Bidirectional enrichment of CityGML and Multi-View Stereo Mesh models

MSc Geomatics Thesis Proposal

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Acronyms

AABB Axis Aligned Bounding Box

BAG Basic register for Addresses and Buildings

CGAL Computational Geometry Algorithms Library

DSM Digital Surface Model

DTM Digital Terrain Model

GIS Geographical Information System

LOD Level of Detail

OGC Open Geospatial Consortium

SDIs Spatial Data Infrastructures

1 Introduction

The generation of 3D data models that represent the urban landscape is recently increasing due to the evolution of technology and the need for information, in order to provide solutions on issues that correspond to the building environment. The whole process includes the acquisition of the data, the data storage, the analysis, the visualisation and the quality control of each stage. Various technological methods can produce numerous outcomes of 3D data models of the same area. The use of different methods, especially in the data acquisition part, generate 3D data models that contain different information, such as geometric, semantic or topological aspects. Depending on the different advantages and drawbacks that these models have, they are usually used for different purposes. For instance, the CityGML models are rich in semantic information, whereas the multi-view stereo mesh models focus on the exchange of geometric data and lack the semantic information. These differences create major difficulties in the integration of the 3D data models. Many problems can occur during the conversion of data from one 3D data model to another, such as loss of information, loss of relationships, topological inconsistencies, etc. Zlatanova et al. (2012), Kumar et al. (2016). The idea of this thesis is to preserve the information that exists in both models and to enrich each model with information from the other one. The linking and the bidirectionally enrichment of the 3D data models will be explored for two different 3D models, a multi-view stereo mesh model and a CityGML model of the same area.

1.1 Theoretical part

1.1.1 Multi-view stereo mesh model

Multi-view stereo mesh models have evolved and they are used in a wide range of applications. The topological and semantic aspects of the objects are absent, while the geometry is well preserved. During the creation of the multi-view stereo mesh model, the input is a set of images of the object that is modeled and the output is a digital representation of the environment in the form of a textured triangle mesh Jonsson (2016). The process of the mesh generation consists of the image acquisition, the structure from motion algorithms and the multi-view stereo algorithms. Firstly, a large set of images with high overlap, is used to obtain high quality results for the generation of the mesh and the texturing. In general, there are different methods to obtain the set of images, either aerial or terrestrial imaging. Moreover, points that correspond to the same point in 3D space are found with the use of structure from motion algorithms and a sparse point cloud together with the orientation of the camera positions, are computed. Then, the dense point cloud for the mesh generation is created with the use of the multi-view stereo algorithms that matches each point in an image to a point in 3D space. The points are connected for the creation of the surface and the texture is provided from the correspondent images Furukawa et al. (2015), Jonsson (2016). The 3D mesh representations are many, but the most common is the triangle polyhedral and it will be used for this thesis.

The most important characteristic of multi-view stereo mesh models is their fast creation. In short time, they provide a large amount of geometric information. Moreover, the texture that they acquire from the images is a very important aspect that cannot be easily obtained by other methods. On the other hand, it is important to notice once again that multi-view stereo mesh models do not contain attributes, topological relations and semantic information. The meshes are usually purely graphic, which means that they consist of a soup of polygons that are painted by textures. Therefore, the millions of polygons of the mesh model cannot be easily distinguished to trees, buildings, streets etc. Computer analyses and simulations on the basis of virtual 3D city models that require meaningful objects with spatial and thematic properties, cannot easily be realized.

1.1.2 CityGML model

The background of the CityGML data models is the urban information modelling. The CityGML data models are semantic 3D city models and they have been developed to provide data homogeneity and to aim at the data integration. CityGML is an XML-based, open data model and an international standard, issued by Open Geospatial Consortium (OGC) for the storage and the exchange of virtual 3D city models Gröger et al. (2012). It provides an incorporation of both geometric, topological and semantic information. It is semantic oriented and it makes use of topological information to store geometry in a more proficient way. The aim of the development of CityGML is to reach a common definition of the basic entities, attributes, and relations of a 3D city model, in order to provide the reuse of the same data for different applications and to aim at the development of Spatial Data Infrastructures (SDIs) (OGC, 2012). Nowdays, the need for a semantic city model is related to the need for computer analyses and simulations. Corresponding analyses are important for several applications, such as security scenario, urban planning, energy assessment for improvements of buildings or insulations, emergency purposes, navigation systems, evacuation, etc. In these cases, a more analytic answer to these questions is needed. Therefore, the city model needs to understand the notion e.g. of a roof, a wall, a ground, a window etc. Moreover, one of the general aspects of CityGML is the multi-scale modeling (5 Level of Detail (LOD)). LODs are required to reflect independent data collection processes with different application requirements (Figure 1). Buildings may be represented in LOD0 by footprint or roof edge polygons. LOD1 is the well-known block model comprising prismatic buildings with flat roof structures. Furthermore, a building in LOD2 has differentiated roof structures and thematically differentiated boundary surfaces. LOD3 denotes architectural models with detailed wall and roof structures potentially including doors and windows. LOD4 completes a LOD3 model by adding interior structures for buildings. For example, buildings in LOD4 are composed of rooms, interior doors, stairs, and furnitures (OGC, 2012), Gröger and Plümer (2012). The creation of the CityGML model is done with the use of point clouds and the footprint information from the cadastre.

