# 3D BUILDING GENERALISATION BY ROOF SIMPLIFICATION AND TYPIFICATION

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**ABSTRACT**

The article presents a cartographic generalisation approach for 3D building models with regard to the thematic visualisation of urban landscapes. Based on our earlier work to utilise approximating planes for generating simplified cell decompositions of the input objects, a new extension is introduced that guarantees well-formed roof structures. This is accomplished by first creating a simplified 2D decomposition of the ground plan polygon and interpreting the original roof geometry in the area of the cell. A matching roof shape is then selected from a pre-defined set of primitives and the 2D cells are transformed into 3D accordingly. This kind of template matching allows for operators other than simplification. By modifying the primitives' parameters, it is possible to alter the roof shapes in order to accentuate certain features or to reduce the number of repetitive features like shed, gabled and hipped roof parts. We also demonstrate how the described techniques can be used to simplify curved building elements which can be commonly found in important landmarks like churches and castles.

## 1. INTRODUCTION

In recent years, the diversity of applications for 3D city models has widened from the traditional analysis and simulation applications more towards the presentations of urban scenes. Most popular are real-time and web-based visualisation systems like digital city or earth viewers that nowadays offer graphics of near photorealistic quality (see e.g. Walter 2005). Such accurate illustrations that are true to detail might, however, not always be the most adequate tool to communicate spatial information. Buchholz et al. (2005) e.g. explore expressive rendering techniques that imitate sketchy drawing styles so that spatial situations are easier to perceive and comprehend. This and numerous other applications for 3D city models, which e.g. have been identified by Albert et al. (2003), rely on models at different levels of detail. Real-time visualisation systems balance rendering performance with fidelity by composing the 3D scene with models of varying complexity. For applications that are not time critical or aim for photorealism, one level of detail is usually sufficient. However, it must fulfil the requirements of the applications. Cartographic visualisations place their emphasis on the global shape of the objects rather than on unimportant details.

Because it is not reasonable to collect and store data for all required levels of detail, an automatic process is necessary that transforms 3D building models towards a more simplified shape. During this transformation, building-specific properties must be preserved. These are, amongst others, the parallel and right-angled arrangement of façade walls and the symmetries of the roof structure. Furthermore, object specific features are especially important for landmarks. The simplified model of a church or cathedral, e.g., must not miss its towers after simplification as otherwise the object is hardly recognisable anymore. A simplification of solitary objects under these spatial constraints is one of the elemental operators of cartographic generalisation. In cartography, both the object's shape and their arrangement are altered with the goal to create maps or map-like presentations to better communicate spatial situations.

In this article, we introduce an extension of our earlier work on generalisation that utilises approximating planes for generating simplified cell decompositions both for 2D ground plans and 3D building models (Kada 2006). Our new extension picks up after the generation of the ground plan decomposition and creates the roof structure by matching pre-defined roof types with the original geometry. As explained in section 4, this results in a set of parameterised primitives, which opens up further possibilities for simplification. E.g. the number of equally shaped repetitive structures like shed, gabled and hipped roof parts can be reduced by modifying the primitive's parameters. In the same way characteristic roof features can also be accentuated.

## 2. RELATED WORK

The automatic generalisation of building models has been a research topic ever since Staufenbiel (1973) proposed a set of generalisation actions for the iterative simplification of 2D ground plans. Several algorithms have been developed that remove line segments under a predefined length by extending and crossing their neighbour segments and by introducing constraints about their angles and minimum distances (Powitz 1973), (Van Kreveld 2001) and (Harrie 1999). Other approaches use vector templates (Meyer 1989), least-squares adjustment (Sester 2000) or techniques from scale space theory (Mayer 1998).

