Defining LoDs to support BIM-based 3D building abstractions in GIS

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Abstract

BIM models of buildings are increasingly being created, and they can be used as a geometrically detailed and semantically rich source for GIS building models without the need for additional data acquisition. However, the existing level of detail (LoD) schemes for buildings are based on models created from very different sources, e.g. 2D topography and remote sensing measurements. In this paper, we propose four novel Levels of Detail (LoDs) specifically tailored for BIM-derived 3D building models. The proposed LoDs—LoDa, LoDb, LoDc, and LoDd offer abstractions that leverage BIM's strengths while mitigating its limitations. LoDa provides a multi-surface representation of the footprint and roof, whereas LoDb, LoDc, and LoDd offer volumetric alternatives that better capture complex facades, vertical variations, and overhangs. The performance of these new LoDs was evaluated against the established LoD framework by Biljecki et al. (2016) using metrics such as area, volume, and spatial deviation. Results demonstrate that the proposed LoDs, particularly LoDa, LoDb, and the refined variants LoDc.2 and LoDd.2, can achieve a closer geometric approximation to the source model than standard LoD2.2, thereby enhancing the usability of BIM data in GIS applications like urban planning and building permit checks.

1. Introduction

A building model's level of detail (LoD) refers to how and to which degree a model's 3D representation has been abstracted from its real-world counterpart. Higher levels of detail approximate the shape of the real-world building more closely, but also require more detailed source data and more complex methods to create and process them. Within GIS, standardised frameworks define preset LoDs that allow users to choose an appropriate level for their particular application. The CityGML standard (OGC, 2012, 2021) defines one such framework of four LoDs (Figure 1), which was refined by Biljecki et al. (2016) into 16 more clearly defined LoDs (Figure 2).

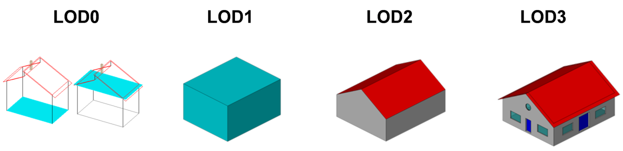

Figure 1. The four LoDs defined by the CityGML 3.0 standard (OGC, 2021)

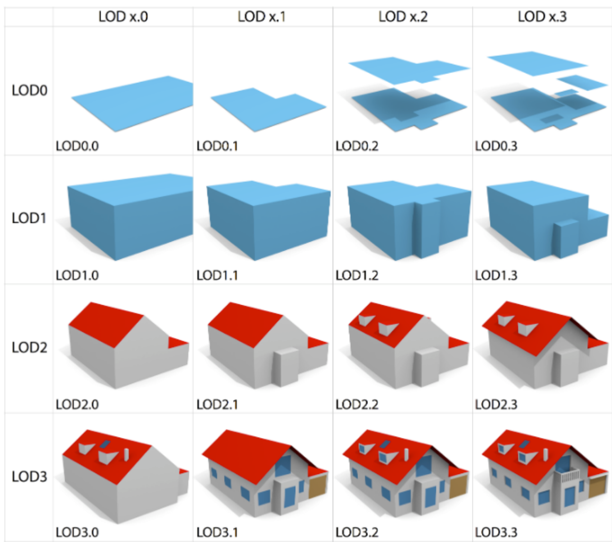

Figure 2. The 16 LoDs from the framework of Biljecki et al. (2016)

Currently, most 3D building models in GIS are created using 2D topographic data (e.g. building footprints), semantic data (e.g. numbers of storeys) and/or 3D measurements (e.g. point clouds). However, in recent years, other data sources have become viable alternatives for 3D building models in GIS. One of these is Building Information Modelling (BIM), where detailed architectural models are often produced during the design and construction process of a building. Using BIM models as a data source to produce 3D building models for GIS has a set of potential advantages, such as the availability of up-to-date building models without acquiring new measurements, the availability of models of buildings that have not yet been constructed (to determine their impact on the environment), the availability of interior data (to model the interiors of the buildings), and the lack of occluded areas and noise compared to airborne LiDAR (e.g. facades or overhangs). Based on BIM models, various conversion methods have been developed to obtain appropriately simplified models for GIS use (Arroyo Ohori et al., 2018; van der Vaart et al., 2023; Wang et al., 2019, 2024).

However, a BIM model is a very different data source from those that are typically used in GIS. For instance, it can include detailed geometries even for smaller features that are hard to capture through other means (e.g. balconies and bay windows). It can also include details of installations that are typically hidden from view (e.g. plumbing and electrical networks). On the other hand, BIM models can be extremely complex geometrically and can contain a large number of geometric errors, which are not a significant issue when the models are used in the BIM software they are created with or when these models are only used for simple operations. However these errors can

