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MASTERARBEIT

The automatic generalisation of buildings whilst maintaining the settlement structure: A case study based on the 1:50‘000 Swiss National Map Series

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Zürich, 28. November 2014

Signature (student)

MASTER‘S THESIS

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Conducted at the Institute for
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Abstract

Within cartographic circles automatic generalisation is one of today's „buzzwords" but yet remains one of the most difficult goals to achieve and is hence a subject of intense research activity.

For most National Mapping Agencies (NMA's) the need for automatic generalisation is of significant interest. With automatic generalisation NMA's are able to not only improve and streamline their map production lines but also save important resources such as time and money. It is for these reasons that many NMAs are either in the process of, or have already introduced automatic generalisation.

The Federal Office of Topography swisstopo, the NMA of Switzerland, already uses automatic generalisation within its map production, is however constantly seeking new approaches and methods to further increase its efficiency. A special generalisation challenge found within this organisation is that of the individual house representation, a trait for which the Swiss national maps are famous for and which is followed with a typical Swiss precision up to a scale of 1:100'000.

This research, not only outlines the challenges faced but also supplies a possible working solution for the following use case. The automatic generalisation of the individual polygon house features of the Swiss TLM (Topographic Landscape Model, scale 1:10'000) whilst retaining the individual representation for an end scale of 1:50'000 and this whilst maintaining the various settlement formations identified within Switzerland.

The final solution was subsequently summited, in form of a questionnaire, to an expert panel consisting of individuals directly involved with the subject of generalisation and represented by three distinctly different users groups (cartographers, software specialists and higher education). The enclosed summary of the questionnaires results supply an interesting insight into the individual perception of generalisation and offer a vision into how this research might be continued.

Keywords: Automatic Generalization, Settlement generalisation, Building generalisation, NMA, Settlement structure

Kurzfassung

Innerhalb der Kartographie ist die Automatische Generalisierung eines der Haupt "Schlagworte", aber zum heutigen Zeitpunkt immer noch ein schwer zu erreichendes Ziel und somit Gegenstand intensiver Forschungstätigkeit.

Die Notwendigkeit der automatischen Generalisierung ist für die meisten NMA‘s von erheblichem Interesse. Mit automatischer Generalisierung sind diese nicht nur in der Lage ihre Produktionslinien zu verbessern und zu optimieren, sondern auch wichtige Ressourcen wie Zeit und Geld einzusparen. Aus diesen Gründen schlagen viele NMA‘s diesen Weg ein oder haben automatische Generalisierung bereits eingeführt.

Das Bundesamt für Landestopografie swisstopo, die NMA der Schweiz, verwendet bereits automatische Generalisierung bei der Kartenproduktion und sucht ständig nach neuen Ansätzen und Methoden um die Effizienz zu verbessern. Von besonderem Interesse ist die Generalisierung von Gebäuden, da das Siedlungsbild in allen Massstäben von grösster Bedeutung ist. Besonders in Schweizer Karten ist die Einzelhausdarstellung über mehrere Massstäbe eine Besonderheit und deshalb zu gewährleisten.

Diese Masterarbeit beschreibt nicht nur die Herausforderungen, sondern liefert vielmehr eine mögliche Arbeitslösung für die automatische Generalisierung der einzelnen Gebäude Polygone des Schweizer TLM (Topographisches Landschaftsmodel, Massstab 1:10‘000) unter Erhalt der Einzelhausdarstellung für einen Endmassstab von 1:50‘000, und dies unter Beibehaltung der verschiedenen Siedlungsformen innerhalb der Schweiz.

Das fertige Ergebnis wurde anschliessend durch eine Expertengruppe, bestehend aus Personen die unmittelbar mit dem Thema Generalisierung vertraut sind, mittels Fragebogen evaluiert. Die Gruppe wurde durch drei verschiedene Expertengruppen repräsentiert (Kartographen, Software Spezialisten und Hochschulausbildung). Die Evaluierungsergebnisse liefern einen interessanten Einblick in die Wahrnehmung der erzielten Generalisierung und bietet eine Vision wie diese Forschung fortgesetzt werden könnte.

Keywords: Automatische Generalisierung, Siedlungsgeneralisierung, Gebäudegeneralisierung, NMA, Siedlungs Struktur

Contents

1 Introduction

This chapter provides an introduction to the topic automatic generalisation of buildings. The context and relevance with respect to this Master‘s Thesis is specified. A special focus lies on the need of generalisation for National Mapping Agencies (NMAs). The task and objectives are highlighted and the audience for which this thesis is aimed identified. Furthermore, an overview about the structure of the thesis is given.

1.1 Context and relevance of the topic

The Cartographic generalisation plays a key role in the creation of maps – particularly in today‘s digital cartography, where generalisation tools are an essential part of any Geographic Information System (GIS) (Weibel, 2004). At the present time the amount of geodata is increasing rapidly. Therefore, new solutions are needed to innovate the map production process of topographic maps in order to save valuable resources. So helping to ensure efficiency and maintain update cycle without suffering any loss of quality. Therefore, the automation of generalisation is a subject of intense research activity and one of the most discussed topics at present (Burghardt et al., 2014). Brassel and Weibel already stated in 1988 that "generalisation is a fuzzy concept and is not well defined". Due to this fuzziness and the importance of the topic, there has been a significant amount of research done to provide and improve possibilities of automating the most critical and repetitive tasks in map production. Since the second half of the 20th century a number of different rules and approaches have been defined for coping with the problem of automatically generalising small scale maps from a large scale base (Weibel, 2004).

For many NMAs the need for automated generalisation is from significant interest [(Duchêne et al., 2014) in (Burghardt et al., 2014)]. With automated generalisation NMAs are able to improve their map production lines and so save important resources such as time and money. This process leads to the other big advantage of being able to derive their smaller scale datasets from a single maintained database (Foerster et al., 2010). For these reasons many NMAs have already introduced automated generalisation and for all the others it can only be a matter of time before they will follow down this path.

The Federal Office of Topography swisstopo [1], the NMA of Switzerland, is responsible for the national survey of Switzerland and production of the national maps. Swisstopo already use automatic generalisation in its map production, is however constantly seeking new approaches and methods to further increase their efficiency. At present the final quality control of all mapping products is still done manually by the skilled cartographic workforce.

This Master‘s Thesis is based upon the automatic generalisation of the building features. The features originate from the 1:10‘000 Topographic Landscape Model (TLM) and the result will be used in the 1:50‘000 Digital Cartographic Model (DCM). For swisstopo the building features are of special importance, not only are their maps renowned for their individual house representation but also for maintaining the tradi-

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[1] Throughout this paper the term swisstopo will be used to refer to "The Federal Office of Topography swisstopo"

tional Swiss settlement patterns and that at all map scales up to 1:100‘000.

The generalisation on large- to midscale map production lines is well known as one of the most time consuming of all generalisation tasks for NMAs (Stoter et al., 2010). Especially the generalisation of individual building features. Only an automatic workflow is acceptable today due to the significant amount of time and costs of a manual generalisation. Hence this topic of this thesis which will investigate the automatic generalisation of buildings for the DCM 1:50‘000 whilst obtaining the settlement structure.

1.2 Task and objectives

Primarily, the thesis will indicate whether it is possible to automatically generalize the buildings for the scale 1:50‘000 under the requirement of keeping the existing settlement structure with ArcGIS out-of-the-box generalisation tools. This poses the following questions, what is the appropriate workflow, the design of the workflow and finally the visual quality and acceptance of the results. The following three objectives have been defined to answer the research questions as stated above.

The first objective is to describe the current state of the art in order to be able to make a decision about the appropriate workflow. The specific objectives are:

- to describe the topic of generalisation
- to describe the automation of generalisation
- to compare the different generalisation frameworks and processes
- to identify the specific generalisation operators

- to identify the considerations when generalising buildings especially for the scale of 1:50‘000
- to describe various kind of settlement structures
- to identify the current state of the art in relation to the automatic generalisation of buildings

The second general objective is to develop an appropriate workflow, here the specific objectives are:

- to identify a test area encompassing the different identified settlement structures
- to describe and analyse the cartographic constraints when generalising buildings
- to identify generalisation process
- to determine the available generalisation tools in order to develop the workflow
- to develop and automate the workflow
- to verify the workflow

The final objective is to verify the quality of the results. The specific objectives are:

- to develop, execute and analyse an expert survey to ascertain the visual impact and acceptance of the results

1.3 Target audience

This work is aimed for an audience with high interest in automated map generalisation. Specifically for NMAs the results of this research maybe of importance for the reasons given above. A further targeted audience are all those interested in using generalisation tools within an automated workflow without presupposing a high knowledge in geoinformatics.

1.4 Structure of the thesis

The Master‘s Thesis is divided into six chapters including the introduction. The following table 1.1 gives an overview of the contents of each chapter.

Chapter 1	**Introduction**: Description of the context and relevance of the topic, the task and objectives of the master thesis as well as the structure.
Chapter 2	**Theoretical foundations & state of the art**: The fundamentals of generalisation which are important for the further understanding are discussed. This includes what generalisation in general is and what considerations have to be taken into account when generalising buildings. Further, the current state of research in generalisation and its automation is described. The special focus is on the generalisation of buildings.
Chapter 3	**Methodology**: This chapter describes the basic methodology which is used in order to fulfil the practical implementation and the expert evaluation. An introduction to the constraint-based generalisation is given. A requirement analysis shows what should be taken into account when generalising buildings according to swisstopo.
Chapter 4	**Practical implementation**: This chapter provides into detail how the practical implementation has been conducted. The generalisation tools are determined and the automated workflow developed. The results are discussed.
Chapter 5	**Evaluation of the results**: It is pointed out how the quality of the generalized results can be indicated. An expert survey is developed and executed. The results of this are analysed into detail.
Chapter 6	**Conclusion**: A summary is given about the conducted research. All the results are discussed and an outlook for further research is given.

Table 1.1: Structur of the thesis

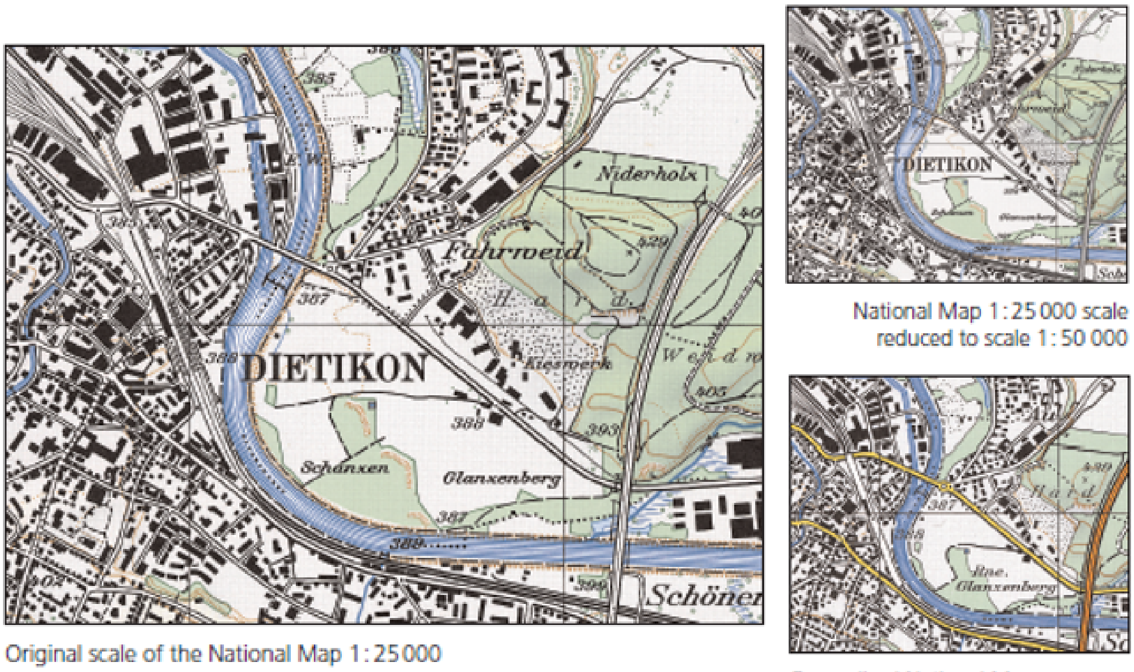
2 Theoretical foundation & state of the art

This chapter provides a general overview of the topic of cartographic generalisation, its automation and defines the current state of the art. The principle, the process and the operators of generalisation are explained in detail. This chapter also outlines the special considerations for building generalisation.

2.1 The main principle of generalisation

The main principles of generalisation is that the available space for cartographic representation of features is proportionally reduced from scale to scale (Spiess et al., 2002). This means with a map scale reduction a larger area is mapped. What would happen if the map scale was to be reduced continually is that at a specific point it would become illegible. Figure 2.1 illustrates why a reduction of the image area forces a restriction on the features appropriate to each scale (Spiess et al., 2002).

The diagram on the left side of Figure 2.1 is an example at the original scale of the 1:25‘000 whereas the top right diagram shows the same map extract represented four times smaller at a scale of 1:50‘000. The diagram to the bottom right shows the same map generalized. Particularly striking is that the map that was reduced from 1:25‘000 to 1:50‘000 without generalisation shows all features however are no longer identifiable.



Original scale of the National Map 1:25 000

National Map 1:25 000 scale reduced to scale 1:50 000

Generalised National Map 1:50 000

Figure 2.1: Necessity for generalisation - modified after (Spiess et al., 2002)

Due to this principle generalisation remains one of the main conceptual concerns in cartography (Brassel, 1990). Brassel and Weibel (1988) defined a map as being a generalized and simplified abstraction of reality. They describe the generalisation as followed: “The term generalisation focuses on the extraction of the general, crucial elements of reality” (Brassel and Weibel, 1988). Due to the fact that cartographic generalisation is one of the main themes and the key process in cartography abundant literature exists (Burghardt et al., 2014; Mackaness et al., 2007; Müller et al., 1995). A current definition of cartographic generalisation can be found in a publication of the Swiss Society of Cartography (SGK) (Spiess et al., 2002). For practical purposes Spiess et al. (2002) recommend within the framework of the production of topographic maps, the following definition:

> *"Generalization is the graphical simplification of digital landscape models, charts or maps at large scales according to the scale and content of the complex real world. Generalization mainly consist of a selection and combination of objects in view of the intended use, as well as in the most positional precise, characteristic, correct and clear graphical representation."* (Spiess et al., 2002)

This definition provides two main points which are of significant importance regarding generalisation. Firstly, the simplification of data from various sources in the graphical and textually context and secondly, it emphasizes the main components of generalisation which are selection, aggregation, and the graphical representation of objects.

