raw data registration and processing as well as the exporting as point cloud model. The next step 'Web visualization of point cloud model' aims to use web rendering technology to visualize the generated point cloud model over the web browser. It is followed by the fourth step which is the web-integration of generated CAD models. The fifth step focuses on how to geo-reference the hybrid 3D model [28], [29] and locate them appropriately on the DTX-Solutions© virtual globe with the background geographic and environmental information. The last step is the further application of the visualized result in the context of digital factory or other related fields.

In order to achieve this workflow, firstly several fundamental requirements need to be clarified for better evaluating and determining which web-based platform or renderer would be qualified: 1) open source library with the possibility to access the source code and second-develop to fit our purposes; 2) 3D models in term of point cloud model and CAD model cloud be located and visualized on top of the corresponding earth surface with map information as an environmental background; 3) ability to load large point cloud data in GB level and view it smoothly. Therefore, an open-source JavaScript library for world-class 3D globes and maps has been chosen as our web-based visualization platform for hybrid 3D models. Figure 4 below gives us a more detailed technical pipeline to achieve the above-proposed workflow through DTX-Solutions© virtual globe library. The pipeline has been composed by 3 major parts: generation of point cloud model, generation of CAD model [30], [31] and web visualization of the hybrid model.
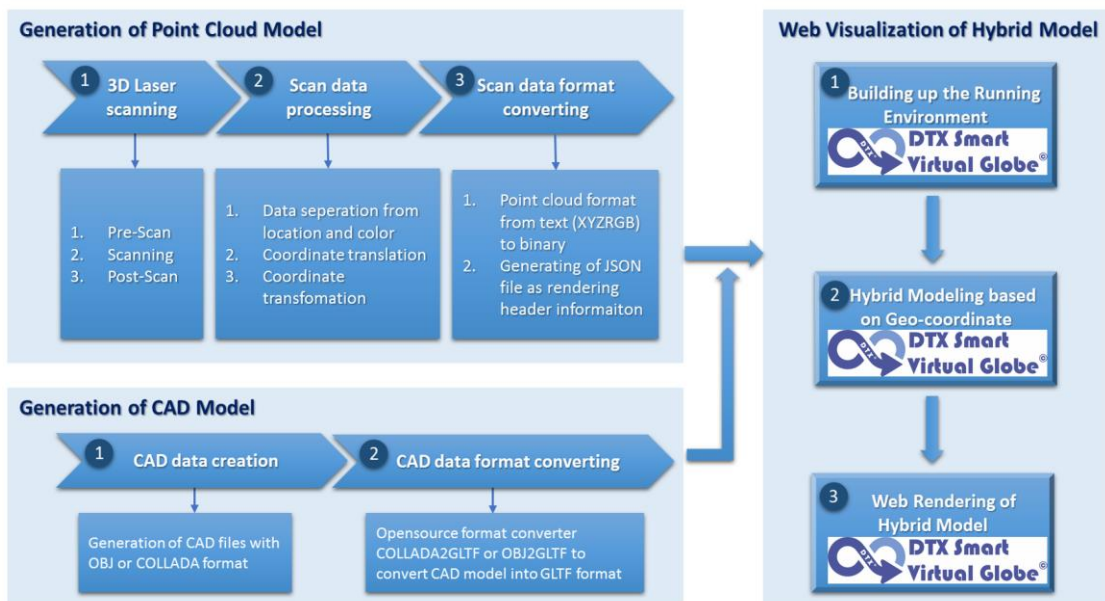
Figure 4: Pipeline to generate and render hybrid 3D factory through web-based *DTX-Solution©* systems virtual globe.

In this section, we focus on the elaboration of the methods which point cloud model and CAD model can be generated and formatted into the web-renderable version on DTX-Solutions© virtual globe library.

3.1   Generation of point cloud model

In order to obtain a point cloud model with high accuracy and resolution in the manufacturing area, a well-planned scan project needs to be performed.