In CityGML, thematic objects are represented with their 3D spatial properties and interrelationships Kolbe (2009). An important drawback of the CityGML models is the amount of work that needs to be done for their creation. Also, they do not contain texture information. CityGML is not optimized with respect to efficient visualization. However, the semantic information given by the explicit association of CityGML objects to thematic classes like buildings, doors, plants, and the provision of thematic attributes, can be exploited to filter objects and to create 3D graphical shapes, appearance properties and materials accordingly. Kolbe (2009)

Figure 1: The five LODs defined by CityGML Biljecki et al. (2016).

1.2 Bidirectional enrichment

As it is mentioned above, this thesis will focus on the bidirectional enrichment of two different 3D models. With the use of the concept of bidirectional enrichment, it is meant the addition of aspects to a 3D model from a different model that includes further information for the same area. The two 3D models that will be used are the multi-view stereo mesh model and the CityGML model. In order to be able to make a distinction between the actions that can be performed for their bidirectional enrichment, the classification that is used in the UML diagram of the CityGML model for a city object, is taken into consideration. The thematic classes of a city object according to the top level class hierarchy of CityGML are, the abstract building, the transportation object, the relief feature, the water body and the vegetation Kolbe (2009). This thesis will be focused on the abstract building class, therefore the different aspects that are related to that class and can be linked between the multi-view stereo mesh model and the CityGMl model, plus the enrichments that each model can provide to the other one, are generally presented in the following table:

CityGML model to Multi-view stereo mesh model	**Multi-view stereo mesh model to CityGML model**
Semantic splitting	Add texture
Transfer attributes	Validate roof shapes
Remove noise	Update of roof shapes
Fix heights	Validate building's existence
Straighten walls	Update missing buildings
	Generate LOD2 from LOD1 or LOD3 from LOD2

Table 1: Bidirectional enrichments of a CityGML model and a multi-view stereo mesh model.

2 Related Work

In general, no related work has been found in the topic of this thesis. The approach of linking and bidirectionally enrichment of a multi-view stereo mesh model and a CityGML model of an area is new. Several fields that have some close relation to the goal that this thesis will try to achieve are the straightening of meshes, the semantic enrichment of 3D models, the interoperability of information, the matching of meshes and the mesh comparison.
More specifically, a method that is linked to the straightening of the meshes of multi-view stereo mesh model, is elaborated by Jonsson (2016) and is related with the detection of approximately flat surfaces in 3D meshes and their replacement with planes. Due to the advancement of 3D GIS analyses, the interest for semantic 3D city models has been growing in the past years. Smart et al. (2011) attempted the ennrichment of the semantic labelling of 3D models using data mined from Web 2.0 sources, while Diakité et al. (2014) provided an automatic propagation approach guided by heuristic rules, designed in a way that the user can decide how many rules are needed to supervise the semantic attribution of a 3D model. Moreover, on the same field, Verdie et al. (2015) created a workflow that produces a semantically rich 3D city model from a triangular mesh, with a classification method that is based on a probabilistic approach. A labelling process, which is proposed by Rook et al. (2016) seems very interesting, where a soup of polygons serves as input and the different spatial features (walls, terrain, roofs and building ground) are recognised, distinguished, and structured in the 3D model, following the CityGML definitions. It has to be noted that none of the above approaches has attempted to enrich semantically a multi-view stereo mesh model with the use of information from a CityGML model and vice versa. Some research has been done into the interoperability of information, that focuses on the way that the data is formated in the format files and the differences between the different 3D data models. An approach of the transformation of one model to another, is done by Kumar et al. (2016), where basically the transformations from COLLADA to CityGML model and from BIM to CityGML model is quite interesting. That study investigates the interoperability between 3D data models and presents a transformative

mapping between them at different levels of detail. Moreover, in Stadler and Kolbe (2007) study, the structure of semantic and spatial information of 3D city models, as well as their correspondence, referred to as spatio-semantic coherence, is analysed.
More relevant with the approach that is chosen for this thesis is the field of research of the mesh comparison and the matching of 3D meshes or shape matching. Studies on the mesh comparison of different simplifications are done by Roy et al. (2002) and Roy et al. (2004), who assessed respectively, the geometric and the attribute mesh quality after a simplification process by comparison between the original and its simplified representation. Furthermore, research on the mesh matching (Veltkamp (2001) and Ericson (2004)) has resulted that Hausdorff distance and point-to-polygonal-mesh distance are more relevant to the approach of this thesis. The Hausdorff distance is the greatest of all the distances from a point in one model to the closest point in the other model. It provides a global comparison between two meshes and not a local comparison Veltkamp (2001). Therefore, the point-to-polygonal mesh distance is judged to be more reliable (Guezlec (2001), Ericson (2004)). According to Ericson (2004) and Eberly (2006) a way of obtaining the closest point between a triangle and a point is to use a vector calculus approach. The minimum of this function must occur in one of three cases: at a vertex, on an edge or in the interior of the triangle. This approach will be used in order to compare the meshes of the two different 3D data models.