As explained in the beginning of this chapter, the generalisation of maps is understood as the process of preserving the readability of a map while changing its scale (Spiess, 1995). Therefore, one of the main goals of cartographic generalisation is to produce a clearly readable and interpretable map image. To enforce this, the main focus in the production of a map, depending on the scale and purpose, is to simplify the content meaningfully, to highlight the important characteristics, and to reduce or omit the less important characteristics accordingly. Following this simple rule, the map image can remain not only harmonious but also clear and legible (Bacher, 2014). Figure 2.2 illustrates which aspects are crucial when generalising: simplification, selection, omission, clarification, retention, combination, emphasis, highlighting, and dependency (Spiess et al., 2002).

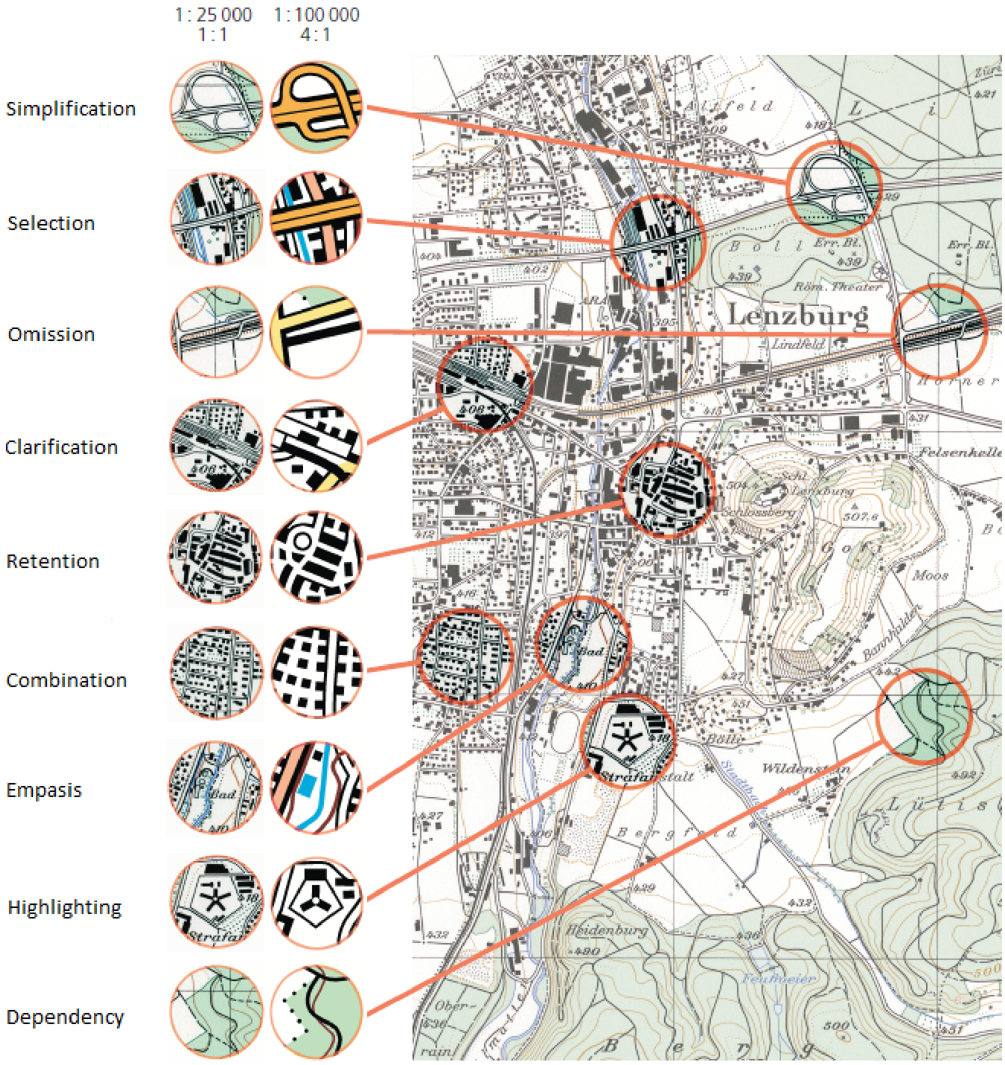


Figure 2.2: Crucial aspects of generalisation (Spiess et al., 2002)

2.2 The concept of generalisation

The current aim of many NMAs is to build a base DLM in a specific large scale from which one or many other scales will be derived (Duchêne et al., 2014; Lee and Hardy, 2007). According to Hake et al. (2002) this process of capturing the basis DLM is called object generalisation. After the object generalisation the concept can be further distinguished into the model- and cartographic generalisation (Hake et al., 2002; Lee and Hardy, 2005) as seen in Figure 2.3.

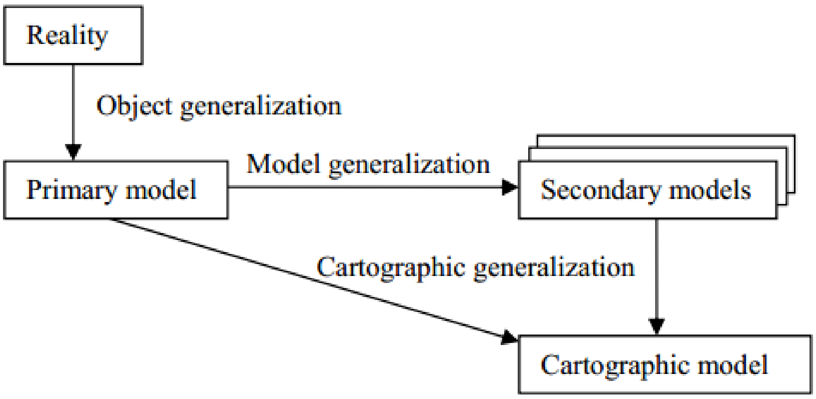


Figure 2.3: Generalization model of Gruenreich 1992

Grünreich‘s model provides an overview of the automated generalisation process suggesting a multi-stage approach (Foerster et al., 2007).

Basically it can be stated that during model generalisation different DLMs for various scales can be derived from the central DLM (Figure 2.4). The main aim is the generalisation of content and semantics which leads to a simplified and generalized model. This model is characterized by a reduced thematic and geometrical resolution. According to Weibel (1995) the major objective is a controlled data reduction in the spatial, thematic, and temporal domains.

The cartographic generalisation results in different DCMs for various predefined target scales can be derived under consideration of the cartographic symbolization and the readability.

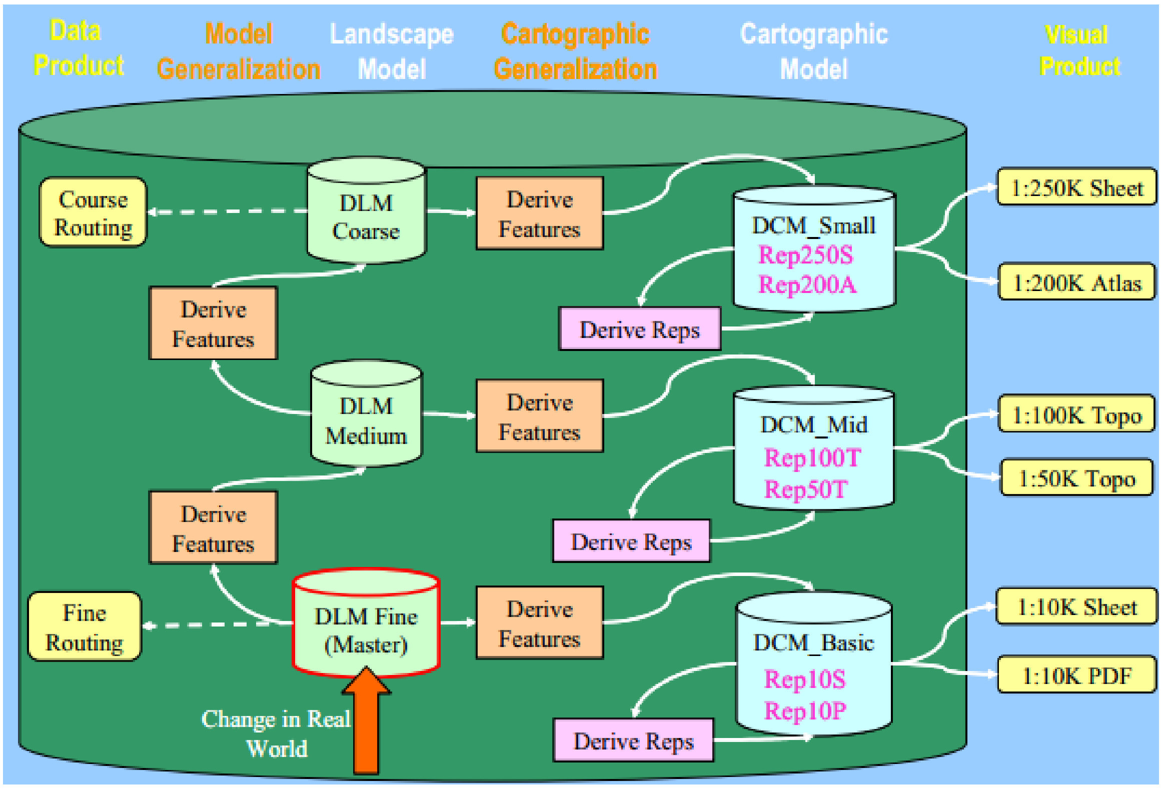


Figure 2.4: Deriviation of different products from a central DLM (Lee and Hardy, 2005)

These two processes, the model- and cartographic generalisation, go hand in hand and cannot be clearly separated. Nevertheless, it can be stated that through the model generalisation a semantic and semantic-geometric simplification takes place while during cartographic generalisation, primarily elementary generalisation operators are used to solve resulting graphic conflicts. It is important to note, that the model generalisation involves no artistic component whereas the cartographic generalisation does (Weibel, 1995). Lee and Hardy (2005) highlighted specifically that “At the heart of such a production strategy is generalisation – the intelligent abstraction of data to a smaller scale.”

Within the context of the conceptual method of generalisation the planned and already partly implemented production process of swisstopo is illustrated in Figure 2.5 and needs to be explained in more detail for a clearer understanding.

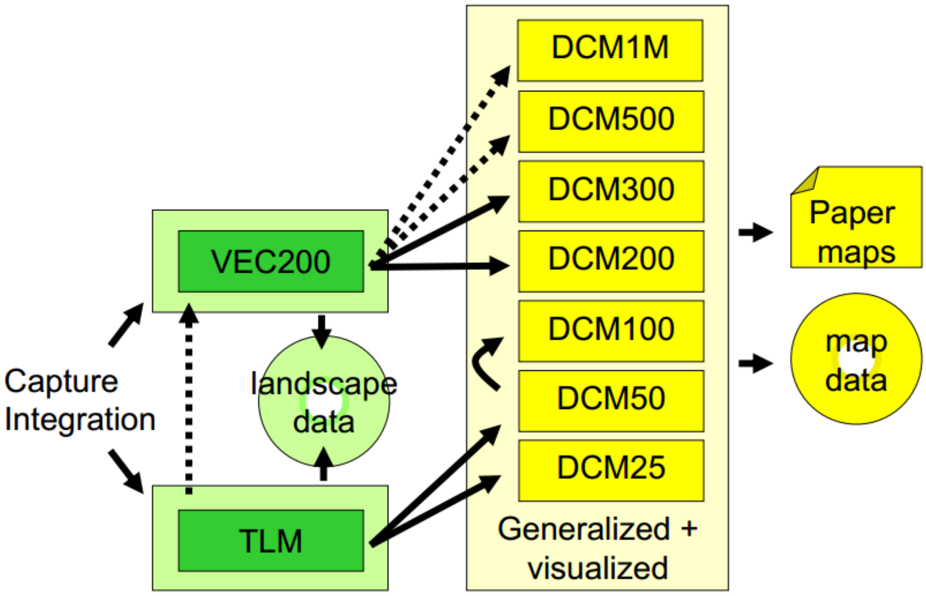


Figure 2.5: The current production process by swisstopo (©swisstopo)

By swisstopo the source data set is the TLM and the target date set is the DCM. VEC200 and TLM are both landscape models. The TLM is at a large scale, ranging from 1:5‘000 to 1:10‘000 (Swisstopo, 2014a) and the VEC200 at a small scale of 1:200‘000 upwards (Swisstopo, 2014b). The TLM corresponds to the previously mentioned base DLM. The DCMs are derived either from one of the two landscape models of from another DCM and form the basis for the production of the topographic maps and map data.

2.3 Frameworks and processes of generalisation

The development of an automated generalisation system is highly dependent on the conceptual view. Since the 1970s and 80s, attempts have been made to incorporate the automated generalisation process in a conceptual schema (Harrie and Weibel, 2007). Basically we can distinguish between the process-oriented view where the framework seeks to conceptually structure the entire generalisation process, and the object-oriented view where the level of map objects is addressed (Steininger and Weibel, 2005).

The process-oriented view considers generalisation as a series of different activities. The first process-oriented approach was provided by Brassel and Weibel (1988), in which the framework of map generalisation is composed of structure and process recognition, process modelling and execution, and the data display. This approach was later taken up and expanded by McMaster and Shea (1992) where there answer their questions “Why is generalized?”, “When is generalized?” and “How is generalized?”. Steininger and Weibel (2005) go even further and combine the two approaches in to a single process model. This model consists of three phases which are structural analysis, generalisation and visualization. The process-oriented approach is from specific interest and is especially useful when developing a workflow based approach.