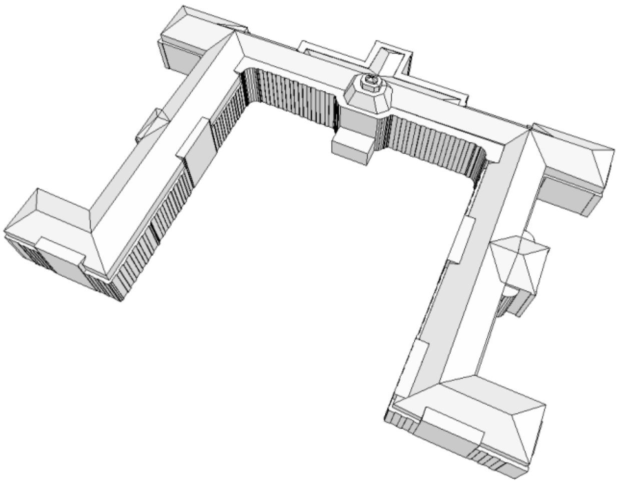
Nowadays, a few algorithms also exist that have been specifically designed for the generalisation of 3D building models. Forberg (2004) adapts the morphology and curvature space operators of the scale space approach to work on 3D building models. Thiemann and Sester (2004) do a segmentation of the building's boundary surface with the purpose of generating a hierarchical generalisation tree. After a semantic interpretation of the tree's elements, they can selectively be removed or reorganized to implement the elemental generalisation operators for simplification, emphasis, aggregation and typification. Another aggregation approach for linearly arranged building groups is proposed by Anders (2005). With a strong focus on the emphasis of landmarks present Thiemann and Sester (2006) adaptive 3D templates. Building models are replaced by similar 3D templates that best fit the real object. Because the semantics of the template is known, the object itself or specific features of the model can be emphasised at will. Coors (2001), Rau et al. (2006) and Kada (2002) show that surface simplification operators and metrics from the field of computer graphics can be modified so that characteristic properties of building models can be preserved during simplification.

Despite the number of available 3D generalisation approaches, a continuous difficulty seems to be the simplification of the roof structure. Most algorithms avoid this problem by simply generating flat or pent roofs or assume that the roof type is already available as the result of a preceding interpretation. In this paper, we describe a generalisation approach for 3D building models and concentrate on a new procedural method to generate reasonable roof geometries.

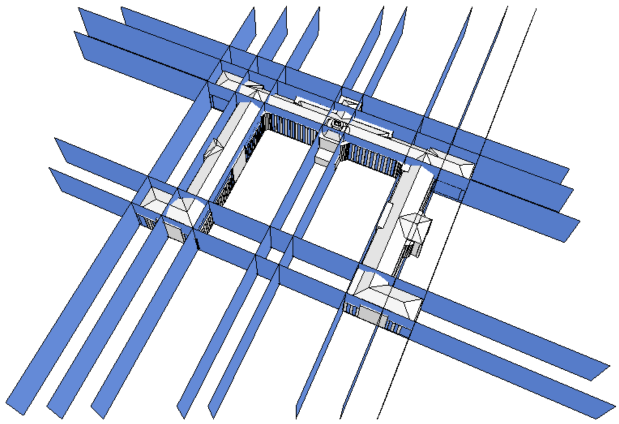
## 3. GENERALISATION OF 3D BUILDING MODELS

We propose a two-stage generalisation algorithm for the geometric simplification of solitary 3D building models. As can be seen from the intermediate results of the example in Figure 1, the two stages consist in a total of five steps. The first stage generates a 2D decomposition of space that approximates the ground plan polygon by a disjoint set of quadrilateral primitives (cp. (Kada 2006)). We accomplish this by deriving plane equations from the major façade walls (1), subdividing the infinite space along these planes (2) and identifying the resulting cells that feature a high percentage of overlap with the original ground plan polygon (3). The second stage reconstructs the simplified geometry of the roof. Here, a new primitive instancing approach is shown where the roof parameters are determined individually for each cell so that they best fit the original model under distinct adjacency constraints (4). By altering those parameters, the simplification of the roof can be properly adjusted. A union operation of the resulting primitives composes the final 3D building model and concludes the generalisation (5).

