Evaluation of a Semi-automated Photogrammetry-based Method for Geometry Creation for Urban Simulations

***†Chinchun Ooi[1], Raymond Quek[1], Zhengwei Ge[1], Hee Joo Poh[1], and George Xu[1]**

[1]Department of Fluid Dynamics, Institute of High Performance Computing, Singapore.

*Presenting author: ooicc@ihpc.a-star.edu.sg
†Corresponding author: ooicc@ihpc.a-star.edu.sg

Abstract

With the increasing accessibility of computing power in recent years, computational fluid dynamics (CFD) has become a vital and routine part of the building design process. However, these simulations require explicit modeling of major structures in the vicinity of the building of interest, as the orientation and placement of these structures can have significant impact on the local wind flow patterns around and within the building of interest. However, the manual generation of these geometries can be extremely tedious. Thus, we propose a semi-automated photogrammetry-based approach to regenerate simplified building geometries for urban simulations. We also examine the actual discrepancy in heights between the photogrammetry-generated buildings and the actual reported building heights from an online database for a sample location in Singapore, and report a mean percentage error of less than 10% under this approach, thus suggesting the applicability of this method to a wide range of urban simulations.

Keywords: Computational Fluid Dynamics, Urban Simulations, Photogrammetry, Automated Geometry Regeneration

Introduction

With the recent advances in availability of computing power, computational fluid dynamics (CFD) has become a vital and routine part of the urban planning and building design process. Singapore's Building and Construction Authority, for example, now has established guidelines for conducting CFD simulations in their Green Mark methodology to aid in performance-based urban planning and building design [1].

Even while these urban simulations become increasingly common, scientific literature now recommends explicit modeling of major structures in the vicinity of the building of interest in the urban built environment, as these local structures can have significant impact on the local wind flow patterns around the building of interest [2, 3]. Assuming a typical building length and spacing of approximately 10 x 10 m^2 to 100 x 100 m^2, there can be on the order of 100 buildings around the building of interest that needs to be explicitly modeled. While one option is to purchase the explicit building footprints and geometries directly from relevant governmental agencies, this may not always be an option due to a variety of issues such as cost, especially for academics, or lack of documentation, especially for older structures and buildings with no appropriately digitized records. A common solution is thus to capitalize on open-source resources such as Google Maps or Open Street Maps to manually obtain the building footprint, and re-generate the buildings in a computer-assisted design (CAD) program by hand. This is laborious, and often also requires the CFD practitioner to resort to other methods to obtain the building heights, such as the enumeration of building floors through on-site visits.

Conversely, photogrammetry is a long developed technique in other applications that has been previously described in literature as an effective means of obtaining 3D-model information for various urban simulations [4, 5]. While image acquisition in the past might have been difficult, the increasingly widespread availability of drone photography now makes photogrammetry for geometry regeneration a feasible solution. In addition, while photogrammetry can produce extremely high fidelity geometries, the sheer scale of CFD urban simulations often necessitate simplifications in the geometry, hence necessitating an additional processing step post-photogrammetry.

In this work, we thus propose a semi-automated photogrammetry-based approach to regenerate building geometries for urban simulations. While this method cannot regenerate the actual building of interest in adequate detail for modeling, it can help expedite the generation of surrounding buildings for explicit modeling which often do not need to be represented in as fine detail. We describe the workflow in the following section, along with a comparison of the actual discrepancy in heights between the photogrammetry-generated buildings and the actual reported building heights in an online database. This is anticipated to provide a quantitative measure for interested urban simulation practitioners to decide if photogrammetry is indeed suitable for further routine use.

Methods and Results

Semi-Automated Photogrammetry Workflow

There are 3 components to the current workflow, with occasional human input required. Two sources of images are required, with the first being 3-dimensional aerial images of the area of interest, such as can be acquired by aerial drone photography, and the second being 2-dimensional images or schematics of the building footprints, similar to the maps available from open source resources such as Open Street Maps. The combination of these images to create an actual water-tight CAD geometry for subsequent urban simulations is described in greater detail in the following subsections. Additionally, the scripts used for the automatic acquisition and conversion of acquired images to the actual CAD geometries are available for referencing at https://github.com/ooichinchun/Maps2Geometry.