The object-oriented view of the generalisation is mainly hierarchical. Ruas and Plazanet (1996) realizes a constraint based modelling approach which is based on Brasel and Weibel‘s model (1988) and supplemented by the suggestions of Mackaness (1995), that only a constraint based and iterative strategy results in a satisfactory solution. This framework distinguish between local and global level treatment and consist of the following three levels. The global master plan, which is the highest level, determines a sequence of generalisation tasks upon the entire map. The next level selects a geographic situation according to a given task. The third and final level is a local generalisation plan which is executed for every situation.

2.4 Modelling the generalisation process

On the basis of the various individual processes requirements for a generalisation system can be derived. This system must be able to control the available generalisation algorithms under consideration of the cartographic requirements. Harrie and Weibel (2007) describe and discuss the different approaches to represent the generalisation process. They deal with the question of when and how algorithms can be used and how they can be initiated and controlled. Harrie and Weibel (2007) stated that there are three types of models which can be applied to the overall generalisation process.

The condition-action modelling can be defined as the following “A condition-action process consist of two phases: structural recognition (condition) and execution (action). In the structural recognition phase identification of objects and relationships between objects is performed. Based on the identified conditions, algorithms for generalisation are triggered in the execution phase” (Harrie and Weibel, 2007). The advantage of a condition-action model is that “if-constructs” can be implemented very easily. The main disadvantages are that countless rules need to be established for complex problems and that the 1:1 relationship between condition and action is too static for the generalisation process.

The human interaction modelling can be defined as the following “Human interaction modelling is based on the principle that the cognitive workload can be shared between computer and human. The computer typically carries out those tasks which can be sufficiently formalised into algorithms, while the human is responsible for guiding and controlling the computer software.” (Harrie and Weibel, 2007). One of the requirements of this model is that a suitable interaction between the human and the system through an appropriate user interface exists. A disadvantage is that it has been shown that interactive systems hardly provide a time saving compared to the manual generalisation.

The third and final type is the constraint-based modelling. Harrie and Weibel (2007) states that “Several requirements must be fulfilled in a generalised map; these requirements can act as constraints to the generalisation process. A constraint based approach seeks a generalisation solution that satisfies as many of the constraints as possible”. The philosophy behind constraint-based modelling is that a generalised map should satisfy several conditions and these will act as constraints in the generalisation process.

Generalisation can be defined as a decision-making process which is represented by its many rules resulting in the necessity to make many decisions. A generalisation issue can often be solved by several different generalisation operations. This fact was taken up by Beard (1991) in her approach to the constraint-based modelling. The constraints are first used to describe the ideal state of a completed generalized map. Based on the condition priorities and the available algorithms the generalisation system must find a solution to satisfy as many constraints as possible. This process corresponds to a continuous optimization process. Currently, the constraint-based modelling is considered as the most promising technique with numerous application examples in both the research and productive environments (Galanda, 2003; Harrie, 1999; Stoter et al., 2010, 2014a). Even workflow systems are capable of implementing constraint-based generalisation processes and other modelling techniques. This is confirmed in Steininger and Weibel‘s summary (2005) where it is stated that “Workflow modelling has shown its applicability in GIS and promises to be a flexible approach to chain together necessary interactivity with algorithmic processing tools also for generalisation purposes.”

2.5 Generalisation operators

“Most of the research in generalisation assumes that the process can be broken down into a series of logical operations that can be classified according to the type of geometry of the feature, into what we call generalisation operators” (Regnauld and McMaster, 2007). In Regnauld and McMaster‘s publication “A synoptic View of Generalisation operators” they review the major generalisation models, Robinson et al. model (1978), Brassel and Weibel model (1988) and the McMaster and Shea model (1992), focusing on the organisation of operators.

Regnauld and McMaster (2007) identified four components of generalisation: selection, simplification, classification, and symbolisation within the Robinson et al. model (1978). However Robinson et al. (1978) defines the process itself into two main steps, Selection, a pre-processing step and Generalisation, the actual process of generalisation which contains simplification, classification and symbolisation.

Regnauld and McMaster (2007) identified in Brassel and Weibel‘s model (1988) that the process recognition is important. Here the necessary generalisation operators and parameters are identified by determining “what is to be done with the original database? which types of conflicts have to be identified and resolved? which types of objects and structures are to be carried in the target database?” [Brassel and Weibel (1988) in Regnauld and McMaster (2007)]. Another important part of this model is the execution process which consists of a sequence of operational steps such as selection/elimination, simplification, symbolization, feature displacement and feature combination (Brassel and Weibel, 1988).

Regnauld and McMaster (2007) identified in McMaster and Shea‘s model (1992) that here the emphasis lies with the special operators required for automated generalisation which is defined under “How to generalize?”. They decomposed this aspect into twelve generalisation operators: Aggregation, Smoothing, Simplification, Amalgamation, Merging, Collapse, Refinement, Typification, Exaggeration, Enhancement, Displacement and Classification.

As stated the operators have been defined in many different generalisation models. However, a uniform classification and designation of these operators has still to be defined. Operators are often defined differently and also the number of operators is dependent upon both the model and its author (Foerster et al., 2007). Foerster et al. (2007) proposed in their publication “Towards a formal classification of generalisation operators” an classification of operators according to Gruenreich‘s model. This model has proved its worth by being adopted by many NMA‘s.

Gruenreich‘s model classifies the operators into two groups model- and cartographic generalisation. This classification by Foerster et al. (2007) is given in the following Table.

Model generalisation	**Cartographic generalisation**:
Class Selection	Enhancement
Reclassification	Displacement
Collapse	Elimination
Combine	Typification
Simplification	Amalgamation
Amalgamation	

Table 2.1: Operator affiliation to Gruenreich‘s model (Foerster et al., 2007)

The following subsections explain the proposed operators in more detail.

2.5.1 Model generalisation operators

- **Class Selection:** geospatial data can be reduced through the selection process. The main challenge in selection, or corresponding elimination, is in deciding which features should be removed and which one should be kept (Regnauld and McMaster, 2007). It also includes filtering on the feature type properties according to the target data model such as a database query (Foerster et al., 2007).
- **Reclassification:** this is a similar operation as classification. However, reclassification is based upon an existing data model. It is an important operator because it can change the attributes of features according to the target data model (Foerster et al., 2007)
- **Collapse:** the collapse operator involves the conversion of geometry. For instance a complex set of buildings are replaced with a simple rectangle. This might also involve amalgamation (Regnauld and McMaster, 2007).
- **Combine:** : this is a result of reclassification, in which the geometric attribute type of the object is changed (Foerster et al., 2007).
- **Simplification:** this is one of the most commonly used generalisation operators. "The goal is to retain as much of the shape of a feature as possible, while eliminating the maximum number of coordinates." (Regnauld and McMaster, 2007). It only deletes aspects of a geometry based on certain criteria which might be defined in cartographic constraints.
- **Amalgamation:** this is a special operator as it can be applied globally on the feature type level during model generalisation and locally on a group of features during cartographic generalisation. Spatially adjacent geometries are amalgamated into a single geometry. Through this operator a new outline boundary for

the new geometry is constructed (Foerster et al., 2007).

2.5.2 Cartographic generalisation operators

It should be noted that cartographic generalisation is normally applied after the symbolization of the features. Therefore the, symbolisation of the features can be considered as a post-process of the model- and a pre-process of the cartographic generalisation.

- **Enhancement:** this involves a symbolisation change to emphasize the importance of a particular object (Regnauld and McMaster, 2007).
- **Displacement:** this moves the complete graphic. This results in a features location changing whilst preserving its original shape (Foerster et al., 2007). Displacement is a very complex operator and has been the subject of numerous research projects (Mackaness, 1994; Ruas, 1998; Sarjakoski and Kilpeläinen, 1999; Sester, 2001).
- **Elimination:** through elimination graphic objects are removed from the map display. This shares some similar properties with the selection operator because both result in a reduced number of features. The difference is that elimination is performed at a feature instance level whereas selection is performed at a global level.
- **Typification:** this is a combined operator and highly complex because it reduces the number of buildings while preserving their distribution pattern (Regnauld and McMaster, 2007). Due to its complexity this has also been subject of intense research (Burghardt and Cecconi, 2007; Regnauld, 2001; Sester, 2001).
- **Amalgamation:** identical to the operator in the model generalisation, but applied at the cartographic object level (Regnauld and McMaster, 2007).

2.5.3 Use of operators within building generalisation

For the building generalisation a large choice of operators is required. This results of the various challenges of the building features itself which are that buildings occur frequently in maps, they are small which requires to enlarge them, they are angular and orthogonal in shape and they often occur in dense clusters which requires feature displacement (Regnauld and McMaster, 2007). Based on the classification by Foerster et al. (2007) an overview is given for which operator can be used for special generalisation challenges.

Class Selection	In this case study used to select specific building features and to reduce the number of buildings
Reclassification	In this case study used to reclassify the hierarchy of buildings
Collapse	This operator is not required in this case study
Combine	This operator plays a non-significant role for the generalisation of buildings
Simplification	In this case study used to simplify the complexity of individual buildings
Amalgamation	In this case study this operator was used to amalgamate buildings

Table 2.2: The use of model generalisation operators within building generalisation

Enhancement	In this case study various buildings were enlarged and their shapes exaggerated
Displacement	In this case study used to move buildings away where a conflict between features occurs. An example is when a building is overlapping with a street
Elimination	In this case study used to remove buildings which are smaller than the minimum dimensions
Typification	In this case study used to preserve the local settlement characteristics
Amalgamation	In this case study used to amalgamate features during the cartographic generalisation

Table 2.3: The use of cartographic generalisation operators within building generalisation

2.6 Generalisation of buildings

The generalisation of buildings presents its own series of challenges, one of which is the challenge of maintain a regions local settlement characteristics through a number of map scales. "The goal is that, even in generalised image, the settlement structure can be recognised" (Spiess et al., 2002). Every settlement has its own characteristics defined through history usually by the local traffic- and/or hydrological network together with the local building types. The following subchapters define firstly the main settlement types found within Switzerland for a scale of 1:50'000 and then the special considerations when generalising buildings.

2.6.1 Main settlement types within Switzerland

The following settlement types have been recognised and need to be considered when generalising the buildings so that their characteristics can be preserved.

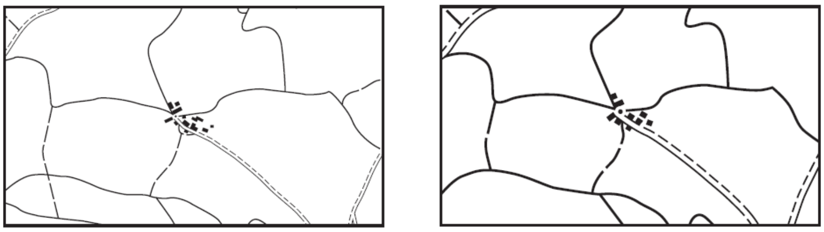
Scattered settlements and remote individual houses

This type of settlement (Figure 2.6) is when the buildings are spread randomly over the terrain. The buildings can occur in small groups or individually. To preserve the typical structure, both large and small isolated buildings are retained and small adjoining buildings are omitted (Spiess et al., 2002).

Figure 2.6: Settlement type: Scattered settlement and remote individual houses (Spiess et al., 2002)

Hamlets

Hamlets, see Figure 2.7, are small rural settlements with only a few buildings. Depending on the densification Hamlets are defined as being either loose or tight (Klett, 2014). Large buildings are retained and small adjoining buildings are omitted. Small buildings maybe generalised or omitted depending on the number of buildings available, however at least two or three buildings must be maintained in order to maintain the Hamlets structure. (Spiess et al., 2002).



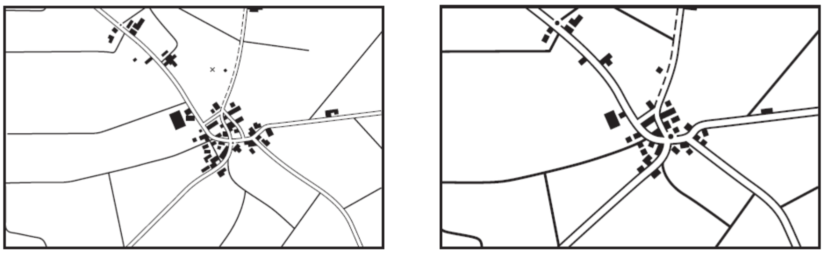
1:25 000

1:50 000 enlarged to 1:25 000

Figure 2.7: Settlement type: Hamlet (Spiess et al., 2002)

Scattered-, street-, and mountain villages

Scattered villages (Figure 2.8) are defined as the Hamlet as being either loose or tight. The structure is irregular with different sizes of buildings. (Spiess et al., 2002)

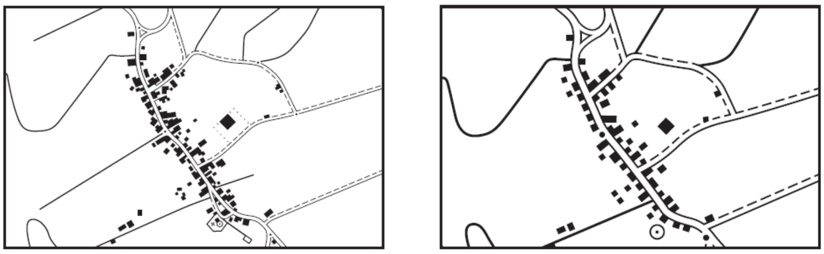


1:25 000

1:50 000 enlarged to 1:25 000

Figure 2.8: Settlement type: Scattered villages (Spiess et al., 2002)

A Street village (Figure 2.9) is a collective term for small linear settlement forms. It is determined by a street along which the buildings run. Here both large buildings and the perimeter of the built-up area are to be retained. (Spiess et al., 2002)

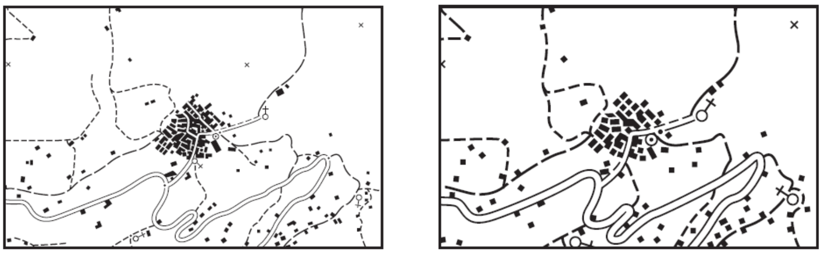


1:25 000

1:50 000 enlarged to 1:25 000

Figure 2.9: Settlement type: Street village (Spiess et al., 2002)

The mountain village (Figure 2.10) is defined by a very dense pattern. Therefore, the minimum spacing have to be retained. (Spiess et al., 2002).