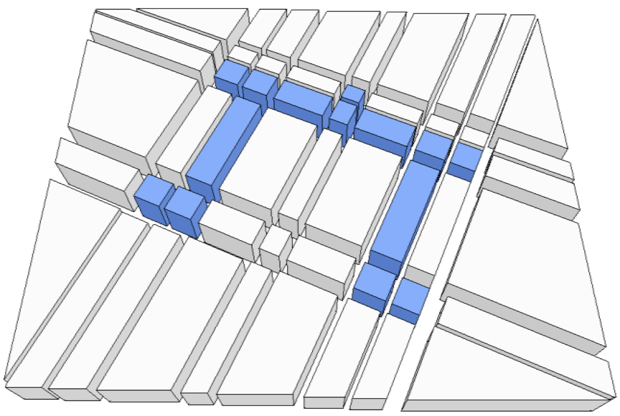
Original 3D Building Model



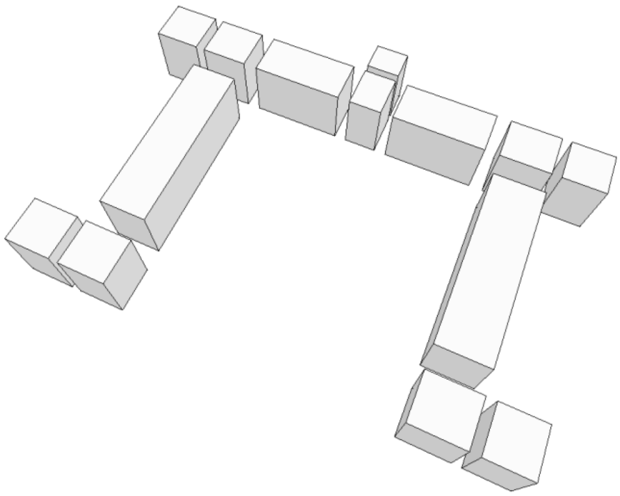
Step 1: Averaging of Decomposition Planes



Step 2: Generation of 2.5D Cell Decomposition



Step 3: Identification of Building Cells



Step 4: Matching of 3D Roof Shapes

Step 5: Union to 3D Building Model

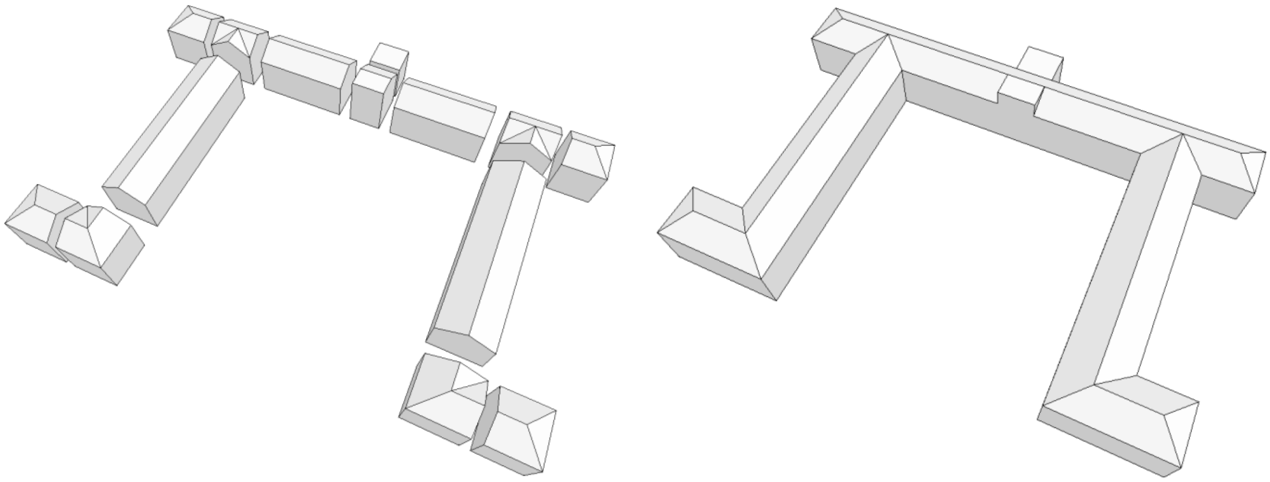


Figure 1: Original 3D building model and the five steps of generalisation.

