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CONTEXT AWARENESS AND TYPIFICATION IN BUILDING GENERALISATION

Relatore: Laureanda:

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A conclusione di questa tesi, che coincide con la fine di questo mio percorso di studi universitari, vorrei ringraziare tutte quelle persone che mi hanno accompagnato durante questi cinque anni.
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Senza contare la sua infinita pazienza e diponibilità.

Contents

Abstract

Cartography is the study and practice of making maps. Combining science, aesthetics, and technique, cartography builds on the premise that reality can be modelled in ways that communicate spatial information effectively.

The scale of a map is responsible for the resolution of the representation. Moving from a large-scale toward a small-scale the size of the minimum perceptible feature's detail is increased. The smaller the scale the more the representation is simplified and abstracted. The process of abstraction of represented information subject to the change of the scale of a map is called generalisation. The purpose of generalisation is to produce a good map, balancing the requirements of accuracy, information content and legibility.

In manual map generalisation the cartographer's work is guided by a few principles such as selection of the essential content to meet the map's purpose, and preservation or accentuation of typical and unusual map elements. The recognition and maintenance of such elements is accomplished by a trained cartographer in an holistic manner. To automate this complex process it is necessary to transfer and decompose the cartographic knowledge and operations into a computer understandable form.

The objective of this thesis is the development of an automated process to perform the generalisation of buildings from 1:5000 to 1:50000 scale. The strategy adopted is applied to partitions of the dataset (blocks) and differs between urban and rural context; ad–hoc typification algorithms have been developed to cope with high–density blocks, medium–density blocks and spatial patterns. Low–density blocks that do not fit the previous classifications are treated with a best–effort approach. The work of this thesis is described in seven chapters as follows.

In chapter one an introduction to cartography and generalisation is given as well as an overview on the entire cartographic process. In chapter two more attention is paid to the topic of building generalisation with regard to the main issues and the related work that addresses them.

In chapter three the approach followed by this thesis is presented. The strategy consists in developing a contextual generalisation aimed at controlling the triggering of algorithms depending on the spatial context in which they are applied. We pursued the objective to distinguish between two main contexts such as urban and rural. In chapter four a data enrichment process is described in order to acquire information on building distribution. In chapter five the method developed to generalise buildings belonging to urban zones is proposed. A distinction is made between areas with high density concentrations of buildings and area with medium concentrations. The generalisation approach to rural areas is discussed in chapter six. In chapter seven we focused on a particular aspect regarding details of individual building representation at the target scale; an algorithm for exaggerating characteristic narrow parts is proposed.

At the end of the thesis a short summary of the work done and a discussion about future developments are given.

Chapter 1

Introduction

In this chapter the basis for cartography is provided. The importance of cartographic maps to describe the surrounding reality by conveying spatial relationship information to the user is discussed as well as the evolution of the cartographic process. This evolution includes the advent of informatics and the subsequent attempts to automate it.

The concept of scale is also explained while describing the steps involved in the production of a map.

Finally, the advantages of an operation to automatically derive a small-scale map from a large-scale one are identified. This operation, called generalisation, is the major concern of this thesis.

1.1 Cartography

Cartography (from Greek *chartis* = map and graphein = *write*) is the study and practice of making maps. Combining science, aesthetics, and technique, cartography builds on the premise that reality can be modelled in ways that communicate spatial information effectively. A map is a symbolized image of geographical reality, representing selected features or characteristics. It results from the creative effort of its author's execution of choices, and is designed for use when spatial relationships are of primary relevance.

Human beings have always felt the need to represent the surrounding actuality by conveying spatial relationships among specific traits. Hence, several types of maps have been developed, each one for a different purpose. We can easily define two main different characterizations based on the quantity of features on a map and the final map destination. First *general maps*, i.e. those that are constructed for a general audience and thus contain a variety of features and second *thematic maps*, i.e. those focused on a precise geographic theme such as hydrography or topography and oriented toward specific audiences. In this thesis we will focus on general maps which can be consulted to have an overview on a territory such as city plans, regional maps, or world maps, depending on the scale of reduction. The scale concept is explained below.

1.2 Scale Concept

One of the most crucial aspects in the design of a map is the *scale* concept. The scale of a map is defined as the ratio of a distance on the map to the corresponding distance on the ground. If the region of the map is small enough for the curvature of the Earth to be neglected, then the scale may be taken as a constant ratio over the whole map e.g. a town plan.

Map scales may be expressed in words, as a ratio, or as a fraction, for example "one centimetre to one hundred meters" or 1:10,000 or 1/10,000.

Scales are often qualified as **small scale**, typically for world maps or large regional maps, or **large scale**, typically for county maps or town plans. The usage of small as against large relates to the expressions as fractions. For example, a town plan may have a scale fraction of 1/10,000: this is much larger than a scale fraction 1/100,000,000 used for a world map. There is no hard and fast dividing line between small and large scales.

The scale is responsible for the resolution of the representation. Moving from a large-scale toward a small-scale the size of the minimum perceptible feature's detail is increased.

If we consider a regional map with a scale of 1:50,000 with a standard minimum line weight of 0.2 mm, drawing a single line corresponds to an area of 10 meters.

Moreover, assuming that the minimum distance in order to perceive two features as distinct is also 0.2 mm, all the features at a distance less then 10 m from one another are no longer recognizable as separate entities.

1.3 Cartographic Process

Map design is essentially a decision making process and broadly includes four stages:

1. Analysis and definition
2. Data gathering
3. Map editing
4. Evaluation

1.3.1 Analysis and Definition

One of a cartographer's first steps is to identify the purpose and audience of the map. The purpose and audience determine how data is displayed, what map elements are included (they may be physical, such as roads or land masses, or may be abstract, such as toponyms or political boundaries), and the general layout and format of the entire map. A map designed to be a military tool for the national army will obviously look different to a map designed to be included in a report for local city counsellors.

Geographic information represents our understanding of the association of geographical features with their location on and near the Earth's surface. When presented in map form, an essential aspect of that information is that it may be adapted in semantic abstraction and level of geometric detail according to the purpose of the map and the extent of the Earth that is being considered at any one time. Another key parameter to set is the scale of representation. Representations of small areas in detail result in so-called large-scale maps, while representations of large regions in lesser detail are referred to as small-scale maps.

Traditionally cartographers have performed the task of adapting the content and the level of detail of a map to suit its scale and purpose and this process is called map **generalisation**. We will discuss more on this task later on in the chapter.

1.3.2 Data Gathering

1.The various geospatial data acquisition methods for modern geographic information systems can be divided into the following types [1] :

- *Terrestrial surveys.* Large-scale topographic data can be acquired through terrestrial surveys. Increasingly, such surveys immediately lead to digital files that can be imported into a GIS.

- *Photogrammetrical surveys.* From aerial photographs object coordinates can be determined in the present analogue or, increasingly, digital stereoplotters, and imported directly into information systems. The attribute information required could be determined either through interpretation or through field checking.

  A new form of data gathering from aeroplanes is *laser altimetry.* For the construction of terrain models aeroplanes are equipped with GPS receivers that allow the path of the aircraft to be determined to within 10 cm, and a laser range finder, which allows for distance measurements with up to 1 cm theoretical precision. If the aeroplane's location is known (through GPS) as well as the time interval between the time the laser pulses are emitted by the Laser Range Finder, reflected and returned again, the position and height of the terrain points that reflect the laser pulses can be ascertained with an actual accuracy that depends on the flying height and terrain characteristics (such as vegetation). Typical operational airborne surveys will have accuracy values of ± 20 cm.

- *Digitizing or scanning analogue maps.* Manual digitizing refers to the registration with a cursor of sequences of characteristics points belonging to lines on a map, through which action the coordinates of the positions touched are recorded digitally.

1.3.3 Map Editing

Once data has been gathered, the cartographer can proceed with the implementation of the map. As in any form of graphic art, cartographers have to consider the layout of all map elements to create a final product that is *informative, accurate*, and *aesthetically pleasing. Visual balance* and *legibility* are always important considerations for design.

To achieve all the objectives mentioned above knowledge and experience of the cartographer are very instrumental to his success. These skills allow him to:

- Eliminate characteristics of the mapped object that are not relevant to the map's purpose.
- Reduce the geometrical complexity of the characteristics that will be mapped.
- Orchestrate the elements of the map to best convey its message to its audience.

At this point is important to reflect on what has been discussed thus far. What has been highlighted so far is the **non-deterministic approach** of map editing, the so-called generalisation. Generalisation is still a research topic because it involves *knowledge*, *experience* and *visual perception* of the cartographer, all skills very difficult to teach to a software.

1.3.4 Evaluation

After the map has been created an evaluation task is performed to verify its correctness and consistency. During this phase some actions can be taken to refine the final product and verify the validity of the representation. One technique consists of checking the map against new measures acquired again via high precision instruments such as the differential global positioning system (DGPS) that uses a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions.

Alternatively a “constraint by constraint” assessment could be applied in order to get an indicator of the global quality of the map to appropriately address the fact that constraints might be violated intentionally to meet more important constraints. This raises questions on weighting and prioritizing different constraints as identified by Bard [2] and Mackaness and Ruas [3].

1.4 Generalisation

As can be understood from the previous paragraphs an important process called generalisation plays a central role in cartography.

The smaller the scale the more the representation is simplified and abstracted. This process of generalisation concerns itself with the process of abstraction of represented information subject to the change of the scale of a map. ***The purpose of generalisation is to produce a good map, balancing the requirements of accuracy, information content and legibility.*** It encompasses the modification of the information in such way that it can be represented on a smaller surface, retaining the geometrical and descriptive characteristics. The essence of the original information should be maintained at all smaller scales.

To keep this complex process as general as possible different attempts have been made to achieve a stringent definition. The International Cartographic Association has defined the process of generalisation as “the selection and simplified representation of detail appropriate to scale and/or the purpose of a map” [5]. McMaster and Shea [4] gives another general definition of generalisation: “Digital generalization can be defined as the process of deriving, from a data source, a symbolically or digitally-encoded cartographic data set through the application of spatial data and attribute transformation”.

Automation of semantic generalisation typically requires that the categories of interest are organized hierarchically with the most important categories at the top of the hierarchies and their more specialized subdivisions at progressively lower levels. Such classification systems facilitate the application of rules to decide which major categories are relevant and the level of semantic detail with which they are presented.

1.5 Cartography in Italy

In this paragraph the evolution of cartography in Italy is briefly described to understand the circumstances that have been favourable for the birth of the CARGEN project, the project I have been working at during my thesis development.

The Italian national mapping agency is the IGM, Istituto Geografico Militare, founded in 1872. This institute is responsible for all the cartographic maps at a small-scale, from 1:25,000 down to 1:1,000,000. The institute was commissioned to map the entire national territory in 1875 and took almost thirty years to realise and complete the Nuova Carta DâItalia. At that time the cartographic process was really an expensive task in terms of time and resources needed. It is reasonable to identify the most expensive steps of the process in data gathering and generalisation and it is not acceptable in todayâs world that so much time is needed to implement a map. In fact, the urban territory landscape is changing constantly and rapidly every day and a map becomes inaccurate after a very short period.

The low-response of maps to quick changes in the reality is even more evident when the subject map is at large-scale, i.e. city plans. In 1977 IGM decentralized its work by hiring the twenty Italian Regions to create the large-scale maps of their own region, i.e. 1:5,000 and 1:10,000 maps.

That is why after the advent of informatics the efforts in this field has been moved toward a way to automate the process keeping it as much cartographer-independent as possible.

As has been described in previous paragraphs, the data gathering step has significantly improved thanks to those techniques based on acquisition through photogrammetries or laser altimetry from an aeroplane. On the contrary, there is still a lot of work to do in the field of generalisation, because once a detailed geospatial data has been gathered, the *derivation* of maps to a small-scale must be performed to avoid costs of re-perform data gathering and restitution.

In the last few years regional agencies started up a digitalization process to store detailed geospatial data on a database and so adding attributes to the collected features such as type of road: urban, secondary, highway, etc...

These DBT, territorial databases, open up a new frontier in the map generalisation, it is easy to understand that in an automatic process it may be helpful to have additional and qualitative information about features rather than only work with geometries expressed as a sequence of coordinates.

There is a recent intent from the CNIPA (national information centre for public administration) on the standardization of the different regional database schemes to have a unique model in order to allow data interchanges between the Regions.

Due to the technological progresses and government efforts outlined above, circumstances were ideal to allow the birth of the CARGEN project.

1.6 The CARGEN Project

The CARGEN project whose name means CARtographic GENeralisation began in 2006 as a cooperation among the Department of Information Engineering of the University of Padova, the local government Regione Veneto and the Italian national mapping agency, the IGM - Istituto Geografico Militare.

CARGEN is a research project. Its aim is to study and develop an automatic process to generalise the IGM geodatabase in 1:25000 scale from the Regional geodatabase in 1:5000 scale.

The algorithms developed during the project embrace all in the field of generalisation, and comprehend, among others, hydrography selection and pruning, simplification of road networks, generalisation of buildings and displacement.

The first part of the project was completed in 2009, and the results were presented at the conference held at Palazzo Bò, in Padova, in July 2009.

A second part of the project was immediately followed, aiming to implement the generalisation of the IGM 1:50000 geodatabase.

The CARGEN project, one of the first (if not the only) in Italy to study the problems of cartographic generalisation, is active not only in a national scope, but also joins the developments of the international research community in this field.

1.7 Approaches to Automated Map Generalisation

Over the past two decades several attempts to develop comprehensive automated generalisation systems have been recorded. A short overview of these approaches is given with respect to the historical development. Generally we focus on the following five approaches:

- Interactive Systems
- Rule-Based Systems
- Workflow Systems
- Multi Agent Systems
- Optimization Approaches

1.7.1 Interactive Systems and Rule-Based Systems

It has been previously pointed out that the acquisition of cartographic knowledge is difficult. This is due to the fact that the cartographer is often unaware of the steps of their reasoning process, because the reasoning seems so obvious. Therefore a simplistic way in the advent of map generalisation systems has been to leave the complete decision process in the cartographer's hands. Thus, the generalisation system provides a set of digital generalisation tools that are interactively selected and applied by a cartographer. This way of using the cartographer's knowledge is called human interaction modelling [6]. However, for some of the tasks to be solved during the generalisation process, the formulation of requirements and actions is not as hard as the artistic components of map making. Examples can be seen in the legibility rules for ensuring minimal dimensions of object size and inter-object distances. Rules such as IF (building area $\leq$ 200 sqm) THEN (apply enlargement algorithm) could be fairly easily accomplished by a computer. As a result, in the late 1980s and early 1990s research focused on the development of rule-based expert systems. This approach requires the generalisation process to be broken down into condition-action pairs. Hence, the approach is also termed condition-action modelling.

