Implications of Automated Height Extrusion and the Selection of Height Reference for LoD 1 SmartKADASTER City Model

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Abstract. This paper discusses the lessons learnt from the SmartKADASTER Phase II city model development project, specifically on the reconstruction of the LoD 1 CityGML models. The LoD 1 models were reconstructed using automated height extrusions, either by creating categorised point clouds or by employing a raster-based equation such as CHM=DSM-DTM. The methods for reconstructing the LoD1 are further elaborated in this study. However, due to the particular nature of Malaysian buildings and inaccurate point cloud classifications, automated height extrusion alone was found to be insufficient to achieve the typical recommended average rooftop height as the LoD1 height reference. Additionally, it was determined that the recommended height reference is also unsuitable for cadastre-based analysis and other beyond cadastre purposes in Malaysia. As a result, this paper will discuss the selection of the LoD1 height reference and suggest the approach to ensure accurate height extrusion of the LoD1 model can be met. Finally, it is hoped that this work will contribute to the body of knowledge by appropriately referencing their 3D models for analysis purposes and raising readers' awareness of the SmartKADASTER application system.

1. 3D Models for City Modelling

Different object/model abstractions (referred to as scales) are created in geospatial modelling (either 2D or 3D) to support various decision-making applications and facilitate a better understanding of real-world phenomena across multiple disciplines. For example, 3D models of city modelling can be represented in a variety level of detail and dimensions, including 0D as a point of interest (POI), 2D as a building footprint, and 3D as a three-dimensional measurement. The higher the dimension, the more details and the more resemblance to real-world phenomena. However, model abstraction typically entails a range of accuracies, requirements, and levels of information to be stored [1], and sharing the same models across domains may result in some conflict of interest (users of the models). As for the purpose of sharing 3D multiple scale models, CityGML is a well-known international standard and schema for spatial modelling. It is a standardised data model in XML format introduced by the Open Geospatial Consortium (OGC). As reported by [2], CityGML defines the three-dimensional geometry, topology, semantics, and appearance of the most significant topographic objects (e.g. building...
structures) in urban areas. Numerous researchers have conducted research on CityGML at multiple scales [3-5], including urban changes in Taranto (simulation from 1800) [6]. Furthermore, [7] and [8] published several works on 3D CityGML building modelling (LoD1 and LoD2). These works were constructed automatically from LiDAR point cloud data. However, there were no in-depth discussions about the best practices and standards for height reference in LoD1 buildings for specific applications such as the Cadastre domain, predominantly on how to minimise potential errors compared to other LoDs or 3D mesh models.

Indeed, the CityGML format enables the exchange of 3D models of urban and landscape features between and among a variety of applications and platforms, including but not limited to mapping, cadastre, environment, navigation, urban planning, architecture, real estate, simulation, and urban facility management [1]. It introduced five (5) LoDs to represent the building, with LoD0 indicating its footprint and LoD4 representing its interior details. The accuracy for each LoD shown in Figure 1, which only provides building relative accuracy, is not determined by the user's domain requirements, particularly for building height reference, which is the primary focus of this paper. There are lesser details regarding the LoD1 rooftop specification, as well as the user's background and information to be retrieved.

![Figure 1. LOD 0-4 of CityGML with its accuracy requirements [9].](image)

This paper builds on previous publications [1, 10-14] on 3D geovisualisation in the SmartKADASTER Phase II environment. This paper aims to discuss the implications of automatically extruding the LoD1 height reference from the LoD0 height reference using only the classified ALS point cloud of a building. The following sections make up the remainder of this paper: Section 2 discusses the proposed building height references for LoD 1 buildings that are available internationally. Section 3 details the implementation of LoD1 (an automated approach to extrusion), while Section 4 highlights the results and findings. Section 5 addresses some discussion on the LoD 1 height reference as well as recommendations. Finally, the paper ends with a conclusion.