## 4. ROOF GENERALISATION VIA PRIMITIVE INSTANCING

The remainder of the paper focuses on the fourth generalisation step. As presented in preceding articles, the roof shapes can be generated as 3D cell decompositions. However, this does not always produce good looking results. This is the consequence of the generality of the approach, which neither interprets the original roof geometry nor restricts the resulting 3D cells to feature valid roof shapes. In this section, we first illustrate exemplarily the more frequent problems we encountered during our studies and then show how we avoid them by using an approach that is based on the solid modelling method called primitive instancing

### 4.1. Common Problems using Cell Decomposition

If the roof structure is very flat, the buffer that creates the first approximating plane will include all roof polygons. And as this plane gets the slope of the first dominant polygon the algorithm encounters, a shed roof is generally generated instead of a hipped or gabled roof (see Figure 2).

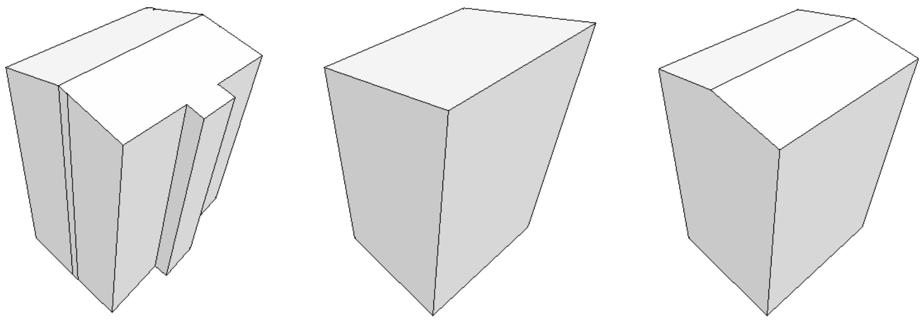


Figure 2 Original 3D building model (left) and its generalisations via cell decomposition (middle) and primitive instancing (right).

Because the opposing slopes of approximating planes are not strictly aligned against each other, the generalisation to hipped and gabled roofs often results in asymmetric shapes (see Figure 3). However, symmetric roof structures are in most cases preferable.

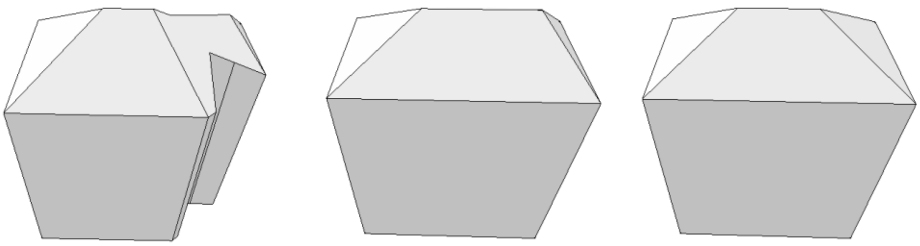
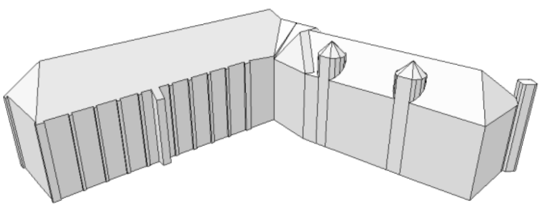


Figure 3 Original 3D building model (left) and its generalisations via cell decomposition (middle) and primitive instancing (right).

For roofs with multiple sections or wings that have different eaves and ridges heights, the building cells close to the roof valley are erroneously discarded. The missing parts disturb the appearance of the generalised building model as such a roof shape is likely to be wrong (see Figure 4).