1:25 000

1:50 000 enlarged to 1:25 000

Figure 2.10: Settlement type: Mountain village (Spiess et al., 2002)

Town centre, residential-, and industrial area

The town centre (Figure 2.11) is usually recognised by a higher building density and special building shapes. These characteristics have to be preserved. If there are rows of houses they should be preserved. Narrow alleys must be represented without road symbols and the buildings defined by their minimum spacing. (Spiess et al., 2002).

1:25 000

1:50 000 enlarged to 1:25 000

Figure 2.11: Settlement type: Town centre (Spiess et al., 2002)

The residential area (Figure 2.12) surrounds the town centre and consists of building blocks or individual buildings. When generalising these proportions have to be retained. It is more important to show gaps between the buildings instead of representing the roads. (Spiess et al., 2002).

1:25 000

1:50 000 enlarged to 1:25 000

Figure 2.12: Settlement type: Residential area (Spiess et al., 2002)

In an industrial area (Figure 2.13) the typical ground plan of the buildings have to be maintained. Smaller buildings are aggregated more often than in other settlement areas. Large parking areas and dominant buildings are of a higher importance than small buildings when representing an industrial area. (Spiess et al., 2002).

Figure 2.13: Settlement type: Industrial area (Spiess et al., 2002)

2.6.2 Considerations when generalising buildings

When generalising buildings there are various unique considerations which have to be taken into account. These considerations are of special importance in order to know which characteristics have to be preserved to keep a settlements typical appearance. The considerations are also later used to define the cartographic constraints 3.2.2. Spiess et al. (2002) has identified and summarised the following considerations together with their corresponding characteristics:

Selection

The selection of buildings depends upon several factors such as the scale, site density, settlement structure and their size. A main point of consideration when performing the selection is also that the settlements structure must be maintained. Of special importance is also the representation of buildings which have a characteristic form and that the structure of a settlements centre is maintained whilst maintaining of the traffic or hydrological network. The selection process is therefore different for general as opposed to special buildings. General buildings may well be maintained in isolated areas whereas in congested areas be selected for aggregation. Special buildings must however be retained throughout the selection process (Spiess et al., 2002).

Graphic generalisation

During graphic generalisation it is of special importance that the legibility of the map is preserved (Spiess, 1995). For this the buildings minimum dimensions as well as the spacing between the buildings play an important role and have to be observed carefully (Spiess et al., 2002). At smaller scales the positional precision of individual houses inevitably decreases. Nevertheless, the aim must be to preserve a high overall positional precision. Positional precision is of more relevance to isolated buildings and at a scale of 1:50‘000 will still need to be high. In built-up areas the positional precision must be higher for special buildings whereas general buildings which may have been subject to generalisation it can be considerably lower (Spiess et al., 2002).

Generalization of the shape

It is important to consider that the true shape of buildings decreases gradually at smaller scales. Spiess et al. (2002) states that “at the smallest scale, when representing individual houses, all individual shapes are reduced into a square or rectangle. Differences between these two basic shapes are maintained as far as possible. Very large buildings and those with an extraordinary ground plan maintain their individual shape.” Figure 2.14 shows that one of the most important characteristics of shape generalisation is the removal of small detailed forms, such as indentations and extensions. Respectively the basic shape of the buildings must be maintained and may even be emphasised whilst still considering the minimum allowed dimensions. This is necessary to preserve the readability of the individual buildings as they appear on the map (Spiess et al., 2002).

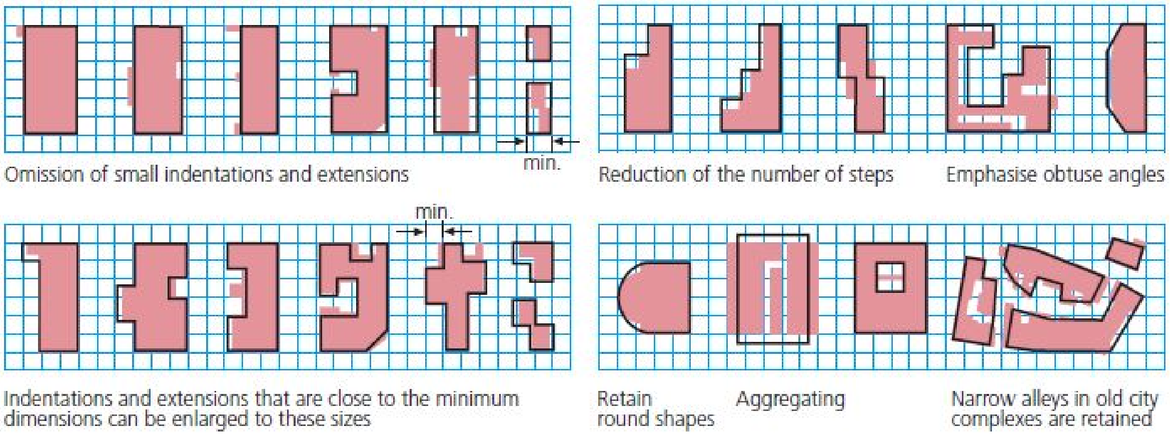


Figure 2.14: Examples for the simplification of building according to Spiess et al. (2002)

Large buildings may also be accentuated to differentiate them from small buildings. Shape generalisation is always performed under the constraints of maintaining the settlements main characteristics such as a historical town centre, large residential buildings and large industrial buildings.

Retaining the settlement structure

According to Spiess et al. (2002) “One of the most important goals of the generalisation of built-up areas is to retain the settlement structure. As the positional precision of individual buildings decreases at smaller scales, the characterisation of the settlement structure becomes more important. The attempt to maintain and clarify this structure ends when the settlement has to be represented by a point symbol.” The following properties have been recognised by Spiess et al. (2002) in helping to maintain the settlement structure:

- **Retaining density:** For the orientation on a map the differences in building density can be a very useful indicator, this especially at a scale of 1:50‘000. Common density characteristics are: vacant, scattered, dense and enclosed built-up areas. To retain the density it is very important to keep the so-called black white ratio (black areas in relation to white areas on a map). Here the minimum spacing in dense built-up areas has to be retained whereas a larger spacing is applied to lightly built-up areas in order to keep the specific density of the settlement (Spiess et al., 2002).

- **Preserving size differences:** In principle the relative size differences of the buildings must be retained. However, the differences in size between small and large buildings decreases with decreasing scale. Characteristics of differentiation in sizes are inconspicuous-, small-, and large buildings. To preserve these it is necessary to group buildings consciously and to enlarge them proportionally (Spiess et al., 2002).
- **Retaining orientation:** "Clearly recognisable differences in the orientation of individual buildings or whole rows of buildings in relation to the traffic network is a good orientation aid." (Spiess et al., 2002). This property is of particular importance at a scale of 1:50‘000. However, when decreasing the scale the orientation becomes practically meaningless. What should be preserved as long as possible is the orientation of buildings to other buildings and from buildings to the transportation network. Roads which have removed by the generalisation process may even be hinted at using the orientation of the buildings which remain.
- **Retaining distribution:** Different kinds of building distributions exist: regular, row, offset, and irregularly scattered. These distributions are important in preserving a settlements structure. It is of significant importance also to maintain a clear distinction between the regular and irregular placement of buildings. Rows of buildings should also be presented at all scales however with decreasing scales the distribution of buildings does become less and less distinguishable, therefore, any gaps which exist, whether in a row or between buildings will have to be

emphasized (Spiess et al., 2002).

- **Retain characteristic ground plan shapes:** Special ground plan shapes help represent a settlement structure in a significant way. The following different ground plan shapes have been recognised: fine and coarse structure, geometrically simple, angular, rectangular, bent and combined. Those characteristics have to be represented in the derived scales. Also typical shapes such as circular and stepped outlines have to be retained (Spiess et al., 2002).

After ascertaining that all these properties are needed to retain a settlements structure, it becomes clear that these cannot be handled individually, but have to be considered when determining the overall picture. Müller (1990) has provided an analysis of various topographic map series with special regard to buildings and settlement areas (Table 2.4 and Table 2.5).

Scale	**Roads**	**Buildings**	**Settlement Areas**
1:5K	no change	no change	no change
1:25K	x4	little change	no change
1:50K	x4 - x8	x1.5 - x2	x1.2
1:100K	x6 - x16	x2 - x4	x1.5
1:200K	x32	x4 - x8	x2

Table 2.4: Size changes for roads, buildings and settlement areas (Müller, 1990)

Scale	**Dense Settlement areas**	**Scattered Settlement areas**
1:5K	no change	no change
1:25K	% 60 - 80 preserved	no change
1:50K	% 30 - 40 preserved	% 80 preserved
1:100K	% 10 amalgamated in blocks	% 30 - 50 preserved
1:200K	% 0-3 amalgamated in blocks	% 0 - 10 preserved

Table 2.5: Changes in building quantities in dense and scattered settlement areas (Müller, 1990)

When summarizing these tables it can be stated that although the sizes of buildings increase in medium scale maps, their numbers are decreased. However, no increase takes place in model generalisation while their amounts are decreased. At a scale of 1:50‘000 the increase factor for buildings is stated as 1.5 - 2 and that for settlement areas as 1.2. In dense settlement areas 30-40% of building objects are preserved which means an increase of almost 60%. Buildings in scattered settlement areas, due to their importance for the orientation, are more likely to be preserved and here a value of 80% is stated for the scale of 1:50’000 (Müller, 1990).

Shifting and Displacement

Through the process of generalisation the necessity to shift and displace features from their precise position occurs. As the complete road network gets realigned and its graphic representation becomes dilated when changing the scale there is an explicit need for the buildings to be displaced accordingly and this although, the building features need more space to be represented when generalising from a scale of 1:10‘000 to 1:50‘000 (Spiess et al., 2002).

2.7 State of the art

The past decade has seen a rapid development in the automation of generalisation and its research has produced many promising results (Burghardt et al., 2014; Mackaness et al., 2007; Stoter et al., 2010, 2014a). In the following section the two most important projects in connection with this thesis have been highlighted. The EuroSDR-Project and the most recent generalisation project of Dutch Cadastre.

2.7.1 EuroSDR-Project

In the context of this research it is important to highlight the EuroSDR-Projekt (European Spatial Data Research Network) which studied the “State-of-the-art” automated generalisation in “commercial software” in a collaboration with NMAs, research institutions and vendors between 2006 – 2009 (Stoter et al., 2010).

The main aim of this study was to identify the NMAs requirements when generalising and to demonstrate the possibilities and limitations of commercial out-of-the-box generalisation systems. Based on the research results, areas for further developments were also identified. The research project consisted of three main steps. Firstly the precise cartographic requirements were defined in order to identify which conditions the generalisation system would need to fulfil. According to these requirements test cases were defined. In the second step, these tests were performed on out-of-the-box versions of the following four generalisation systems: ArcGIS (ESRI), Change/Push/-Typify (University of Hanover), Radius Clarity (1Spatial) and axpand (Axes Systems). Last but not least, the test results were evaluated in three main parts: The automated constraint-based evaluation, the visually evaluation which compared different outputs for one of the test cases, and a qualitative evaluation by cartographic experts. Stoter et al. (2010) concluded, that all the tested systems offer a high potential for automated generalisation. However, it is worthy to note that no single software achieved good results in all areas. Some of the missing functionalities which were found were fixed through the vendors whilst conducting parallel testing, these included the building elimination and displacement algorithms in ArcGIS and Radius Clarity.

2.7.2 Existing Algorithms in the context of automated building generalisation

The following four subsections go into further detail of what each of the four tested generalisation systems within the EuroSDR-Project offer by way of automated generalisation. The advantages and limitations regarding the building generalisation functionalities have been extracted from Stoter et al. (2010).

- **ArcGIS:** ArcGIS is a complete GIS platform provided by America software supplier ESRI. At the time of the EuroSDR-Projekt only the ArcGIS 9.3 version was available which was not specifically developed for map generalisation. At this time, the ArcGIS version contained only a few tools for automated generalisation, these were Simplify Line, Collapse Dual Lines To Centerline, Dissolve, Eliminate, Simplify Building, Aggregate Polygons, Simplify Polygon and Smooth Line. In the concept of building generalisation acceptable results were produced using the Simplify Building tool. The main limitations were missing operators such as building enlargement, simplifying buildings based on width and depth of protrusions and the displacement of buildings (Stoter et al., 2010).

- **Change, Push and Typify (CPT):** The software provided by the University of Hannover consists of three modules: Change, Push and Typify. This software has been developed specifically to solve generalisation problems. For the generalisation of buildings the products CHANGE and TYPIFY are available. CHANGE is responsible for the simplification and aggregation of single buildings up to the scale 1:25‘000 whereas TYPIFY performs the building generalisation for large and medium scales. PUSH is an algorithm for the displacement of objects (Stoter et al., 2010). Summarized by Stoter et al. (2010) the main advantages are the good results for building simplification, aggregation and typification as well as those achieved for displacement.

- **Radius Clarity:** Radius Clarity is a rule-based environment for automated generalisation. Small-scale digital data can be automatically derived from large-scale source data. The approach of Clarity is based on intelligent software Agents. Agents are an advanced artificial intelligence technique where the generalisation environment requires configuration at several levels. Several algorithms for building generalisation are available and therefore good results can be achieved. One of the main limitations are missing operations such as displacement and typification (Stoter et al., 2010).