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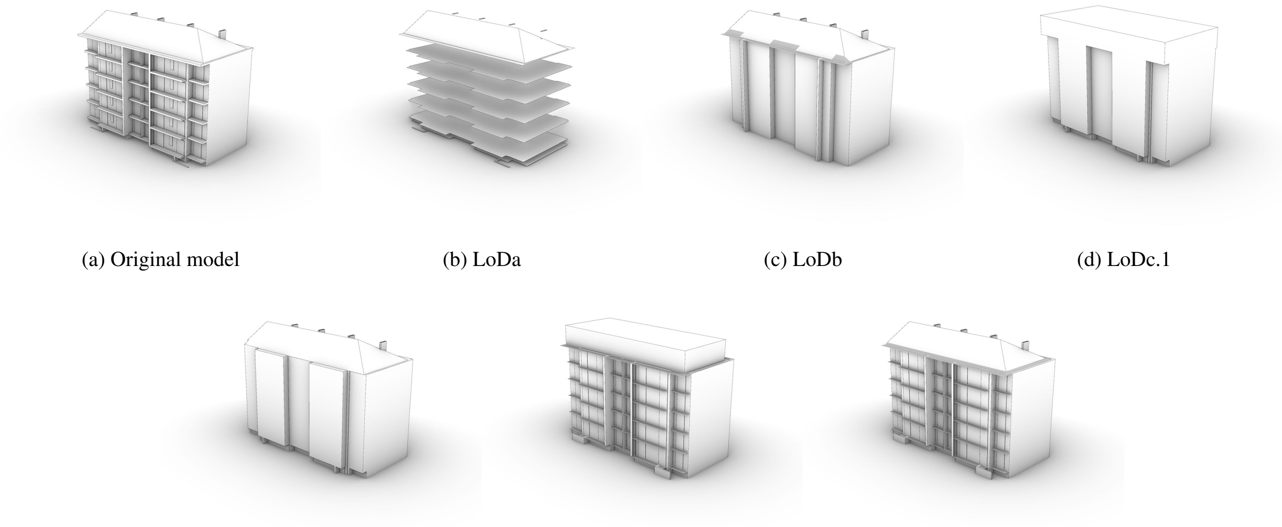


(a) Original model (b) LoDa (c) LoDb (d) LoDc.1

(e) LoDc.2 (f) LoDd.1 (g) LoDd.2

Figure 3. The proposed LoD compared to the original input model

cause problems in complex geometric processes. This is for example the case for the creation of abstracted LoD3 (3.1, 3.2 and 3.3) models from BIM, in which these geometric errors can often prevent the models from being made successfully in an automated manner (van der Vaart et al., 2025).

Consequently, in many cases, the highest LoD that can be successfully abstracted from a BIM model is LoD2 (2.1 and 2.2). Unfortunately, LoD2 abstractions are fairly simple models, which often do not fully capture the buildings shape. Because of this, we believe that for BIM sourced models, GIS abstractions that are simpler than LoD3 but more complex than LoD2 would be of significance.

In this paper, we summarise four new LoDs that we believe are especially valuable for BIM-derived models. Three of these fall somewhere between LoD2 and LoD3 in the framework of Biljecki et al. (2016) while one expands on the LoD0 sub levels. These proposed LoDs are honed in to the opportunities and limitations of BIM. The LoDs were developed with the IFC format (the open-source format for BIM models) as starting point, and hence BIM models structured according to the IFC data model. The LoD definitions also take into account that the quality of IFC models in practice can vary. This impacts the LoDs that can be obtained from the input BIM model, resulting in lower LoDs for low-quality input models.

The user requirements for these LoDs have been identified in the Horizon Europe funded CHEK (Change Toolkit for Digital Building Permits) project. In this project, new and renovated buildings (modelled in BIM) are checked against urban regulations (e.g. maximum building height) by integrating the BIM models into the 3D city models. To support this integration, abstractions of the BIM models need to be derived containing the geometrical and semantic properties required in the regulations checking. In the CHEK project, a method was developed, and implemented in the IfcEnvelopeExtractor, to convert BIM models into 3D building models at different LoDs (van der Vaart et al., 2025).

The overview of this paper is as follows. The proposed LoDs are described in Section 2. The LoDs are compared to the established LoDs of Biljecki et al. (2016) to test their performance. Section 3 covers how these tests are done. The results of these tests are covered in Section 4. The discussion of the results and the quality of the proposed LoDs are presented in Section 5.

2. LoD definitions for BIM-derived 3D building models

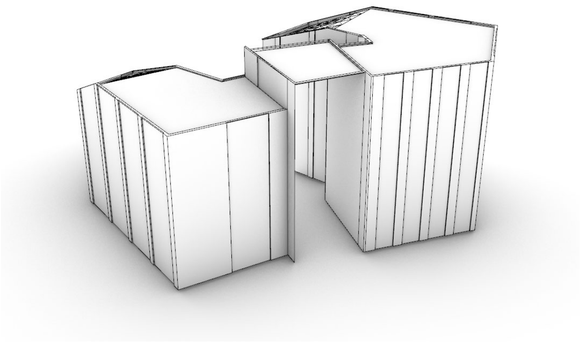
The four proposed new LODs for a BIM model-derived 3D GIS building model are represented in Figure 3 and consist of: LoDa, b, c, and d. We chose to name these LoD with letters because these are only proposed LoDs. They need further considerations and testing to be fitted in an established LoD framework. The difference in naming between the established LoD (signified with one, or multiple numbers) and the proposed LoD (signified with a letter) should alert a user that our proposed LoDs are not yet related to the commonly used LoDs when encountered in a file.

The remainder of this section will cover each of the proposed LoD.