2. Available Proposed Building Height Reference (LoD1)

According to [15], a common practice in building modelling is to use the average height of the rooftop, particularly for LoD1 and LoD2. The guideline discusses two (2) categories of rooftops as a valid height reference (propose) based on the following rooftop shapes as shown in Figure 2.
However, the guideline did not include discussion of other rooftop shapes, multi-story buildings (e.g., towers, mixed-use developments, and complexes), and a particular case of traditional (localised) design buildings. Few researchers have pursued this subject; for example, [16] model buildings with multiple variations depending on how the building's component is treated in terms of rooftop height (floor count*3 m + 1.5 m). While [17] discussed downscaling and upscaling between LoD1 and LoD2, they did not mention the LoD1 height reference (option). Only [18] focuses explicitly on the height options (Figure 3) for LoD1’s standard rooftop, which may vary depending on the user's needs and the building's design.

Seven frequently used height references for the top surface elevation of LoD1 models of individual buildings are derived from the INSPIRE building model and their research. Each of them (rooftop heights) meets the CityGML standard. The distinction between the resulting geometric representations is critical for both simple and complex structures.

i. H0 Height at the roof edges - the lowest possible reference of the top surface.
ii. H1 Height at the roof eaves.
iii. H2 Height at one-third of the height of the roof.
iv. H3 Height at half of the height of the roof. This reference is related to the extrusion coupled with LiDAR point clouds, where it is typical to use the median value of the height of the points within a footprint [19].
v. H4 Height at two thirds of the height of the roof - Extrusion of superstructures such as dormers and chimneys.
vi. H5 Height at the top of the roof. This is a value that is representative of LOD2 generalisation. If necessary, it can also be derived from point clouds.
vii. H6 Height at the top of the construction of the building.

[18] concludes from a simulation study using the LoD1 computational volume that the most suitable roof height variance for geospatial modelling is the average (half of the roof height). However, the study does not examine the effect of selecting different roof height reference variations on a specific domain, such as cadastre. Thus, pilot areas covering buildings of various shapes, designs, and other characteristics are required to determine the most appropriate height reference for LoD1 in the context of cadastre and related domain information, particularly in the case of beyond cadastre purpose within the SmartKADASTER Interactive Portal (SKiP). Beyond cadastre purposes refers to purposes or applications other than land registration that possess the characteristics highlighted by [20] and would benefit from cadastre information depicting the relationships between people, land, and objects.

3. LoD1 Modelling Process in SmartKADASTER Phase II

In general, the 3D reconstruction of LOD1 models in SmartKADASTER Phase II is on the basis of 3D point clouds, DTM, and 2D footprints of buildings. As illustrated in Figure 4, the 3D reconstruction process for the LoD1 CityGML model consisted of four (4) phases.

**Figure 4.** Flowchart on deriving LoD1 model in SmartKADASTER2 project.

Phase 1 shows the data input process for the classified point cloud obtained from the Airborne LiDAR System (ALS) (Leica City Mapper) and the LoD0 building footprint with assigned 3D UPI ID. The classified ALS point cloud data was focused on building class classifications only, as the objective of the project is to develop a 3D city model of the Area of Interest (AOI), specifically LoD 1 buildings which according to [21] although simple, they are widely used in a variety of applications. The classified ALS point cloud data was used to determine the required Digital Terrain Model (DTM) for the individual tiles within the AOI, in order to obtain elevation information for the building footprint areas. The process was then repeated by extracting the building class from the classified ALS point cloud and using the
normalisation tools included in the LiDAR360 software to remove the effect of terrain relief on the point cloud data's elevation value. Following that, a Digital Surface Model (DSM) was created to represent the height of the surface, which includes buildings, bridges, and other surface objects. The DSM contained additional elevation data, such as buildings or other objects that were not included in the DTM. After subtracting the DTM from DSM, the Canopy Height Model (CHM) was created. In this project, normalised DTM and CHM results were overlaid on the building footprint and building height extraction was performed using ArcGIS 10.8 software.

Phase 2 illustrates the process of extracting building heights within the ArcGIS 10.8 software environment. The dissolve tool in the software's generalisation toolset was used to calculate the minimum and mean values from the generated normalised DTM. Then, using the Zonal Statistics tool as table tools within spatial analyst tools, the elevation (z) value of the building's area and height (z) of the building were calculated. Following that, the z values and z height table is joined and related to the newly created dissolve layers by using the FID field as the field for the join layer and then adding a new field for both z values and z height. The next step was to export the created dissolve layers as the final layer for the building shapefile, along with the z value corresponding to the minimum values and the z height corresponding to the mean_1 value computed.