- **axpand:** The axpand technology is based on a true multi-representation data base (MRDB). All different algorithms are combined into a single workflow. The constraints can be stored in files which are accessed by the algorithms. In Stoter et al. there is no clear statement about the building generalisation however he does mention the limitations of missing operators such as collapse and typification (Stoter et al., 2010).

2.7.3 Dutch Cadastre

One of the most current projects within generalisation is the fully automated generalisation workflow which was successfully implemented in 2013 by the Dutch Cadastre (Dutch Cadastral and National Mapping Agency). Stoter et al. (2014a)'s paper focuses on the research enabling the implementation of a fully automated generalisation workflow to generalize a 1:50‘000 topographic map from 1:10‘000 base data. To attain this, Dutch Cadastre configured the out-of the-box ArcGIS tools (version 10.0) to automate the generalisation complemented by self-developed tools within an Esri Model-Builder environment and using a series of FME workbenches. The complete generalisation workflow is implemented within the Model builder tool of Arcgis [Stoter et al. (2014b) in Burghardt et al. (2014)]. They first started with a feasibility study where an initial 1:50‘000 map was produced in a semiautomatic manner with the goal to prove how much automation can be achieved with current available tools (Stoter et al., 2014a). After verification of the result the process was improved, refined and implemented as a workflow [Stoter et al. (2014b) in Burghardt et al. (2014); (Stoter et al., 2014a)]. Stoter et al. (2014a) also applied constraints but proposed a different approach than it is common in constraint-based generalisation. Usually the constraint-based method is used to express user requirements and to control and evaluate the automated generalisation process (Beard, 1991). The Dutch Cadastre formulated the constraints “in terms of new map specifications that need to be addressed by the workflow, while iterative controlling and evaluation of the process was used to obtain the best generalisation workflow. This process made it possible to define and adjust the map specifications (i.e. constraints) as part of the process.” (Stoter et al., 2014a). According to Stoter et al. (2014a), the implemented generalisation workflow consists of the following steps: Model generalisation aiming at reducing the data that has to be visualised, symbolisation of the data and graphic generalisation to solve cartographic conflicts of the symbolised features.

Generally it can be stated that Stoter et al. (2014a) present very interesting and promising findings about a fully automated generalisation process. A significant contributing factor is that this was possible because map specifications were adjusted in order to meet the technological possibilities. The Cadastre and its users benefit from the implementation of the automated generalisation process not only because valuable resources can be saved and/or reallocated but also because the cartographic products can now be produced significantly quicker and so supply the end-users with more currant data.

3 Methodology

This chapter explains the chosen methodologies used to conduct the practical implementation, the quality control of the results and goes on to answer the question if it is indeed possible to generalize building features automatically, working from a base scale of 1:10’000 towards the scale of 1:50‘000 under the requirement of keeping the settlement structure.

Having fulfilled the first objective, of describing the current state of the art, the necessary theoretical basis has been established in order to develop an appropriate workflow for the automated generalisation of buildings. Therefore the next logical step is to identify a test area which contains the various different types of settlements (Chapter 3.1), followed by defining the cartographic constraints and considerations when automatically generalising buildings (Chapter 3.2). The test process is then explained in detail which was used for the practical implementation (Chapter 3.3). Finally after the workflow has been established and the data automatically generalized, the results must be put through a rigorous and extensive quality control. The results must not only be technically sound but must also be cartographically acceptable (Chapter 3.4).

3.1 Defining the test case

The first step is to define a test case which is representative of typical generalisation problems in regard to settlement structures [(Spiess et al., 2002) compare Chapter 2.6.2]. The test area should cover a large variety of different settlement patterns, including scattered settlements, remote individual houses, hamlets, scattered villages, street- and mountain villages as well as distinctive urban areas such as town centre, residential and industrial for comparison [(Spiess et al., 2002) Chapter 2.6.1]. This is important because later it should be possible to draw conclusions as to how the various algorithms have been applied to different patterns. One shortcoming of the selected area for this test case is that specific problems related to mountainous areas cannot be covered satisfactorily. This is directly resulted to the fact that at the time the test area had to be selected only four regions, Aarau, Hauenstein, Murgenthal and Schöftland were available.

Furthermore, the generalisation of buildings was to be based on an already generalised road network at the scale of 1:50‘000. Therefore, the possible test area was further reduced as only the area of Aarau met all these criteria and was therefore selected after close consultation with the various experts of swisstopo.

The following figures 3.1 and 3.2 show an extract from the current Swiss national map 1:25‘000 and 1:50‘000 in the selected test area of Aarau. All these examples are readily available and can be accessed via an online map viewer in different scales at the following website http://map.geo.admin.ch.

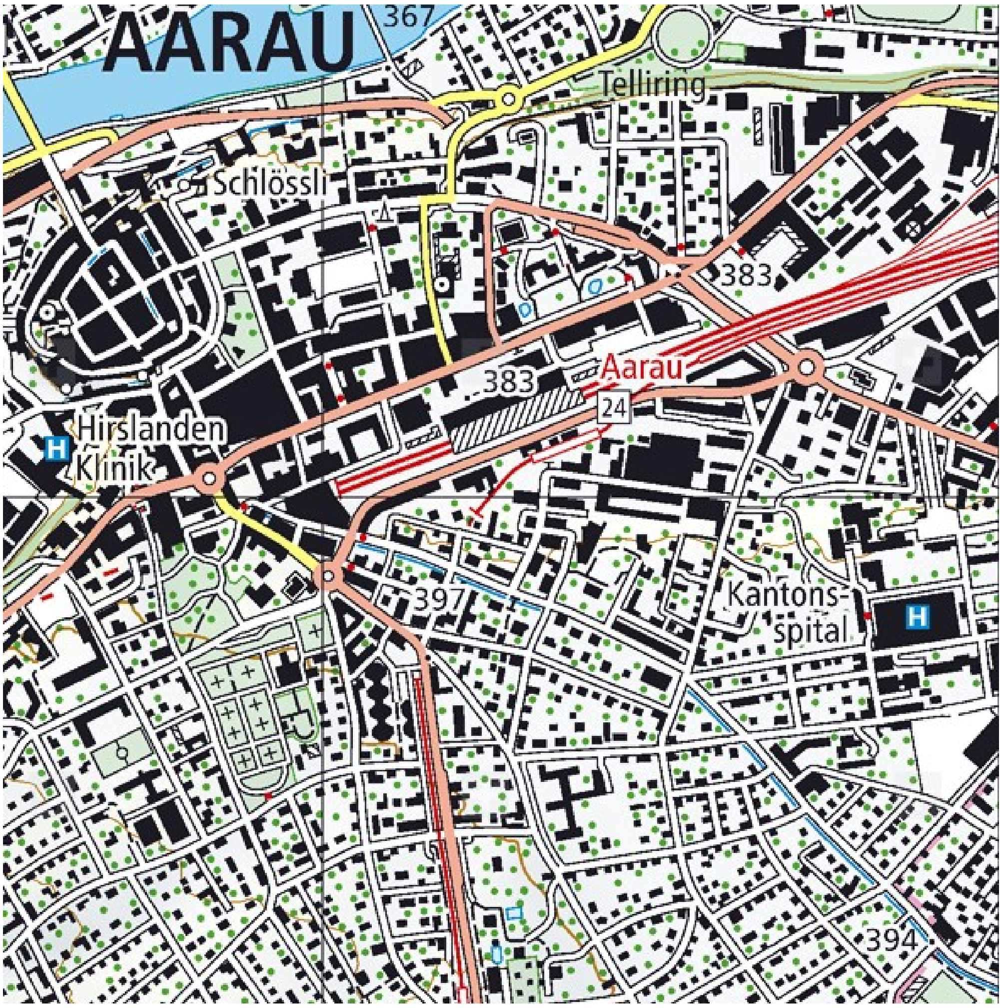


Figure 3.1: Extracted from the Swiss national map sheet Aarau (1089) 1:25'000 showing the historical centre enlarged. (©http://map.geo.admin.ch)

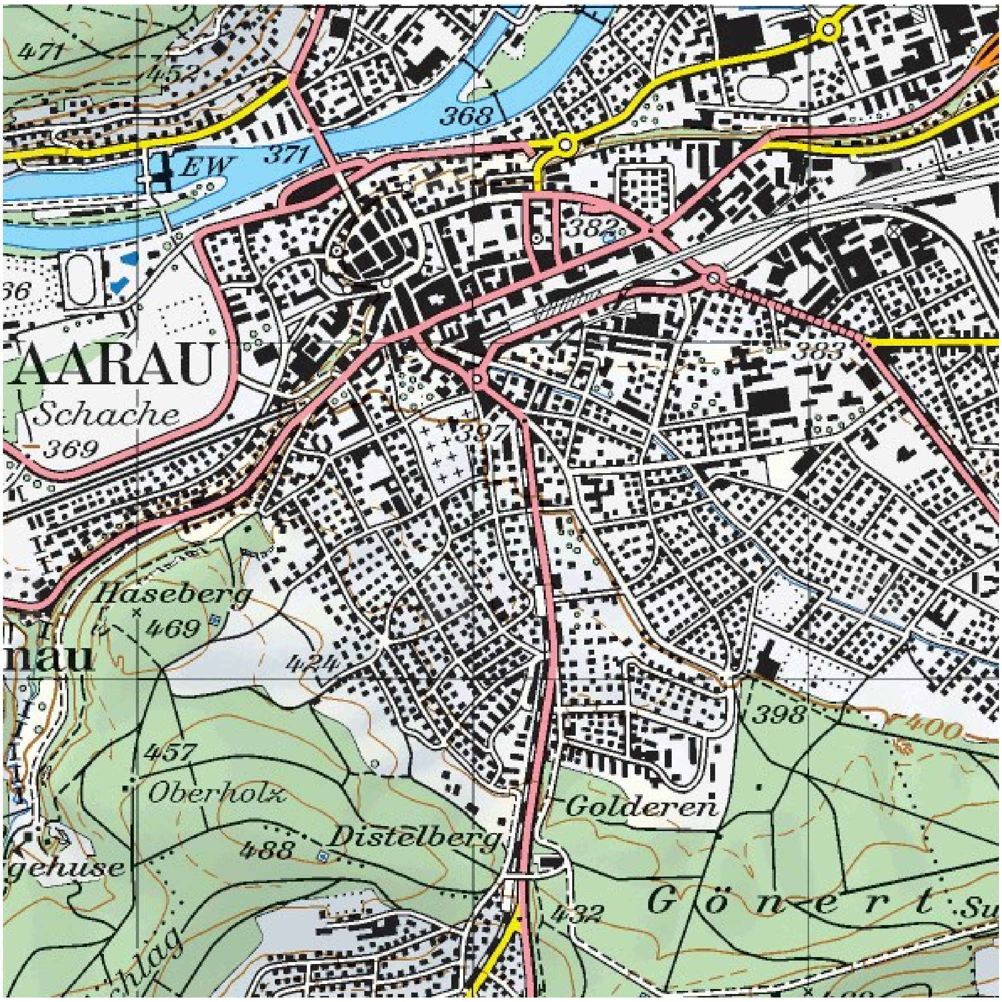


Figure 3.2: Extract from the Swiss national map sheet in the area of Aarau (224) 1:50‘000 enlarged (©http://map.geo.admin.ch)

3.2 Requirement analyses

3.2.1 Constrained-based generalisation

To implement research theories map specifications have to be defined as a set of cartographic constraints (Stoter et al., 2010). Over the last decades there has been much research done about the effectiveness of defining generalisation in terms of constraints and the topic has be discussed to a significant amount, Beard (1991), Ruas and Plazanet

(1996), Weibel and Borning (1998), and Harrie and Weibel (2007). For the purpose of this work, the constraints discussed in Harrie and Weibel (2007) have been applied which are mainly based on the typology as set forth by Ruas and Plazanet (1996). According to this, the constraints, as defined by swisstopo (see section 3.2.2) can be assigned to one or more of the following categories:

- **Position constraints [P]:** Position constraints limit the movement of features (in absolute and relative terms).
- **Topology constraints [T]:** Topology constraints ensure that the relationship between features are maintained.
- **Shape constraints [S]:**These constraints are used to ensure that the shape characteristics of individual features will be preserved.
- **Structural constraints [ST]:** Insure that the structural patterns of the original map are maintained.
- **Functional constraints [F]:** Functional constraints are used to ensure that the functionality is maintained.
- **Legibility constraints [L]:** These constraints are used to limit or exclude spatial conflicts which will limit the legibility.

3.2.2 Constraints defined by swisstopo

The cartographic constraints defined to be satisfied within the results were developed in close co-operation with cartographic experts from swisstopo and are mainly based on (Spiess et al., 2002). The constraints are sorted regarding the defined considerations when generalising buildings. All constraints apply for the scale of 1: 50,000.

- **Constraints for the selection of buildings**

Constraint	**Constraints for the selection of buildings**
1 [ST]:	Buildings smaller than 5 m^2 are not to be considered and can be omitted
2 [ST]:	In dense settlement areas features smaller than 50 m^2 are to be deleted
3 [ST]:	Isolated features must be preserved

Table 3.1: Constraints for the selection of buildings

- **Constraints for the graphic generalisation** are from special importance. The minimum dimensions and minimum distance constraints play a key role in preserving the legibility of the map (Spiess et al., 2002). The following constraints define which minimum dimensions and which minimum distances have to be preserved for the scale of 1:50‘000 in order to maintain the maps legibility. The following distance values must defined from “signature edge to signature edge” which means for example from the signature edge of a street to the signature edge of a building.