1.7.2 From Rules to Constraints

Both interactive generalisation systems and rule–based systems have their disadvantages. A weakness of rule-based systems is the difficulty of acquiring and formalizing (cartographic) rules in a consistent manner [7]. Another disadvantage is the large number of rules required to describe requirements and actions between map objects sufficiently well. Further problems arise from the sequencing of generalisation operations, since the different operations may affect each other and potentially cause secondary conflicts. For example one geometric condition demands the simplification of a complex building outline, while at the same time a size condition requires an enlargement of the building to be visible on the map, and finally a third condition will not allow a building enlargement due to a resulting geometry overlap with a neighbouring building. Thus, a need exists for a flexible sequencing approach that must be capable of handling several requirements at the same time [6].

Prompted by the drawbacks of rule–based systems, Beard [8] proposed the use of constraint based modelling for automated generalisation. Constraints formulate requirements of a generalised map, that is, conditions that a generalised map should adhere to. However, in contrast to rules the violation or fulfilment of a condition is not bound to an action. Here, choosing an action to solve a problem is the result of a synthesis of conditions. But constraints are not only useful to decide on the generalisation algorithm to apply if several requirements have to be considered. Their primary role is simply to evaluate whether the requirements on the map, a situation, or a single map object are fulfilled or not.

1.7.3 Constraint–based Automated Map Generalisation using Workflow Systems, Multi Agent Systems and Optimization

The introduction of constraint–based modelling did not only enable new approaches to automated map generalisation, such as agent modelling, but also enabled the integration of interactive and rule–based methods in a more sophisticated way by workflow systems.

Workflow models provide an intuitive way of chaining together several processing tasks (e.g. building elimination, simplification, displacement, etc.), whereby the final order of the tasks is interactively defined by an expert. Thus, rules can be executed in a dynamic order in contrast to batch systems that execute rules in a fixed order. Constraints can be used in the workflow approach to characterize the map in a first step. In the second step, based on the characterization results, map partitions, themes and map objects can be assigned different processing paths that have been setup interactively as a workflow. An example for a constraint and workflow-based generalisation system has been presented in Petzold et al. [9].

The Multi Agent System developed during the AGENT project [10] is a further approach to automated map generalisation that utilizes constraints. The system follows the conceptual generalisation model presented by Ruas and Plazanet [11]. Every map object is represented by a so–called agent object that knows the constraints that apply to it. While agents representing individual map objects (e.g. a building) are termed micro–agents, these agents can be managed by so–called meso–agents that represent groups of map objects, e.g. the buildings of a city block. All agent objects carry out a self–evaluation, using the constraints, and apply the appropriate generalisation algorithms if a constraint is not satisfied. Two different approaches for agent modelling have been proposed for map generalisation. In the original approach by Ruas [12] a strictly hierarchical model of macro, meso, and micro object agents were employed, where communication was restricted to a top-down process. Communication is necessary for instance if objects within a group need to be selectively deleted, or displaced from each other. In the second agent modeling approach proposed by Duchêne [13], the communication is accomplished non–hierarchically between the single–object agents.

Chapter 2

Building generalisation

In this chapter a detailed description of building generalisation operations and issues is provided. The related work is then briefly summarise to give an idea on how the main problems are addressed by researches both theoretically and practically with some attempts to develop a software for generalisation. The operations involved during the generalisation are then described to get confidence with technical language that belongs to the specific topic of building generalisation. Finally the aim of this thesis is provided along with a synthetic description of the approach followed in this work.

2.1 Introduction

When human cartographers generalise a map, they know by looking at the original map, the relationships between each object, what information is conveyed by each object, both as a single entity (the house) and collectively (a residential area).

An automated generalisation process starts from a limited set of information. It has at its disposal a database describing each object individually and independently from one another. This means that the data describing a building is just a list of the coordinates of its boundary and a set of attribute. With this information, only the most direct measures are easily computed (e.g. the area of the building or the length of its perimeter), whereas other measures require a more complex algorithm such as its size relative to other buildings.

For this relative information we need to compare each building among a set of buildings. In a similar vein, the system has no information about the distribution of the objects: which ones are neighbours, or part of the same town, or which ones are isolated. It is important to identify such additional information in order to generalise buildings in an urban area successfully.

This information is needed to control the generalisation process in response to a set of (sometimes) competing objectives/constraints. Some objectives are well defined (legibility constraints) whilst others are not because they include aesthetic criteria or are difficult to formalize (such as spatial pattern or homogeneity).

When generalising buildings it is very important to maintain [14]:

1. Legibility.
2. The visual identity of each building.
3. The pattern among a local group of buildings.
4. The overall density of buildings across a region of the map.

2.1.1 Legibility Constraints

Legibility constraints can be divided in three classes:

- **Perception.** Perception constraints are those that specify a minimum size for objects or the detail of objects. Figure2.1 shows two constraints. The first one specifies the minimum size of a building (a square of 0.4 mm), and the second one specifies the minimum length for an edge of a building boundary (0.2 mm). These values come from "Norme e Segni convenzionali per la realizzazione dei fogli della Carta d'Italia alla scala 1:50,000" (Italian specifications on generalisation to the scale 1:50,000) [15].
- **Separation.** The separation threshold is the minimum distance between two features (0.2 mm).
- **Maximum density.** The maximum density is the point at which the map becomes locally unreadable.

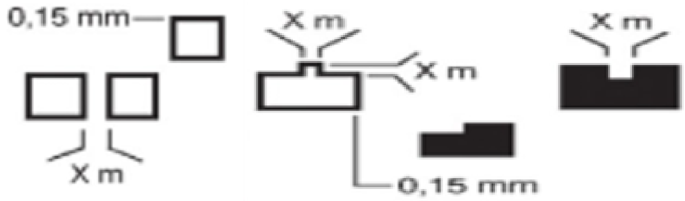

Figure 2.1: Perception constraints, with X = 11 m.

2.1.2 Visual Identity

The following qualities are intended to preserve the visual characteristics that help the reader to identify an object as a building. We identified three qualities:

- **Shape and orientation.** In general, a building is represented in a map by an area whose boundary has orthogonal angles.

- **Size.** The size of a building helps to convey its type. Usually the smallest ones are residential buildings, while the largest are industrial or administrative. There tends to be a correlation between shape and size. The smaller a building is, the less detailed its boundary can afford to be for reasons of legibility.

2.1.3 Spatial Organization

In addition to individual characteristics, the spatial relationships between the objects in a map contribute collectively to the information conveyed by the entire map. To express this information, we use ideas drawn from *Gestalt theory* (the study of the factors influencing grouping perception). Three of them – proximity, similarity and continuity, drawn from [16] – are relevant to the distribution of buildings.

- **Proximity.** Proximity is one of the most critical criteria for the visual grouping of objects. In Figure similarity three groups of buildings can be identified. Based on proximity the three buildings on the right can be grouped together while other association can be done with buildings on the left based on similarity.

- **Similarity.** This criterion relates to our capacity to group objects that look similar. Similarity can be expressed in terms of shape, size and orientation. See the four buildings on the left in Figure2.2.

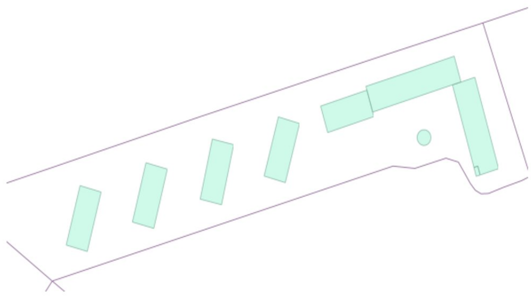

Figure 2.2: The group of buildings on the right can be identified in terms of proximity, while the group on the left can be identified in terms of their shape and orientation.

- **Continuity.** The last criterion is continuity or linearity. We can identify groups of objects according to their regular linear disposition, as in Figure2.3. This characteristic is important for our purposes because buildings are usually located along roads, often with a strong regularity in their position, especially within small residential areas.

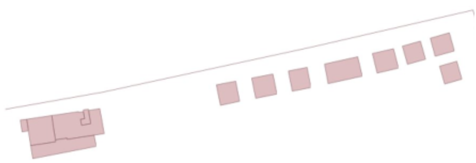

Figure 2.3: Buildings are usually located along roads, often with a strong regularity in their position and orientation, especially within small residential areas.

When generalizing, these constraints become somewhat in competition with one another. For example enlarging objects to satisfy minimum size constraint tends to reduce the distance between them and increase the density of objects.

2.2 Related work

Some methods have been proposed by researchers to address the aforementioned issues. One of the most remarkable efforts has been made by the AGENT project as previously mentioned. AGENT is part of the ESPRIT Long Term Research program. It began on the 1st of December 1997 and lasted three years. The partners are : Institut Géographique National (France), Laser-Scan Ltd (UK), Institut National Polytechnique de Grenoble (France), University of Edinburgh (UK), University of Zurich (Switzerland). It approaches generalisation with a Multi-Agent paradigm.

Figure2.4 proposes the jurisdiction of the agents: at the top of the hierarchy we find macro-agents that refer to a big group of buildings forming a town, in the middle meso-agents represent smaller groups of buildings such as urban blocks, finally at the bottom micro-agents which refer to an individual building.

- The first step consists of the partition of the map space in terms of responsibilities and activities between agents using the road network, see Figure2.5. The resulting partitions are called blocks.
- Then, a more accurate classification is performed on the blocks to distinguish them among urban zone, suburban zone, industrial area, isolated building,etc..(see Figure2.6)
- Every zone is now associated a meso agent which performs a generalisation inside the block. An example can be seen in Figure2.7. In this example at point b) some buildings have been deleted due to density constraints violation, at point c) simplification of geometrical shapes is performed to improve legibility and aesthetic perception, and finally at point d) displacement of some overlapped features is accomplished.

All agent objects carry out a self–evaluation, using the constraints, and apply the appropriate generalisation algorithms if a constraint is not satisfied. The crucial point in using agents is that constraints vary based on the type of the agent and so the priorities vary.

When generalising, these constraints become somewhat in competition with one another. For this reason agents not only push the system toward their local maximum "happiness" but they also communicate and cooperate to reach a global optimum.

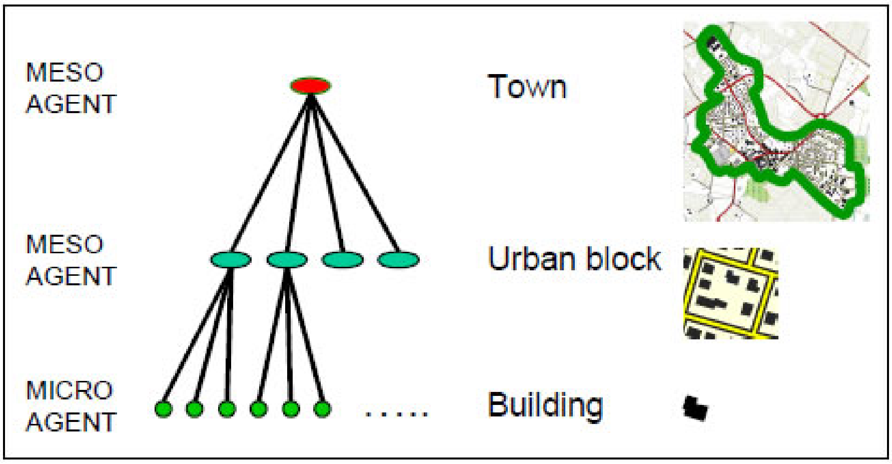

Figure 2.4: A hierarchical structure of micro, meso and macro agents.

Figure 2.5: Using the road network to partition the map space in terms of responsibilities and activities between agents.

Several algorithms have been developed by scientists so far regarding to other important operations of the generalisation process such as simplification, squaring and displacement.

One of the most robust and efficient algorithms in simplification is based on "Least Squares Adjustments" by Monika Sester [17] . It modifies the geometrical shape to fulfil the minimum length constraints for edges.

The decision of how to substitute a short facade depends on the geometry of the neighbouring sides:

Figure 2.6: Creation and characterization of urban zones. Cities are highlighted in red while rural zones are colored in green.

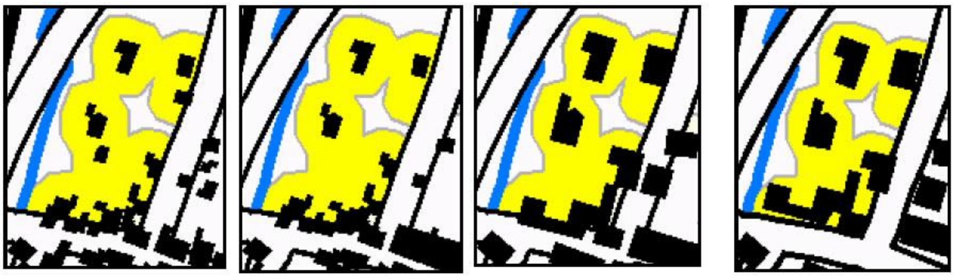

Figure 2.7: A generalisation sequence inside a suburban zone. a) Initial data b) After elimination c) After generalisation d) After displacement.

- Intrusion / extrusion: the angle between the preceding and the subsequent side is approximately 180°. The small side is set back to the level of the main facade.

- Offset: the angle between the preceding and the subsequent side is approximately 0°. The longer one of the adjacent building sides is extended, and the shorter side is dropped.

- Corner: the angle between the preceding and the subsequent side is approximately 90°. The adjacent facades are intersected.

These rules are iteratively applied to all the small sides of a building, starting with the shortest ones. See Figure2.8

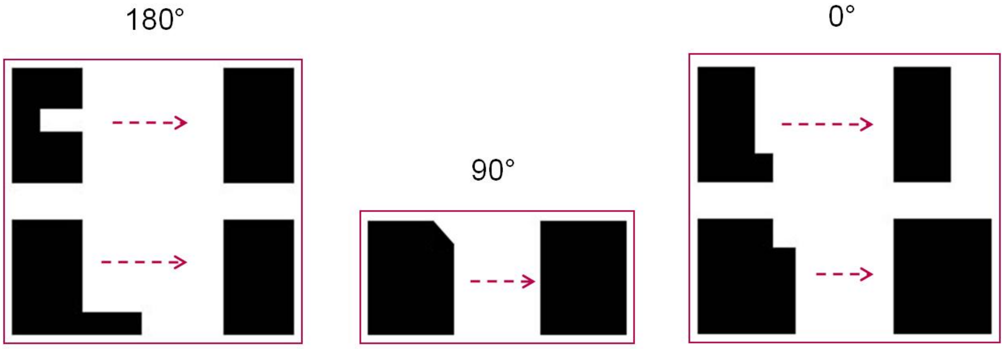

Figure 2.8: Possible actions operated by Sester's algorithm.