LoDa - a multi-surface made of 3D surfaces representing the footprint, the storeys (ceilings, floor) and the roof structure, see Figure 3b. This representation is in line with the LoD0.x representations in the existing framework of Biljecki et al. (2016). But, it expands this framework by allowing the surfaces of LoDa to be non-horizontal (multi-)surfaces. This allows the surfaces to follow the shape of the actual object they represent. This is unlike LoD0.3, currently the highest LoD0 sub level, which is constructed out of horizontal planar surfaces only. The LoDa roof structure can however be considered similar to the relationship of the roof structure of LoD0.3 and 1.3, where LoD0.3 represents the roof structure as used in LoD1.3. LoDa will represent the roof structure as used in LoD2.2.

The LoDa exterior (footprint(s) and roof outline(s)) as a multi-surface (without walls) can play different roles in the processing of GIS data. It implicitly stores the same data as is explicitly stored in LoD2. LoDa contains the roof structure and the footprint z height, While LoD2.2 contains the roof structure extruded downwards to the footprint z height. LoDa can therefore

(a) Original model



(b) LoDb abstraction

Figure 4. A model that has a large overhanging element will not be properly abstracted with LoDb. The model in the example has an under passage which will be enlarged to cover the complete vertical span of the LoDb abstraction.

function as a compressed way of storing LoD2 data. Additionally, it can also function as an alternative of LoD2 when, for example, the roof structure is too complex for automated conversion into solid geometry (LoD2), but the roof structure is still required, such as in solar panel potential analysis. LoDa also represents the roof structure and footprint as a whole, including overhangs over the footprint. This is something which is not explicit in LoD2 definitions and could create ambiguity. It is often unclear how LoD2 was generated: either from upwards extruded footprints or downwards extruded roof structure (van der Vaart et al., 2023)).

As implemented in the IfcEnvelopeExtractor (identified as LoD0.4), the surfaces representing the roof structure of this LoD can easily be derived from BIM models, also from low-quality models. It is extracted by isolating the top surfaces of the BIM model and trimming these so that they do not overhang over each other. The surfaces representing the footprint and the storey geometry can be isolated by following a similar process. The related *IfcSlab* objects to an *IfcStorey* object can be selected and the top surfaces of these objects can be isolated.

LoDb - a spatial aggregate consisting of a solid as an extruded footprint with roof structure (essentially a footprint restricted LoD2.2) enriched with a multi-surface representing the roof element that overhangs the footprint, see Figure 3c. LoD2 models generated from traditional GIS sources are often the result of a downwards extrusion of the roof surfaces. LoDb (always) uses the geometry of both the footprint and the roof. In addition, roof overhangs are explicitly modelled.

Depending on the shape of the building, this abstraction can be used as an alternative for a full detail LoD3. It does not contain as much geometric complexity as LoD3. Therefore, it could be used as a compressed/simplified way of storing high-detailed building data. Additionally, the abstraction method for LoDb is robust and relies only on two different surfaces (or surface groups) that can be derived from the BIM model, i.e. ground floor/footprint and roof structure (also generated for LoDa). This limited reliance on the input BIM data ensures that errors in the BIM model (which can be many) have a minimal effect on the converting processes and their outcome. But it also means that not all aspects of the input model can be properly reconstructed. If the building has a simple roof structure and primarily vertical facade walls, the resulting shape will closely represent the building. Otherwise, the result, specifically the generated wall surfaces of the facade, will deviate from the real building, see figure 4.

LoDc - a solid created by sampling and extruding horizontal sections of the building at each floor elevation and merging the resulting extrusions into a solid shape, see Figure 3d and 3e. This shape can be used as is (LoDc.1), or possibly refined with the roof structure (LoDc.2). Since the source data is sampled at multiple intervals (each storey elevation), the surfaces represent the building facade more accurately compared to a 3D building model that is generated from an extruded footprint (as LoDb, or footprint restricted LoD1.3 and 2.2) or downwards extruded roof structure (such as LoD1.3 and 2.2). The sample rate of LoDc scales with the size of the building. Usually, higher buildings will have more storeys. This increases the complexity of the conversion but also reduces the error of missing overhang or incorrectly representing of non-straight facade walls if present in the input model.

The volumetric representations per storey are generated by extruding refined horizontal intersections through the entire building's geometry at each storey's elevation to the elevation of the storey above it. If the storey elevation of the top storey is not at the top height of the building, the storey section will be extruded upwards to the top building height. All the generated solids are merged into a single volume. The refinement of the surfaces created by the intersection is done by a Boolean intersection between the storey's section and the projected section of the storey above it. Executing this process will prevent roofs at storey elevation level from being improperly extruded upwards into a solid.

LoDc allows to obtain an LoD1 or LoD2 model (depending whether a horizontal roof surface or the real roof structure is used) that also incorporates facade details. This facade detail is not available in the earlier mentioned LoDb and other equivalent established LoDs generated by extrusion. LoDc would be particularly useful in high-rise buildings with many floors and non-vertical facades. Creating an abstracted model from a BIM source that has facade detail fitting the established LoD framework(s) (i.e. LoD3, 3.1, 3.2, or 3.3) requires a significantly more complex approach that is less robust and requires an input model with almost no modelling errors. In contrast, the LoDc approach is fairly robust and only samples the building at the storey elevation. Any error in the BIM models that falls outside of these few sections will have no effect on the outcome.