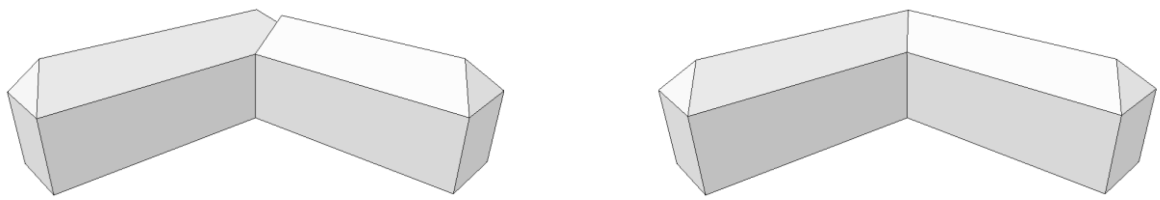


Figure 4: Original 3D building model (top) and its generalisation via cell decomposition (left) and primitive instancing (right).

#### 4.2. Primitive Matching

In each of the above mentioned example situations, it is necessary to interpret the roof geometry in order to create a shape that resembles the original model and is symmetric and valid. In this article, we describe an interpretation that is both locally done for individual ground plan cells and also later on globally for the entire set of cells.

The interpretation is first done per cell by instancing 3D primitives, each given one of the eight supported roof shapes and the ground plan quadrilateral of the base cell. At this point, we support the four most common roof types and their connecting elements as they are depicted in Figure 5. To ensure symmetric roof shapes, all the gabled and hipped primitives need a ground plan in the shape of a parallelogram. This prerequisite of the cells can be ensured during the generation of the ground plan decomposition by using only approximating planes parallel and rectangular to the general orientation of the building.

Each primitive type is parameterised in terms of roof properties like eaves height, ridge height, ridge length, etc. They are then matched with all possible combinations of parameter values against the original geometry of the cell area and the best match is kept. To find this best match, we have experimented with two comparison functions: the sum of squared height differences and the percentage of equal roof slopes measured between the roof surfaces of the primitive and the original model. For easier comparison, the original roof geometry is subsampled so that for each sample point the height and normal direction of the surface is known. The sample points can then be compared with the primitives' faces. For the comparison of roof slopes, the normal directions of the two surfaces must be below a threshold which we defined to be below ten degrees.