Aerial Image Acquisition

Images acquired in this work are 3-dimensional screen grabs from Google Maps instead of actual drone photography images. However, it is anticipated that aerial drone photography would be able to obtain images of a similar quality and type. The set of images acquired should span a complete rotation around the area of interest, and should ideally comprise a set of images at different azimuths as well. A representative example of a potential image that can be used is presented in Figure 1.

Figure 1. Example aerial photograph of the area of interest to be modeled.

Building Footprint Modeling

Images of the simplified building footprints can be acquired from sources such as Open Street Maps as .svg vector files. From these files, it is possible to obtain the vertices and lines that make up individual building polygons. In addition, the convex hull algorithm can be used to simplify the geometry, as illustrated in Figure 2 [6]. The convex hull algorithm essentially seals off small gaps and undulations within the buildings, which are often not meshed in actual CFD urban simulations due to their comparatively small length scales. For example, the two buildings in the top right corner of Figure 2 with the undulating edges are simplified by the convex hull algorithm into relatively simpler polygons. The resulting set of vertices and edges can then be written out into a CAD file for import into any CAD program.

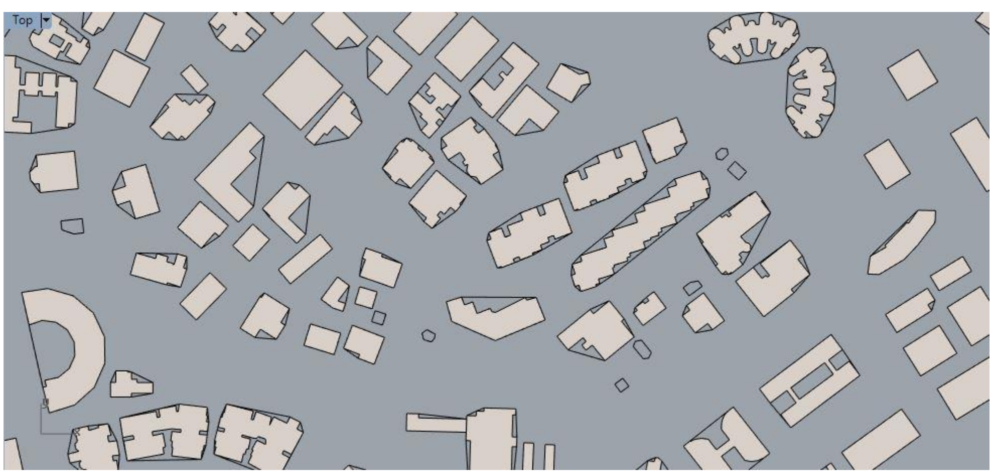

Figure 2. Example of the geometries regenerated from Open Street Maps (objects with the solid brown fill) and the convex hull geometries generated (black lines).

Geometry Regeneration

The aerial images acquired in the prior step are then used to re-generate the geometry via photogrammetry. Agisoft Photoscan is used in this work to convert the set of images into an actual 3-dimensional point cloud. Rescaling and re-alignment to a North-South orientation are required at this stage to ensure consistency with the geometry file generated from Open Street Maps. The individual mesh points generated by photogrammetry are then filtered by their Cartesian coordinates for the building locations as defined by the geometry file such that the respective building heights can be obtained and the individual building footprints can be extruded accordingly. Representative output images for this process are displayed in Figure 3.

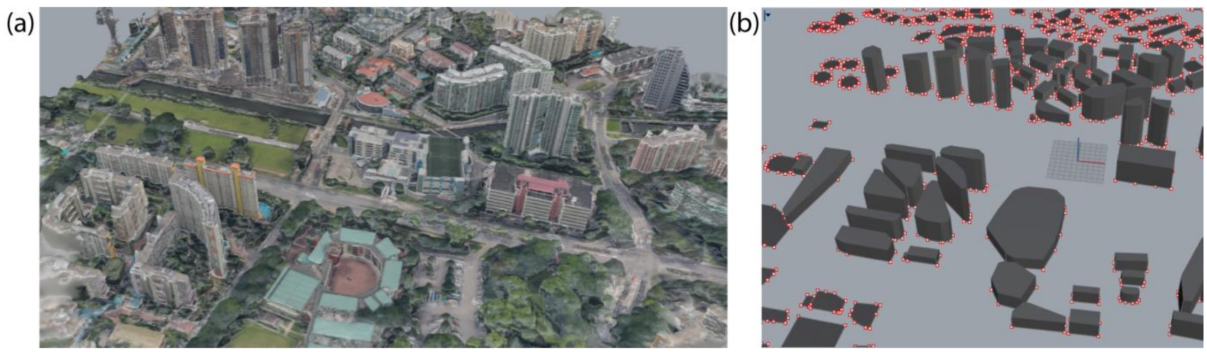

Figure 3. (a) Sample output of the mesh from photogrammetry for the aerial images obtained (b) Corresponding output of the scripts for the simplified extruded buildings around the region of interest.

