Enhancing photogrammetric 3d city models with procedural modeling techniques for urban planning support

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Abstract. This paper presents a workflow to increase the level of detail of reality-based 3D urban models. It combines the established workflows from photogrammetry and procedural modeling in order to exploit distinct advantages of both approaches. The combination has advantages over purely automatic acquisition in terms of visual quality, accuracy and model semantics. Compared to manual modeling, procedural techniques can be much more time effective while maintaining the qualitative properties of the modeled environment. In addition, our method includes processes for procedurally adding additional features such as road and rail networks. The resulting models meet the increasing needs in urban environments for planning, inventory, and analysis.

1. Introduction
Capturing as-built environments in 3D for today’s planning and development projects gains importance with the ongoing densification and urbanization [1]. Although several automatic or semi-automatic 3D acquisition workflows exist, extensive manual 3D modeling is often required to meet visual quality and accuracy goals. This paper presents a workflow to make reality-based 3D urban models more detailed and to make them available to urban planning purposes. It combines the established workflows from photogrammetry and procedural modeling in order to exploit distinct advantages of both approaches. The presented workflow was originally developed at ETH Zurich’s Future Cities Laboratory in Singapore, and uses photogrammetry for measuring geo-referenced satellite imagery to create 3D building models and textured roof geometry. The results are then used to create attributed building footprints, which can be applied in the procedural modeling part of the workflow. Thereby procedural building models and detailed façade structures, based on street-level photos, are created. The final step merges the textured roof geometry with the procedural façade geometry, resulting in an improved model compared with using each technique alone. In addition to the original workflow, here we also include support for adding additional city model layers, such as transportation networks, which are important for urban planning scenarios.

2. Background
Photogrammetry [2] is a well-established technique for the acquisition of large-scale 3D data. It combines multiple views of an area with a sensor model in order to create a 3D representation. The views come from sources such as satellite images, aerial images, oblique aerial images, or imagery captured by UAVs. The quality of the 3D data can be further enhanced by integrating LiDAR data and using geometrical models such as rational polynomial coefficients [3].

Manual 3D modeling of urban structures is often done in cases when a more detailed model is required, additional structural information (such as floors or accurate building footprints) is required or simply the imagery does not include the required information (e.g. street-level textures are difficult...
to capture from the air). Besides the traditional polygon-based 3D modeling, procedural modeling languages such as the Computer Generated Architecture (CGA) implementation in Esri’s CityEngine [4] gain importance and have specific advantages over the traditional approaches. Procedural modeling is a rule-based system to describe spatial relationships between geometric objects. A typical procedural model is created by recursively refining a starting geometry such as a building massing into floors, façade tiles, windows, doors, balconies down to the required level of detail for the final 3D model. In addition, procedural modeling techniques are a powerful tool for handling additional urban layers, such as transportation networks, including detailed street geometry generation, or vegetation.

3. The workflow
The combined photogrammetry and procedural modeling workflow was originally developed by Müller Arisona et al [5] at ETH Zurich’s Future Cities Laboratory. It was successfully applied and validated as a case study to reconstruct Singapore’s Punggol new town area in 3D. Figure 1 illustrates the workflow, which in this paper has been generalized and allows for additional handling for transportation networks.

![Figure 1. Combined photogrammetric & procedural modelling process, adapted from [5] and with added process for procedural street generation.](image)

The photogrammetric process started with satellite imagery captured by WorldView-2 (Figure 2), which was combined with additional ground control points acquired with Trimble GPS technology to produce an accurate, geo-referenced stereo model. This model was then used on the one hand for the digital terrain model and on the other hand for building measurements with ERDAS Stereo Analyst in order to create mass models with CC-Modeler and CC-Edit [6]. The image data was then re-projected onto the buildings and the terrain resulting in a reality-based, accurate 3D model with textured terrain and buildings.
The next step towards a realistic looking building was adding textured facades. Figure 3 shows the plan-based footprints of an excerpt and an example façade of the study area, illustrating the challenge when modeling Punggol’s high-rise buildings in 3D. Typically manual modeling needs to be applied after initial photogrammetric modeling if detailed 3D façade structures and high quality textures are required. This is where procedural modeling comes into play, and therefore for further processing the dataset was imported into CityEngine. Using CityEngine’s façade wizard, street level imagery is
easily rectified and converted into a procedural façade model, which then can be applied to the building massing (Figure 4).

Figure 4. CityEngine façade wizard in action. Left: Original image, rectified. Middle: Generated 3D façade. Right: Final 3D building model.

Thanks to the procedural model, it is very easy to create multiple levels of detail of the same building as well as extracting semantic information such as number of floors and floor area which were not available with original the input data. The procedural modeling step is even further simplified when the input data adheres to Esri’s 3D City information model [7]. The 3D City information model defines a data schema which together with Esri’s procedural rule library turns attributed 2D GIS data automatically into 3D buildings and vegetation which then can be used for visualization, scenario planning and analysis without the need to do any procedural modeling at all. Moreover, rendering of highly detailed, textured 3D facades can be implemented on GPUs, allowing for real-time rendering of very large-scale 3D city models [8].

As indicated earlier, in this work, the combined workflow was enhanced with processes of augmenting the building models with additional layers such as transportation networks, street geometry or vegetation. This addition is illustrated in Figures 5 and 6, where the photogrammetric building models were combined with procedural detail and texturing and the planned scenario of an elevated rail system in Honolulu [9].

4. Conclusion

As-built environments become increasingly important in urban environments for planning, inventory, and analysis. Photogrammetry combined with procedural modeling has advantages over purely automatic acquisition in terms of visual quality, accuracy and model semantics. Compared to manual modeling, procedural techniques are typically more time effective. For future work, we plan to further investigate optimizing the workflow, such as for instance integrating semi-automatic façade subdivision and generation. In addition overlaying urban analysis techniques such as land-use or building functions for planning purposes is an area that would make the approach more integrative.
**Figure 5.** Honolulu elevated rail system planning [9]: Photogrammetry-based building volumes, combined with procedurally added elevated rail path.

**Figure 6.** Honolulu elevated rail system planning [9]: Final urban model, with procedurally enhanced buildings, street networks and additional assets such as the ship.

**References**

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