3 Research Objectives

The objectives and the scope of the research of this thesis will be presented in this section.

3.1 Objectives

For this thesis, the main research question is:
To what extent an automatic bidirectional enrichment of a multi-view stereo mesh model and a CityGML model can be done?

The linking and the bidirectional enrichment of the two models is the main aim of this thesis. The following sub-questions will be investigated, in order to meet the expectations of the final goal:

- What kind of enrichment is possible between a multi-view stereo mesh model and a CityGML model?
- How to semantically split a multi-view stereo mesh with the use of a CityGML model?
- How to transfer attributes from a CityGML model to a multi-view stereo mesh model?
- How to split a multi-view stereo mesh model on each building?
- To what extend can the building parts (doors, windows) and the non-building parts (vegetation, streets, lamps, signs) be recognizable in a multi-view stereo mesh model? Is it possible to remove the non-building parts from the multi-view stereo mesh model?
- How to provide texture on the buildings of a CityGML model with the use of the texture from a multi-view stereo mesh model?
- How to validate the information that a CityGML model provides? To what extend does the roofs of the buildings differ from reality? Are all the buildings that appear in a multi-view stereo mesh model in a CityGML model?

3.2 Scope of research

First of all, this thesis will include an inventory of what can be linked between a multi-view stereo mesh model and a CityGML model, for their automatic bidirectional enrichment. Apart from the exploratory part, some automated techniques for the transfer of aspects from the one to the other model and conversely, will be done. The different techniques will be investigated for a smaller part of an area with four buildings in Amsterdam and then, for a larger part of the same area. With the increase of the study area, the performance of the processes will be examined. The enrichment of the multi-view stereo mesh model from the CityGML model will be focused on the semantic splitting of the mesh and the removal of elements that are not building parts, such as vegetation, streets etc. In the other direction, the improvements of the CityGML model from the multi-view stereo mesh model will include the transfer of the textures of the buildings and the validation of the buildings. During the validation, the absence of buildings in the CityGML model will be investigated and the shapes of the roofs in a CityGML model, will be compared with the roofs of the multi-view stereo mesh model, in order to check the failures that might exist in a CityGML model. In case of a satisfying result of the above steps, the enrichment of the LOD2 CityGML model with windows and doors, will be explored, in order to investigate the possibility of an automatic transformation of an LOD2 to an LOD3 CityGML model.

4 Methodology

In this part, the methodology that will be used, is analysed. The steps of the enrichment of the multi-view stereo mesh model from the CityGML model and the opposite direction, are presented in the following flowchart (Figure 2). The basic steps of the methodology that will follow are three, the semantic splitting of the multi-view stereo mesh model, the subdivision of the multi-view stereo mesh model on buildings and the connection of the buildings of the multi-view stereo mesh model with the buildings of the CityGML model.

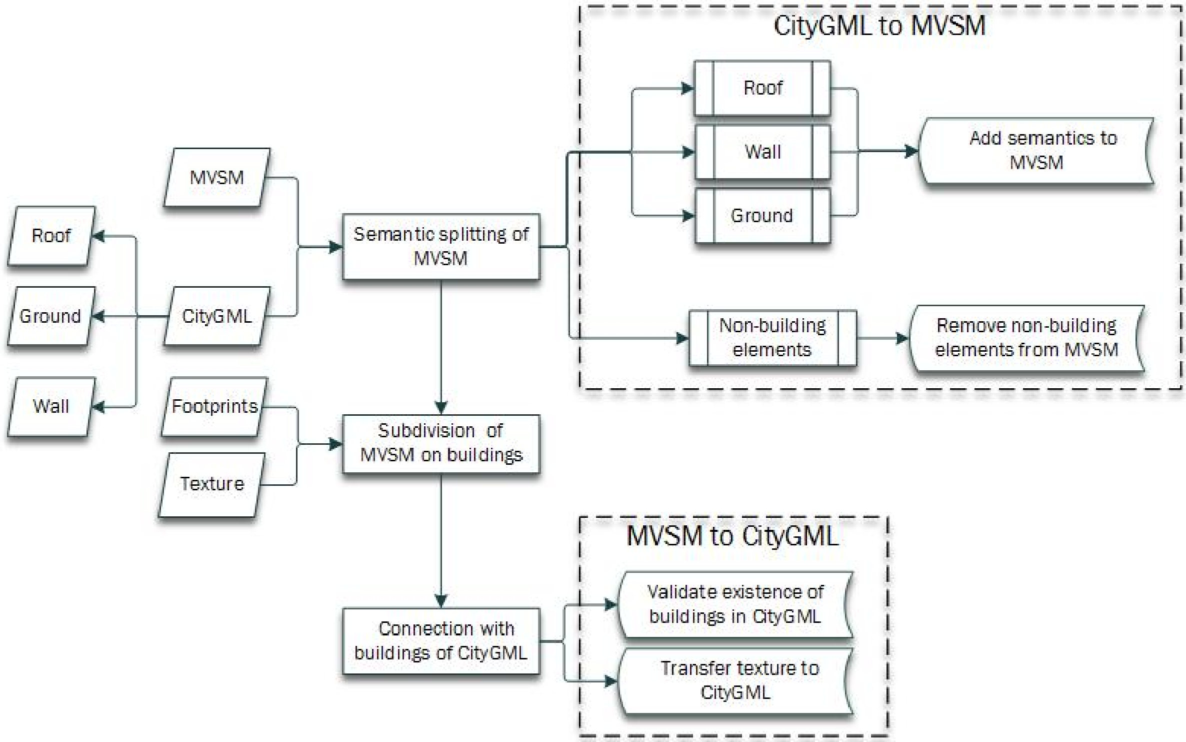
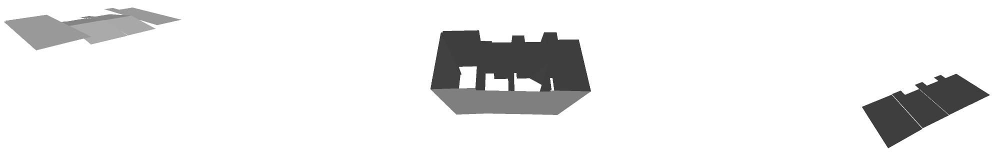