Sester's algorithm or Douglas-Peucker's geometry simplification algorithm, cannot be performed in any situation. For example, a building inside an urban block with high density at 1:50,000 will not be simplified even though it has one or more edges under the threshold due to the fact that there is not enough space to preserve individuality for each building. It will instead aggregate with its closest neighbour or it is likely the a new symbol will be adopted such as a filled black block as shown in Figure4.3.

Figure 2.9: Rome cartographic map at 1:50,000

It is becoming increasingly clear that when referring to a generalisation at a small-scale more considerations have to be taken about the context in which a building is located. In fact, in the previous example, if the building was isolated, It would have been simplified and maybe enlarged if needed.

The latest developments in building generalisation deal with *contextual generalisation*, aimed at controlling the triggering of algorithms depending on the spatial context in which they are applied. This includes studies on modelling issues [18], spatial analysis tools development [19] graph theory to generalise network [20], [21] and extension of the Delaunay triangulation to support displacements. At every stage of the generalisation process, the key issue is to provide the system with knowledge (condition of use of an algorithm, how to tune parameters, which sequence gives the best results in which situation). This has justified researches on knowledge acquisition, such as [22].

Regnauld [14] focuses on the development of an algorithm for generalising buildings from 1:15,000 to 1:50,000. His attention is no longer on generalisation of building shapes, which has already been studied, but on the generalisation of groups of buildings in order to transform them into a readable form at a smaller scale. His paper discusses the automation of a process traditionally done using manual techniques and attempts to achieve the goals associated with the manual approach, i.e. reducing the number of buildings in a built-up area while preserving the pattern and local characteristics.

Analysis is undertaken to partition the space into meaningful groups of buildings. Meaningful groups of buildings are those that would be typically identified by visual inspection.

Moreover, Regnauld describes the analysis method that makes explicit the relationships between buildings prior to generalisation and subsequently segments the dataset into groups by using *minimum spanning trees, size and orientation homogeneity, and other perception criteria*. These groups are used to perform global typification, which reduce the number of buildings in each group, preserving the visual separation between the groups and their intrinsic characteristics.

This thesis has found a great inspiration in the aforementioned Regnauld's work. In particular *context aware* and *typification* strategies have been undertaken to trigger every generalisation operation performed in order to derive a 1:50,000 map from a 1:5,000 one. In the next chapter the aim of this thesis and the general goals will be presented in addition to the solutions adopted and the software implemented.

Chapter 3

My Approach

In this chapter the approach followed by this thesis is presented.

The strategy consists in developing a contextual generalisation aimed at controlling the triggering of algorithms depending on the spatial context in which they are applied. We purse the objective to distinguish two main contexts such as urban and rural. The set of buildings in which the map will be partitioned are then given in input to two different generalisation processes.

Both urban and rural generalisation issues are faces with a Constraint–based Automated Map Generalisation approach with the key observation that order and importance of the constrains to be satisfied vary significantly between urban and rural contexts.

3.1 Constraints definition

As can be understood in the previous chapter, building generalisation at medium or small scales is commonly modelled with a Constraint–based or Rule–based paradigm. In this work a Constraint–based Automated Map Generalisation approach is followed.

Our generalisation approach purses the aim of preserving **visual identity, density and global information** about buildings distribution on the territory landscape.

Visual identity requirements want to preserve the characterization of an individual building based on its shape, orientation, and size. Usually the smallest ones are residential buildings, while the largest are industrial or administrative ones. There tends to be a correlation between shape and size. The smaller a building is, the less detailed its boundary can afford to be for reasons of legibility.

Density requirements in a building group consist in maintaining the ratio between the total area of buildings and the area of the complex geometry enclosing them. By preserving this ratio, the distinction between a very populated urban neighbourhood and a sparse sub–urban district remain evident.

Global information refers to the intrinsic peculiarities about building's distribution that can be inferred when looking at a cartographic map. At first sight it is easy to deduce where a town centre, a rural area or an industrial zone are located by simply observing the different densities in building concentrations . With a more accurate observation it is easy possible to visually separate buildings in groups based on their proximity relationships or similarities. These groups may convey other information about the territory. As an example, when looking at the original map it is easy to detect a pattern of similar rectangles placed along a road and infer that these geometries probably represent a modern residential area.

In fact, in addition to individual characteristics, the spatial relationships between the objects on a map contribute collectively to the information conveyed by the entire map.

Visual identity is a well–defined requirement expressed in terms of building minimum width, edge minimum length and minimum gap between buildings. All of these are quantitative constraints scale dependent. Density can also be considered as metric scale–dependent although no parameters have been provided along with the IGM Specifications. On the other hand global spatial information, group homogeneity and similar patterns are qualitative guidelines applied to aesthetic criteria and visual perception.

3.2 Are constraints competitors?

The biggest effort in automatic generalisation deals with constraints being competitors and the impossibility to satisfy them all at the same time when deriving a small–scale map. The issues that need to be resolved can be best discussed by looking at some examples. A first approach to treat these constraints could consist of ordering them by importance. Let us suppose that we would like primarily to fulfil visual identity metrics because they are well-defined and its reasonable to have as much details as possible about the buildings.

Figure3.1 shows a screenshot taken from the map of Verona at 5k. Some buildings are too small to be represented at 1:50000 scale, therefore they need to be enlarged. Figure3.2 shows the situation after some buildings have been modified to reach the minimum visible area. According to specifications, when representing buildings at the target scale they must have edges of length greater then or equal to 0,4 mm, this implies that real dimensions must exceed 400 sqm.

In Figure3.3 the gap between buildings is increased to reach the minimum threshold of 11m.

Building sizes and gaps now comply with IGM specifications, but the question arises of what to do next? Clearly we cannot let buildings to overlap other features and in this case there is not enough space to individually generalise every building. Therefore, the only possibility is to proceed with a selection of the most characteristic buildings. IGM gives us some indication about importance in terms of size and function. As an example churches and hospitals must be kept in the map while small civil buildings under 50 sqm can be removed.

However these rules do not fit to our case because every building is above that threshold. At the beginning we could have proceeded by simply removing the smallest buildings and then displacing the remaining buildings into the area at our disposal. What is obtained is shown in Figure3.4. Is this a good generalisation? The answer will be discussed later.

Let us now observe what would have happened if we applied the same procedure to another block of buildings similar to that in Figure3.1 but having an original density significantly inferior. Figure3.5 shows on the left side a block with exactly

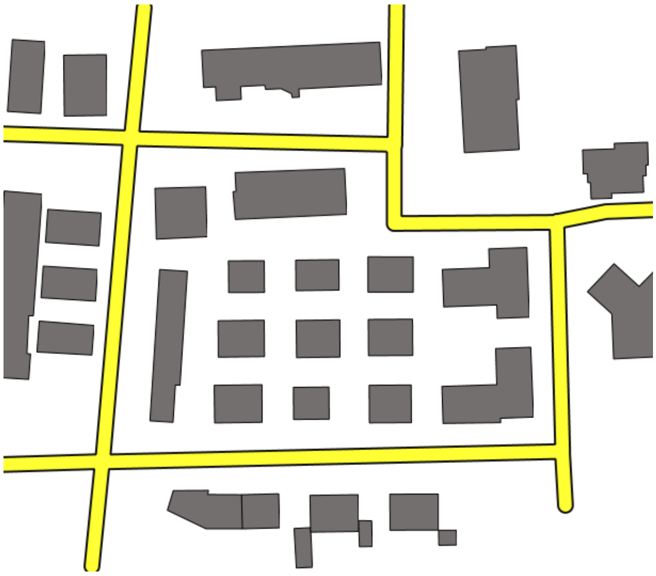

Figure 3.1: A building block defined by cycling streets which circumscribe buildings.

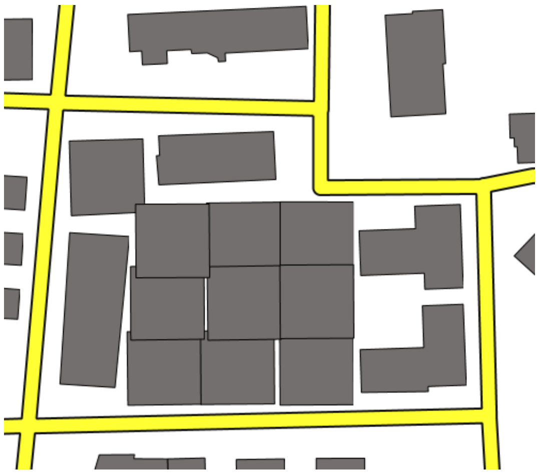

Figure 3.2: Some buildings are enlarged to reach the minimum visible area.

half of the number of buildings of the one in Figure3.1 and on the right side its generalisation obtained following the same approach discussed above.

Both blocks, shown in Figure3.1 and Figure3.5, lead to generalisation results that are quite similar. Looking at the resulting blocks is impossible to retrieve information on their original nature, whether they belong to a high-density urban area or to a scattered settlement one. In fact, the information on their original density has been lost, as has the difference on the number of buildings lying in the block.

To encompass these issues we could try to modify constraints priorities and

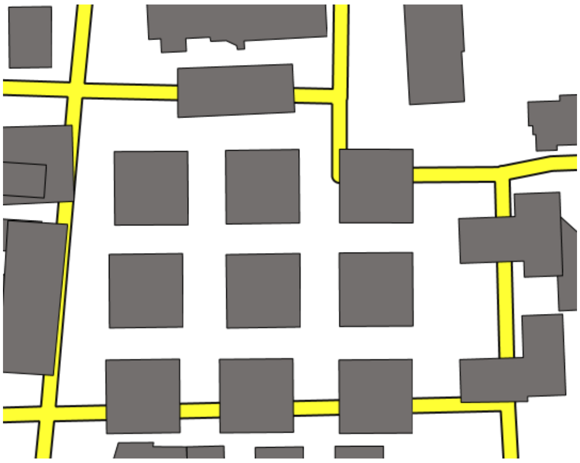

Figure 3.3: The gap between buildings is increased to reach the minimum threshold of 11m.

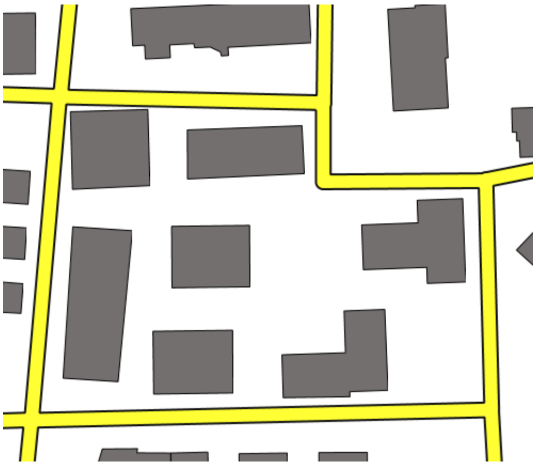

Figure 3.4: Biggest buildings are displaced over the available area while the smallest have been removed.

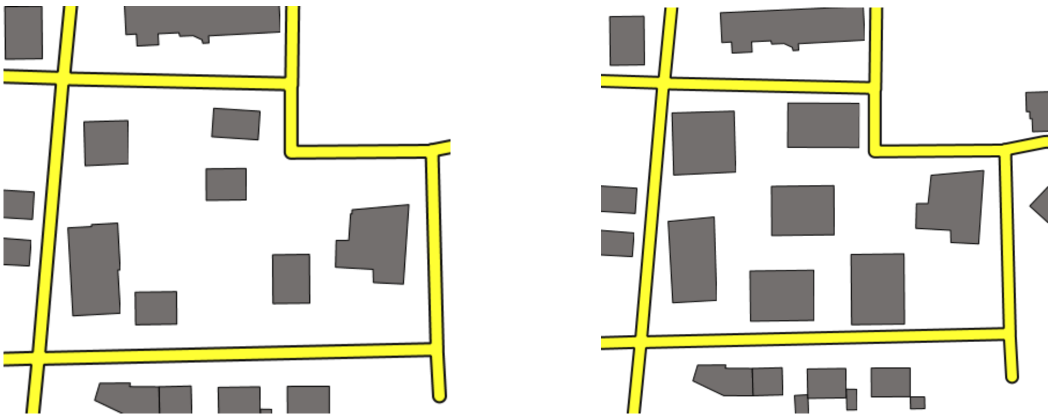

Figure 3.5: On the left a low density block and on the right its generalisation.

choose density requirement as the most important.

Considering again the urban block in Figure3.1, to maintain original block density the buildings this time are not enlarged. In order to fulfil minimum visual perception specifications an *amalgamation* operation is performed.

Amalgamation is one of the main operations used in map generalisation. Its generic behaviour can be defined as the replacement of several features by a single one. It can refer to mainly two types of action: the fusion of two adjacent polygons usually due to their reclassification to a single theme, or the aggregation of several polygons which are initially not touching.

The approach of amalgamating every neighbouring buildings is applied on Figure3.1 and Figure3.5, the results obtained are showed in Figure3.6 . Following this approach, density constraint has been met but the aesthetic quality is very poor especially in case a) where information about the original number of buildings and their conformation has been lost and it is no longer retrievable by the map's user.

At this point we claim to be able to reach a better generalisation result by following a context aware approach. The solution will become more clear as we keep discussing other examples.

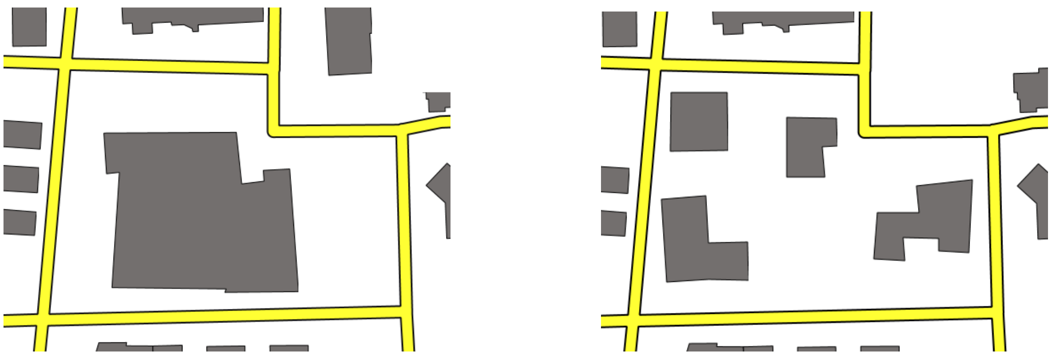

Figure 3.6: On the left Amalgamation of buildings in Figure 3.1 and on the right Amalgamation of buildings in Figure 3.5

In Figure3.1 nine buildings can be identified as homogeneous with regard to size, orientation and proximity. Therefore, this cluster can be used to perform *typification*, which reduce the number of buildings in a group, preserving the visual separation between the groups and their intrinsic characteristics.

