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3D Model Generation of CFS Members from Surface Data

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Abstract **-** Cold-formed steel (CFS) members have been increasingly used in construction since CFS construction provides efficient, affordable, and resilient building systems. CFS members are produced by forming thin steel sheets into specific cross-sections, thus the most significant advantage of CFS construction is its high strength-to-weight ratio. However, the thin steel sheets that form CFS members are prone to geometrical changes resulting from production, transportation, and installation. These geometric changes also referred to as geometric imperfections may cause changes in the predicted physical response of CFS members. Thus, it is important to extract the as-is condition of CFS members and model them based on their actual geometry. In this paper, a method for converting the surface data collected from a CFS member into a 3D solid model via voxelization is discussed.

Keywords**:** 3D solid model, point clouds, surface data, voxelization, cold-formed steel members.

1. Introduction

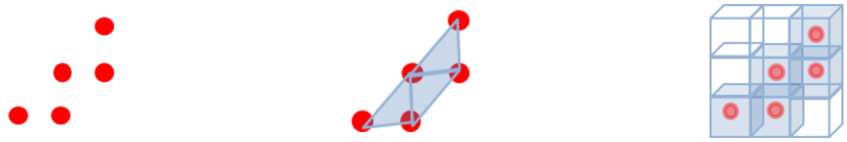
3D modelling of CFS members is generally performed based on the design geometry rather than the actual geometry of the member. However, the geometric imperfections that resulted from several factors such as production, transportation, and installation effect the physical behaviour of CFS members. Thus, it is necessary to extract the actual geometry and embed the effects of the recorded geometric imperfections in the 3D model. In order to achieve this, first, the surface data of a CFS member is collected with a scanner. Later, the 3D model is constructed based on the actual geometry.

Surface data-based modeling, which is one of the major civil engineering applications for surface data scanners, includes incorporation of scan data with the generation or validation of both computer-aided design (CAD) models and building information models (BIMs). CAD models generally represent structures with sets of independent planer surfaces, whereas BIMs, which provides adjacency relationships between connected elements in a model, represent facilities in a semantically rich manner. The modeling of a BIM from a given point cloud involves three tasks, which are modeling the geometry of the components, assigning material properties and an object category to a component and finally, establishing relationships between components [1]. Some key examples of laser-based modeling from literature are discussed in the following paragraph.

In a prior study, laser scanners have been used to augment measurements from other sensors to determine the geometry of existing structures [2]. In another application, Vosselman, Gorte [3] reviewed several techniques that can be used for recognizing specific geometric shapes in order to implement an automatic processing of the point clouds. Industrial components are modeled from point clouds into surfaces without using triangulation but by using a feature-based strategy and surface feature-based strategy [4]. Accurate 2D plan models of building interiors have also been created by an automated method in which 3D point cloud data was used as input [5]. Adan, Xiong [6] discussed a method that converts raw 3D point data to a semantic model automatically. This method identifies objects in an indoor environment including walls, floors, ceilings, windows and doorways even in the presence of significant clutter and occlusion. Ip and Gupta [7] used a partial 3D point cloud of an artifact for retrieving the CAD model consists of polygonal meshes for segmenting the point cloud and searched for a potential model match. An extensive review for extracting as-built building information models from laser point cloud is given in Tang, Huber [8].

2. Voxelization and 3D Modeling

In this research, voxelization is used for creating a 3D solid model from the collected surface data, which is also referred as a point cloud. Voxelization is the process of converting the geometric representation of a point cloud into a set of voxels that accurately represents the investigated point cloud within a discrete voxel space. It is an important tool to extract both 2D and 3D information from unorganized point clouds. Most of the existing voxelization methods that are used for operating on surface representations of objects (such as aerial laser scanner or terrestrial laser scanner data) could be divided into two sub-categories: surface-based voxelization methods [9] and point-based voxelization methods [10]. The representations of both surface-based and point-based methods are shown in Fig. 1. The voxelization method used for this research is a point-based voxelization technique, which does not require an initial surface model of the object, and hence allows direct point cloud processing.



(a) Points (b) Surface-based (c) Point-based

Fig. 1: (a) A sample point set, (b) surface-based voxelization (also called surface meshing) result, and (c) point-based voxelization result.