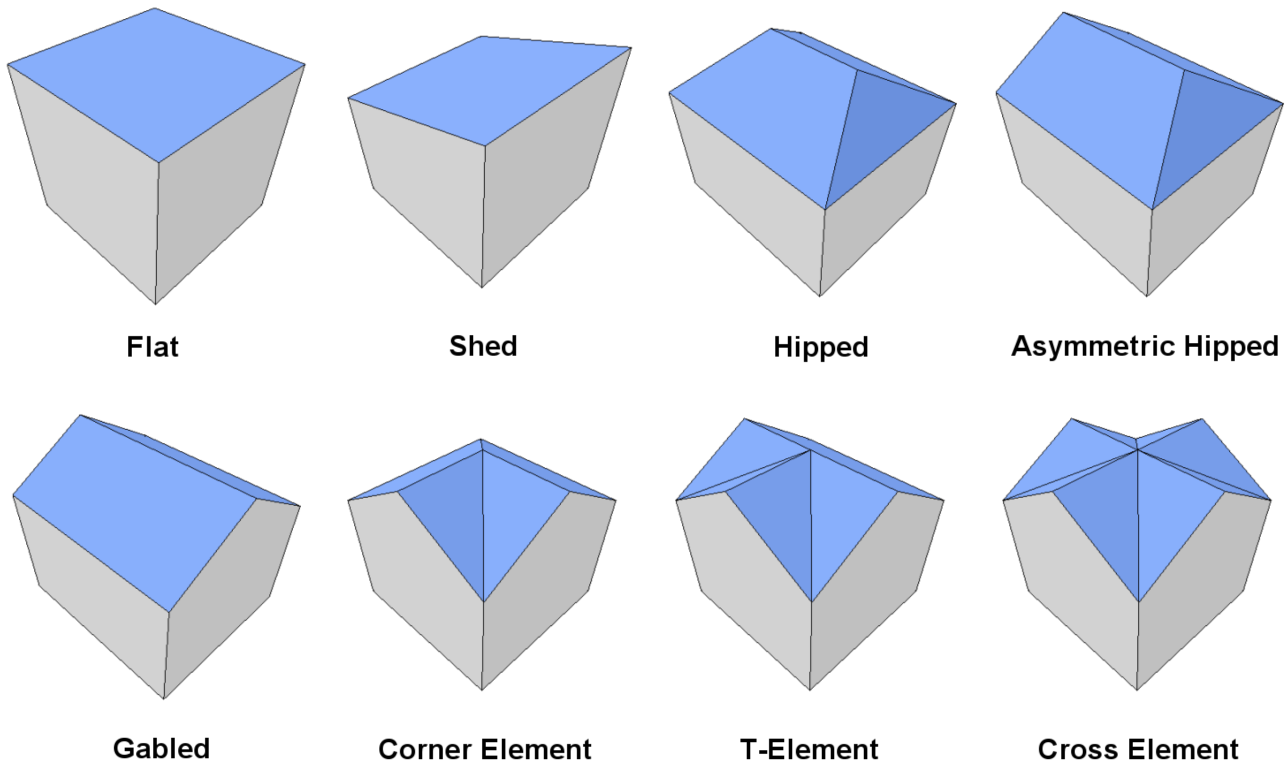



Figure 5: The eight primitive types supported by the roof simplification.

Because the height difference is a squared distance and the comparison of roof slopes a percentage value, both functions are difficult to unite. So as yet, we mainly use the slopes to determine the primitive type. And only if the highest percentages are about the same value we use the distance value to make the final decision.

### 4.3. Multiple Primitive Matching

Occasionally, the decomposition of the ground plan produces too many small cells for which it is impossible to find roof types that fit well. We therefore join cells together to find combinations that better match the supported roof shapes. This is done by recursively joining two neighbour cells together in an exhaustive search. In addition, the comparison functions are now evaluated for all cells at once and the candidate cell set with the best total value is our new solution (e.g. Figure 6).

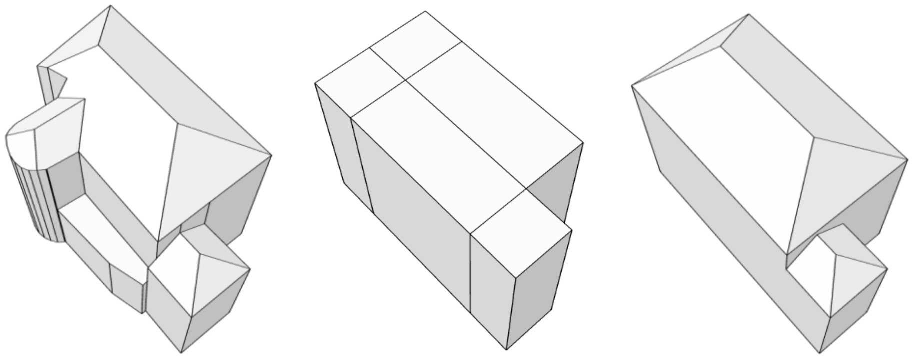


Figure 6 Original 3D building model (left), cell decomposition (middle) and simplified version generalised with multiple primitive matching (right).

The union of cells must form a proper roof structure when they are built together. However, some primitive shapes, in particular the connecting elements, are only valid for cells with the right number and arrangement of neighbour cells. To ensure that a cell receives a valid roof shape, we check and discard solutions that violate a set of rules that state whether the derived primitive is valid depending on the number and arrangement of neighbour cells.

**4.4. Roof Typification**

So far, we have only discussed the simplification of 3D building models. There are, however, other generalisation operators. One is typification, which is the replacement of a number of similar looking features by a lower number of features. This concept is applicable to recurring roof elements like e.g. parallel shed, gabled and hipped roofs that are quiet common for factories or shopping halls. Once the roof parameters of a cell have been determined, the number of recurring elements can be reduced for typification. See Figure 7 for an example where the rim is simplified and the seven hipped roof elements of a building have been replaced by five elements.