Figure3.7 shows a possible generalisation where five buildings from the homogeneous group have been removed to free enough space for the other elements to be enlarged and in the meanwhile keeping the regular grid pattern. Moreover, to improve the aesthetic quality of the result, buildings are aligned along the roads and slightly modified in their orientation.

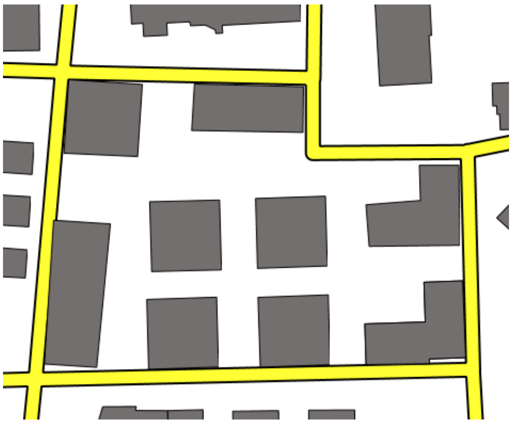

Figure 3.7

The examples illustrated above provides important observations about the generalisation process and the possible strategies to address it:

- Changing the order of the operations performed may significantly vary the quality and it may lead to a bad generalisation.
- Applying the same algorithms to every input situation will possibly lead to a good generalisation in a dense urban context and to a poor quality generalisation in a less populated environment or vice–versa.
- It is a key point to acquire additional information on the territory conformation because an automated generalisation process starts from a limited amount of information. It has at its disposal a database describing each object individually and independently from one another. However, for the sake of global information maintenance the system should be aware of the distribution of the objects: which ones are neighbours, or part of the same town, or which ones are isolated. It is important to identify such additional information in order to generalise buildings in an urban area successfully.

This information is needed to control the generalisation process in response to a set of, sometimes, competing objectives.

Based on these observations the work of this thesis has been focused on **context awareness** and **typification** to develop a process for building generalisation.

3.3 Solution Design

The generalisation at the 50k scale is performed using algorithms tailored to solve specific issues on the data. As seen above we cannot apply the same operation to the data without knowing the context, i.e. whether a building is located in an urban context which is supposed to have high density or in sub-urban or rural context with typically spare buildings distribution. In fact, the sequence of algorithms adopted will vary dramatically between urban and rural areas. Therefore, the solution design relies heavily on the detection of the two different contexts. The main steps can be summarize as follows.

3.3.1 Partitioning

The source map is divided in partitions formed by the structuring network of roads, rivers and railways. Roads are considered to be a pragmatic and meaningful way of partitioning buildings into groups because there is a close interdependence between roads and building location. Moreover rivers and railways identify an obstacle beyond which there is no point in looking for a similarity between buildings lying on one side and those lying on the other side of the obstacle.

The partitions are identified by closed paths of the network graph and are called *blocks*.

3.3.2 Analysis

The classification is an attempt to apply context aware strategies to building generalisation. Some parameters are calculated on the blocks in order to classify them into urban or rural. Although the distinction is mentioned on the IGM document, no criteria are provided along with it to make the separation automatically.

To overcome this issue some observations have been made on the data source to derive possibly automatic criteria. The most important turned out to be *density*, i.e. the ratio of buildings area to block area, *dominant building topology*, i.e. the number of buildings of the same type weighted by their size and *number of items*.

3.3.3 Urban blocks generalisation

Once all the blocks have been analysed and classified, those marked as urban are given as input to the process dealing with generalisation in an urban context.

In this step further partitions have been made based on the density of the block.

- High density blocks at the target scale cannot keep building individuality due to legibility constraints. In this case an extreme generalisation has been found to be the only possible way to carry out the process.

  The group of features belonging to high density urban blocks will be replaced by a single polygon. The boundary of the resulting polygon is related to the extent of the group rather then the geometry of the initial features. This operation is called *amalgamation by flooding*.

- Medium density urban blocks are treated differently. The group of features will be replaced by a single polygon and some internal spaces. The boundary of the resulting polygon is related to the extent of the group and gaps are inserted where significant free spaces stand.

3.3.4 Rural blocks generalisation

In this context free space available in a block might be sufficient to perform several operations in order to preserve building individuality and fulfil visibility requirements at the same time. As previously discussed in the introduction of this chapter a key point to achieve satisfactory generalisation is to detect homogeneous groups. In this step the generalisation is faced with typification.

Typification is not an easy task to be performed and research is still active on this topic. In this thesis an approach with minimum spanning tree has been implemented to group buildings together as suggested by Regnauld [14].

What make buildings part of the same group is either proximity relationships or homogeneity in terms of size and orientation. Different generalisation operations are then applied to the detected groups:

- Close buildings are all merged together and replaced by a single polygon that might have a very articulated shape which will need a further simplification.
- In homogeneous groups the number of buildings is iteratively decreased to increasingly free space in the block.

  The aim of doing this is to preserve the pattern as far as possible and maintain similarities and differences between the groups with regard to density, size and orientation of buildings.

3.3.5 Isolated building generalisation

Isolated buildings are those located to a minimum distance from their neighbours of at least 30m. In this case there is enough space to enlarge them, if necessary, to reach minimum visible width and if required an exaggeration operation can be performed to enhance a characteristic narrow side.

3.4 Solution Development

The software produced in this work has been developed in *Java* and integrated into the *OpenJUMP*'s environment. Several algorithms for basic operations on the geometries have been taken from the JTS library, also known as "Java Topology Suite". Spatial data stored on Oracle Spatial database at the Cargen Laboratory have been used to test the algorithms developed.

OpenJUMP is an open source Geographic Information System (GIS) written in the Java programming language. It is developed and maintained by a group of volunteers from around the globe. OpenJUMP started as JUMP GIS designed by Vivid Solutions [23].

The current version can read and write shape files and simple GML files. It has limited support for the display of images and good support for showing data retrieved from WFS and WMS web-services. It can be used as GIS Data Viewer. However, it's particular strength is the editing of geometry and attribute data. One can style the appearance of data in OpenJUMP's map display and can export the view to SVG. A growing number of vector analysis tools for topologic analysis and overlay operations are also available.

The *JTS Topology Suite* is an API of spatial predicates and functions for processing geometry. It has the following design goals:

- JTS conforms to the Simple Features Specification for SQL published by the Open GIS Consortium
- JTS provides a complete, consistent, robust implementation of fundamental algorithms for processing linear geometry on the 2–dimensional Cartesian plane
- JTS is fast enough for production use
- JTS is written in 100% pure Java

Chapter 4

Partitioning and Analysis

4.1 Partitioning

The aim of this phase is to partition the spatial region to be generalised into smaller areas in a "*divide and conquer*" manner.

Dividing the large data set into smaller instances is essential to our strategy; furthermore it has some positive effects as it is time saving from a computational point of view.

The building data set is divided in blocks formed by the structuring network of roads, rivers and railways, see the AGENT project [13]. Roads are considered to be a pragmatic and meaningful way of partitioning buildings into groups because there being a close interdependence between roads and building location.

It was my choice to further partitioning the space using rivers and railways networks. In fact, they identify a natural obstacle beyond which there is no point to looking for a similarity between buildings lying one side and those lying on the other side of the obstacle.

4.1.1 Blocks composition

Blocks generalisation has been performed using the class of algorithms supplied by *geomgraph* package of the JTS library.

In particular, class *PlanarGraph* relies on the implementation of a structure called "topology graph". The topology graph contains nodes and edges corresponding to the nodes and line segments of a geometry. To obtain a correct topology graph for our purpose, geometries must be self–noded before constructing their graphs. This class does automatically computes the intersections between all the linear components given in input and returns the edges and nodes found in output.

With the set of edges producted is now possible to generate new polygonal entities formed by closed paths of the network graph, these are called *blocks*. This operation has been performed using the class *Polygonizer* of the JTS API. It polygonizes a set of geometries which contain line work that represents the edges of a planar graph. The processed edges must be correctly noded; that is, they must only meet at their endpoints. The Polygonizer will run on incorrectly noded input but will not form polygons from non–noded edges, and will report them as errors.

The Polygonizer reports three types of errors, however, we are interested in the following one:

- *Dangles*: edges which have one or both ends which are not incident on another edge endpoint. In a real map these type of roads appears quite often and are those that give access for instance to a residential area or to an isolated group of buildings, see Figure4.1 . These edges do not belong to the outline of a block, however it is important to be aware of their existence when proceeding with blocks generalisation.

The results of the partitioning procedure can be seen in Figure4.2 . The algorithms have been applied to a file shape of Verona city at 5k scale [25].

Enhancing lines thickness is easy to identify the blocks and see how they circumscribe buildings.

4.2 Analysis

According to IGM specifications, three main situations should be distinguished:

- Building groups in a dense *urban context*.
- Building groups in a scattered settlement area from now on called *rural context* meaning sparse building groups independently from their functionality

Figure 4.1: Dangling edges are highlighted in orange.

Figure 4.2: Results of partitioning procedure applied to Verona city.

either civil or rural. By rural block, we mean a block that cannot be classified as urban.

- Isolated buildings

The aim of this section is to find criteria and values in order to classify whether a block is urban or rural.

Although the distinction is mentioned on the IGM document, no criteria are provided along with it to make the separation automatically. To overcome this issue some observations have been made on the data source to derive possibly automatic criteria. The three most important turned out to be:

- $Density = \sum(buildingArea)/blockArea$

  It is the ratio between the total are covered by buildings and the total area of each block. The Density of a block conveys information on its nature and function on a map. Therefore, it is crucial to conduct the generalisation process towards one solving methodology rather than the other.

- *Dominant building topology* =

  $$max(\sum_i(areaOfType_i) : i \in buildingtypology)$$

  In the 5k data model each building has an attribute LIVCOD that tells what is its type or functionality. Some examples are: LIVCOD = 0101 means "civil building"

  LIVCOD = 0105 means "church"

  LIVCOD = 0105 means "rural building"

  LIVCOD = 0110 means "cemetery"

  LIVCOD = 0116 means "monument"

  LIVCOD = 0127 means "hospital"

  These criteria are useful to better identify a dense urban area as a part of a city centre if its dominant building topology is equal to 0101. We should bear in mind that even two blocks with the same density can be generalised in a different way depending on their location on the map.

- *Number of items.*

  This number is useful both to compute average metrics and to identify what we call "unary block", that is, a block comprising only one building.

The solitary building is treated as isolated; although this case would seem trivial we will see in chapter seven that attention should be paid handling this case too.

The data thus enriched will be then provided as input to the following classification procedure.

4.2.1 Classification Procedure

Thanks to the data enrichment process described in the previous paragraph, it is possible now to classify each building block.

Observations from existing IGM 50k scale map revealed that the generalisation of buildings differs quite significantly between dense conurbations and sparser settlements.

Figure4.3 illustrates that the urban buildings in the centre are represented as either filled black blocks or black blocks with some white inner holes, adhering to the road curvature, whereas in the surrounding "rural" area the buildings are represented by isolated angular amalgams. Hence, it is clear that distinct processes are required to deal with urban and rural building generalisation. For this reasons we are going to classify building blocks into **urban** and **rural** blocks, furthermore classifying urban blocks into high-density urban blocks and medium-density urban blocks.

The classification relies on two density thresholds A, B: all the blocks with density greater then threshold A are initially classified as high–density urban blocks whilst the remaining with density greater then B but smaller than A are candidates to be marked as medium-density urban blocks; the blocks with density smaller than B are classified as rural. The exact algorithm will be explained in the section below.

The density thresholds have been found empirically by looking at the original data at 5k scale and displaying them simulating their representation at 50k scale. The buildings were plotted with enlarged black outlines, which visually merged them together. Some buildings appeared to be a unique complex amalgam without left free space in the block. These situations gave us the first threshold to directly classify blocks as high–density urban blocks. Other buildings also looked like a unique amalgam but with some small recognizable free white spaces. This led us to the definition of the second threshold to classify blocks as medium–density urban blocks and, consequently, to rural blocks.

The differences at the target scale in the representation of buildings belonging to these three class of blocks made clear to us the need to develop three distinct generalization procedures.

Figure 4.3: Faces classified as urban are highlighted in yellow.

4.2.2 Algorithm

The algorithm takes as input all the blocks in which the original data has been previously partitioned.

An initial scan is performed on the blocks to classify those that are urban: if the density of a block is greater then or equal to 0.65 and its dominant_topology equal to "civil building" then the block is marked as urban.

Tests revealed that below this first threshold a classification based solely on density could misclassify blocks belonging to a rural settlement as medium–density blocks belonging to a city centre. As we already remarked, the distinction between these two types of contexts is fundamental to perform a good generalisation able to retain the characteristic information on the blocks.

Our strategy was then to perform the classification of the medium–density urban blocks taking into account both the density and a spatial proximity constraint. The idea is to proceed on the detection of medium-density urban blocks starting from those blocks that are close to urban ones and extending the search from them: hence, the algorithm recursively iterates on the blocks that are neighbours of urban blocks to seek for other blocks to classify as urban. If density greater then or equal to 0.35 and dominant_topology equal to "civil building" then mark the block as urban. Results of analysis can be seen in Figure4.4. The remaining blocks are marked as rural.

In the following chapter, the generalization of high and medium density blocks will be described. As the generalization of low density blocks is more complex and requires further analysis, it is treated separately in chapter 6.

Figure 4.4: Faces classified as urban are highlighted in yellow.

Chapter 5

Generalisation in an urban context

The previous phases of partitioning and analysis were meant to automatically gather new information about the context in order to control the triggering of algorithms depending on the spatial context in which they are applied. After these *learning* steps our process is ready to afford the generalisation in detail.

At this stage buildings are no longer individual entities stored in a database without any other information on their mutual location.

The whole region has been divided and classified into urban or rural blocks and each building has a new attribute ID_FACE corresponding to the id of the block in which it is located. Blocks and their enclosed buildings are sent as input to the real generalisation phase. At this stage the process is context aware and thus we can finally go deeper in the generalisation operations. In Figure5.1 some statistics are given to intuitively understand the computational advantages produced by a divide and conquer procedure working with blocks containing 23 buildings on average rather than 5000.

As discussed during the classification phase a further subdivision of urban blocks can be made between those with high density where there is not enough free white space and those width medium density where small white spaces are still perceptible at the target scale. Hence, two ad–hoc solutions have been developed and are now proposed in detail.