3.1.1   3D laser scanning

In general, the 3D laser scanning procedure could be divided into 3 steps: Pre-Scan, Scanning, and Post-Scan.

1) Pre-scan: preparations for 3D laser scanning includes a) design of scan route; b) estimation of scan number; c) demand manpower; d) parameters for setting up the scanner; e) positioning of reference objects and so on. They are based on the layouts and images of manufacturing area to ensure that all of the necessary objects can be captured.

2) 3D laser scanning: during scanning, multiple scans are carried out on different positions one after another in the manufacturing plant. For achieving satisfying results, it is important that the scanned environment remains motionless throughout the scanning process.

3) Post-scan: the scan data will be transferred from an SD card in the 3D scanner to a computer system which is installed with corresponding software, e.g. Faro Scene, Bentley Pointools V8i, etc. After registration, all the scans to align them to one scan data set, an overall point cloud model will be generated. Then, it is necessary to check the scan result in terms of resolution, point density, and distribution. Then we can clean up the model from any unwanted points. Finally, the different data format of point cloud model such as XYZ, TXT, ASCII, etc. can be exported.

3.1.2   Scan data processing

A point cloud is a set of points in a three-dimensional coordinate system which defined by X, Y and Z coordinates and often with intensity or color information. For better perform the processing of point cloud data especially regarding the position transformation of each point, it is highly recommended to divide the data into 2 parts: position information and color information. The point cloud model, which exported from scan processing software, has its local coordinate system based on the registration result of different scans. In day to day use, Cartesian coordinates, which have a direct reference to concepts such as length, width, and height, rather than polar coordinates from the original scanning has been widely applied. However, in order to visualize the point cloud data in a global coordinate system, the processing of the coordinate system is unavoidable.

1) Coordinate translation: to achieve the translation from the local coordinate system to the global Cartesian system [27], first of all, we need to match the origin (0, 0, 0) from point cloud model to the position where the origin located on earth surface on DTX-Solutions© virtual globe (from longitude and latitude to global Cartesian coordinate). The coordinates have been defined as latitude, longitude, and elevation on DTX-Solutions© virtual globe but with actual RTC (Relative To earth Center) based on the global Cartesian system.

2) Coordinate transformation: the coordinate transformation aims to match the orientation of the coordinate axes from two coordinate systems through axis rotation. Generally, any rotation can be described with three separate rotations around the x, y, and z coordinate axes. This calculation will be easily performed by standard matrix notations.

3.1.3   Format conversion of point cloud 3D model

On web-based DTX-Solutions© virtual globe, 3D tiles are an open specification for streaming massive 3D geospatial datasets. Point cloud tile format is one of the 3D tiles which defined by position and optional application-specific properties such as color and normal to specify its appearance. Using 3D Tiles terminology, each point is a feature. Therefore, it is necessary to convert the point cloud data format to make it compatible with the specifications which defined by the web-based renderer. A point cloud tile is composed of a header section immediately followed by a body section. Web-based DTX-Solutions© virtual globe loads the point cloud data with the header format [19]. Furthermore, a JSON file is needed for indicating the URL to the corresponding point cloud file with additional information such as bounding volume, geometric error, children file, etc.

3.2   Generation of CAD model

Web-based DTX-Solutions© virtual globe supports 3D models, including key-frame animation, skinning, and individual node picking, using glTF, an emerging industry-standard format for 3D models on the web by the Khronos Group. glTF (gl Transmission Format) is a new 3D file format positioning itself as "the JPEG of 3D" for the Web. glTF has features such as JSON descriptions of entire scenes included binary-encoded data (e.g., vertex positions, normals) that requires no intermediate processing when uploading to GPU. Khronos Group, the consortium behind WebGL and COLLADA.