LoDd - is similar to LoDc, but the horizontal surfaces are filtered based on the condition if they represent the exterior (balconies, overhangs) or interior elements (floors, sections through

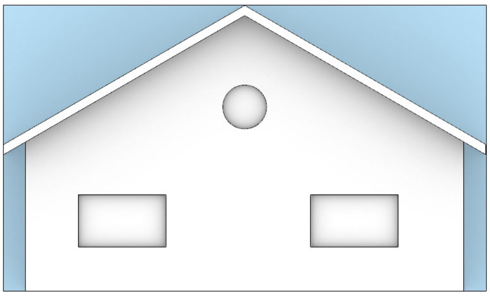


Figure 5. Side view of the FZK Haus LoD1.0 abstraction with the ground truth model superimposed over it. Any ray that would go through the blue highlighted zone only will intersect with the LoD1.0 model and not the ground truth.

walls). Only the interior elements are used for the upwards extrusion to create the solid geometry. This extruded geometry is augmented with the (multi) surfaces representing the exterior elements, such as balconies. This results in a refined version of LoDc, see Figure 3f and 3g. Like LoDc, the LoDd roof structure can be represented by simplified horizontal geometry (LoDd.1) or by following the actual roof structure (LoDd.2). This abstraction can be used for the same use cases as LoDc, as it also brings the same advantages as LoDc does. It expands these advantages by reducing the errors that can be introduced by the exterior elements of the model. This comes at the cost of a more complex process that is less robust, but this process is still considerably less complex and more robust than creating LoD3.1, 3.2, or 3.3, which in many cases supply similar detail.

The volume representations per storey are generated by extruding the filtered horizontal intersections through the entire building's geometry at each storey's elevation. The surfaces created by this section are filtered based on the condition if they are representing interior or exterior surfaces. The interior surfaces are used while all the exterior surfaces are discarded. All the created extruded solids are merged into a single volume. Similar as for LoDc, if the storey elevation of the top storey is not at the top height of the building, the exterior surfaces will be extruded upwards to the top building height.

The exterior (multi-)surface representations are generated by taking refined horizontal intersections per storey through the building objects that are related to each of the *IfcStorey* objects instead of through the entire building's geometry. The exterior surfaces from this section are collected for output. The interior surfaces from these intersections are discarded.

3. Comparison to established LoD

To test the performance of the proposed LoDs, they are compared to the LoD framework of Biljecki et al. (2016). This is done visually, but augmented with some quantitative comparisons, i.e. the area, volume (if LoD is a volumetric shape), and spatial deviation. LoDa is compared to LoD0.0, 0.2, and 0.3. The volumetric alternative LoDs proposed in this paper (LoDb, c, and d) are compared to LoD1.0, 1.2, 1.3, and 2.2.

The abstracted models that are tested are all generated from four IFC models, see Figure 6. The LoD0.0, 0.2, 0.3, 1.0, 1.2, 1.3, and 2.2 abstractions are created by the IfcEnvelopeExtractor[1]. This is a software application that can automatically abstract BIM models to GIS models that adhere to the LoD framework of Biljecki et al. (2016). The LoDb abstractions are manually created but based on the LoDa (LoD0.4 in the IfcEnvelopeExtractor) roof surfaces and footprint generated by the IfcEnvelopeExtractor. LoDc.1, c.2, d.1, and d.2 are also manually generated but based on the LoD0.2 (for LoDc.1 and c.2) and 0.3 (for LoDd.1 and d.2) storey extraction generated by the IfcEnvelopeExtractor.

The models that are used as the ground truth for these evaluations are the LoD3.2 abstractions. These are also created by the IfcEnvelopeExtractor. The IfcEnvelopeExtractor is not always able to create an airtight LoD3.2 model. When the output model is not closed, these minor issues are manually fixed. For LoDa only the roof structure is compared to the LoD3.2 roof structure.

The volume and area of the models are calculated with Rhino3D. For the area computation, the (multi) surfaces of LoDb, d.1, and d.2 that model overhang are counted twice. These non-volumetric overhangs represent features from the BIM model that are volumetric. The volumetric features will most likely have a top and bottom face. To respect this, the single surface area is counted twice to represent the top and the bottom area of the surface.

To compare the spatial deviation, a grid of points is created on the surfaces of the bounding box of the model. From these points rays are cast in the x, y or z direction. The distance between the first intersection of a ray with the abstracted geometry and the first intersection of this ray with geometry of the ground truth LoD3.2 model is measured. The average of the distances of all rays is computed for the comparison.

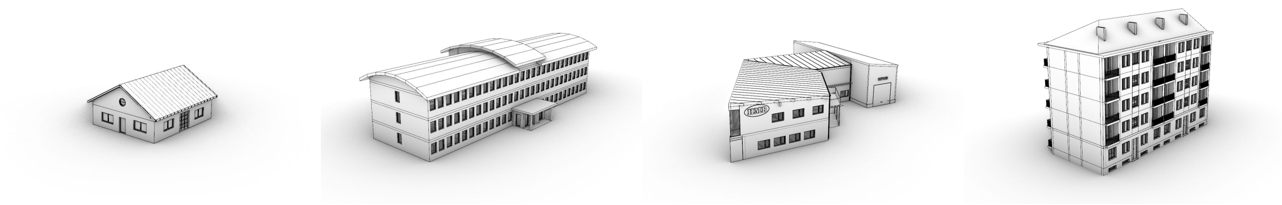
The results of the spatial deviation computation could be misleading. In complex models, there can be cases where a ray only intersects with the ground truth or only with the abstraction shape and not with both. E.g. an LoD1.0 model can intersect with rays that miss the ground truth model because at the location of intersection a sloped roof was present, see Figure 5. For these single intersection cases, it is not possible to compute a distance. These cases are ignored in the evaluation. However, this is still clearly a notable spatial deviation, which should in theory have effect on the results. To quantify the magnitude of this effect a test is added where the difference in the amount of rays intersecting with each abstraction and the ground truth are counted. These outcomes can be used to evaluate how trustworthy the spatial deviation values are. The larger the intersection count deviation, the less reliable the spatial deviation values will be. If the intersection count error is large, the models can be evaluated visually to find the cause of this.