Attribute	Attribute type	minimum	mean/mo...	maximum	standard...	sum
ID	INTEGER	3	644.8727...	1,329	353.058	141,872
AREA	DOUBLE	392.006	9170.171...	90,807.55	10,655.284	2,017,437.654
AREA_EDIFC	DOUBLE	212.373	4810.111...	31,915.078	4,467.223	1,058,224.426
PERIMETER	DOUBLE	91.857	382.0225...	1,561.802	197.049	84,044.965
DENSITY	DOUBLE	0.351	0.566110...	0.783	0.104	124.544
NUMBER_ITEM	INTEGER	1	23.00909...	217	23.494	5,062
DOMINANT_T...	STRING		0101			
ROSS_CLASS	INTEGER	1	1.0	1	0	220

Figure 5.1

5.1 High density block generalisation

Figure5.2 shows an urban block of the city centre of Verona. Its density is equal to 0.7 and the number of items is 23. Because of the high density it would be very difficult if not impossible to maintain buildings individuality while generalizing.

Amalgamating every building would generate small courtyards under the minimum allowed size at the target scale. For this reason, the strategy adopted in this case is very simple: it consists in substitute every building with a single polygon that has the same extension of the whole block outline and has no inner holes. This approach is justified by the high density of the block which appears as if the buildings have been evenly distributed over the block area. This operation is also called *amalgamation by flooding* [31].

5.1.1 Algorithm

The group of buildings belonging to high-density urban blocks (density greater than or equal to 0.7) are replaced by a single polygon.

The new polygon outline is built by taking a negative buffer of the block polygon. The buffer size corresponds to half the symbol width used in the final representation of roads at the target scale.

In this way the boundary of the resulting polygon is related to the extent of the group rather then the geometry of the singular initial features. This operation is justified by the high density of the block which does not present enough free space to perform any sort of generalisation operations such as displacement or

Figure 5.2: Shows an urban block from the city centre of Verona. Its density is equal to 0.76 and the number of items is 23.

exaggeration. Replacing the whole block with a single building has the same effect of performing the amalgamation of all the buildings inside the block, but is faster and furthermore avoids the eventual creation of holes among the buildings too small for the target scale. Figure5.3 shows the results obtained.

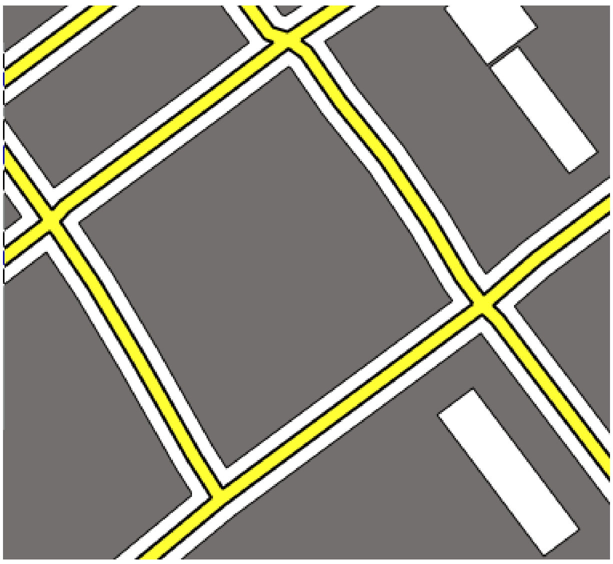

Figure 5.3: Shows the results obtained.

5.2 Medium density block generalisation

Much more work has to be done in this context and many possible approaches have been suggested by researchers. Amalgamation in a dense environment is not an easy task to perform and it often leads to very complex geometries which are difficult to simplify in order to preserve legibility and clarity on the map.

Referring to the flooding amalgamation illustrated above, Regnauld [27] proposes two different techniques to amalgamate features. The first one (growing tide) gradually increases the amalgam until covering all the footprints of the original features, while the second (decreasing tide) starts by filling a whole region and inserts holes where significant areas don't contain any features. Growing tide is essential for amalgamating buildings for small scales outside the city centre. Decreasing tide will be more suitable to amalgamate buildings in city centres to a target scale smaller then the one of this thesis such as 100k where less accuracy in building geometries is required.

The approach followed to generalise medium density block can be outlined as a decreasing tide even though the operation performed to simulate this behaviour differ significantly from those proposed by Regnauld [27].

5.2.1 Duality in medium-density blocks

Approaching the generalization of medium-density urban blocks, we found out that trying to modify the geometries of the buildings could lead to irregular shapes in the resulting polygons, as small slivers and spikes. Furthermore, generalizing each building resulted in redundant and pointless operations that slowed the process (e.g. expanding each building to comply with the legibility constraints resulted in multiple overlaps with the other buildings that needed to be dissolved).

Our choice was then to change approach, and to work on the dual of our problem, that is, instead of generalizing the buildings, to generalize the spaces among them. Free space might be defined as a significant part of an urban block without any building inside [24].

Free spaces in a block are a representation of the particular configuration of the buildings surrounding them; as such, handling these spaces as polygons and generalizing them leads to a generalization of the whole block that while being faster (the number of spaces is smaller than that of buildings), is still connected with the original distribution of the buildings in the block.

5.2.2 Algorithm

The methodology developed to carry out medium dense urban block is described below:

1. Compute Geometry.difference between block polygon and every building geometry belonging to it. To decide whether or not a building belongs to a block it is sufficient to look at its attribute ID_FACE which is the primary key on the BLOCK table. What we expect is a complex geometry composed of many separated polygons: this geometry is stored as a MultiPolygon object. From this object we can easily extract single white space polygons. As an example see original situation in Figure5.4 and the result obtained in Figure5.5 .

2. Check if there are dangling edges inside this face and compute the difference between the face and the buffer of these edges. This operation aims to leave the space necessary to represent this feature; from a logical point of view this means that we are not amalgamating buildings crossing a feature, as this would lead to a topological error.

3. Delete polygons with area less then 200 sqm. These free spaces are not relevant at the target scale.

4. Perform simplification with Sester's algorithm with parameters to fit the target scale, such as minimum edge length of 11m and minimum area to be simplified of 200sqm. Sester is a simplification algorithm that helps us to remove meaningless irregular juts with size under a minimum length threshold. See Figure5.6 .

5. Perform Squaring operation. This is done by using an existing algorithm that aims to reduce the variety of angles on a geometry by slightly modifying the orientation of the segments. At the target scale, it is desirable to have orthogonal angles. See Figure5.7 .

6. Delete narrow corridors from polygon shapes with *triangulation.* Triangulation is widely used in the generalisation context to represent the proximity of relationships between features [29] [28] [30]. We need to model the triangulation in a robust and flexible way, to be able to use it at different stages of the generalisation process, and for different purposes. In this case we use a constrained Delaunay triangulation [28] based on the vertices of a white polygon. The constraint is that each edge part of the geometry of a feature should be matched by an edge of the triangulation. After building the triangulation, a way to detect and remove narrow corridors consists in:

   - Computing the height for each internal triangle with precisely one constrained edge, sometimes called a wall. The height is calculated with respect to the opposite vertex of the constrained edge and if it is under the minimum width threshold of 10m this will be deleted by applying the operator difference to the polygon with the triangle as the argument. See Figure5.8 .

7. Remove slivers. Slivers are another common issue when operating with union or difference on polygons. Because of the several orientations and big variety in buildings' angles when performing union or difference between two neighbouring buildings the outcome could present a weird shape with a sharp, almost imperceivable, jut.

   To tackle slivers issues, triangulation turned out to be very helpful to detect narrow corridors. In this case, we are interested in triangles with two or three constrained edges. The algorithm evaluates the angles between the constrained edges and decides to delete those with an angle less then 0.3 degrees. See Figure5.9 .

8. Perform Squaring again. Operations that deal with removing triangles from a geometry might cause a deterioration on the aesthetic quality of the shapes

because final angles are no longer orthogonal. To restore the previous level of quality another squaring operation is performed to force angles to be multiples of 90 degrees.

9. Build final generalisation polygon.

   Fill the area with a single amalgam polygon and insert the polygons computed in previous steps to symbolize where significant free spaces stand. The amalgam polygon is obtained from the block shape clipped to take into account the increased width of the road features.

   Figure5.10 shows the final results.

Figure 5.4: Original situation

Figure 5.5: After difference operation

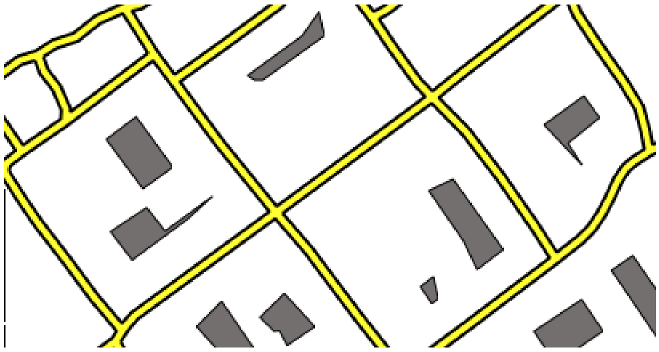

Figure 5.6: Sester

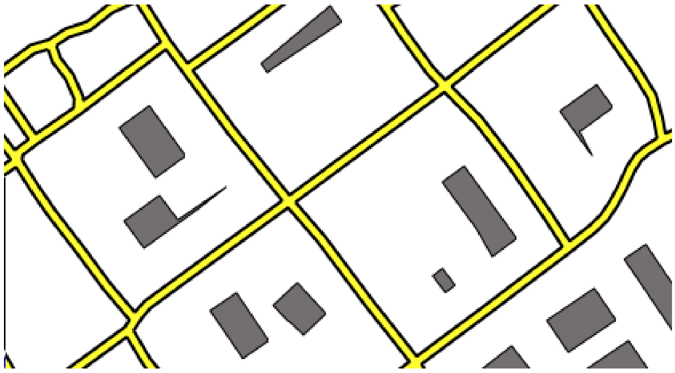

Figure 5.7: Squaring

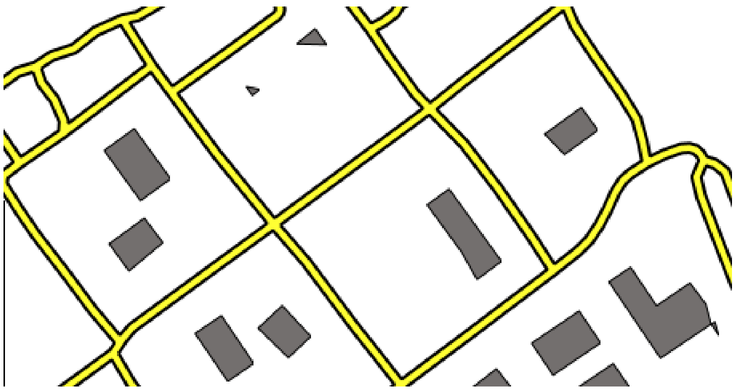

Figure 5.8: Cut Narrow parts

5.3 Refinements

Refinements might be necessary in both high density and medium density generalisations for two reasons:

- To deal with characteristic buildings such as churches or hospitals that we have to keep separated to comply with IGM specifications.

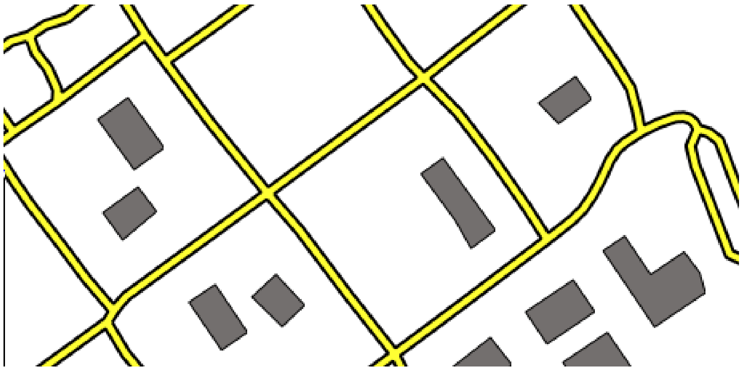

Figure 5.9: Remove slivers

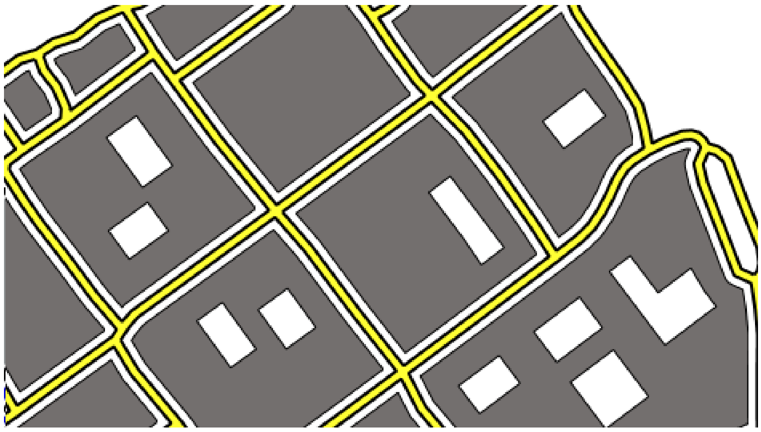

Figure 5.10: Generalisation result

- To avoid narrow corridors in the resulting amalgam between its external boundary and those of its holes.

5.3.1 Dealing with characteristic buildings

Characteristic buildings are identified using their semantic attributes; in our test data, we used the attribute LIVCOD, that stores a code that classifies the use of each building.

Figure5.11 on the left shows a common situation where several buildings with the same livcod are joined together. In reality it is common to find the presbytery and the bell tower closed to a church, or a hospital complex comprised of many distinct buildings although adjacent to each other. Our objective is to preserve the location and specificity of these classes of special buildings . To do so, close buildings with same livcod are merged together to form a single entity.

Features that we want to keep should now be treated like holes. To pursue the main goal of this thesis it is sufficient to add a record to the result generalisation table storing merged special geometry and common livcod.

In order to eventually adopt the correct symbolisation at the target scale other considerations have to be taken into account such as compute the optimal size and position of the new symbol, however this is not the concern of this thesis. Figure5.11 on the right shows final results.

Figure 5.11

5.3.2 Removing narrow corridors

To remove narrow corridors in the resulting amalgam we rely, again, on constrained triangulation. In this case we build a constrained triangulation based on the vertices of the final polygon including the possible internal holes. The approach adopted is equal to the one used in cutting narrow corridors, see sectionAlgorithm.9. Figure5.12 shows one of the results obtained.