Figure 2: Flowchart.

First of all, in order to achieve the semantic splitting of the multi-view stereo mesh model, both 3D models, the CityGML model that consists of the three thematic layers, roof, ground, wall and the multi-view stereo mesh model, will be used. In this part, the building part of the multi-view stereo mesh model will be distinguished from the non-building part, in order to achieve the removal of the non-building parts from the multi-view stereo mesh model and to add semantics to the model, such as roof, ground, wall and if possible, windows and doors. Furthermore, the subdivision of the mesh on the different buildings will be attained, with the use of the different colors on the texture that correspond to the buildings of the multi-view stereo mesh model and the use of the footprints of the buildings. The connection of the buildings of the multi-view stereo mesh model with the buildings of the CityGML model will follow. After that, the shape of the roofs and the existence of buildings will be validated in the CityGML model. Also, the transfer of the texture of the buildings of the multi-view stereo mesh model to the buildings of the CityGML model, will be possible.

4.1 Semantic splitting of the multi-view stereo mesh model

The semantic splitting of the multi-view stereo mesh model will provide information for the building and the non-building parts of the 3D mesh. In this way, two basic results will be achieved, the removal of the non-building parts, such as trees from the 3D mesh and the addition of thematic information to the multi-view stereo mesh model. As far as it concerns the removal of the non-building parts from the multi-view stereo mesh model, the mesh of the multi-view stereo mesh model will be firstly distinguished into two categories, the building and the non-building parts. Initially, the multi-view stereo mesh model will be splitted into three different categories (roof, wall and ground) that the CityGML model consists of. Examples of the layers of the CityGML model that will be used for the splitting of the mesh, are shown below:



(a) (b) (c)

Figure 3: Example of the different layers. (a) Roof surface layer. (b) Wall surface layer. (c) Ground surface layer.

The process for the removal of the non-building parts will be the following:

- Distinguise the mesh into roof, wall, ground by computing the distances between the meshes of the two models (1^{st} attempt).
- The removal of the roof surface from the multi-view stereo mesh model.
- The wall surface of the 1^{st} attempt will also contain information of the ground. Therefore, a 2^{nd} attempt for the subdivision of the wall surface, to the ground and to the correct-wall surfaces, will be done. It has to be added that the ground surface in this case, does not correspond to the same ground surface of the CityGML model. The distinction of the wall surface will be achieved with the following steps:
    1. Usage of the boundaries of the footprints of the buildings.
    2. Creation of a buffer from the limits of the footprints and according to the normals of the triangles and some heuristic rules, distinguish the meshes that correspond to the wall or to the ground.
    3. Achievement of the distinction.
- Usage of the ground surface with heuristic rules, in order to make distinctions on its aspects, with major goal the detection of the vegetation.
- Removal of the vegetation and other non-building parts from the multi-view stereo mesh model.