Constraint	**Constraints to preserve the minimum dimensions**
4 [L]:	The minimal dimension for a single house is 400 m^2 which translates at a scale 1:50‘000 to an area of 0.4 x 0.4mm
5 [L]:	The minimal dimensions for a cultivation, indentation and a step-shaped outline is 160 m^2 which translates at a scale 1:50‘000 to an area of 0.25 x 0.25mm
6 [L]:	The minimum dimension for an inner courtyard is 400 m^2

Table 3.2: Constraints to preserve the minimum dimensions

Constraint	Constraints to preserve the minimum distances
7 [L]:	Between buildings the minimum distance to be preserved is 10m which translates to a distance of 0.2mm at a scale of 1:50‘000
8 [L]:	Minimum distance between buildings and black traffic signatures: the house edge is overlapped by the road signature with 3m which means at a scale of 1:50‘000 (distance = -0.06mm) or the minimum distance is 10m (distance = + 0.2mm)
9 [L]:	Between buildings and red traffic signatures and water features a minimum distance of 4m (0.08mm) is to be maintained
10 [L]:	In densely built-up areas all minimum distances must be maintained
11 [L]:	A less dense settlement must be represented by correspondingly larger distances

Table 3.3: Constraints to preserve the minimum distances

Constraint	Constraints to preserve the positional accuracy
12 [P]:	The features of the following feature types must retain a high positional accuracy, especially outside of a settlement area: Lookout tower, tower, water tower, cooling tower

Table 3.4: Constraints to preserve the positional accuracy

- **Constraints for generalising the shape of buildings**.

Constraint	Constraints for retaining the shape
13 [S]:	Particular shapes of building footprints are to be retained
14 [T/S]:	Buildings are only merged if they are not separated by a road axis
15 [T/S]:	Buildings which are closer than 1m together in the source data can be merged together under consideration of the following rules: only features from the same object type, use of buildings, stage and name are merged; only buildings which are not separated by the road system are merged; only features within the same areal are merged. In several cases there are exceptions to these rules which must be defined.
16 [P/S/ST]:	Special structures such as the town centre, industrial areas, residential areas with single family homes, residential areas with large apartment blocks, scattered settlements and isolated single buildings should be obtained

Table 3.5: Constraints for generalising the shape of buildings

- **Constraints for retaining the building structure** such as the density of a built-up area, differentiation of buildings sizes, orientation and arrangement of buildings, and the characteristic of the ground plan shape (Spiess et al., 2002). The thinning of the buildings density is on average about 35% in the DKM50 and describes the density of the built-up area after the algorithms have been applied (compared is the number of buildings before and after generalisation and represented as a percentage). This is only a guideline and will vary depending on the settlement area:

Constraint	Constraints to retain the density
17 [ST]:	The ratio between built-up and vacant areas (black-white ratio) should be preserved when possible
18 [ST]:	The thinning is 50% for a dense settlement structure (single family homes, small apartment blocks)
19 [ST]:	The thinning is 30% at loosely built settlement structure (single family homes, small apartment blocks)
20 [ST]:	The thinning is 15% by a medium to coarse settlement structure and sparsely spaced housing (larger apartment blocks and industrial buildings)
21 [ST]:	The thinning is 40% by a widely dispersed settlement with isolated single houses.
22 [ST]:	The thinning is 10% in the historic old town
23 [P/ST]:	The size of the settlement must not be changed by the generalisation which means that peripheral buildings should not be displaced into free space.

Table 3.6: Constraints for retaining the building Density

Constraint	Constraints to retain the differentiations of building sizes
24 [ST/L]:	The relative size differences of the buildings are to be preserved
25 [ST/L]:	Small buildings (single family homes, small apartment blocks) which are smaller than 250 m^2 are to be scaled to 400 m^2 (0.4 x 0.4 mm)
26 [ST/L]:	Medium buildings (larger apartment blocks and industrial buildings) in a range from 250 m^2 to 756 m^2 are scaled to 756 m^2 (0.55 x 0.55mm)
27 [ST/L]:	When scaling medium sized buildings up to 756 m^2 there are special requirements: Elongated features should keep their length. From a certain size upwards and with a special length to width ratio the features should only be scaled in width.
28 [ST/L]:	Large buildings (large apartment blocks and industrial buildings) which are bigger than 756 m^2 are not to be scaled. They are shown in their real size as captured.

Table 3.7: Constraints to retain the differentiations of building sizes

Constraint	Constraints to retain the orientation of buildings
29 [T/ST]:	The orientation of building footprints should be obtained.
30 [T/ST]:	The orientation of buildings to their neighbouring buildings should be obtained
31 [T/ST]:	The orientation of buildings to the road network should be obtained
32 [T/ST]:	Roads which are no longer shown are to be implied using the orientation of the buildings

Table 3.8: Constraints to retain the orientation of buildings

Constraint	Constraints to retain the arrangement of buildings
33 [T/ST]:	Rows of houses should be preserved
34 [T/ST]:	The differences between regular and irregular arrangement of buildings have to be obtained.

Table 3.9: Constraints to retain the arrangement of buildings

3.3 The test process for the practical implementation

The research for this thesis was purely conducted with the tools existing in version 10.2 of ArcGIS. As Stoter et al. (2014a) says "this may not seem innovative". However, Stoter et al. (2010) highlighted that there are main problems of applying existing generalisation tools in commercial software. Firstly, the tools are often difficult to parameterize and secondly, it is also often hard to put them in the correct order. Based on Stoter et al. (2014a) this thesis's research addresses these two main problems. The constructed automated workflow implements the generalisation operators in the correct order with the correct parameter values. The main difference to Stoter et al. (2014a) is that this research is focused only on the generalisation of buildings whilst maintaining the existing settlement structure for the scale of 1:50‘000 instead of taking all themes of a topographic map into account. Furthermore, the focus is on generalising the individual buildings and therefore no aggregation of the urban areas takes place. During the EuroSDR-Project, limitations for the building generalisation were indicated for ArcGIS 9.3. ArcGIS is now available in the version 10.2, and this thesis will prove that an acceptable result for the building generalisation under the constraint of maintaining the existing settlement structure using only standard ArcGIS tools can be achieved. To prove this, an appropriate workflow for the automatic generalisation of buildings for a scale 1:50‘000 was developed. The development of the workflow was done schematically and consists of the following steps:

- Identification of all the available tools which are necessary for the generalisation of building within ArcGIS 10.2
- Performing model generalisation which is aimed at reducing the amount of data to be visualized
- Solving cartographic conflicts between symbolised features (e.g. Streets and Buildings) and performing a graphic generalisation
- Improving the generalisation process by reviewing each step of the process thoroughly and enriching the source data wherever necessary (Stoter et al., 2014a).
- Verifying the workflow at different stages and adapting where needed
- After the process has been optimised the evolved workflow is then linked together. The complete generalisation workflow is finally implemented within the Model builder tool of ArcGIS 10.2

In order to develop a correct workflow it is very important to verify the results after each applied operator and compare them with the cartographic requirements. This allows the process to be improved step-by-step until an acceptable solution is found. This is of significant importance throughout the practical implementation in order to develop a suitable workflow. Mackaness highlighted this necessity in 1995 as seen in the following quote.

> *"we start with some hazy thumbnail sketch of what we want, we then source the data, apply some set of generalisation operators, view the result and repeat and refine subsequence application of generalisation operators in a cycle until a satisfactory solution is found"* (Mackaness, 1995)

3.4 Evaluation of the generalised output

Finally it is necessary to evaluate the quality of the results accomplished by the developed workflow. This is highly significant and allows a general statement regarding the quality of the generalized result to be formulated. To enable this an expert survey which verifies the cartographic quality according to the formulated cartographic constraints was developed. In determining the expert survey it was necessary to consider which user groups would be questioned. After the conduction of the survey the results of the evaluation have to be analysed in detail and a conclusion about the quality of the generalised result has been extracted.

4 Practical implementation

With the methodology discussed, this chapter now reflects on the planning and actual practical implementation of the case study. During the first step all the relevant tools which are necessary for the generalisation of buildings were determined. Once these tools have been determined then the model- and cartographic generalisation are implemented. Following this the corresponding methods are explained and the results discussed in detail. In a final step all the tools are chained together to accomplish an automated workflow.

4.1 Determination of the appropriate generalisation tools

As highlighted in chapter 2.2, Gruenreich's model, which distinguishes between model- and cartographic generalisation, has been found to be the most suitable for the data and maps within the NMAs. Therefore, all tools are categorised corresponding to the classification of the operators according to Foerster et al. (2007). The operators for model generalisation are: class selection, reclassification, collapse, combine, simplification and amalgamation whereas those for cartographic generalisation are: enhancement, displacement, elimination, typification and amalgamation. Foerster et al. (2010) emphasises that "generalisation operators are always applied to a specific feature type". He also indicated the importance of generalisation operators in relation to different feature types for both the model- and cartographic generalisation operators.

In this research the focus is set on the feature type buildings. In the following list and explains, all the available out-of-the-box tools within the ArcGIS version 10.2 which might be considered of importance when generalising buildings.

4.1.1 Operators for model generalisation

According to Foerster et al. (2010) NMAs consider the operator's amalgamation and simplification to be the most important when considering the scale of 1:50'000 within model generalisation. These are followed by class selection, reclassification and collapse. The operator combine was found to have no significant role within building generalisation. The table 4.1 indicates the ArcGIS tools which correspond to the proposed classification of Foerster et al. (2007). Here only model generalisation operators which are relevant for the feature type building have been taken into account.

Operators by Foerster et al.	**Corresponding operators within ArcGIS**:
Amalgamation	Aggregate Polygons
Simplification	Simplify Building
Class Selection	Select Layer by Attribute Select Layer by Location Select (SQL expression)
Reclassification	Field calculator
Collapse	Delineate-Built-Up Areas

Table 4.1: Operators by Foerster et al. (2007) and their corresponding operators for model generalisation within ArcGIS

- **Aggregate Polygons:** combines polygons within a specified distance of each other into new polygons. A minimum gap size may be defined in order retain inner courtyards for example. When considering buildings the orthogonally function is of particular advantage to help specify the characteristic for the aggregated boundary. Barrier features may also be defined to help protect features from being aggregated across streets or other line features (Esri, 2014a).

- **Simplify Building:** simplifies the boundary or footprint of building polygons while maintaining their essential shape and size. Small details such as indentations are deleted by setting a simplification tolerance (Esri, 2014a).
- **Select Layer by Attribute:** adds, updates or removes a selection on a layer or table view based on an attribute query.
- **Select Layer by Location:** selects features in a layer based on a spatial relationship to features in another layer. Each feature in the input feature layer is evaluated against the features in the selecting features layer or feature class and if the specified relationship is met, the input feature is selected.
- **Select:** extracts features from an input feature class or input feature layer, typically using a select or Structured Query Language (SQL) expression and stores them in an output feature class.
- **Field Calculator:** performs simple and advanced calculations on all or only selected records. With allows for example a reclassification of the building hierarchy.
- **Delineate Built-Up Areas:** creates polygons to represent built-up areas by delineating densely clustered arrangements of buildings on small-scale maps. This tool is useful to identify dense settlement arrangements. Buildings are clustered based upon a grouping distance (Esri, 2014a).

4.1.2 Operators for cartographic generalisation

Foerster et al. (2010) states that the importance of cartographic generalisation operators is significantly higher at larger scales (1:10‘000 – 1:50‘000) than at smaller scales (1:50‘000 – 1:250‘000). This results from the fact that model generalisation is more important at smaller scales and therefore the number of features partaking in cartographic generalisation is higher. For the scale of 1:50‘000 NMAs consider displacement as the most important operator followed by enhancement, enlargement, typification and amalgamation. The operator Elimination is considered as not being that relevant. Table 4.2 indicates which tools within ArcGIS correspond to the proposed classification by Foerster et al. (2007). Only cartographic generalisation operators which are relevant for the feature type building are taken into account.

Operators by Foerster et al. (2007)	**Corresponding operators within ArcGIS**:
Displacement Typification Enhancement Amalgamation Elimination	Resolve Building Conflict

Table 4.2: Operators by Foerster et al. (2007) and their corresponding operators for cartographic generalisation within ArcGIS

- **Resolve Building Conflicts:** assesses graphic conflicts of symbolised features under consideration of a given reference scale. Firstly, the buildings are enlarged to a specified minimum size. Next symbol conflicts within buildings and with respect to linear barrier features are then resolved by moving or hiding buildings. This ensures that the buildings do not graphically overlap or violate the minimum spacing requirements (Esri, 2014b). The cartographic operators Displacement, Typification, Enhancement, Amalgamation and Elimination are all handled by this algorithm. The operator improves the display of the buildings by adjusting the position, orientation, size and visibility whilst maintaining the representative pattern and distribution of buildings. This algorithm, which is explained in Punt and Watkins (2010) in detail, resolves symbol conflicts applying an optimization technique. The optimization approach means that each task is made up of constraints, reflexes, and actions. A constraint is for example that a building cannot be closer than a distance of x to another, a reflex might be that a building cannot be moved onto a road and an action that the building has to move away or moved back. An underlying optimiser kernel seeks to improve the fulfilment of constraints by applying various actions.

4.2 The development of an automated workflow

This chapter describes the development together with and resulting workflow which executes an automated generalisation process for buildings at a scale of 1:50‘000.

The input data is supplied by the building features existing in the TLM of swisstopo. The corresponding road network has been already generalised for the scale of 1:50‘000. The workflow consists of both the model generalisation which aims to, reduce the feature count and simplify the data, the symbolisation the data and the cartographic generalisation which aims to resolve any conflicts between the symbolised features. The final output is the DCM50. Figure 4.1 illustrates this workflow.

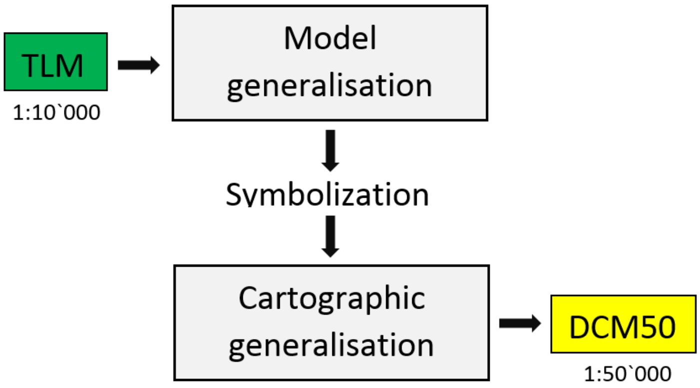


Figure 4.1: The automated workflow for the generalisation process of the 1:50‘000 buildings.