The point cloud that is composed of the surface data points of the investigated CFS member, which are rotated to fit a given axis by using the results of orthogonal linear regression Jolliffe [11], is given as $P = \{p_0, \dots, p_{n-1}\}$ where n_p is the number of points, and each point p_i is in the form of $p_i = (x_i, y_i, z_i)$. Principle component analysis, which is used to compute the eigenvalues λ and the eigenvectors $\vec{v}$, is used to determine the direction of the fitted line. The direction vector that defines the fitted line is represented by the coefficients of the first principle component. This direction vector $\vec{v_1}$ and a reference rotation vector $\vec{r}$, which is taken as [0 0 1] (z-direction) of a reference coordinate system, are used for rotation. All the points in P are rotated to align with $\vec{r}$ by using the Eqs. (1) and (2). First, the rotation matrix R is computed by using the Rodriques' rotation formula. The original P is then multiplied with R to get the rotated point cloud P_{rot}. This step is performed to enable the selection of a height function along the z-axis. The height function increment $h_p = \Delta_z$, which also refers to the resolution in z-direction, is an input parameter defined by the user. Its value is determined based on the requirements of the 3D model. Δ_z is taken as 1 mm for this research.

$$[\vec{v_1}]_x \vec{r} = \vec{v_1} \times \vec{r} = \begin{bmatrix} 0 & -\vec{v_1}_3 & \vec{v_1}_2 \\ \vec{v_1}_3 & 0 & -\vec{v_1}_1 \\ -\vec{v_1}_2 & \vec{v_1}_1 & 0 \end{bmatrix} \vec{r} \tag{1}$$

$$R = I + \sin\beta\, [\vec{v_1}]_x + (1 - \cos\beta)(\vec{v_1}\vec{v_1}' - I) \tag{2}$$

where β is the angle between $\vec{v_1}$ and $\vec{r}$.

The voxelization method implemented here is explained in Hinks [12], and it consists of three main steps. These steps can be listed as construction of a voxel grid based on the laser point clouds, mapping of the given laser point cloud to the generated voxel grid, and determination of active voxels based on the performed point mapping. The bounds of the voxel grid assure that every point $p_i \in P$ has an accurate voxel mapping. These bounds are defined by the minimum and maximum values of all points in P along x, y, and z-directions: (x_{min}, x_{max}), (y_{min}, y_{max}), and (z_{min}, z_{max}). The voxel grid dimensions in x, y, and z directions are determined by using a targeted resolution value r_p $(\Delta_x = \Delta_y)$ provided by the user or computed based on the point cloud resolution. For thin walled members, Δ_x and Δ_y are both determined to be equal to the thickness of the steel sheet that forms the CFS member. The number of voxels along each axis X_n, Y_n and Z_n is determined by using Eqs (3), (4), and (5). Fig. 2 represents samples of a voxel grid and a single voxel.

$$X_n = \frac{|x_{max} - x_{min}|}{\Delta x} \tag{3}$$

$$Y_n = \frac{|y_{max} - y_{min}|}{\Delta y} \tag{4}$$

$$Z_n = \frac{|z_{max} - z_{min}|}{\Delta z} \tag{5}$$

(a) Voxel grid

(b) Voxel (v_i, v_j, v_k)

Fig. 2: Representation of (a) a sample voxel grid and (b) a single voxel.

Once the suitable voxel grid is created, active voxels are determined based on the point mapping results. Mapping is performed by using Eqs. (6), (7), and (8). Voxels that contain more points than a given threshold value T_n are marked as an active voxel. In this research the threshold value T_n is taken as 1, thus each voxel that has at least one point is marked as active. This process converts the 3D dataset into a 3D binary image.

$$v_i = \left\lfloor (X_n - 1)\frac{(x_i - x_{min})}{(x_{max} - x_{min})} + 0.5 \right\rfloor \tag{3}$$

$$v_j = \left\lfloor (Y_n - 1)\frac{(y_i - y_{min})}{(y_{max} - y_{min})} + 0.5 \right\rfloor \tag{4}$$

$$v_k = \left\lfloor (Z_n - 1)\frac{(z_i - z_{min})}{(z_{max} - z_{min})} + 0.5 \right\rfloor \tag{5}$$

where $\lfloor x \rfloor$ operator rounds down the computed voxel coordinates to the closest integer value.

As explained above, the voxel grid is a volumetric representation, and for T_n=1 it can be treated as a 3D binary image that forms the 3D solid model of the investigated CFS member.

3. Data Collection and Results

Surface data of a CFS member with the dimensions given in Table 1 is collected by using an Breuckmann 3D scanner with a 2 megapiksel camera that utilizes green light technology. The lens used for scanning the CFS member has a 700 mm field of view and the scanning resolution is 60 microns. The collected point cloud consists of 383219 points and the generated surface model has 756154 faces. The collected point cloud is shown in Fig. 3.

Table 1: Dimensions of the scanned CFS member.