Phase 3 is dedicated to the LoD1 extrusion using the FME workbench, with z height values serving as the field reference for the building height to extrude from the LoD0 building footprint. In this project, LoD1 was automatically extruded and translated to the CityGML 2.0 format using several transformers embedded in the FME desktop environment. The FME workbench developed for the extrusion of LoD1 from LoD0 and the ALS point cloud using average roof height as suggested by [18] is shown in Figure 5. Figure 6 illustrates a sample of the generated LoD 1 buildings draped over with orthophoto and DTM for 2D and 3D positional reference.

Finally, Phase 4 illustrates the LoD1 CityGML migration process into the 3D database. Further explanation on the 3D database development can be found in [14].

![Figure 5. FME workbench model builder for extrusion of CityGML LoD0 (building footprint) to LoD1 using point cloud data](image)

![Figure 6. The generated LoD1 buildings (draped with orthophoto and DTM).](image)
4. Results and Findings

After comparing the LoD 1 and LoD3 models, it was found that the majority of typical buildings within the AOI produced satisfactory results (using the suggested average roof height) and were within the accepted tolerance (as shown in Figure 1). Figure 7 depicts several overlayed LoD1 and LoD3 models, all of which are widely accepted for most beyond cadastre applications. The height (z) differences between LoD 1 (blue colour) and LoD 3 (white colour) is +/- 1.05m, which is also within the accepted spatial tolerance of +/-5m for LoD 1.

Although most typical straightforward designs of residential (such as terraces, single housing including bungalows and wooden homes) and commercial buildings' LoD 1 3D reconstructions are acceptable, nearly 30% of LoD 1 in the AOI’s vicinity are remark not acceptable because they do not meet the requirements for cadastre (strata), planner (viewshed, wind, noise, shadow, and other analysis), and aviation application purposes. Unlike in other countries, where the majority of city buildings have straightforward flat or gable roofs, Malaysia, on the other hand, does not. The 30% of LoD 1 models that were rejected was the result of the complexity and uniqueness of the building's roof structure (height), which includes traditional design roofs, the complex architecture of the modern building, the presence of multilevel block heights in the mixed development building complexes, and classification errors between the building and the ground within the AOI, where the LoD1 model is automatically extruded to represent only half of the building's actual height instead. Furthermore, incorrect classification of point clouds directly affects the height of the building when it is overlaid with LoD0 and the maximum or minimum height is extracted from the point clouds. For example, trees complicate the extraction of height information from buildings, particularly in areas where trees may obscure buildings. Consequently, the maximum top height of the classified building point cloud was found to be the most appropriate LoD 1 height reference in this study for depicting special case buildings in Malaysia, as shown in Figure 8.

Figure 7. The automatic generated LoD1 building models with respective manual sketched of LoD3.

Figure 8. Two examples of complex building heights (mosque and mix-development building) LoD1 models suitable for cadaster and aviation related domain.
Additionally, the LoD1 models’ were visually compared between automated extrusion based on the average (H3) and automated extrusion based on the highest top roof structure (H6) for these special case scenarios in Malaysia, as illustrated in Figure 9 below.

4.1 Potential Errors Resulting From the Defects Aside From the Building Structure Itself
Apart from the roof and structure of the building, several factors contributed to the automated extrusion of LoD 1 rejected results. It was observed that errors occurred most frequently during the pre-processing phases, such as ALS data containing processing noises (e.g., in Figure 10), the digitised building footprint (LoD0) containing elevation noise point clouds (e.g., tree leaves covering the roof, flying birds, telecommunication antenna, and others in Figure 11), LoD0 overshoot toward ground elevation point clouds (Figure 12), and incorrectly assigned classification group (Figure 13).