Since LoDa only models the footprint and roof structure of the exterior, it is excluded from the spatial deviation tests. Including it would result in a very large number of missing intersections that would not give a clear objective insight.

4. Results

Figures 7, 8, and 9 show the results of the area and volume comparisons. It shows, as expected, that out of the established volumetric LoDs (LoD1.0, 1.2, 1.3, 2.2), LoD2.2 is able to approach the area and volume of the ground truth the best. The established LoDs do show a gradual improvement of both area

[1] https://github.com/tudelft3d/IFC_BuildingEnvExtractor



(a) FZK Haus (b) Institute (c) Myrian (d) Via Capua

Figure 6. The used models to test the propsed LoD abstraction's performance.

and volume approximation with each finer LoD. The proposed LoDs do not show this gradual improvement of values. All of the alternative volumetric LoDs, show improved scores over LoD1.0, 1.2 and 1.3. LoDb, c.2, and d.2 approach the area and volume of the ground truth closer than the LoD2.2 abstraction in all of the evaluated models. However, LoDc.1 and d.1 always perform worse than LoDb, c.2, and d.2.

In Figure 7 it can be seen that LoDa falls in line with the gradual improvement of the established LoD. It falls after LoD0.3 as a more refined LoD. It has an area deviation of 0% from the ground truth in every model except for the Institute model.

Figures 10 and 11 show the results of the spatial deviation comparison in the horizontal (xy) plane and z direction respectively. As with the area and volume comparisons, it shows that from the established LoDs (LoD1.0, 1.2, 1.3, 2.2), LoD2.2 has the lowest spatial deviation in both the xy plane and z direction. Similarly to the area and volume comparisons, gradual improvement of the values can be noted with each finer LoD. And again, as with the area and volume comparisons, the proposed LoDs do not show this gradual improvement. All of the alternative LoDs show improved scores over LoD1.0, 1.2 and 1.3. The z-deviation of LoDb, c.2, and d.2 are very close to the deviations of LoD2.2. LoDc.1 and d.1 perform worse, similar to LoD1.2 and 1.3 respectively. The x and y-deviation are significantly less for the LoDb, c.2, and d.2 models. For the LoDc.1 and d.1, it varies if the x or y-deviation is smaller compared to LoD2.2.

Table 12 shows the ray intersection count of the abstracted shapes compared to the ground truth. This figure shows that, as with the area, volume, and spatial deviation comparisons, the difference is gradually reduced for finer LoDs. It can also be seen that the established LoDs tend to intersect with more rays than the ground truth ($> 0\%$). In contrast, some of the abstractions of the alternative LoDs intersect with less rays than the ground truth ($< 0\%$). On average, the alternative LoDs are closer in the amount of intersecting rays to the ground truth than the established LoDs are. However, there are exceptions for specific IFC models. The FZK Haus model has an intersection count for LoDc.1 that is 12.93% lower than the ground truth. This is a notable difference compared to the LoD2.2 6.33% extra intersections but also compared to the other model's LoDc.1 performance.

When inspecting the abstracted models visually, it can be seen that volumetric proposed LoD approximate the buildings to a different degree of accuracy. The LoDb is able to approximate the shapes very closely. However, basing the extrusion on the footprint in some cases results in some geometry that does not comply with the actual input model, see Figure 13. Regardless, the performance of LoDb on the evaluated models is strong.

Both LoDc.1 and d.1 show that when a building has a non-flat roof, the shape of these abstractions will deviate noticeably. Especially when the roof also has an overhanging element, the resulting shape can deviate significantly. However, the facade elements (ignoring the roof parts) are visually approximated more accurately than the established LoD2.2, see Figure 14, with the added benefit of LoDd.1 having balconies represented. These features are not supported by established LoD frameworks. The refined LoDc.2 and d.2 utilizing the LoDa roof structure visually show very close approximation to the input model.

LoDb, c, and d are able to model overhang. However, in many cases this overhang is non-volumetric, see Figure 14d, while these overhanging features are volumetric in the input models.

In certain cases, LoDc and d can result in an abstraction that consists of multiple unconnected solids. For example, the institute model's LoDc and d both consist of three different solids while the input model is a single building with all parts connected to each other, see Figure 15.

5. Discussion

The results show mixed performances of the proposed LoDs. LoDa, b, c.2, and d.2 perform very well. However, for certain criteria, LoDc.1 and d.1 perform poorly.

LoDc and d are developed to better represent large/tall buildings with a large number of storeys than LoD2.2. However, the models that were tested were all fairly small models that have non-flat roofs, small amounts of overhang, and fairly simple vertical facades. These types of models are easy to approximate at LoD2.2. Therefore, in comparison, the area, volume and spatial deviation results of LoD2.2 were good while these results were worse for LoDc.1 and d.1. Presumably, the LoDc.1 and d.1 abstractions would approximate the area and volume of a building more accurately than LoD1.3/2.2 if the building had a more complex facade structure, or if the building had flat roofs.