The 1^{st} attempt of the splitting of the mesh is achieved for a testing area. The triangles of the multi-view stereo mesh model that are closer to the triangles of the CityGML model that correspond to a single layer, retrieved the corresponding attributes. In order to compute the distance of each mesh of the multi-view stereo mesh with the meshes of the three layers of the CityGML model (Figure 3), the method that is used, is based on the computation of the closest point between a triangle and a point, an approach that is performed by Eberly (2006) and Ericson (2004). The distances of the closest points from the one model with the compared points from the other model are computed and they are used for the distinction of the semantics that need to be linked from the one model to the other. For this step, the Computational Geometry Algorithms Library (CGAL) is used, which uses the Axis Aligned Bounding Box (AABB) that builds a datastructure from a sequence of primitives. More specifically, the algorithm that is used for the 1^{st} attempt of the distinction of the semantics, is shown below:

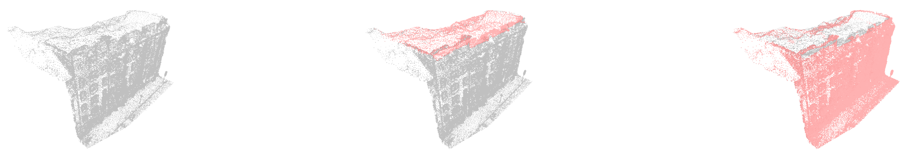
Algorithm 1: SEMSPLIT (*mesh*, *WallT*, *RoofT*, *GroundT*)

Input: List of the triangles of a mesh model and lists of the layers from a CityGML model (Wall, Roof, Ground)

Output: *Wall*: triangles of the mesh model that correspond to the WallSurface, *Roof*: triangles of the mesh model that correspond to the RoofSurface, *Ground*: triangles of the mesh model that correspond to the GroundSurface

```
trianglesW, trianglesR, trianglesG ← assign empty list of the triangles of the
    WallSurface, RoofSurface and GroundSurface of CityGML model respectively
for triangle ← 0 to length of WallT list do
    a, b, c ← assign the points of triangle as 3D point with the use of CGAL
    trianglesW ← append the triangle that derive from a, b, c points with the use of
    CGAL
end

for triangle ← 0 to length of RoofT list do
    a, b, c ← assign the points of triangle as 3D point with CGAL trianglesR ← append
    the triangle that derive from a, b, c points with CGAL
end

for triangle ← 0 to length of GroundT list do
    a, b, c ← assign the points of triangle as 3D point with CGAL trianglesW ← append
    the triangle that derive from a, b, c points with CGAL
end
treeW, treeR, treeG ← assign an AABB tree triangle soup to triangleW, triangleR and
    triangleG respectively, with CGAL

Wall, Roof, Ground ← assign empty lists
for triangle ← 0 to length of mesh list do
    a, b, c ← assign the points of triangle as 3D point with CGAL

    sqdaW, sqdbW, sqdcW ← compute square distance of point a, b and c to treeW
    sqdminW ← assign min(sqdaW, sqdbW, sqdcW)

    sqdaR, sqdbR, sqdcR ← compute square distance of point a, b and c to treeR
    sqdminR ← assign min(sqdaR, sqdbR, sqdcR)

    sqdaG, sqdbG, sqdcG ← compute square distance of point a, b and c to treeG
    sqdminG ← assign min(sqdaG, sqdbG, sqdcG)

    if sqdminW <= sqdminR and sqdminW <= sqdminG then
        Wall ← append triangle
    end
    if sqdminR < sqdminW and sqdminR <= sqdminG then
        Roof ← append triangle
    end
    if sqdminG < sqdminR and sqdminG <= sqdminW then
        Ground ← append triangle
    end
end
```

The result of the above process is illustrated in the following figure:



(a) (b) (c)

Figure 4: (a) Testing area of a multi-view stereo mesh model. (b) Result of the points that correspond to the roof surface. (c) Result of the points that correspond to the wall surface.

Some information on the data and the results that are related to the above example, are shown in the following table:

	CityGML model (number of triangles)	Multi-view stereo mesh model (number of triangles)
Roof	65	150 079
Ground	20	0
Wall	25	11 749
Total	110	161 828

Table 2: Details concerning the data and the results of the semantic splitting example.

After the observation of the above results from Figure 4 and Table 2, it can be easily observed that the ground layer of the multi-view stereo mesh model cannot be distinguished with the use of this method. The reason is that the ground surface, which is related as ground in a CityGML model does not correspond to the ground that is included in a multi-view stereo mesh model. The ground surface of the CityGML is too far from the ground points of the multi-view stereo mesh. It is important to notice that the ground surface of the multi-view stereo mesh that is related with the non-building parts, such as streets, lamps, signs, noise etc. with the use of the above method, is assigned in the wall layer of the multi-view stereo mesh model (Figure 4c).
After the semantic splitting of the multi-view stereo mesh model and the distinction of the 3D mesh to building and non-building parts, the next step is to distinguish and assign the semantic information of the building parts to the multi-view stereo mesh model. As building parts, the categories of the roof, the ground and the wall are the main split that this thesis will try to achieve. In this part, the distinction of the windows and the doors from the wall surface will be investigated and the way of transferring the thematic information to the multi-view stereo mesh model will be discussed. The basic steps that will be followed for this goal are the following:

- Distinguish more attributes (windows, doors) with the use of heuristic rules.
- Remove the noise from the roof.
- Find the corresponding triangles in the multi-view stereo mesh model.
- Add the related attributes in the multi-view stereo mesh model.