Figure 10. ALS point cloud data received contain noises which might lead to wrongly picked as maximum value of building height.
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Figure 11. Foreign objects (noises) on rooftop as point-cloud

Figure 12. Classified point-cloud received focusing on the residential and nearest building wrongly classified as vegetation classes which lead to the zero value for that building height.

Figure 13. Wrong classification of Building Classes (building wrongly classified into other feature classes i.e., vegetation) resulting from the zero value of LoD1 building height.

5. Discussion and Recommendations
The completely automated LoD1 extrusion (from LoD0) used in this study is based on building height using either building classified point clouds or a raster-based equation such as CHM=DSM-DTM. Both algorithms have advantages within LoD0 building footprint areas (point clouds can easily determine the highest rooftop height, whereas CHM can calculate the average building height). Because the technique relies solely on elevation height, neither method can extract the average/quarter height of a building's roof (e.g., A-framed, gable, or dormer roof types). Rooftop height is highly dependent on cultural, artistic, and modern design shapes, which are difficult to distinguish without deep learning or artificial intelligence technology (training algorithm by samples). Manual intervention is required (and should be considered) in determining the average height of the rooftop based on its unique shape. Otherwise, complicated structures (like multistorey roof towers) will be averaged at half their actual height.

Due to limitations such as intersecting delineated building polygons and lack of building segmentation, the LoD1 is prone to over-generalisation. As such, to overcome the disadvantages of
automated extrusion from LoD0 to LoD1 using the point-cloud technique, several improvements are suggested:

i. Double-check for noises at ALS data;
ii. Increase a level of quality check for classified point-cloud (ground, vegetation and building);
iii. Remove the noises on the building rooftop;
iv. Revise the rules of moving/adjusting the rooftop extraction (orthophoto) to the building footprint;
v. Implement segmentation upon the 2D cadastral lot as a temporary lot; and
vi. Manual height editing on complex structure/multiple height level building [16] as in Figure 14.

![Figure 14. Manual adjustment on the building shape using modelling software such as SketchUp.](image)

In relation to the above, even though LoD 1 can be used for various applications, the model's building height reference is critical to determining the proper application usage. In this study, LoD 1 height reference based on the top of the roof (H5) or the top of the construction of the building (H6) are deemed more suitable for the SmartKADASTER Phase II application than the average rooftop. This is because the SmartKADASTER Phase II project aims to enable beyond cadastral applications with a focus on cadastral relationships to support smart city implementations.

Naturally, ownership of strata multistorey buildings (e.g. mix-development apartment) will be invalid using average roof height to represent the cadaster domain (owned space without geometry model in LoD1), as there are cases where duplex homes or penthouses are not represented in the LoD1 model. Furthermore, there are spaces in the rooftops and interior typically referred to as common properties of the strata titles that can be enjoyed by all the owners of parcels [22] that need to be included in the LoD1 model. Modern but traditional roof designs, such as the Minangkabau roof; the curving roof is a symbolic mimicry of a bull's horns that can be found in Negeri Sembilan's AOI region, may incorporate space zoning that includes the roof interior that has ownership or designated for a specific communal or private use [23]. Multi-Title Development complexes for properties to be operated horizontally and vertically should have the air spaces in between building blocks or provisions (Figure 9) accounted into the LoD1 reconstruction because some strata parcels are attached with air space permits [24]. Other property or land development and city planning related applications such as viewshed, shadow analysis and population estimation, as well as other analysis that relies on building height estimations such as drone flight planning, may not also be appropriate if the height reference for LoD1 is the average rooftop or average building height. However, it should be noted that other beyond cadastral applications such as disaster management, water rise analysis, valuation management, change detection and emergency routing is sufficient with any height reference for LoD 1. Additional scientific research should be conducted to determine the usability of LoD1 building height reference in the SmartKADASTER environment applications.

6. Conclusion
In conclusion, it is hoped that this paper has contributed to the body of knowledge in determining the LoD1 building height reference model reconstruction and the proposed LoD1 height reference for
SmartKADASTER and beyond cadastre purpose. 3D geovisualisation holds the future of beyond cadastre purposes and the resulting city model of SmartKADASTER is envisioned to support its application in Malaysia’s urban areas.

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