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High-detailed city reconstruction for urban flow simulations

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SUMMARY:
This work deals with geometry creation and preparation, one of the main bottlenecks of microscale urban flow simulations. While most automatic building reconstruction algorithms rely on building footprint extrusion to a certain height, previous research results indicated that this simple method creating block-shaped buildings may not be sufficient for urban microscale simulations. To address this issue, we propose an automatic building reconstruction workflow that enables geometry creation at higher levels of abstraction. The input data for reconstruction are building footprints in form of polygons and point cloud data such as airborne LiDAR or photogrammetry. The workflow aims to reconstruct geometries with satisfactory quality for typical body-fitted finite volume mesh generators, i.e. without self intersections, missing or duplicate faces, and non-manifold edges. The workflow is implemented as part of a framework that reconstructs and smooths terrain, imprints different surfaces into terrain (different roughness characteristics), and also automatically denotes the region of interest and domain boundaries. We tested the reconstruction on two different datasets, one in the Netherlands, and another one in the USA, and will investigate the feasibility of body-fitted mesh generation using an unstructured hexagonal grid generator.

Keywords: geometry preparation, pre-processing, automatic building reconstruction

1. INTRODUCTION

Geometry pre-processing for urban microscale simulation is still a tedious job. It requires multiple steps such as data acquisition, preparation, and reconstruction while adhering to the specific requirements imposed by the simulation software. There are a lot of already existing 3D city models available, however, most of them are not created with simulation requirements in mind (Biljecki, Ledoux, Du, et al., 2016). That being the case, such models typically contain two main issues:

1. They are riddled with errors (Biljecki, Ledoux, Du, et al., 2016), some of which are detrimental for numerical simulations; which errors have significant impact depends on the numerical method used, but generally include duplicate faces, non-manifolds, self intersections, and missing faces.
2. Even in the presence of building geometries, other information relevant to numerical simulations is often omitted from these models, including terrain, designation of different rough surfaces (e.g. water, grass-covered surfaces, impervious ground surfaces), higher vegetation such as trees. Connecting pieces of this puzzle is not a trivial task.

The usage of such detailed models containing buildings, terrain, vegetation, and different surfaces has been increasing in recent years, an example being the work of Brozovsky et al. (2021). To mitigate the large amount of manual work required to prepare those models, a few automation solutions were proposed by researchers, such as Deininger et al. (2020).

We proposed a workflow in Pađen et al. (2022) that reconstructs buildings to the level of detail (LoD) 1.2 (i.e. footprint extrusion, according to the classification by Biljecki, Ledoux, and Stoter (2016)) along with smooth terrain inclusion, imprinting of different surface layers used to denote rough surfaces, and automatic region of interest and domain boundary definition according to best practice guidelines (Franke et al., 2007; Liu et al., 2018; Tominaga et al., 2008). Some levels of detail (LoDs) relevant for urban flow simulations are shown in the figure below.

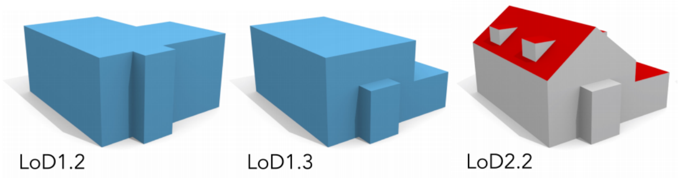

Figure 1. LoD definitions for buildings. Adapted from Biljecki, Ledoux, and Stoter (2016).

Automatic building reconstruction algorithms for LoDs above 1.2 are scarce and practically non-existent for urban flow simulations. However, the works of Ricci et al. (2017) and García-Sánchez et al. (2021) have indicated that LoD1.2 might be insufficient to capture phenomena typical in urban microscale investigations. For those reasons, we have expanded our methodology from Pađen et al. (2022) with an automatic LoD1.3 and LoD2.2 reconstruction workflow.

2. METHODOLOGY

Our workflow is based on the automatic reconstruction algorithm by Peters et al. (2022). It uses the combination of a point cloud and building footprints to automatically reconstruct buildings in LoD1.3 or LoD2.2. The methodology consists of five main points (see Fig 2): first, the roof planes are detected using a region-growing algorithm. Second, the edge lines of planes are detected using the α-shape calculation of respective planes (Edelsbrunner et al., 1983). Third, detected lines are projected downwards, regularized, and duplicate lines are removed. Fourth, the remaining lines are used to form a planar partition of roof surfaces; the partition can contain many small surfaces whose complexity is then reduced through the graph-cut optimization (Zebedin et al., 2008). As a result, edges of partitions belonging to the same roof plane are removed, resulting in larger roof parts. Last, the resulting roof parts are then extruded to form a final 2.5D mesh. It is important to address that the parameters of the algorithm enable the inclusion or removal of details of buildings, such as chimneys or other smaller surfaces.