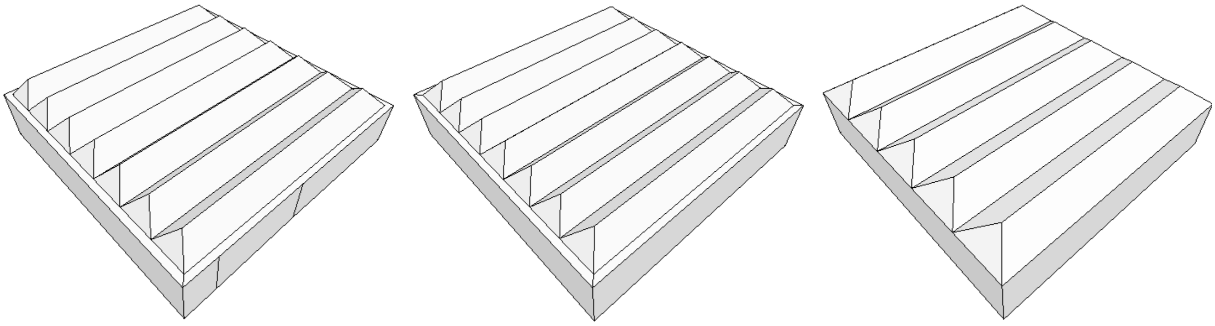


Figure 7: 3D building model with uniform parallel hipped roof elements in its original shape (left) and before (middle) and after (right) typification.

### 4.5. Simplification of Curved Elements

Similar works the simplification of round and curved building elements. For the palace in Figure 8, the three tower elements were first identified from the ground plan polygon by their circular arranged façade segments. After their parameters were determined, all tower polygons were removed and the simplification of the remaining building model was performed by the primitive instancing approach as described. Afterwards, the towers were added again to the final model as simplified versions.

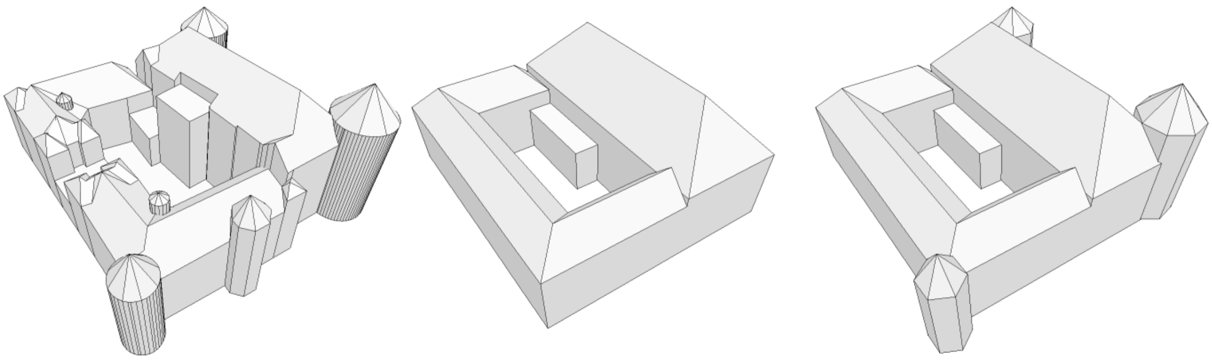


Figure 8: 3D building model with circular tower elements in its original shape (left), after generalisation of the main building (middle) and with simplified towers (right).

## 5. CONCLUSION

We proposed an extension for the simplification of solitary 3D building models that is based on primitive instancing. The partition of the algorithm into two stages proved to be very effective as the cell decomposition of the building's ground plan simplifies the generalisation of the roof structure. We think that the interpretation of the roof shape is necessary in order to execute more elaborate simplification operations. Also, the geometric properties that are specific to buildings like the coplanarity, parallelism and rectangularity of façade segments are preserved during simplification or can even be enforced if needed. The generalisation is solely controlled by an intuitive distance threshold value that specifies the minimum size of the building elements that are created.

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