Quantification of Error in Geometry Regeneration

The generated geometries are then analyzed for discrepancies to assess the accuracy of this particular method. Heights as obtained from the photogrammetry point cloud are compared to heights obtained from an online reference (www.emporis.com), and the results are plotted in Figure 4.

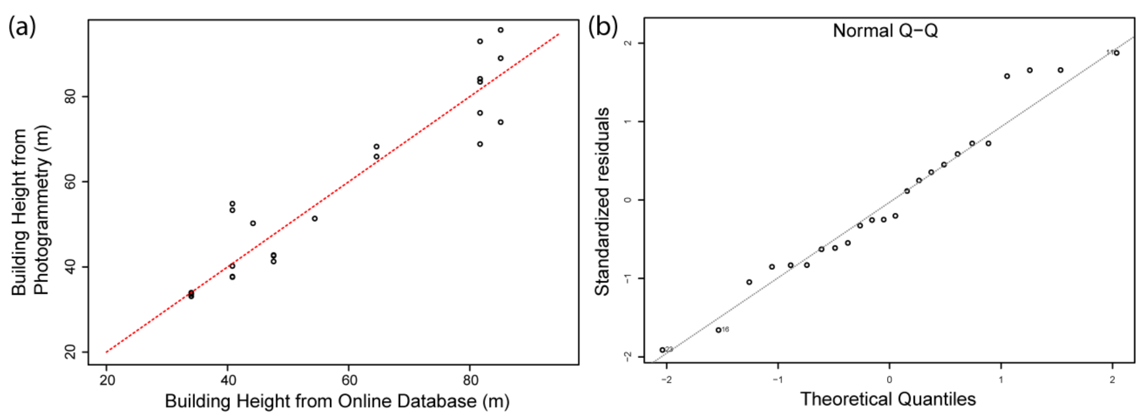

Figure 4. (a) Plot of the building heights as obtained from an online database against the building heights obtained by the photogrammetry-based method described in this work. (b) A normal Q-Q plot for the standardized residuals for the regression line from (a).

The results indicate that there is a very good match between the building heights as reported by the online reference and as produced from photogrammetry. The gradient of the line in Figure 4a is 0.97, while the R^2 of the regression is 0.88. The Q-Q normal plot of the scaled residuals as per Figure 4b also indicates that there is no systemic error in the photogrammetry, with the regression exhibiting normally-distributed errors. More critically, we determine the mean and median absolute percentage error in heights to be 9.7% and 7.7% respectively, which can be a helpful measure for the CFD practitioner to determine if this method is appropriate for their purposes.

Conclusions

In this work, we demonstrate the application of photogrammetry to rapidly regenerate simplified building geometries for urban CFD simulations. More critically, we show that the discrepancy in heights obtained via this method are less than 10%, which is probably much less than the typical uncertainty in other parameters such as appropriate inlet wind velocity for urban simulations. We anticipate that this method would be of increasing interest to CFD practitioners, as the necessity for accurate representation of surrounding buildings in CFD simulations gradually becomes more evident to industry.

References

1. Authority BaC. BCA GREEN MARK : Technical Guide and Requirements. 2015.
2. Tominaga Y, Mochida A, Yoshie R, Kataoka H, Nozu T, Yoshikawa M, et al. AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. Journal of wind engineering and industrial aerodynamics. 2008;96(10-11):1749-61.
3. Blocken B. Computational Fluid Dynamics for urban physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations. Building and Environment. 2015;91:219-45.
4. Hu J, You S, Neumann U. Approaches to large-scale urban modeling. IEEE Computer Graphics and Applications. 2003;23(6):62-9.
5. Shiode N. 3D urban models: Recent developments in the digital modelling of urban environments in three-dimensions. GeoJournal. 2000;52(3):263-9.
6. Barber CB, Dobkin DP, Dobkin DP, Huhdanpaa H. The quickhull algorithm for convex hulls. ACM Transactions on Mathematical Software (TOMS). 1996;22(4):469-83.