Regardless of the tested models, the visual inspection showed that the LoDc.1 and LoDd.1 abstractions were able to model the shape of the facade of the evaluated models more closely than LoD2.2. In addition, LoDd.1 was able to reconstruct the balconies accurately. This shows the potential strength of these two LoDs on larger buildings.

The refinement of LoDc.1 and d.1 (c.2 and d.2 respectively) both performed very well. Unlike LoDc.1 and d.1, not only the facades were visually very accurately approximated but also the roofs. Additionally, the models performed well for the area, volume, and spatial deviation tests. However, these models are also the most complex models among the proposed LoDs. The

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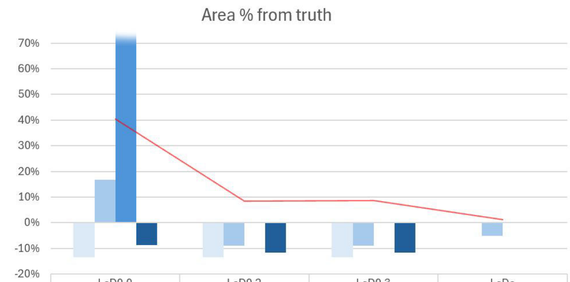
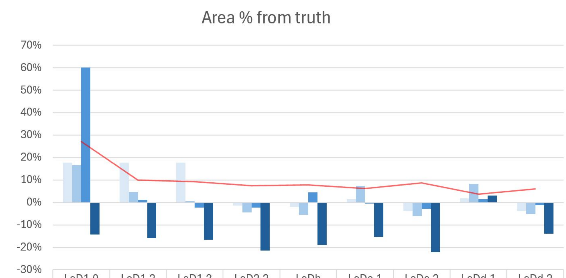


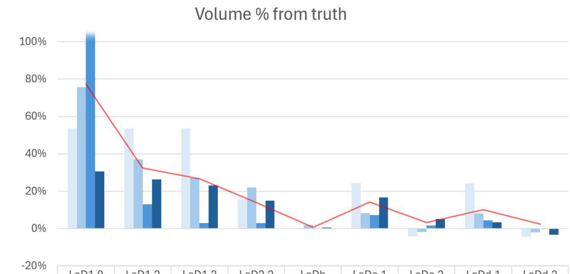
	LoD0.0	LoD0.2	LoD0.3	LoDa
Haus	-13%	-13%	-13%	0%
Institute	17%	-9%	-9%	-5%
Myran	123%	0%	0%	0%
Via	-9%	-12%	-12%	0%
Average	40%	9%	9%	1%

Figure 7. The deviation (in percentages) of the area of the non-volumetric abstraction shapes compared to the ground truth. The average line shows the absolute average of all values.



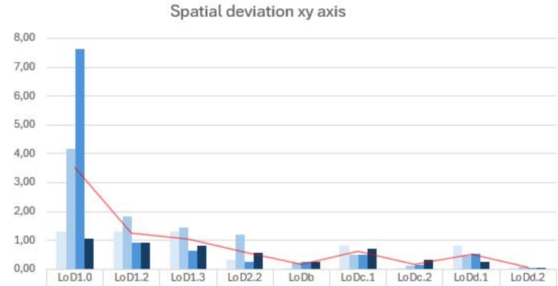
	LoD1.0	LoD1.2	LoD1.3	LoD2.2	LoDb	LoDc.1	LoDc.2	LoDd.1	LoDd.2
Haus	18%	18%	18%	-1%	-2%	1%	-4%	2%	-4%
Institute	17%	5%	1%	-4%	-6%	7%	-6%	8%	-5%
Myran	60%	1%	-2%	-2%	4%	0%	-3%	2%	-1%
Via	-14%	-16%	-17%	-21%	-19%	-15%	-22%	3%	-14%
Average	27%	10%	9%	7%	8%	6%	9%	4%	6%

Figure 8. The deviation (in percentages) of the area of the volumetric abstraction shapes compared to the ground truth. The average line shows the absolute average of all values.



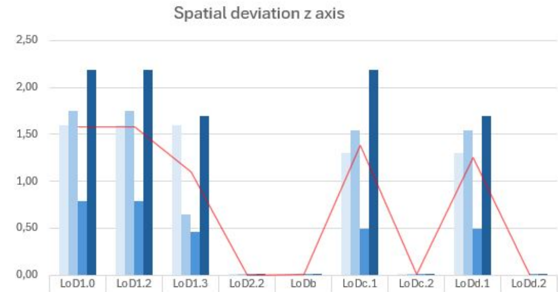
	LoD1.0	LoD1.2	LoD1.3	LoD2.2	LoDb	LoDc.1	LoDc.2	LoDd.1	LoDd.2
Haus	54%	54%	54%	16%	0%	24%	-4%	24%	-4%
Institute	76%	37%	27%	22%	2%	8%	-2%	8%	-2%
Myran	149%	13%	3%	3%	0%	7%	2%	5%	0%
Via	31%	26%	23%	15%	1%	17%	5%	3%	-3%
Average	77%	32%	27%	14%	1%	14%	3%	10%	2%

Figure 9. The deviation (in percentages) of the volume of the volumetric abstraction shapes compared to the ground truth. The average line shows the absolute average of all values.