Each glTF file component is designed to be as lightweight as possible for minimizing the processing and rendering demands placed upon the Web Browser. Using the JSON format for the scene hierarchy is practical because it is much more easily parsed than XML and is also more compact so will take less time to download as well. The GLSL shader files are very small and passed without modification into WebGL. Textures are simply png, jpeg or similar file types that likewise need no further modification. The mesh binary data, which can be the largest of all the component files, is raw binary data meant to be passed directly into buffers directly [4].
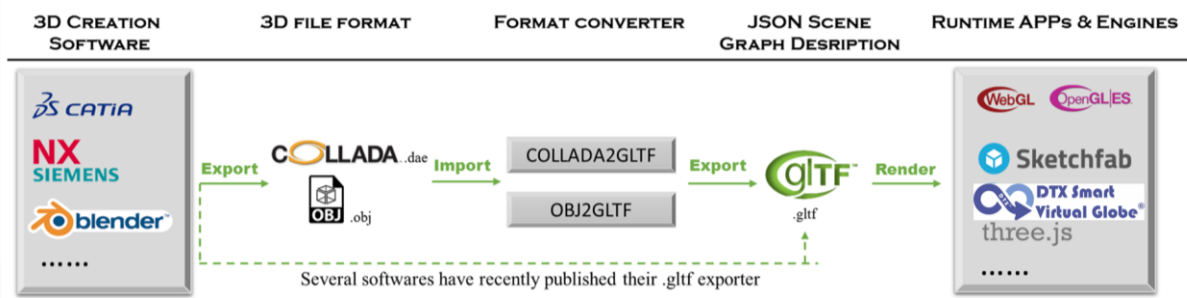
Figure 5: Pipeline to generate and render CAD models through web-based renderers.

Figure 5 shows us the detailed workflow to create glTF format for CAD models. Any CAD models can be created by 3D creation software such as SketchUp, 3ds Max, Blender, etc. After exporting them into either COLLADA or OBJ formats, Cesium and KhronosGroup provides a JavaScript tool to convert COLLADA (.dae) models or OBJ models to glTF for optimized use with Cesium and other runtime apps and engines which support glTF model format such as Sketchfab and threeJS.

4   IMPLEMENTATION WITH A CASE STUDY

In this section, we will follow the methodology illustrated in section 3 and apply a case study in a small and medium-sized enterprise (SME) which focuses on insert molding and tooling technologies with headquarter in Saal a. d. Donau, Germany. As described in Section 3.1, before we perform the scanning project in the manufacturing area, we first made a scan strategy regarding the amount of scan, scan route, and scan clusters for later post-processing of scan data based on the 2D plant layout of the manufacturing hall as shown in figure 6 (a). It is necessary to notice that every 2 scans must have at least 30% overlapping to perform further registration.
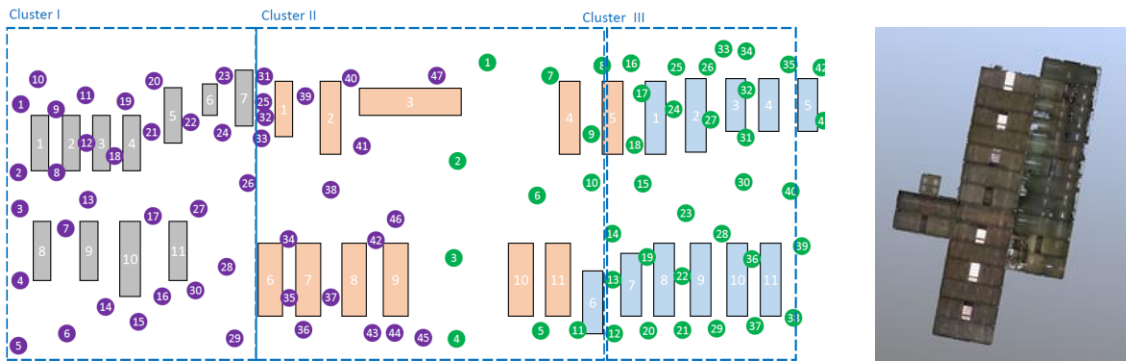

Figure 6: generation of point cloud model: (a) Scan strategy in Cetto manufacturing hall (b) Orthographic view of point cloud model of Cetto manufacturing hall.