4.2 Subdivision of the multi-view stereo mesh model on buildings

The next step of the methodology is related to the subdivision of the multi-view stereo mesh model. The 3D mesh will be subdivided according to the buildings of the area. A combination of information needs to be performed, in order to achieve the split of the mesh on the different buildings. Apart from the characteristics of the buildings that sometimes can be recognized on the mesh surface, the footprints of the buildings from the CityGML model and the colors of the texture that is included in the multi-view stereo mesh model, can somehow distinguish the boundaries of the buildings on the multi-view stereo mesh model. The steps that will be followed in this part of the methodology are:

- Take the footprints of the buildings from CityGML model.
- Take the texture of the buildings from the multi-view stereo mesh model.
- Create planes on the walls of the CityGML model (use the information from the footprints).
- Create planes on the parts where the texture of the multi-view stereo mesh model change.
- Compare the planes and with the use of heuristic rules, decide the boundaries of each building in the multi-view stereo mesh model.

4.3 Connection of the buildings of both models

The final basic step of the methodology aims to connect the buildings of both models, in order to be able to enrich bidirectionally information that is related to the buildings. According to the distance that will be computed between the decided boundaries of the buildings in the multi-view stereo mesh model and the boundaries of the buildings from the footprints in the CityGML model, the connection of the same buildings will be done. In this step, some failures are expected due to the default shapes of the roofs that are usually placed during the creation of a CityGML model and due to the noise that exists from the creation of the multi-view stereo mesh model. Moreover, disconnections are expected in some cases, where buildings are missing from the cadastre information. These buildings are not included in the CityGML model, while they are in the correspondent multi-view stereo mesh model. The basic issues of this part of this thesis will be focused on the connection of the buildings, the validation of their characteristics and their update with useful aspects. The steps that will be followed are:

- Take the boundaries of the buildings from CityGML model.
- Take the boundaries of the buildings from the multi-view stereo mesh model (results from the previous section).
- Compare and connect the buildings.
- Validate the shapes of the roofs in the CityGML model.
- Update the shapes of the roofs in the CityGML model.
- Validate the existence of buildings in the CityGML model.
- Update the existence of buildings in the CityGML model.
- Transfer texture to the buildings of the CityGML model.

5 Schedule

In this section, the activities that are scheduled and the meetings that will be organized in order to reach the expectations of this thesis, are presented.

5.1 Activities

The time planning of the activities that are needed in order to meet the research objectives are shown in the following table:

Start	End	Activity
20 Sep	26 Sep	Explore graduation topics
27 Sep	13 Nov	Preparation for P1
		P1 - Progress review Graduation Plan
15 Nov	28 Nov	Literature study
29 Nov	12 Dec	Research on the mesh matching
13 Dec	26 Dec	Study and implementation of Hausdorff distance and point-to-triangle distance
27 Dec	15 Jan	Preparation for P2
		P2 - Formal assessment Graduation Plan
17 Jan	30 Jan	Add semantics to the multi-view stereo mesh model
31 Jan	13 Feb	Remove the non-building parts from the multi-view stereo mesh model
14 Feb	27 Feb	Validate the shape of the roofs in the CityGML model
28 Feb	13 Mar	Validate the existence of buildings in the CityGML model
14 Mar	27 Mar	Transfer texture to the buildings of the CityGML model
		P3 - Colloquium midterm
24 Mar	12 May	Write final implementation
01 May	12 May	Thesis writing
		P4 - Formal process assessment
12 May	15 Jun	Finalize thesis
12 Jun	22 Jun	Prepare final presentation
		P5 - Public presentation and final assessment

Table 3: Time planning for the activities of this thesis.

The graduation calendar is presented below:

Date	Event
P1	14 November
P2	16 January
P3	March week 12
P4	May week 20-21
P5	June week 26-27

Table 4: Graduation calendar.

5.2 Meetings

Meetings will be scheduled with the mentors, in order to provide guidance and feedback on the project. Every week, meetings will be appointed with the daily supervisor dr. H. Ledoux.

Additional advice and assessment will be given by R.Y. Peters and prof. dr. T. H. Kolbe. Co-reader ??

6 Tools and Data

In this section, the tools and the data that will be used in this thesis, are presented.

6.1 Tools

The CityGML model will be validated with the use of the val3dity tool, created by Hugo Ledoux. For file format conversions of the 3D models, the FME software will be used. Code will be written in Python along with several packages, such as Numpy,lxml, Rtree, CGAL etc. to conduct the linking and the bidirectional enrichment of the multi-view stereo mesh model and the CityGML model. The 3D data visualization and some analyses of the meshes of the models will take place in CloudCompare and MeshLab software. The thesis will be written in LaTeX.

6.2 Data

The dataset that will be used on this thesis, consists of two 3D models, a multi-view stereo mesh model and a CityGML model of an area in Amsterdam. The original file formats are, COLLADA format for the multi-view stereo mesh model and xml format, for the CityGML model. A map of the related area is illustrated in Figure 5.