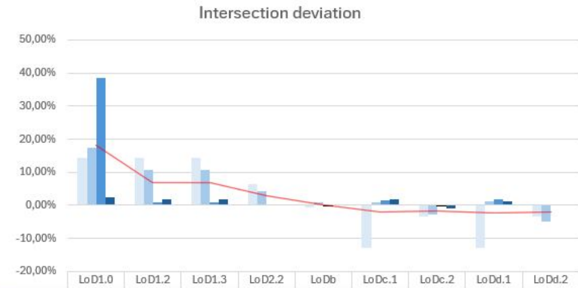
	LoD1.0	LoD1.2	LoD1.3	LoD2.2	LoDb	LoDc.1	LoDc.2	LoDd.1	LoDd.2
Haus	1,31	1,31	1,31	0,32	0,04	0,81	0,04	0,81	0,04
Institute	4,17	1,84	1,45	1,18	0,21	0,48	0,10	0,46	0,08
Myran	7,62	0,90	0,62	0,24	0,24	0,51	0,13	0,53	0,05
Via	1,05	0,92	0,81	0,55	0,24	0,70	0,33	0,25	0,05
Average	3,54	1,24	1,05	0,57	0,18	0,63	0,15	0,51	0,05

Figure 10. The average spatial deviation in the x and y direction in meters compared to the ground truth model. The average line shows the absolute average of all values.



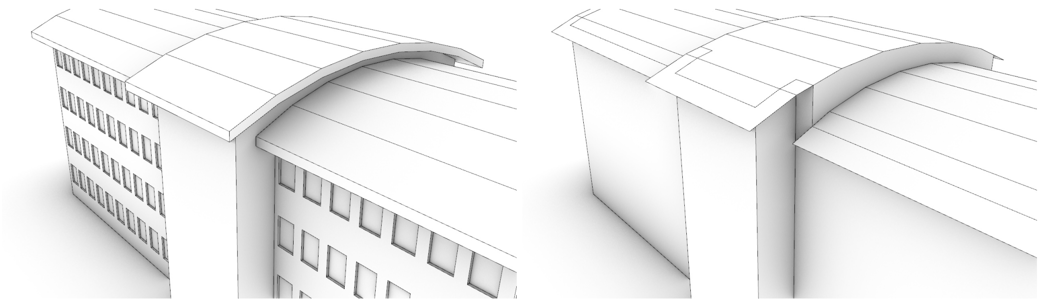
	LoD1.0	LoD1.2	LoD1.3	LoD2.2	LoDb	LoDc.1	LoDc.2	LoDd.1	LoDd.2
Haus	1,60	1,60	1,60	0,00	0,00	1,30	0,00	1,30	0,00
Institute	1,76	1,76	0,65	0,00	0,00	1,54	0,00	1,54	0,00
Myran	0,79	0,79	0,47	0,00	0,01	0,50	0,01	0,49	0,01
Via	2,19	2,19	1,69	0,00	0,00	2,19	0,00	1,70	0,01
Average	1,58	1,58	1,10	0,00	0,00	1,38	0,00	1,26	0,01

Figure 11. The average spatial deviation in the z direction in meters compared to the ground truth model. The average line shows the absolute average of all values.



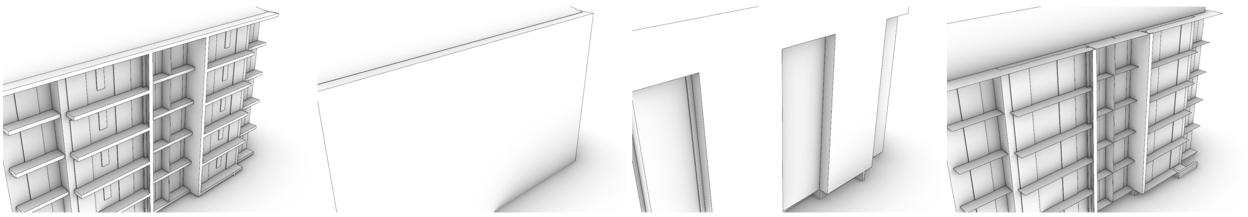
	LoD1.0	LoD1.2	LoD1.3	LoD2.2	LoDb	LoDc.1	LoDc.2	LoDd.1	LoDd.2
Haus	14,25%	14,25%	14,25%	6,33%	-0,53%	-12,93%	-3,43%	-12,93%	-3,43%
Institute	17,37%	10,57%	10,57%	4,30%	0,72%	0,79%	-2,72%	1,21%	-5,10%
Myran	38,54%	0,87%	0,87%	0,20%	-0,28%	1,61%	-0,15%	1,84%	0,08%
Via	2,31%	1,94%	1,64%	0,00%	0,00%	1,94%	-0,89%	1,04%	0,00%
Average	18,12%	6,91%	6,83%	2,71%	-0,02%	-2,15%	-1,80%	-2,21%	-2,11%

Figure 12. The difference in ray intersection count of the abstraction models compared to the ground truth model. The average line is the average of all values.



(a) Original model (b) LoDb abstraction

Figure 13. Close up of the Institute model. It can be seen that for the LoDb abstraction the vertical geometry surrounding the top roof structure is different from the original model.



(a) Original model (b) LoD2.2 abstraction (c) LoDc.1 abstraction (d) LoDd.1 abstraction

Figure 14. Close up of the Via Capua model. It can be seen that the LoD2.2 abstraction includes less facade detail than both c.1 and d.1.