Type	Thickness (mm)	Web (mm)	Flange (mm)	Lip (mm)	Length (mm)
C	1.2	90	45	10	900

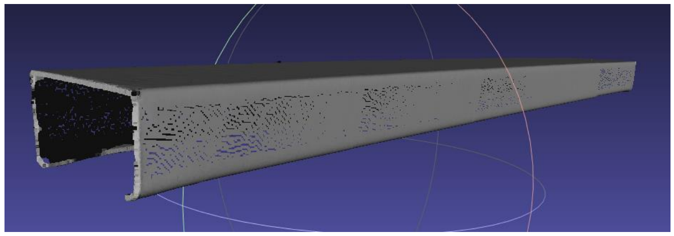


Fig. 3: Point cloud of the scanned CFS member.

Once the surface data is collected, the voxelization process is performed. The resulting 3D geometry obtained through voxelization is then imported into a finite element analysis suite, ANSYS v17. The resulting model is presented in Fig. 3. It should be noted that the accuracy of the model is correlated with the accuracy of the collected point cloud.

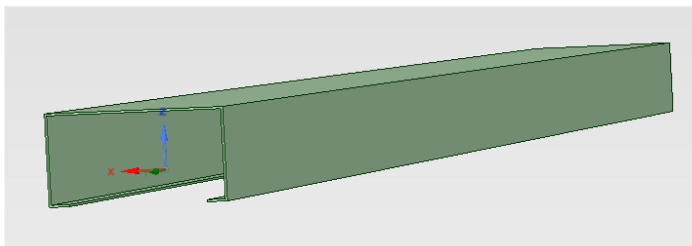


Fig. 4: 3D solid model exported to ANSYS v17.

4. Conclusions

This paper focuses on extracting the 3D solid model representation of a scanned CFS member by using voxelization. The surface point cloud is first captured via a laser scanner. The 3D model is then generated by performing voxelization on the unorganized point cloud. Future work will investigate how the physical response is affected based on the utilized 3D model. Both actual and design geometries will be modelled and the obtained results will be compared.

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References

[1] D. Huber, B. Akinci, A. Oliver, E. Anil, B. Okorn, and X. Xiong, "Methods for Automatically Modeling and Representing as-built Building Information Models," in *NSF Engineering Research and Innovation Conference*, Atlanta, GA, 2011.

[2] F. Gielsdorf, A. Rietdorf, and L. Gründig, "Geometrical Modelling of Buildings - the Frame for the Integration of Data Acquisition Techniques," in *Proceedings of FIG Working Week*, Athens, Greece, 2004.

[3] G. Vosselman, B. G. Gorte, G. Sithole, and T. Rabbani, "Recognising Structure in Laser Scanner Point Clouds," *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 46, no. 8, pp. 33-38, 2004.

[4] Y. Ke, S. Fan, W. Zhu, A. Li, F. Liu, and X. Shi, "Feature-based Reverse Modeling Strategies," *Computer-Aided Design*, vol. 38, no. 5, pp. 485-506, 2006.

[5] B. Okorn, X. Xiong, B. Akinci, and D. Huber, "Toward Automated Modeling of Floor Plans," in *Proceedings of the Symposium on 3D Data Processing, Visualization and Transmission*, Paris, France, 2010.

[6] A. Adan, X. Xiong, B. Akinci, and D. Huber, "Automatic Creation of Semantically Rich 3D Building Models from Laser Scanner Data," in *Proceedings of the International Symposium on Automation and Robotics in Construction (ISARC)*, Seoul, Korea, 2011.

[7] C. Y. Ip and S. K. Gupta. "Retrieving Matching CAD Models by using Partial 3D Point Clouds," *Computer-Aided Design & Applications*, vol. 4, no. 5, pp. 629-638, 2007.

[8] P. Tang, D. Huber, B. Akinci, R. Lipman, and A. Lytle, "Automatic Reconstruction of As-built Building Information Models from Laser-scanned Point Clouds: A Review of Related Techniques," *Automation in Construction*, vol. 19, no. 7, pp. 829-843, 2010.

[9] S. F. F. Gibson, "Beyond Volume Rendering: Visualization, Haptic Exploration, and Physical Modeling of Voxel-based Objects," in *Visualization in Scientific Computing*, Chia, Italy, 1995.

[10] D. Nehab and P. Shilane, "Stratified Point Sampling of 3D Models," in *Proceedings of the First Eurographics Conference on Point-Based Graphics*, Aire-la-Ville, Switzerland, 2004.

[11] I. Jolliffe, "Principal Components in Regression Analysis," 2nd Edition, *Principal Component Analysis*. Medford, MA: Springer, pp. 129-155, 2002.

[12] T. Hinks, "Geometric Processing Techniques for Urban Aerial Laser Scan Data," in *College of Engineering, Mathematical and Physical Sciences*, University College Dublin: Dublin, Ireland, 2011.