To develop the best possible workflow, intense and iterative testing of both the model- and cartographic generalisation phases was necessary. The main challenge was to figure out which operators had to be executed in which order and what were the optimal parameters. The final stage after intensive testing was linking all the operators together in order to automate the model.

4.2.1 Model generalisation

This subsection deals with testing the tools required for the model generalisation, working at the scale of 1:50‘000. At this point it is also important that the results are verified carefully step by step after the execution of each operator and that the results meet the cartographic requirements as defined by swisstopo. The operators used within ArcGIS are Aggregate, Simplify Building, Selection, Reclassification using the field calculator and Delineate-Built-Up Area. A further distinction of operators within the model generalisation is given in the following table 4.3.

Reduction of feature count	**Reduction of feature complexity**:
Selection/Elimination Aggregate Polygon Delineate-Built-Up Area	Simplify Building

Table 4.3: Distinction of operators in reduction of feature count and reduction of feature complexity

Step 1: The first step is the aggregation of all buildings. This is especially important because of the way in which the buildings have been captured. In TLM the building features are captured by the individual house roofs and not by the outline of the buildings. During the generalisation process it is very important that the footprint of a building is used by the operator and not the roof polygons. The intention is that overlapping polygons are aggregated together when within a distance of 1 meter, this being set as the aggregation distance. Because buildings are orthogonal shapes the optional setting available to preserve this form is used. In order to only aggregate buildings which are not separated by other feature classes, such as roads, these are set as so-called barrier features. To illustrate the results of this operator, figure 4.2 shows the original data on the left-hand side and the aggregated buildings on the right side.

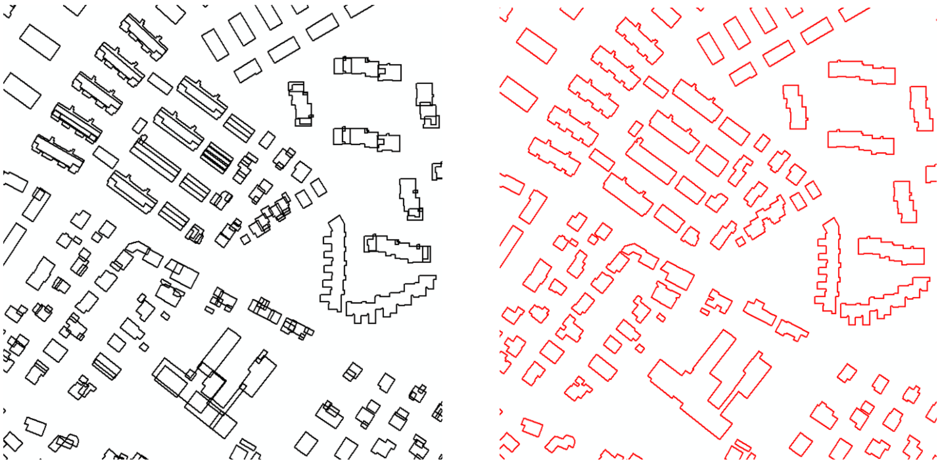


Figure 4.2: Aggregate Polygon: before and after processing

Step 2: The removal of inner courtyards below a minimum dimension, here the aggregate operator is used a second time. The same settings are used as in Step 1 complemented by setting a minimum gap size of 400 m^2. The following figure 4.3 illustrates how this setting works. The left-hand side shows the result from Step 1 with all inner courtyards whereas the right-hand side shows which courtyards are removed when using the minimum gap size setting.

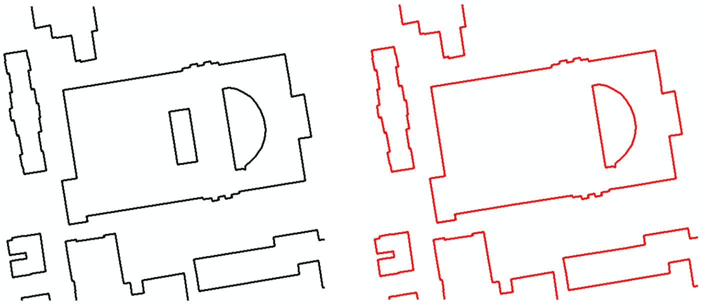


Figure 4.3: Aggregate Polygon to remove courtyards: before and after processing

Step 3: Due to the fact that all attributes are lost during aggregation there is the requirement to reattach these attributes by use of a Spatial Join.

Step 4: To apply an initial general simplification of the resulting buildings the operator Simplify Building is applied with a simplification tolerance of 4 meters. The decision to apply this operator after Aggregation was as a result of the intense testing done to define the optimal order execution. It was found that processing the Simplification operator before Aggregation lend to many more errors such as the overlapping of features which in turn lead to the wrong buildings being aggregated. The following figure 4.4 shows the results of the operator simplified buildings (on the right-hand side).

Figure 4.4: The result of the operator Simplify Building is represented on the right

Step 5: This is a pre-processing step used to add a hierarchy field to the attribute table thus allowing different hierarchies for different building sizes to be calculated. The idea behind this is that the new hierarchy value can then be used to simplify the buildings differently.

Step 6: This step consists of Selection and Reclassification. The buildings are firstly selected according to their building sizes, this selection is based on a building size classification as defined by swisstopo. Based on this classification buildings smaller than 250 m^2 are given a hierarchy value of 3, buildings ranging from 250 – 756 m^2 a value of 2, buildings ranging from 756 – 1000 m^2 a value of 1 and buildings larger than 1000 m^2 a hierarchy value of 0.

Step 7: In this step the buildings are simplified according to the selection process defined in step 6. A different simplification tolerance is set for each of the four building classes. This decision was made due to the fact that small buildings should be squared off whereas larger buildings should retain their particular footprint, hence the simplification tolerance is reduced the larger the buildings are. Once more after intense testing a simplification tolerance of 12 meters for buildings smaller than 250 m^2 (hierarchy 3), 8 meters for buildings ranging from 250 – 756 m^2 (hierarchy 2), 7 meters for buildings from 756 – 1000 m^2 (hierarchy 1) and 6 meters for buildings larger than 1000 m^2 (hierarchy 0) was decided upon. Figures 4.5 and 4.6 show the results of both first simplification (left-hand side) and the simplification according to the hierarchy (right-hand side). The colours on the right-hand side indicate the building sizes according to hierarchy 0 to 3: blue, green, orange, yellow.

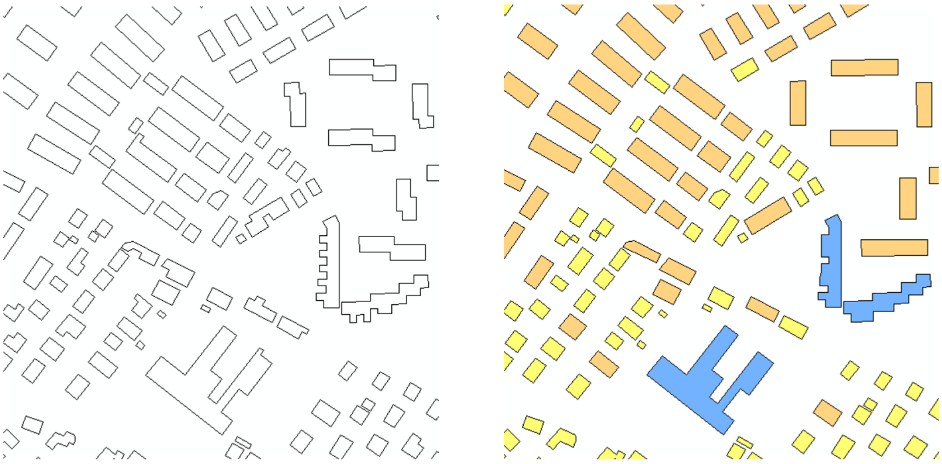


Figure 4.5: Simplify Building Area 1: before and after processing

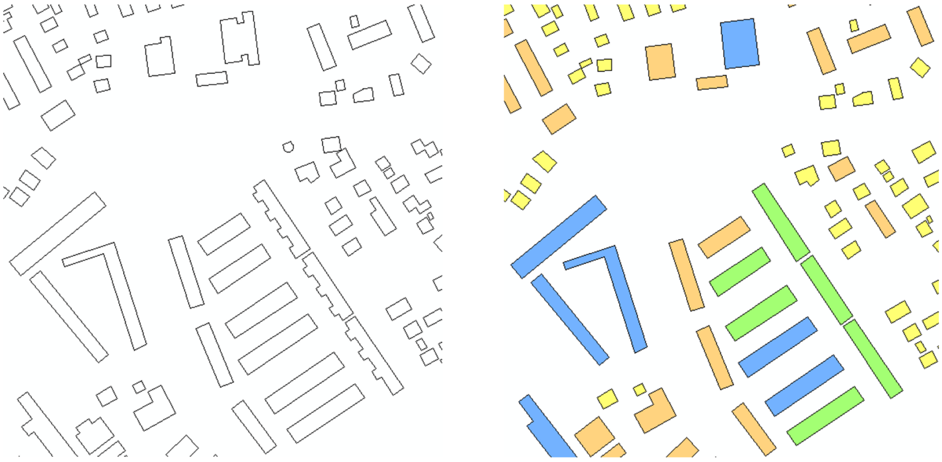


Figure 4.6: Simplify Building Area 1: before and after processing

Step 8: In this step the smallest buildings, those below a size of 10m^2 are selected and eliminated. These small buildings where found to be mostly private garages next to the corresponding house. In order to keep a better structure it was decided to delete these before conducting the cartographic generalisation. Figure 4.7 highlights these small buildings and shows the pleasing result after their deletion.

Figure 4.7: Selection and Elimination of small buildings

Step 9: In dense settlement areas features smaller than 60 m^2 are selected and deleted. In order to achieve this there is firstly the need to identify these areas. As there is no clear guideline as to what defines a dense area this is done using the operator Delineate Built-Up Areas. With this tool it is necessary to define both the grouping distance (50m) as well as the minimum building count (4). Based on the created built-up area it is possible to select the features by location. This results in all buildings within the built-up-area being selected and then deleted. In Figure 4.8 the grey area indicates an area of dense settlement where the buildings under the defined minimum size, here represented in black, will be deleted.

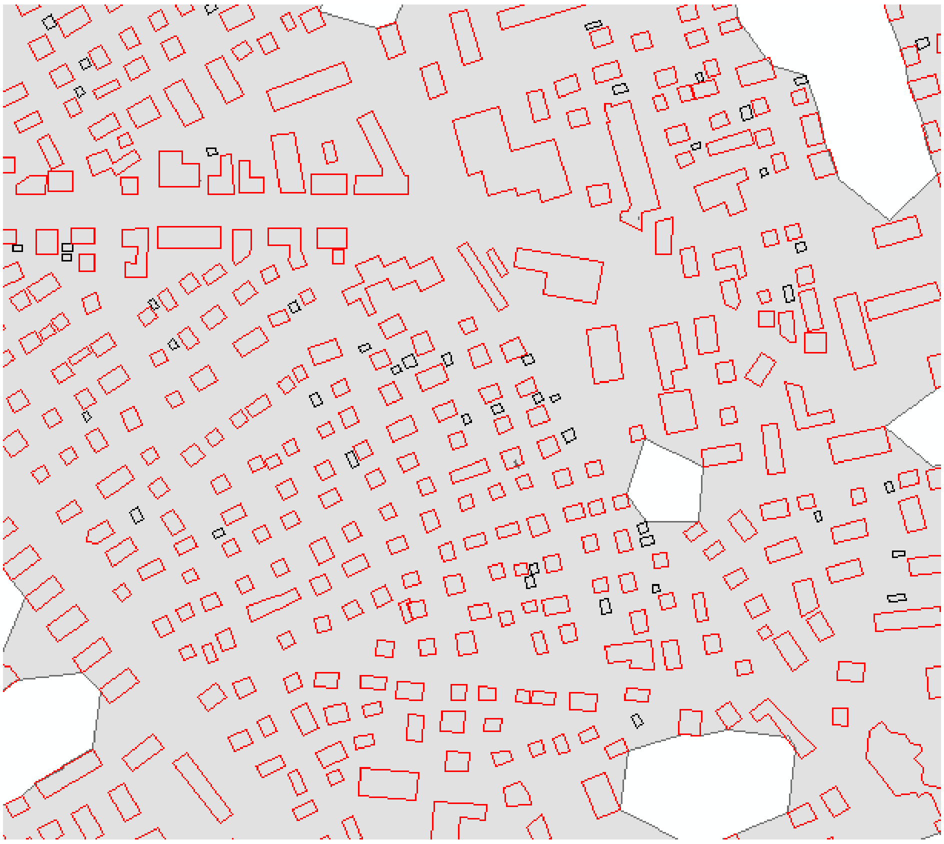


Figure 4.8: Selection and Elimination of small buildings within dense settlement areas

Step 10: Large buildings are of major importance and will notably require more space in order to be preserved whilst conducting the graphic generalisation. Therefore small buildings within a specific distance of a large building are selected and eliminated.

Figure 4.9 illustrates the small buildings (represented in black) which have been selected for deletion due to their proximity to a large building.

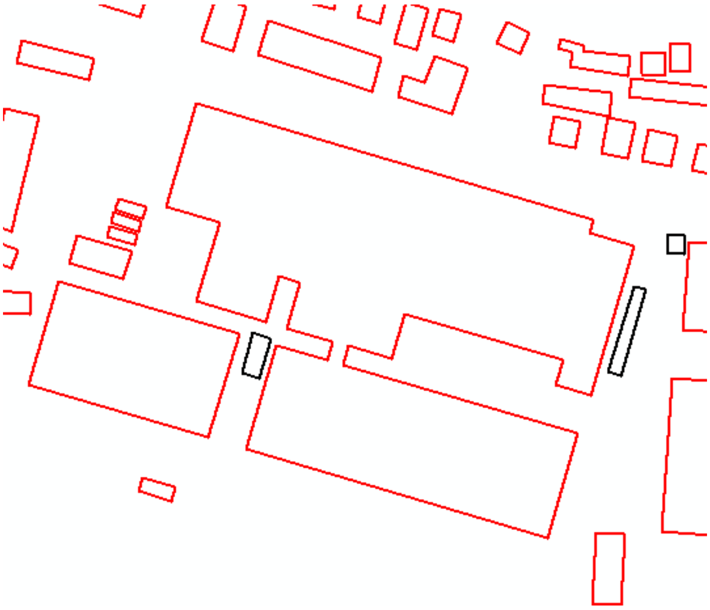


Figure 4.9: Selection and Elimination of small buildings around large buildings

Step 11: The existing tool for the graphic generalisation uses the hierarchy of buildings. After running several tests it was clear that the classification of a buildings hierarchy which run along a street needed to be modified as too many buildings were being deleted and the structure of the settlement was also being lost. The solution was to buffer the generalised street data.