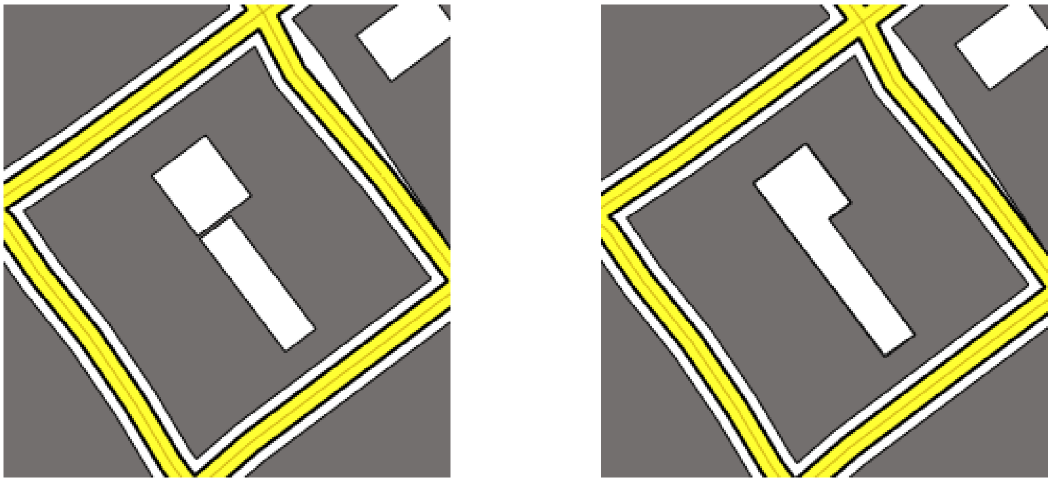

Figure 5.12

Chapter 6

Generalisation in a rural context

In a rural context, characterised by a low density of buildings, the free space available inside a block might be sufficient to perform several operations in order to preserve building individuality, legibility and maintain the overall density across a region of a map. *However, to be readable at the target scale, geographical objects often need to be enlarged, which generates problems of overlapping features or map congestion.*

To manage this problem with regard to buildings, a method of **selection** based on the **typification principle** is presented.

Typification is an operation that reduces the number of buildings in each group while preserving the visual separation between the groups and their intrinsic characteristics. Typification is not an easy task to be performed and research is still active on this topic. In this thesis our approach follows the work of Regnauld [14] on the use of a *minimum spanning tree.* The strategy developed first computes the proximity graph of buildings that is then analysed and segmented, leading to the identification of groups of buildings with respect to their proximity and similarity in size and orientation.

The information gathered from the analysis of the groups of buildings is used to trigger different generalization algorithms whose purpose is to make the representation of each group to fit the target scale. The aim is to maintain legibility of the map,while at the same time preserving as far as possible the patterns and the similarities in each group. In order to achieve these objectives a crucial point consists in **free space** and **reduced congestion**; especially, it should be avoided to increase the original density of the block.

6.1 Methodology

The methodology adopted to divide the buildings into groups is derived from Regnauld's work and is based on the "divide and conquer" principle. We segment the initial set of buildings belonging to a block into possibly homogeneous groups. Then the characteristics of each group are used to build a **new representation** of them according to the target scale, whilst preserving the essential building characteristics. Workflow can be summarize in two big parts:

- The first step consists of the analysis of the source set of buildings in order to partition the set into groups. The analysis is based on information relative to the spatial relationships of buildings supplied by the proximity graph and their individual characteristics. This results in a partition of the source set into groups of buildings whose characteristics make them visually distinguishable.

- Then the global typification step processes each group in turn and creates a graphical representation suitable for the target scale. The term "global typification" is used to identify a typification operation extended to process each group taking, at the same time, into account the interrelationships with surrounding groups. In general the typification operation will involve enlarging buildings, eliminating some of them and giving the remainder a pattern that reflects the distribution of the source data.

6.2 Building a Proximity Graph.

Initially, we have a set of buildings that belong to the same block. The first task is to make explicit the proximity relationships between these buildings. This is done by computing a proximity graph.

Proximity is the primary criterion for grouping buildings. Ahuja and Tuceryan [34] observe that the minimum spanning tree (MST) is not an ideal method of defining proximity between "clouds" of points because the tree is sensitive to small changes in the position of points.

However, for the purpose of this thesis, the distribution of buildings made it an ideal method for the following reasons:

- It links each building with its nearest neighbour, thus making explicit a very important relationship (proximity).
- It stores "chains" of buildings, preserving the order between the buildings and implicitly conveying the linear shape of the group.

The principle of computing an MST is the same as the classical algorithms described in [35] [36]. The nodes are represented by building centroids and the edges are made by line segments connecting centroids. However, the edges are labelled with the minimum distance between the two boundaries of the linked buildings, instead of the real length of the connecting segments.

We used an iterative process to build the spanning tree. At the first step, each building is linked with its nearest neighbour, the resulting groups are then linked to their nearest neighbouring group and so on until all the buildings are member of the same group. Figure6.1 illustrates this process for a set of points. Figure6.2 shows the spanning tree obtained for a real block of buildings.

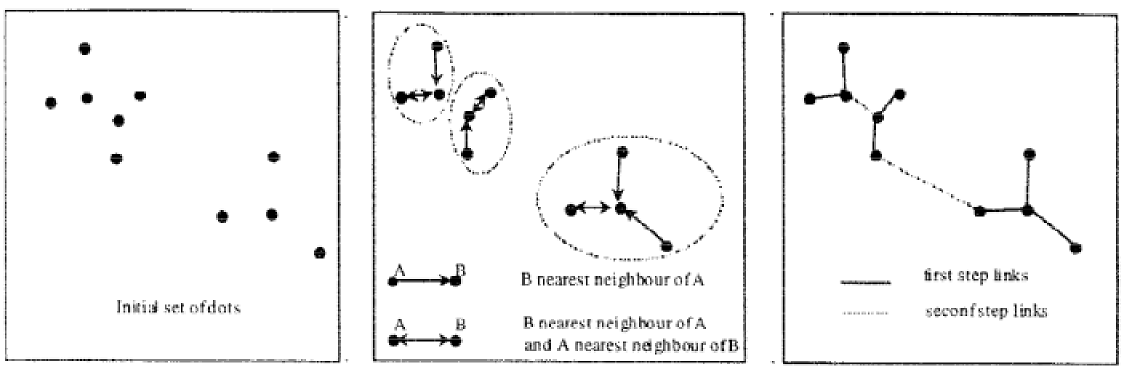

Figure 6.1: The process applied to a set of points.

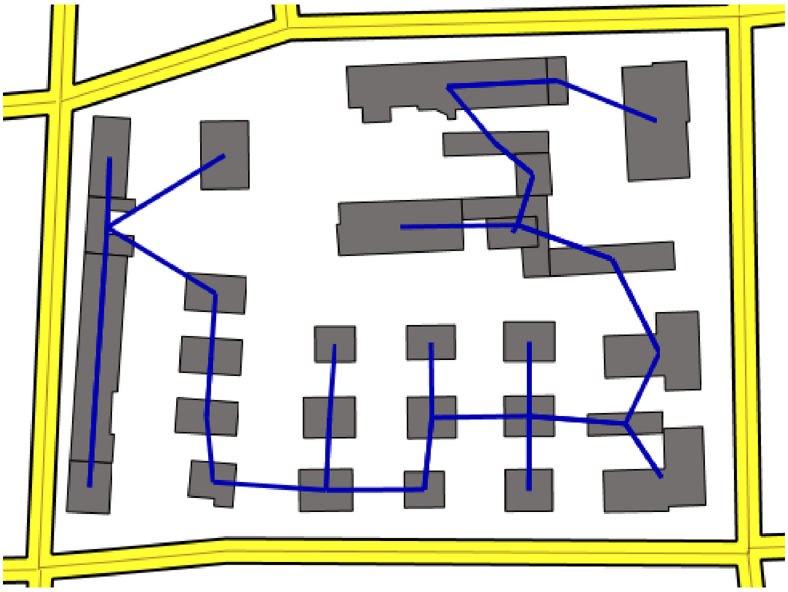

Figure 6.2: Spanning tree obtained for a real block of buildings

6.3 Analysing and grouping criteria

Analysis is undertaken to partition the space into meaningful groups of buildings. *Meaningful groups of buildings are those that would be typically identified by visual inspection.* From Gestalt theory, (see Section Spatial Organization), some criteria are proximity, similarity and continuity.

At the target scale small changes in shape are not significant because geometries need to be simplified before being suitable to be represented in the final map. In general, a building is represented in a map by an area whose boundary has orthogonal angles and whose shape does not present narrow corridors, juts or edges under the threshold (that in our target scale corresponds to 11m). As a result, after that asimplification process is accomplished, geometries would probably be rectangular or quadratic-shaped. We remind the reader to the last chapter for a deep discussion concerning isolated building generalisation.

What makes buildings part of the same group is either **proximity relationships** or **similarities**. To find homogeneity we limited our study to two types of criterion: *size* and *orientation* of a building. Orientation is studied because buildings are often oriented with regard to the bordering road, and their orientation can make them homogeneous in the case of straight roads.

To determine if a group is homogeneous with regard to a given criterion we proposed a parametric method that works by computing the mean and standard deviation of a collection of values for a group of n buildings and a particular criterion.

To apply this method to size and orientation, parameters suitable to our target scale have been identified. In case of area, the standard deviation must be under 50 sqm, this value is justified by the target scale, where isolated buildings under this thresholds are eliminated. In case of orientation, the maximum standard deviation value was empirically identified as 15 degrees.

6.4 Constituting the Groups

The creation of groups, starting from the initial MST, is a recursive process which has been proposed by Zahn [37] for grouping points and that we have adapted to the buildings according to Regnauld [14]. Starting from the minimum spanning tree, the group is analysed to determine how regular the pattern of buildings is. If it is insufficiently regular, the graph is segmented into two subgraphs. Then the process starts again for each of the subgraphs, giving a tree hierarchical decomposition of the initial MST. The process stops at a branch when a regular pattern is found or when the group becomes too small or too dense.

At the completion of this stage, we know if a group is homogeneous with regard to one, two or none of our criteria. If the group is not homogeneous for the two criteria, we segment it, seeking homogeneity in its subgroups.

6.4.1 Segmenting a group

The segmentation of a group of buildings is done by the elimination of one edge of the MST, the critical issue being the choice of edge. The objective is to segment a graph where there is a "break" in the distances separating neighbouring buildings. This means that the choice is not done with regard to a threshold distance, but on a threshold variation of distances [14]. To do that, each edge is compared with the neighbouring edges at both ends of an edge. Neighbours on the side A of an edge AB are defined as edges reached by moving through the graph from vertex A up to a distance of two edges from A with the exception of the edge AB. For each edge, two *coefficients of homogeneity* are deduced by comparing each end and its neighbouring edges:

Let e be an edge of length l_e .

E_l (E_r) is the set of the neighbouring edges to the edge's left (right) vertex.

μ_l (μ_r) is the mean of the lengths of the edges of E_l (E_r), and σ_l (σ_r) is the corresponding standard deviation.

$h_{(e,E_l)}$ ($h_{(e,E_r)}$) is the coefficient of homogeneity of A with regard to its neighbours at the left (right) end of e: $h_{(e,E_l)} = l_e/(1.2\mu_l + \sigma_l)$ (same principle for ($h_{(e,E_r)}$)). Regnauld [38] empirically set the coefficient 1.2 to allow minimum tolerance around the mean value in case the standard deviation is null. He also proposed a coefficient 2 for the standard deviation to increase the tolerance around a mean value when the respective standard deviation shows an inhomogeneous set of values. However, in our data we found the algorithm to perform better without a coefficient for the standard deviation.

The final coefficient assigned to an edge is $h_e = max(h_{(e,E_l)}, h_{(e,E_r)})$. *The eliminated edge by the segmentation process is the one whose coefficient h is the highest.*

Figure6.3 from [14] shows an example where the maximum h is being calculated for AB. The solid edges are the 2–depth neighbours of AB for vertex B. This set of edges has a low standard deviation and a low mean length with respect to AB. For the edge AB, the coefficient h has a higher value than for A. This means that AB is at variance with the regular pattern near B, and should be deleted.

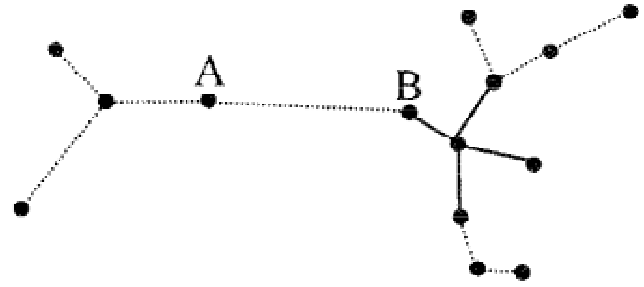

Figure 6.3

6.4.2 Stopping conditions for segmentation

In the analysis section we identified the criteria to segment the dataset into meaningful groups as *proximity relations, size and orientation similarities.* The stopping conditions for segmentation are:

- **Size of the group**: if the group has less than three elements, it will no longer be segmented. Further decomposition would be meaningless for typification purposes.

- **Homogeneity**: the group is homogeneous for both criteria size and orientation.

- **Distance regularity**: the group is very regular (maximum coefficient value is very low). There is no place to segment the group because the spacing between the buildings is very regular.

- **Density**: the longest edge is shorter than the separation threshold (see SectionlegibilityConstraint) , thereby defining a dense group. Segmentation is therefore stopped.

It is important to remark that when a stopping condition is met then the others are also checked to be true, this is because the more information available the better the typification can be tailored to a group. After the termination of the recursive segmenting procedure every building has been assigned to a group each of those is marked with the computed information.

These groups are used to perform global typification, which attempts to reduce the number of buildings in each group while at the same time preserving the visual separation between the groups, their intrinsic characteristics and, most importantly, not increasing the total density of the block.

Global typification is performed differently on the basis of group characterisations. They trigger ad–hoc algorithms that will be discussed in the next sections.

6.5 Typification

As it was stated at the beginning of this chapter, the typification is used as a selection operator to reduce the number of building to represent at the target scale. It is important to stress that the necessity of a selection operation is due to the fact that at the target scale, *buildings have to be enlarged in order to reach the minimum perceptible area of 400 sqm*, to assure their legibility. The enlarged buildings may overlap or touch other buildings, causing the loss of the group individuality or, in general, visual congestion.

The typification algorithm developed, by reducing the number of buildings, attempts to enforce the legibility constraint, to ensure that the representation at the target scale complies with the minimum size and minimum distance requirements of the IGM specifications.

To reduce the number of buildings in each group, the algorithms basically can perform only two operations: deletion and amalgamation; the difficulty in the development of a good typification algorithm lies then in choosing what and when to amalgamate or delete.