Then, the laser scanning procedure by using FARO Focus3D X 330 laser scanner in the manufacturing hall has been performed. After registration, processing, and filtering of all the raw scan data in FARO Scene 6.1, a 35.7 GB point cloud file with 8.3 million points in text format has been generated with XYZ coordinates and color information. Figure 6 (b) is an orthographic view of the entire post-processed point cloud model.

In order to render the generated point cloud model over web-based _DTX-Solutions©_ systems, firstly we need to build up the runtime environment. It requires a web server such as NodeJS,

Apache, IIS, etc. as well as its own library which is available and free to use on GitHub. Secondly, it is necessary to geo-locate the scanned location on the DTX-Solutions© virtual globe and determine the scanned area based on the scan strategy and scan results as illustrated in Figure 7 (a)(b). Thirdly, following the specification of web-based DTX-Solutions© virtual globe point cloud rendering, we transformed the original local coordinate system of point cloud model to match with a global coordinate system of the DTX-Solutions© virtual globe. Then, converted the text-formatted point cloud data into a binary-formatted file which is PNTS file with JSON file as header information. At last, the point cloud model has been rendered and visualized as shown in Figure 7 (c)(d).
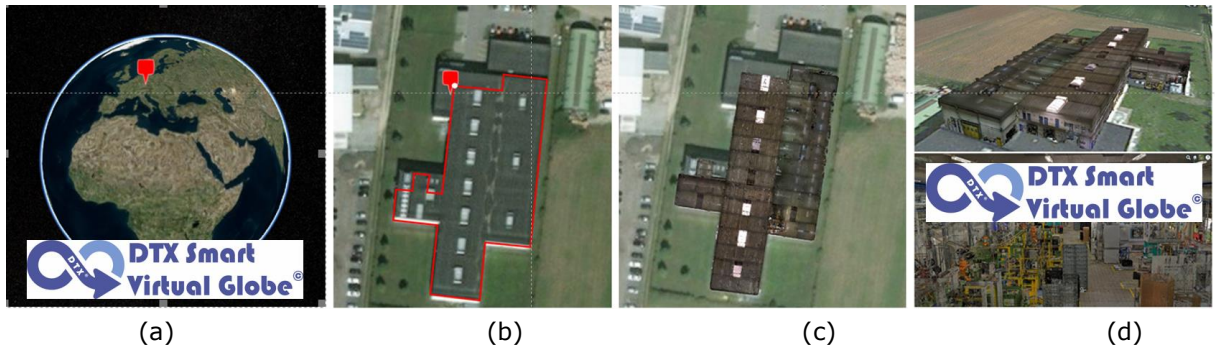

(a)   (b)   (c)   (d)

Figure 7: Point cloud model rendering over DTX-Solutions© virtual globe: (a) Locate the scan area (b) illustrate the scanning boundary and origin (c) position the processed point cloud model (d) outer and inner view of point cloud model.

Then, for the sake of render CAD models into the above-rendered point cloud model on virtual globe, we first created a scene in Blender 2.78c which combines with robot arm [5], table and several components to simulate the manufacturing component assembly. These CAD models can be exported from Blender as either COLLADA or OBJ format and converted into virtual globe rendering format glTF through the open source convertor from Cesium or KhronosGroup. Here the web-based JavaScript virtual globe offers 2 options to load and render glTF model onto virtual globe: 1) each model as Primitive - *scene.primitives.add(Cesium.Model.fromGltf())* (script to load Primitive) and 2) each model as Entity - *viewer.entities.add({model ()})* (script to load Entity)*. The different between this two methods is that Primitives are lower-level graphical elements within web-based JavaScript virtual globe, and Entities are built on top of Primitives. A single Entity may represent a point-of-interest or a moving vehicle, and that single Entity may contain several different kinds of Primitives [26]. Generally, the web-based JavaScript virtual globe team recommends using Entities where possible, since they more directly correspond to real-world objects. Therefore, in our use case, we choose entity API to load our glTF models.