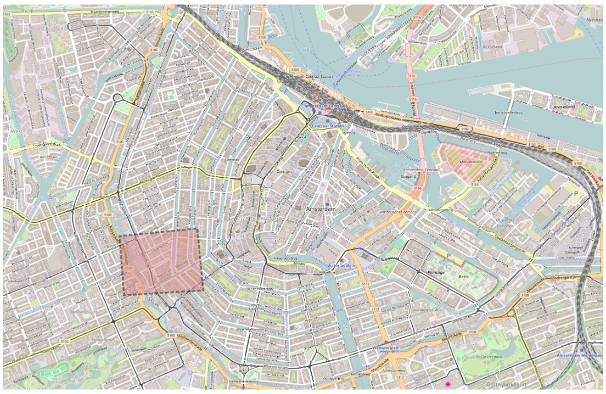


Figure 5: Study area in Amsterdam.

In particular, the multi-view stereo mesh model is given by Cyclomedia in seven differentLODs. The LODs that are provided are numbered in the opposite direction of what is standard. For example, LOD0 is created from the original deliverables, but each LOD numbered higher, was simplified and smoothed. The data that remains in LOD6 is approximately one quarter of the original size. Examples of the different levels are shown in Figure 6. For this thesis, all these LODs might not be used. The focus will be at LOD0 that is more precise.

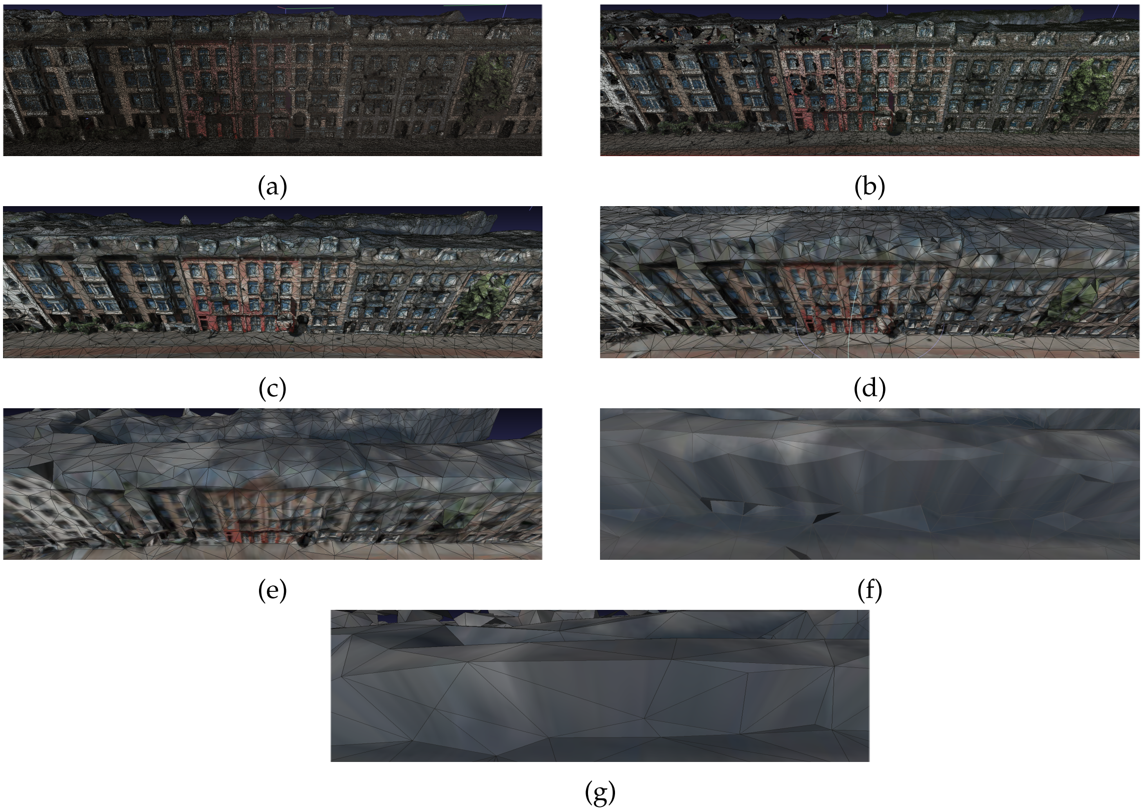


Figure 6: Levels of detail of the multi-view stere mesh model. (a) LOD0. (b) LOD1. (c) LOD2. (d) LOD3. (e) LOD4. (f) LOD5. (g) LOD6.

An important characteristic of the multi-view stereo mesh model is the texture information. With the use of the texture, the different buildings can be distinguished, because they have different colors, therefore different texture information. An example of the differences on the texturing between the buildings is depicted in the following figure:

Figure 7: Texture.

Moreover, the related CityGML model of the study area is given in LOD2 standard, from virtualcitySYSTEMS. They created the CityGML with the use of the Basic register for Addresses and Buildings (BAG) that contains the footprints of the buildings, the Digital Surface Model (DSM), the Digital Terrain Model (DTM) and an orthophoto of the area. Figure 8 and figure 9 shows the footprints and the CityGML model that is created to be used for this thesis, respectively.