In the case of homogeneous groups, the task is further complicated by the possible presence of spatial patterns in the distribution of the buildings. Since spatial patterns constitute a characteristic of the territory, they should be preserved during the generalization. Hence the typification process developed processes differently:

- homogeneous groups with spatial patterns
- groups with no spatial pattern

To the latter a best-effort typification algorithm is applied, while homogeneous groups with spatial pattern are further divided into:

- groups in linear pattern
- groups in grid patterns
- groups in multi-line pattern

To each of these group a specific typification algorithm is applied, described in the following sections.

6.6 Typification of spatial patterns

Buildings with similarities in size and orientation are likely to be found organized in a regular spatial pattern. In this cases is possible to identify a "model" that can be used to replace two or more buildings, if this replacement is executed respecting the existing alignments among the buildings, the result will be a new group with a decreased number of items but conveying the same information about orientation and shape of the original buildings. According to this consideration we developed three distinct algorithms for the typification of buildings arranged in spatial pattern, covering with the most common alignments.

- groups in linear pattern
- groups in grid patterns
- groups in multi-line pattern

6.6.1 Typification of linear patterns

In this phase we try to identify if a linear pattern exists.

From the proximity graph we know the skeleton of the group is made by the edges connecting the centroid of each building in the group. The pattern is detected by extending an edge in order to have a sufficiently long straight line. This line is the tool to detect straight line building alignments. If every building is crossed by the line then the process can proceed with typification.

The operation's aim is to preserve the pattern as much as possible. The algorithm seeks to remove as least amount of buildings as possible. It works as follows. The group total extension is computed to know the domain inside which the buildings can be placed. The smallest building is enlarged and it constitutes a *model* for the typification and it will be "stamped" in each new computed centroid. Its length, with regard to the direction of the line, is used to compute the available space. The use of a model is justified by the homogeneity of the group which guarantees a low deviation between areas and orientations.

At the first step it seeks to maintain the original cardinality. If

$$(totalLength - buildingWidth * num - (num - 1) * minSeparationThreshold) > 0$$

then there is enough space to place every building along the line. The model is printed at new centroids with an inter-gap that spare them equally along the line. Else if

$$(totalLength - buildingWdth * num(num - 1)/2 * minSeparationThreshold) > 0$$

Another possibility consists of grouping them by two in order to decrease the number of inter-gaps between buildings.

If none of these solutions is possible then remove one building. This is done by decreasing the cardinality of the final pattern. The algorithm cycles until one condition is satisfied. Note that in the worst case we could obtain a single building and in this case we would have lost information about the original pattern. A result of straight line building alignments generalisation is showed in Figure6.6 . Figure6.7 shows another result obtained with our algorithm.

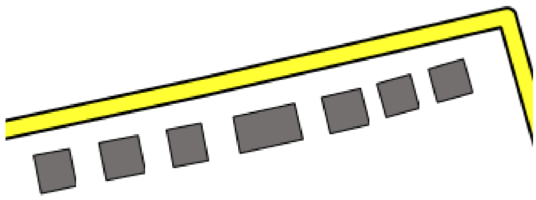

Figure 6.4: Shows the original situation.

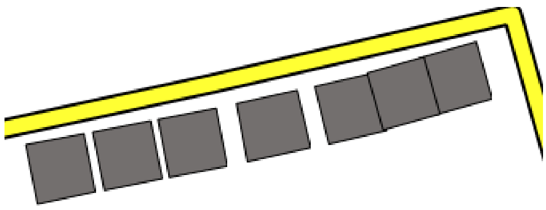

Figure 6.5: Shows the buildings after being enlarged.

6.6.2 Typification of grid patterns

In some cases building are aligned in a grid pattern; this means that the buildings are aligned along two main directions, usually orthogonal one to each other, and

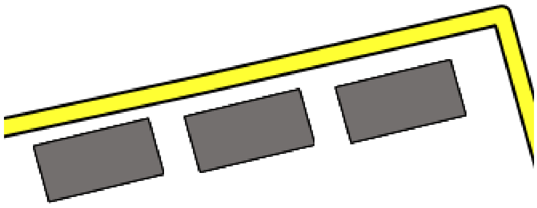

Figure 6.6: Shows the typification result.

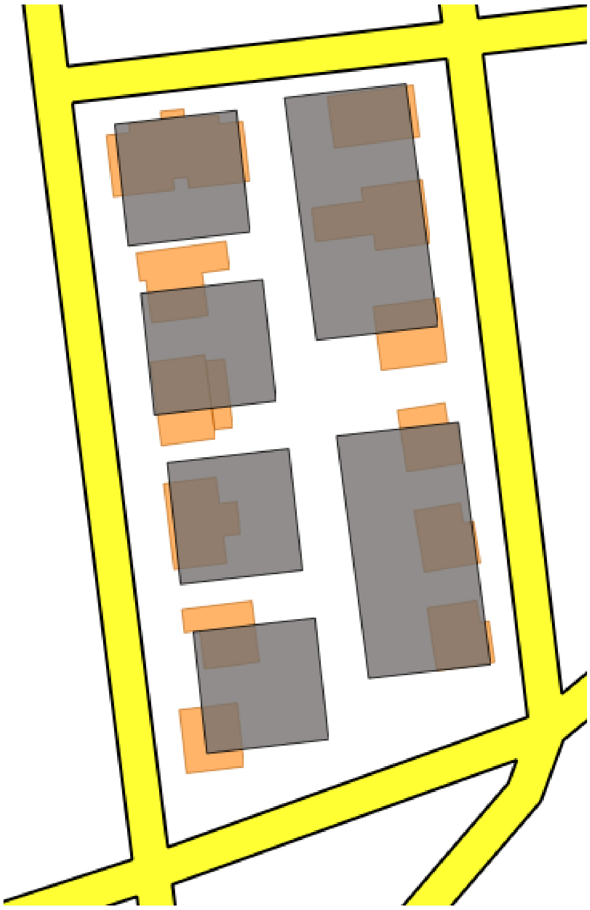

Figure 6.7

that every building belongs to exactly two linear patterns, each parallel to one main direction. Although this kind of pattern is not as common as linear patterns, it represents a distinctive feature on a map and, as such, it should be preserved during typification.

To generalize grid patterns the idea is to consider them as a 2D extension of a single linear pattern: the algorithm is iteratively applied to generalize the linear patterns along one direction and then along the other direction. Comparing a grid pattern to a matrix, the algorithm will first solve all the rows and then all the columns; each row (or column) is treated as a single linear pattern. The process is iterated until the typification led to a reduction of the number of items (along both directions) that allows for their representation at the target scale. In details, the algorithm works as follows.

The first straight line to work with is made by the extension of a line segment linking two neighbouring buildings. This line is the basis of the grid pattern because it determines the two directions of the orthogonal grid.

Having typified the buildings lying along the initial line, a new straight line pattern parallel to the previous one is used to detect alignment. The offset between the two lines is given by the distance between a building intersected by the first line end its nearest neighbour.

The linear pattern typification algorithm is repeated until all the buildings have been taken into account. Obviously, if the number of buildings intersected by a line differs from the ones intersected by its parallel this means that we are not in presence of a grid–like building distribution.

Once the typification has been accomplished in one direction, it needs to be repeated along the orthogonal direction.

Figure6.8 shows a result of the implemented algorithm applied to a grid of nine elements.

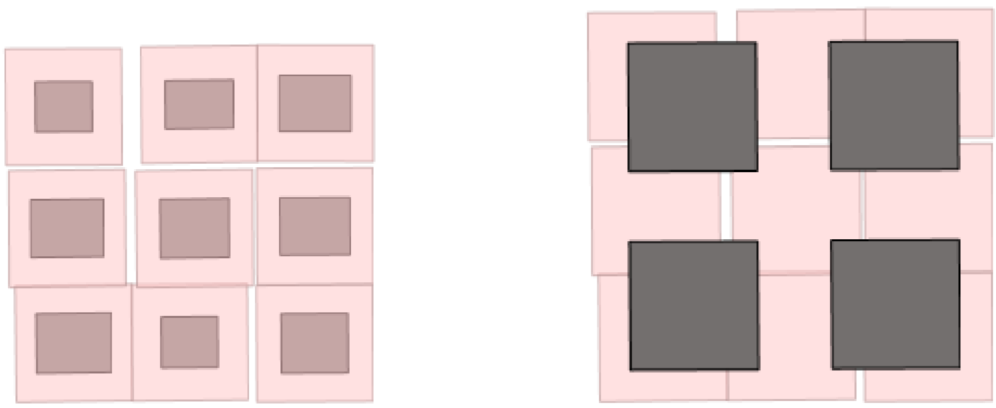

Figure 6.8: Shows a result of the implemented algorithm applied to a grid of nine elements. On the left side enlarged original buildings are depicted in pink; on the right side the typification result is shown.

Figure6.9 shows another grid detected and correctly typified.

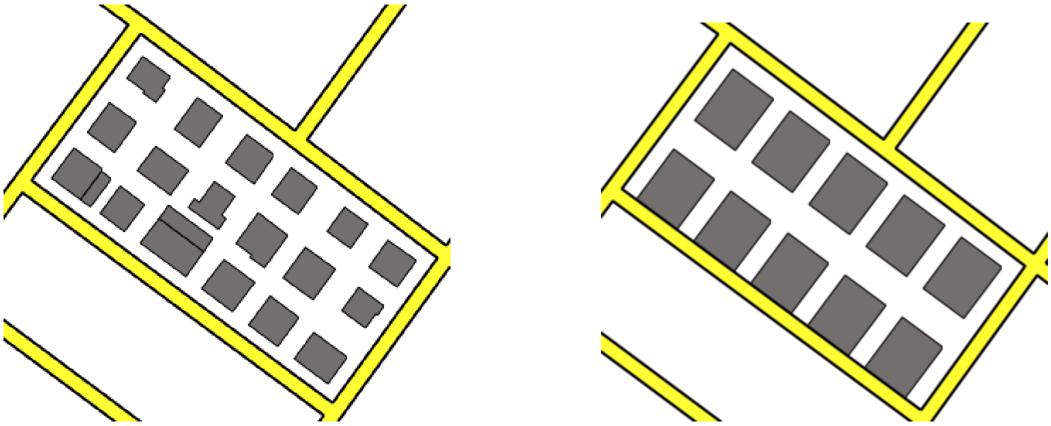

Figure 6.9

6.6.3 Typification of multi-line pattern

Another detectable pattern, is represented by multi-line pattern such as L-pattern, T-pattern or similar. In such a pattern, more than one linear pattern can be identified in the group, with some buildings belonging to more than one linear pattern (this building are called corner buildings). Counting the number of buildings belonging to each pattern it's possible to identify a primary linear pattern and some secondary ones (if all the patterns count the same number of buildings, we are looking at a grid pattern). Usually primary and secondary patterns are orthogonal.

The initial step of the algorithm consists of detecting primary and secondary linear patterns, identifying at the same time the location of the corner buildings. The algorithm then generalizes the secondary linear patterns, starting from the smallest: this is performed applying the linear pattern typification algorithm previously described to each of them.

Once all the secondary patterns have been typified, it's possible to generalise the primary linear pattern. Before than this, an adjustment task is performed, which moves the generalised secondary pattern in order to align each of them to the corner building shared with the linear pattern. Once the primary pattern has been typified, eventual overlaps can occur between the typified primary and secondary patterns on the location of the corner buildings: these are solved merging and simplifying the overlapping buildings.

Figure6.10 shows a case of L-pattern and its generalisation Figure6.11

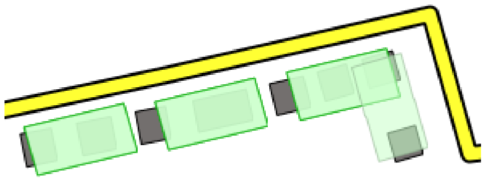

Figure 6.10

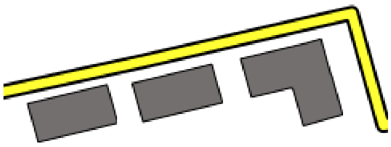

Figure 6.11

6.7 Generalisation of groups too much dense

Obviously, we cannot expect to have to deal only with homogenous groups. Most of the times segmentation produces very dense groups that do not have any remarkable characteristic, neither of homogeneity nor of spatial distribution. Nevertheless we need a strategy to reduce the number of the buildings in the group, in order to free enough space to allow a representation complying with the legibility constraints. The first solution is to merge together buildings of the same group that are adjacent: although this will not free any space, considering all the merged buildings as a single one is likely to increase the size above the minimum value and furthermore limit the number of conflicts due to the minimum distance threshold. Simplifying the building could also produce a more regular shape (e.g. removing juts) that could improve the legibility of the object avoiding any further elaboration. In some cases, though, the minimum distance between the components of a group of buildings could fall under the allowed measure. Moreover this could happen also among groups; in fact, despite the segmentation process creates groups that are guaranteed to be no closer than the minimum distance threshold, because of the enforcement of the minimum size constraint, it may happen that the distance between two groups reduces below the minimum. A specific strategy needed to be found to solve these situations. In general, buildings found to be closer than the allowed minimum distance, should be amalgamated, with the aim to reduce both the number of buildings and the space occupied by them. We devised an amalgamation algorithm that replaces not adjacent building with a new geometry that we called a **placeholder**.

6.7.1 Amalgamating not adjacent buildings

Two main types of amalgamation exists: *amalgamation by bridging features* and *amalgamation by displacement* [31].

Amalgamation by displacement is not an easy operation and is still a research topic. It involves the displacement of the features toward each other and then their amalgamation. The displacement can involve all the features, or be limited to one of them.

The main advantage of the amalgamation by displacement is that it **does not increase** the area occupied by the theme of the amalgamated features, or in general, when it does, it limits the amount of area added in order to merge the buildings (especially if compared with the amalgamation with bridging technique). It also **frees some space** on the side of the displaced object which is opposite to the displacement direction. The main drawback of this method is that **it changes the position of the features**, thus affecting the spatial relationships among the neighbouring features and might cause overlapping.

On the contrary, amalgamation by bridging is a more consolidated task [31]. The amalgamation is performed by means of a fictitious geometry that is placed among each pair of buildings in order to connect them.

The main advantage of this method is that it preserves the position of the features. The drawback is that by creating the fictitious geometries that connect the buildings, it actually increases the density of the theme, which increases the overcrowding effect.

Both this amalgamation techniques lead to a resulting geometry that is a combination of the original ones. In particular, the shape of the result might be as complex (i.e. detailed) as the original ones.

Observations from existing 50k scale maps reveal that at this scale the generalisation of buildings is more similar to a symbolisation which attempt to convey information on the buildings distribution rather then maintain the information on the shape of every single building.

For this reason, the amalgamation techniques described above have been deemed not suitable and another amalgamation technique has been developed. This simpler technique amalgamates dense building groups replacing them with a **placeholder**, i.e. a polygon with rectangular shape and area corresponding to the total building area.