While the algorithm aims to reconstruct valid buildings, it is possible for a reconstruction to fail or to result in invalid buildings, with up to 2% as indicated by the benchmark conducted in Dukai et al. (2021). As part of the workflow, the validity check of every single building according to the ISO 19107 standard (ISO, 2019) is conducted. In the case of invalid buildings with problems known to cause issues for finite volume mesh generators, different fallback mechanisms are provided. Potential issues and their solutions are listed in Tab 1.

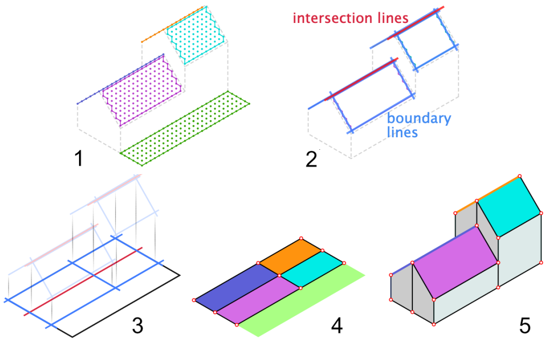

Figure 2. The main steps of the reconstruction algorithm. 1) plane detection, 2) line extraction, 3) regularisation and 2D projection of lines, 4) roof paritions creation and optimisation, 5) extrusion of roof partitions to 3D. Adapted from Peters et al. (2022).

Table 1. Potential issues with reconstruction and their fallbacks.

Issue	Solution
Non-manifold faces	Repair according to Huang et al., 2020
Self intersections	Repair according to Huang et al., 2020
Missing faces	Hole-filling algorithm

In case the non-manifold/self-intersection repair algorithm fails, the last fallback is the alpha wrapping algorithm by Alliez et al. (2022). Alternatively, those problematic buildings can be reconstructed in lower LoDs, with LoD1.2 used as the last resort. The workflow also provides seamless terrain integration and solves eventual overlaps between surface layers and buildings caused by low-quality data.

3. CASE STUDIES

We investigated the reconstruction workflow with two different datasets – one in the Netherlands, the Delft University of Technology's (TUD) campus, and the other one in the USA, the campus of Stanford University. The input data for the TUD's campus were national open building footprint and airborne LiDAR datasets, BAG and AHN3, both accessible at PDOK (2022). The input for the Stanford campus were also freely available building polygons from OpenStreetMap (OpenStreetMap contributors, 2022) and the Santa Clara county point cloud (U.S. Geological Survey, 2021). Fig 3 shows preliminary results of the reconstruction workflow for both locations.

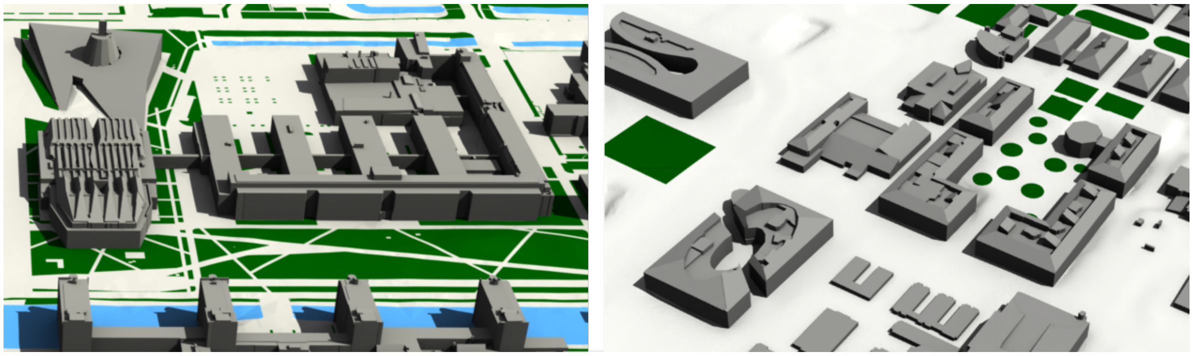

Figure 3. LoD2.2 reconstruction results with terrain, water, and water surfaces, Delft (left) and Stanford (right).

Detailed quality and benchmark metrics regarding the reconstruction, as well as the computational grid generation for body-fitted finite volume meshes, will follow.

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