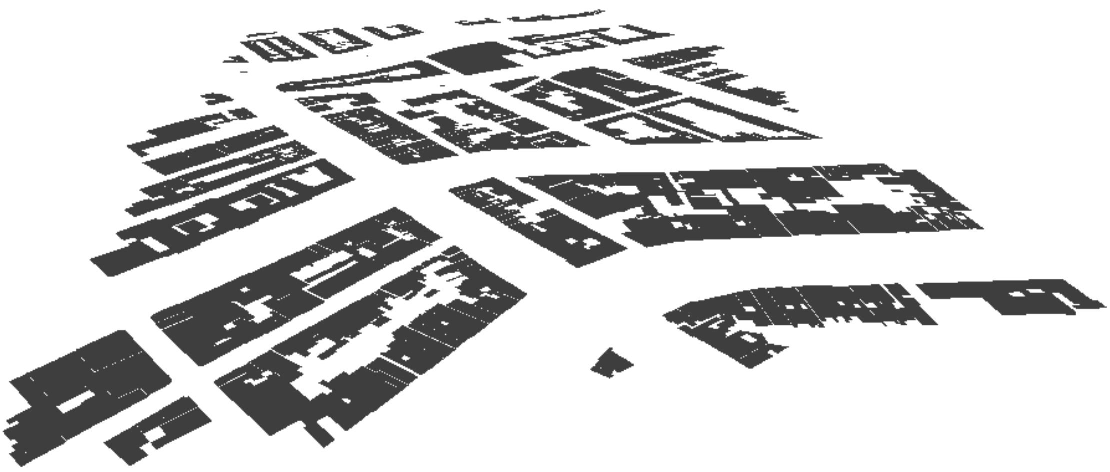


Figure 8: Footprints.

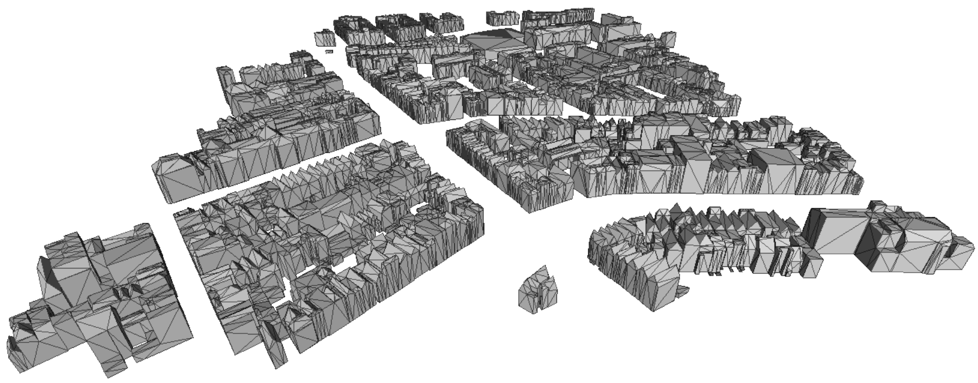
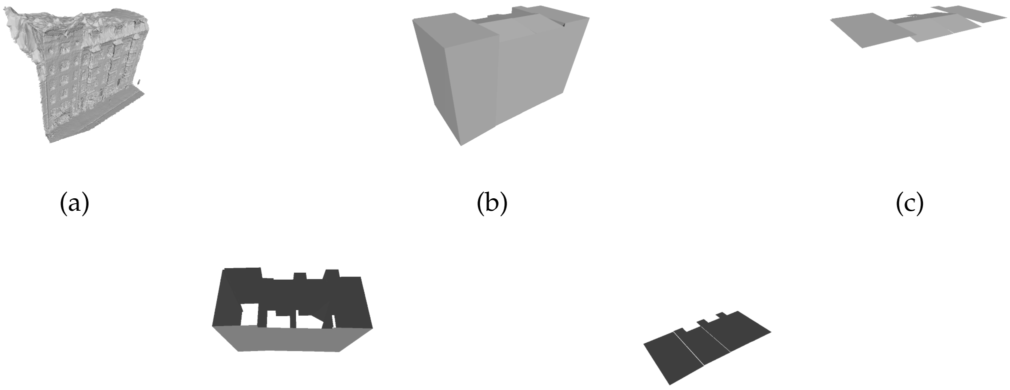


Figure 9: LOD2 CityGML model of the study area in Amsterdam.

The methodology will be tested in a smaller part of the study area. Examples of the multi-view stereo mesh model and the different layers of the CityGML model of the testing area, are illustrated below:



(a) (b) (c)

(d) (e)

Figure 10: Example of the multi-view stereo mesh model and the different layers of the CityGML model of the testing area. (a) Multi-view stereo mesh model. (b) Buildings in the CityGML model. (c) Roof layer of the CityGML model. (d) Wall layer of the CityGML model. (e) Ground layer of the CityGML model.

How to add it??? OGC, 2012. OGC City Geography Markup Language (CityGML) Encoding Standard 2.0. Technical Report OGC 12-019, Open Geospatial Consortium.

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