The placeholder is built by computing the oriented minimum bounding rectangle of the building collection and resizing it to reach the total building area. The placeholder is guaranteed by construction to comply the minimum size and minimum distance constraints: while the former comes automatically as it has an area that is the sum of the other buildings, the latter can be easily enforced checking that the placeholder is bound by the convex–hull of the group of buildings.

Figure6.12 shows a result obtained applying algorithms discussed above and shows the situation after building proximity graph and segmentation. In blue very dense groups, in yellow and purple homogeneous groups, in orange group with similarity in orientation and in light purple group obtained because of cardinality stopping condition.

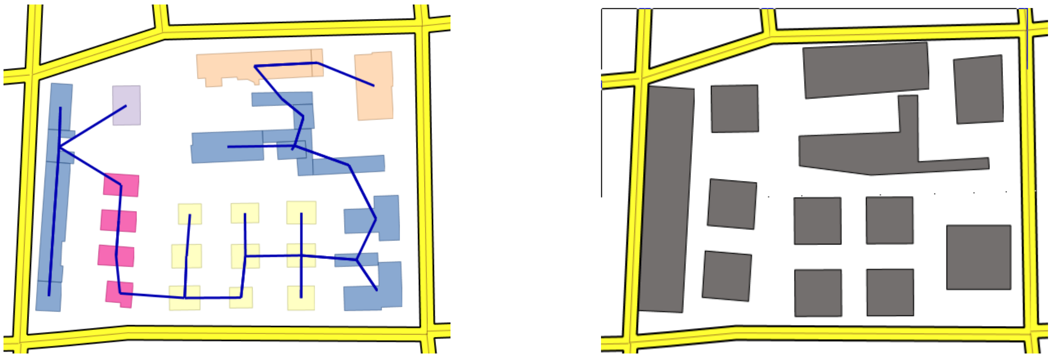

Figure 6.12: On the left, Detected groups : in blue very dense groups, in yellow and purple homogeneous groups, in orange group with similarity in orientation and in light purple group obtained because of cardinality stopping condition. On the right, generalisation obtained where buildings in touch have been merged and simplified with Sester's algorithm, homogeneous groups have been typified thanks to the detection of a straight line alignment and a grid patter, dense but not in touch buildings on the bottom-right corner have been replaced by a placeholder.

Chapter 7

Isolated building generalisation

It is important to remember that buildings have been partitioned into blocks and classified as urban or rural mainly on the basis of their density.

Isolated buildings are clearly contained in low density blocks and can be detected when segmenting the proximity graph. In fact, having connected every group at each step with its nearest neighbour, it is easy to derive which buildings can be treated as isolated. Isolated buildings are those without a neighbouring building in the radius of 30 meters. Hence, at the beginning of the segmentation process, edges whose length is under 30 m are cut away and segmentation can proceed on the subgraphs. Finally, isolated buildings are those that belong to a singleton group.

In case of isolated buildings, the threshold guarantees that there is enough space to enlarge them, if necessary, without causing overlaps with other buildings. Much attention has to be paid on a single building when generalising it. In fact, as we said in the previous chapters, there are quantitative constraints about minimum size, minimum edge length and representable boundary details to be met.

Since the beginning of the Cargen project several algorithms have been implemented to simplify a geometry boundary to suit IGM requirements.

A new algorithm has been developed in this work to complete the implementation of Sester's algorithm [40] in the case of long narrow parts which might need to be exaggerated.

7.1 Exaggeration

In some cases, building outline has to be exaggerated. Consider e.g. a building part that is very long, however very narrow. If the length of the narrow side is below the minimal side, this structure is dropped. If, however, the total area of the structure is greater than a threshold it is considered to be an important part of the building which has to be preserved.

This is achieved by enlarging the smaller side to the minimum side threshold. The algorithm works as follows. It starts with the shortest edge below the threshold, let L be its length. If previous and subsequent edges describe a narrow part with area above the threshold (120 sqm) then extends the current edge by projecting start node and end node of an offset of (L-minEdgeLength)/2.

Let n be the index of the current edge. It tries to project new start node onto the $(n-2)^{th}$ segment along a line parallel to the $(n-1)^{th}$ segment, if projection returns a coordinate then that point is the candidate to be the new point of the boundary.

Repeat the same for the end point considering the projection onto the $(n+1)^{th}$ segment. If both return valid coordinates then it re-builds new geometry with the new computed points. Otherwise if one of them produced a null projection, e.g. the start point, then it keeps fixed the original start point of the current segment, extends end point of an offset of (L-minEdgeLength) and projects new end point as described above. Figure7.1 shows the three possible cases.

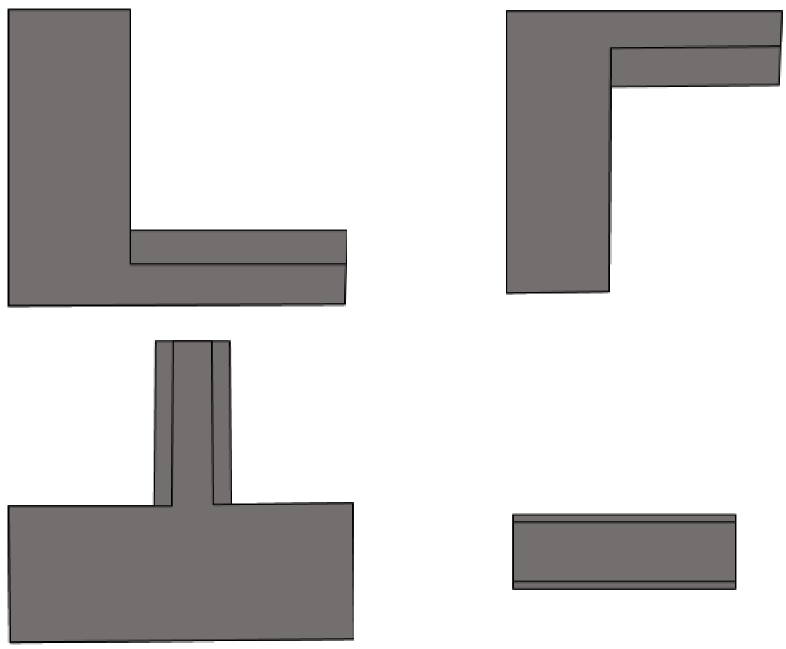

Figure 7.1

Chapter 8

Conclusion

The approaches described in this thesis have been implemented as plug-ins for the OpenJump workbench. In this way, it has been possible to test the results by looking them directly through the GIS. The algorithms developed have been tested on the data of the city of Verona , a medium–large sized Italian city comprising high, medium and low density urban blocks. The results obtained were good; especially I found interesting those obtained working with the duality in medium–density blocks. Also high–density block generalisation performed well and quickly. In my opinion, to devise an approach that is context aware was essential to face the complexity of building generalisation.

The strategy to generalise medium density blocks working in a dual manner with white spaces, instead of buildings, has produced interesting results. However, considerable improvements can be made in this context by, for example, defining a better methodology to deal with characteristic buildings, which have only been mentioned in this work.

The generalisation in a low density rural context represented a difficult task in which many papers and approaches have been proposed. Research is particularly active on this topic, mainly focusing on typification with alignment detection and other forms of pattern recognition. On the contrary, it does not deeply explore situations where buildings are not found to be in a regular pattern even though pattern detection is comparatively rare.

In this work the advantages of typification as selection criteria have been highlighted, such as the ability to free space while maintaining global information. The algorithms developed for pattern detection have produced good results in the presence of really clear, straight, orthogonal patterns. In the presence of slight deviations in the pattern distribution the algorithms are not completely robust and further improvements are probably needed to handle these cases.

Although the target scale was 1:50000, some of the solutions developed are also suitable to generalize the data to the 25k scale: typification, amalgamation by flooding and dual generalisation of courtyards will be soon integrated in the 1:25000 generalization process. Furthermore, the solutions devised can probably be extended to the generalization at lower scales.

The exaggeration algorithm that was developed has turned out to be very useful when applied not only to narrow parts, but also to square or rectangular-shaped buildings. In this way, it allowed buildings to reach the minimum representable size and helped us to have an idea of the real area occupied by buildings at the target scale.

This work has been the first approach to the generalisation of buildings at 50k scale inside the Cargen project and i believe that it brings concrete and good results, setting also a solid basis for future improvements. Although the design of the algorithms relied heavily on the observation of existing maps, it was not easy to compare the same region before and after generalisation because of the scarcity of updated maps. Without doubt this is one of the most important reasons at the basis of the international interest in developing an automatic generalisation process. As such, it is my hope that this work could soon be useful in the setup of an automated cartographic generalisation process that could enable a cheaper and faster production and update of the Italian maps.

Bibliography

[1] Di Menno-Jan Kraak, Ferjan Ormeling, *Cartography: visualization of geospatial data*, Pearson Education, 2003.

[2] *Quality Assessment of Cartographic Generalisation*, Transactions in GIS, 2004.

[3] W.A. Mackaness and A. Ruas, *Evaluation in the map generalisation process*, Series of International Cartographic Association, Elsevier, 2007.

[4] R. McMaster and S. Shea, *Generalization in Digital Cartography*, Association of American Geographers, Washington, USA, 1992.

[5] http://icaci.org/ , International Cartographic Association.

[6] L. Harrie and R. Weibel, *Modelling the overall process of generalisation*, In Generalisation of Geographic Information: Cartographic Modelling and Applications, 2007.

[7] P. Compton, G. Edwards, B. Kang, R. Malor, T. Menzies, P. Preston, A. Srinivasan and S. Sammut, *Ripple down rules: possibilities and limitations*, In Proceedings of the Sixth AAAI Knowledge Acquisition for Knowledge-Based Systems Workshop, Calgary, Canada, 1991.

[8] M. Beard, *Constraints on rule formation.* In Map Generalization: Making Rules for Knowledge Representation, 1991.

[9] I. Petzold, D. Burghardt and M. Bobzien, *Workflow management and generalisation services.* In The 9th ICA Workshop on Generalization and Multiple Representation, Portland, WA, 2006.

[10] M. Barrault, N. Regnalud, C. Duchêne, K. Haire, C. Baeijs, Y. Demazeau, P. Hardy, W.A. Mackaness, A. Ruas and R. Weibel, 2001, *Integrating multi-agent, object-oriented and algorithmic techniques for improved automated map generalization.* In Proceedings of the XX Int. Cartographic Conference, Beijing, China.

[11] A. Ruas and C. Plazanet, *Strategies for automated generalization.* In Advances in GIS Research II, (Proceedings of SDH 1996, Delft), 1996.

[12] A. Ruas, *Modèle de généralisation de données géographiques à base de contraintes et d'autonomie*, PhD thesis, Université de Marne la Vallée (in French), 1999.

[13] A. Ruas and C. Duchêne, *A prototype generalisation system based on the multi- agent system paradigm.* In Generalisation of Geographic Information: Cartographic Modelling and Applications, 2007.

[14] N. Regnauld, *Contextual Building Typification in Automated Map Generalization*, Algorithmica, 2001.

[15] *Norme e Segni convenzionali per la realizzazione dei fogli della Carta dâItalia alla scala 1:50 000* .

[16] K. Thorisson, *Simulated perceptual grouping: an application to human–computer interaction*, in Proceedings of the 6th Annual Conference of the Cognitive Science Society, 1994.

[17] M. Sester, *Generalization Based On Least Squares Adjustment*, International Archives of Photogrammetry and Remote Sensing, 2000.

[18] D.M. Mark, *Object modelling and phenomenon-based generalization*, in Map Generalization: Making Rules for Knowledge Representation, 1991.

[19] M. Beard and W.A. Mackaness, *Graph theory and network generalization in map design*, in Proceedings of the 16th ICA Conference, Cologne,1993.

[20] A. Ruas, *Multiple paradigms for automating map generalization: geometry, topology, hierarchical partitioning and local triangulation*, Proceedings of Auto Carto 12, 1995.

[21] J.M. Ware and C.B. Jones, *A spatial model for detecting (and resolving) conflict caused by scale reduction*, in Proceedings of the 7th International Conference on Spatial Data Handling, Delft, 1996.

[22] R. Weibel, *Amplified intelligence and rule–based systems*, in Map Generalization: Making Rules for Knowledge Representation, 1991.

[23] http://www.openjump.org

[24] A. Boffet and S. Rocca-Serra, *Identification of spatial structures whithin urban blocks for town characterisation.* In: Proceedings 20th International Cartographic Conference, Beijing, 2001.

[25] http://www.regione.veneto.it

[26] *Carta Tecnica Regionale Numerica*, Regione del Veneto, Segreteria Regionale per il Territorio , Unità Complessa per il Sistema Informativo Territoriale e la Cartografia.

[27] N. Regnauld, *Algorithms for the amalgamation of topographic data*, Proceedings of the 21st International Cartographic Conference (ICC), 2003.

[28] C.B. Jones, G.L. Bundy and J.M. Ware, *Map generalisation with a triangulated data structure*, Cartography and GIS, 1995.

[29] A. DeLucia and R.T. Black, *A comprehensive approach to automatic feature generalisation*, Proceedings of 13th International Cartographic Conference,1987.

[30] A. Ruas, *A method for building displacement in automated map generalisation*, International Journal of GIS, 1998.

[31] N. Regnauld, *Algorithms for the amalgamation of topographic data*, Proceedings of the 21st International Cartographic Conference (ICC), 2003.

[32] W.A. Mackaness, K. Beard, *Generalization Operations and Supporting Structures Proceedings of Auto Carto 10*, 1991.

[33] K.S. Shea and R.B. McMaster, *Cartographic generalization in a digital environment: when and how to generalize*, Proceedings of Auto Carto 9, 1989.

[34] N. Ahuja and M. Tuceryan, *Extraction of early perceptual structure in dot patterns: integrating region, boundary, and component gestalt* , Computer Vision, Graphics and Image Processing, 1989.

[35] J. Kruskal, *On the shortest spanning subtree of a graph and the traveling salesman problem*, Transactions of the American Mathematical Society,1956.

[36] R. Prim, *Shortest connection networks and some generalizations*, Bell System Technical Journal, 1957.

[37] C. Zahn, *Graph-theoretical methods for detecting and describing gestalt clusters*, IEEE Transactions on Computers, 1971 .

[38] .N. Regnauld, *Recognition of building cluster for generalization*, in Proceedings of the 7th International Symposium on Spatial Data Handling, 1996.

[39] N. Regnauld and P. Revell, *Automatic Amalgamation of Buildings for Producing Ordnance Survey*, The Cartographic Journal, 2007.

[40] D. Callegari, *Sviluppo di algoritmi per la generalizzazione cartografica degli edifici*, Tesi di laurea specialistica, Università degli Studi di Padova, 2008.