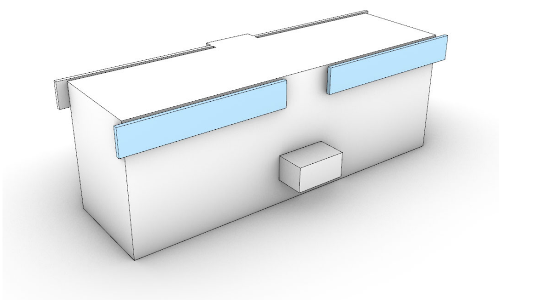


Figure 15. The LoDc abstraction of the Institute model consists out of three unconnected solids. The main part of the building in white and the two shapes highlighted in blue.

process of creating them is less complex than the LoD3 creation, but the complexity and reduced robustness can result in a slow and unreliable outcome. The fairly high area accuracy and very high volume and spatial deviation accuracy still make these very interesting LoDs for abstracting smaller building models. For bigger models, LoDc.1 and LoDd.1 might be more suitable. This should however be further tested.

Interestingly, the intersection deviation test showed that the proposed LoDs could have less intersections than the ground truth. This is the opposite from the established LoD which all had a larger amount of intersections than the ground truth. A visual inspection exposed three reasons for this.

Firstly, the proposed LoDs use the elevations of the storeys as data points. These elevations are usually the top of the constructive slab of the floors. This means that the lowest floor slab will always be excluded from the abstraction. The top of the slab is used as the base of the model, but the rest is ignored. So, each of the models extends slightly less downwards than the ground truth, which has this slab included.

Secondly, balconies and certain overhangs are modelled by the proposed LoDd as non-volumetric surfaces. These shapes are never intersected with rays projected in the xy plane, so this causes an increase in missing intersections.

Thirdly, if the models have overhanging roofs that do not, or do not completely, intersect with a storey elevation, their overhang is not included in the LoDc and d models. This is the case for the FZK Haus model. This model has a gable roof. This roof is not represented by the LoDc.1 and d.1 models, causing a very large intersection count deviation.

Regardless of the input model's size and complexity, LoDa and LoDb show a very remarkable accuracy for the tested models. In the case of LoDb, this is partially due to the same reason as why LoDc.1 and d.1 abstractions perform so weakly for the quantitative evaluations: the input models are fairly simple. The footprint and the roof outline of each of the input models is fairly similar and the facades of all the models are primarily vertical. There are some balconies and other overhangs present in some of the models, but the majority of the models are fairly simple. These models are ideal for the LoDb abstraction approach. It is however interesting to see that even such a small nuance as incorporating the footprint in the abstraction process can yield a significant improvement. Still, it will perform worse for more complex models, see Figure 4.

LoDa performed very well. However, this is generated following the simplest extraction method and does not create any new data that was not yet available in the established LoD framework of Biljecki et al. (2016). It is effectively only a new manner of storing the data. The LoDa roof structure is identical to the LoD2.2 roof structure. As mentioned before, this closely resembles the relation between LoD0.3 and 1.3. However, established LoD frameworks do currently not allow for an option to store this data. This is unfortunate because the results show that it is very accurate data which can be utilized even in cases where it is too complex to create a volumetric LoD2.2 representation.

LoDa being the roof structure of LoD2.2 also explains the deviation of LoDa from the ground truth roof structure's area. The LoDa roof surfaces are like the LoD0.3 roof surfaces. A roof structure is not allowed to overlap over itself. If the surfaces are extruded downwards to create a solid it should not self intersect. The Institute model has a roof structure that overlaps over itself, which is eliminated in LoDa, this results in a underestimation of the roof structure's total area.

6. Conclusion

This paper introduced four new LoDs that are specifically tailored for deriving 3D building models from BIM data for use in GIS environments. These proposed LoDs (LoDa, LoDb, LoDc, and LoDd) fill important gaps between existing standardised LoD definitions, particularly between LoD2 and LoD3, by addressing the unique opportunities and limitations of BIM as a data source.

Testing the performance of the LoDs in terms of preserving area, volume and minimising spatial deviation on four example IFC models demonstrate that LoDa and b perform particularly well, offering accurate and robust abstractions that are simple to derive from BIM while maintaining geometric and semantic reliability suitable for GIS applications. LoDc and d provide more detailed alternatives that can better represent complex facades and vertical variations, although at the cost of greater computational complexity and reduced robustness compared to LoDb. Notably, the refined LoDc.2 and d.2 models achieved strong results in both geometric accuracy and volume approximation, showing their potential for high-quality urban modelling when BIM input quality is sufficient.

Overall, our study shows that our proposed LoDs derived from BIM models can significantly enhance the usability of BIM data in GIS, especially in contexts where LoD2 abstractions are too simplistic and LoD3 models are too complex or error-prone to generate automatically. The findings also highlight the importance of the quality of the input IFC models and the specific method used for the abstraction in ensuring that BIM-to-GIS transformations remain both accurate and computationally efficient.

Future work should focus on extending the evaluation of the newly proposed LoDs to larger and more complex buildings and aligning them with existing LoD frameworks. Further integration of these LoDs in real-world applications, such as automated building permit checks within the CHEK project, will help validate their practical relevance and inform incorporating them in a unified LoD framework that bridges BIM and GIS domains.

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