As can be seen in Figure 8, the place of interested (POI) in point cloud model has been chosen first to geo-reference the position where CAD models need to be loaded. Next, we rendered the CAD models as different Entities and developed the functionality to move each Entity by drag and drop to the target position. Finally, a hybrid 3D factory layout where the point cloud model is combined with CAD objects of new manufacturing equipment has been visualized through web-based DTX-Solutions© virtual globe.

Additionally, a point cloud conversion tool based on Python and JavaScript called 'DTX SmartPntsConverter' has been developed as presented by figure 9, which could easily perform the conversion procedures based on the input parameters such as latitude and longitude of origin coordinates, height adjustment, model rotation, axis flipping, etc. for DTX-Solutions© virtual globe rendering.
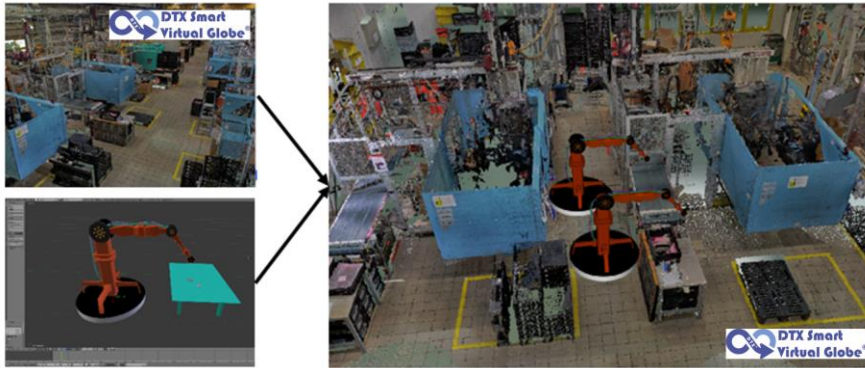
Figure 8: Rendering hybrid 3D models from point cloud data and CAD data over DTX-Solutions© virtual globe.

Figure 9: DTX Solutions SmartPntsConverter.

5 CONCLUSION AND DISCUSSION

A satisfying visualization of 3D virtual factory enables workers, engineers, and managers to have a straightforward view of plant layout. Most importantly, it could facilitate and optimize the further planning of manufacturing facilities and systems. In this paper, we proposed a systematic and sustainable pipeline to generate hybrid 3D factory layout where the point cloud model is combined with CAD objects of new manufacturing equipment through a web-based DTX-Solutions© virtual globe library. Compare to the conventional method which is purely CAD modeling, this new methodology has advantages in 1) offering a rapid and effective method for 3D factory layout visualization; 2) minimizing the visualization requirements and dependencies; 3) comforts industrial companies to demonstrate and share the internal visual information with external contractor and customers; 4) holds the potential to be a generic methodology for different

kinds of 3D scan data and CAD data; 5) provides the possibility to improve the digital factory information over the web.

However, there are several aspects which could be improved in the future:

1) Currently, the point cloud model is normally huge in data size. This brings difficulties in browser-based visualization due to the limited rendering performance. Therefore, a good data structure needs to be applied to load the point cloud data sequentially from different levels of detail.

2) The upcoming version of glTF 2.0 will have the feature to enable the physically-based rendering (PBR) using WebGL for 3D models. It provides the more realistic rendering of material shading such as metallic and roughness. Therefore, a better visualization result of 3D factory layout can be provided in the future.

3) So far, the convertible format for CAD data is limited to OBJ and COLLADA from certain 3D creating software and in regard to point cloud model, the text-based format (e.g. ASCII, XYZ, txt, etc.) is required. In the future, a bigger range of data formats should be supported for extensible usage of the proposed pipeline.

4) In order to facilitate the engineers, managers and customers of the industrial companies with more practical and valuable information from the web-based 3D factory layout model, a JavaScript-based tool box on the visualization interface to adjust, move, measure, clipping, and attach semantic information (e.g. requirement, resource info, videos, etc.) to the 3D factory model could be developed.

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