Step one was to select all buildings with a hierarchy two within the buffer and reclassify these to have hierarchy of one. In step two, all buildings within the buffer and having a hierarchy of three were selected and reclassified to have a hierarchy of two. Figure 4.10 shows the differences between the classifications along the streets (The colours indicate the building sizes according to the reclassified hierarchy 0 to 3: blue, green, orange, yellow).

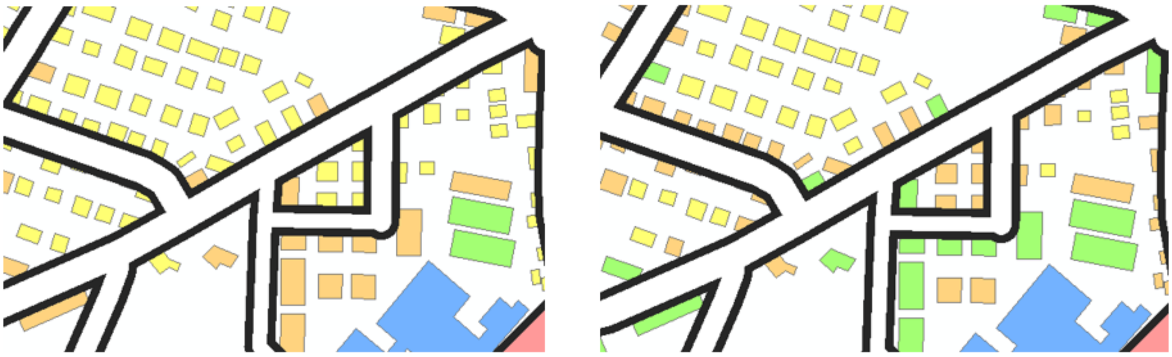


Figure 4.10: Reclassification of buildings along a street

4.2.2 Cartographic generalisation

The graphic generalisation process for buildings consists of only a single operator within ArcGIS – the Resolve Building Conflict operator. Nevertheless, there are a number of pre-processing steps necessary in order to get a reasonable result.

Step 12: The first pre-processing step is the addition of two extra attribute fields, this is in order to run the resolve building conflict operator. These are an invisibility and the resolve building conflict size field. These fields will be populated with values when the operator is executed.

Step 13: All the building features have to be symbolised.

Step 14: One of the possibilities of this operator is that of being able to define so-called conflict barrier layers. This allows for a set gap to be defined for any buildings which orient themselves along these barriers. For swisstopo it is a requirement that the buildings overlap with the road network. To accomplish this the original streets symbol width is reduced to that of a smaller street, this is because the operator automatically snaps the buildings to the defined barrier features. After running this operator the streets are then re-categorised back to the original symbol.

Step 15: The Resolve Building Conflict tool separates buildings from each other and from any defined barriers whilst retaining the relative density and pattern. By defining the minimum allowed building size to 20 meters, which is 400m^2, the size can be enforced. It is also possible to adjust a features visibility as well as the spacing between buildings. In this case study the gap size is defined at 11 meters. Another possibility is that of managing the distance and orientation from and to the barrier features. It was also decided to not orient the buildings to the road because the orientation from the initial data is taken anyway. A hierarchy value can be optionally assigned which was done in this research. Figure 4.11 shows before (left-hand side) and after running this operator.

Figure 4.11: Resolve Road Conflicts

4.2.3 Concatenation of the operators to an workflow

After the intense testing of the tools for the model- and cartographic generalisation, the operators were chained together to create an automated workflow. For this purpose, ArcGIS provides a very good environment to automate simple or complex tasks especially for generalisation. The automation is possible using the ModelBuilder which is an application to create, edit and mange models. Models can be defined as workflows that chain together operators and their outputs. The so-called "outputs" can then be used as the input for the next operator. It can also be viewed as a visual programming language for building workflows. The main benefit is that ModelBuilder is an easy-to-use application for creating and running workflows containing a sequence of tools. For this case study a main model consisting of five sub-models was created (see Figure 4.12).

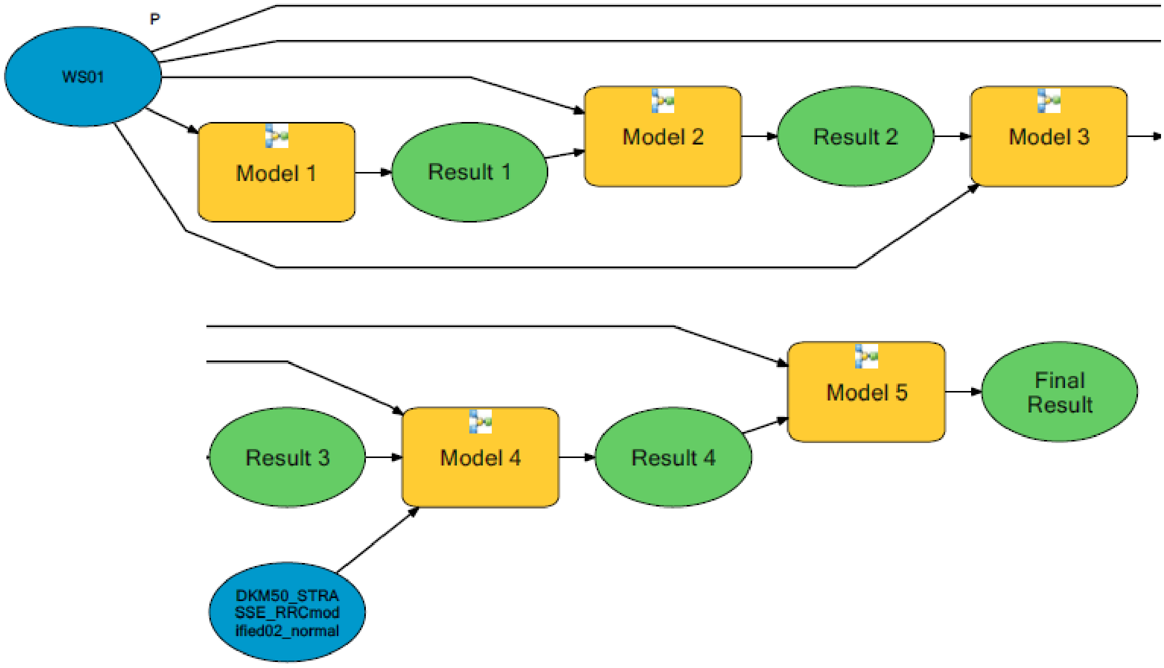


Figure 4.12: Main model consisting of five submodels

In the following the steps of each individual sub-model are listed. The detailed model diagrams can be found in Appendix A.

Model 1 - Aggregation, Reclassification and Simplification (Step 1 - 7):

- Aggregate buildings with a distance of 1 meter
- Eliminate inner courtyards which are below the minimum dimension of 400 m^2
- Simplify all buildings by a 4 meter tolerance

- Reclassify all buildings according to their size into four hierarchy types
- Simplify the small buildings which are below 250 m^2 by a 12 meter tolerance
- Simplify the middle sized buildings which range from 250 – 756 m^2 by a 8 meter tolerance
- Simplify the large buildings which range from 756 – 1000 m^2 by a 7 meter tolerance
- Simplify the very large buildings which are over 1000 m^2 by a 6 meter tolerance

Model 2 – Selection and Elimination of small buildings according to density (Step 8 – 9):

- Select and eliminate all buildings with a shape area smaller than 10 m^2
- Create built-up areas to identify dense settlement patterns
- Select and eliminate all buildings with a shape area smaller than 60 m^2 within dense settlement patterns

Model 3 – Selection and Elimination of small buildings around large buildings (Step 10):

- Select all very large buildings with a hierarchy 0
- Buffer the selected buildings with a 5 meter distance
- Select and eliminate all small buildings (hierarchy 3) which are inside the buffer of the very large buildings

Model 4 - Selection of buildings a buffer zone to the road network and Reclassification (Step 11):

- Buffer the input road network with a 20 meter distance

- Select all buildings with a hierarchy 2 which intersect the road buffer
- Reclassify all selected buildings to a hierarchy 1
- Select all buildings with a hierarchy 3 which intersect the road buffer
- Reclassify all selected buildings to a hierarchy 2

Model 5 - Symbol creation and cartographic conflict resolution (Step 12 - 15):

- Add a predefined symbol to the buildings
- Create a cartographic representation
- Add a road class with a manipulated width as a barrier feature
- Resolve building conflicts with a minimum building gap of 11 meters and an minimum allowable building size of 20 meters

4.3 Results and discussion

Figure 4.13 presents a section of the 1:50‘000 map, showing the generalised road network as well as the automatically generalised buildings as created using the workflow described in the previous chapter (right-hand side). By comparison, the original TLM building data is depicted on the left. The complete results of the test area may be found in Appendix C.

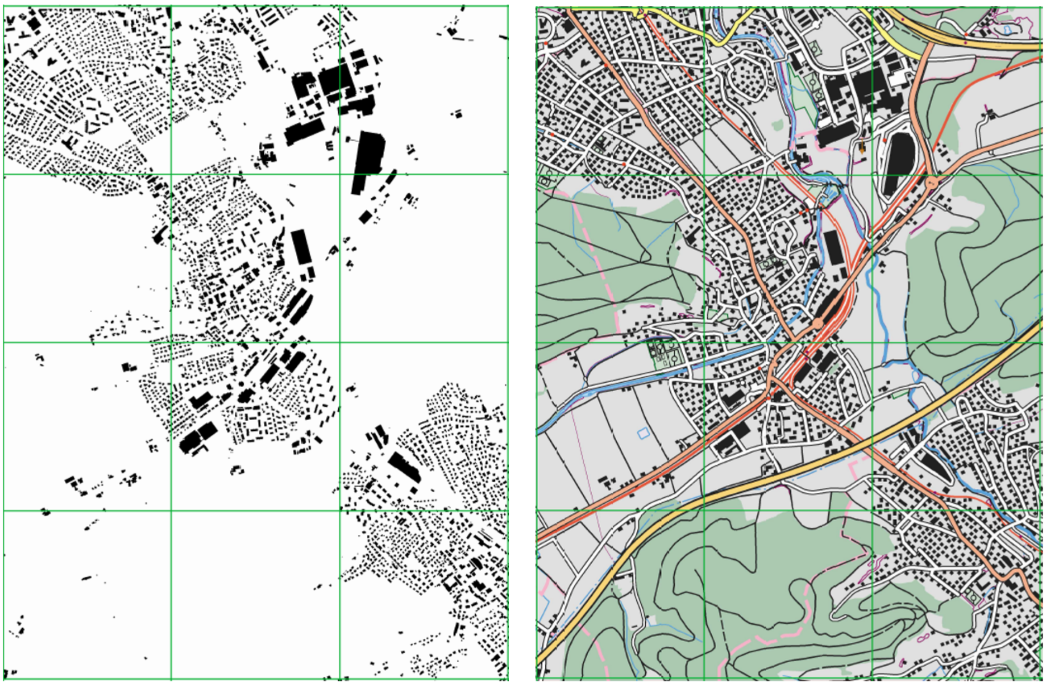


Figure 4.13: Left side: TLM data; Right side: 1:50‘000 map extract, buildings obtained fully automatically

In section 3.2.2, several important cartographic constraints were defined, which need to be fulfilled for the resulting 1:50‘000 scale.

During the development of the workflow it has already become apparent that there are many opportunities for automating the generalisation within ArcGIS using the ModelBuilder. Nevertheless there remains the necessity to verify which cartographic constraints have been successful resolved by the chosen generalisation operators. Problems related to these chosen operators, which occurred during the process of testing, will be revealed.

Constraints for the selection of buildings (1 - 3): **Constraint 1** defines that buildings smaller than 5m^2 are not to be considered and can be omitted. **Constraint 2**

defines that in dense settlement areas, features smaller than 50m^2 are to be deleted and **Constraint 3** defines that isolated features must be preserved. All three constraints are successfully resolved with the operators of *Selection* and *Elimination*. However, adjustments to the defined buildings sizes were necessary and deduced through a process of testing. **Constraint 1** was resolved using a normal selection methodology based upon the attribute size. **Constraint 2** was reached using a selection within a defined location, in the use case the location was a dense settlement area. Here the question arises what exactly defines a settlement area as dense and how can this definition be applied generally. In this research it was defined using the *Create Build Up Area* operator as no predefined definition for a dense area existed. This delineation of what defines a dense settlement area might well require adjustment and has to be highlighted as a critical point requiring further attention. The compliance of **constraint 3** is brought about upon by the compliance of constraint 2 as isolated features have not been eliminated.

Constraints to preserve minimum dimensions (4 - 6): **Constraint 4** defines the minimal dimension for a building as being 400m^2. This is satisfied with the *Resolve Building Conflict* operator; within this operator there exists the possibility to define the minimum building size. **Constraint 5** defines the dimensions for cultivation, indentation and a step-shaped outline of a building. Within the *Simplify Building* operator it is only possible to define a simplification tolerance in meters and not individual different dimensions. Therefore, a feasible result is only reached after intense testing and fine adjustment of the simplification tolerance value. This fact lead to the necessity that the results be evaluated as part of an expert evaluation. **Constraint 6** describes the minimum dimension for an inner courtyard which can be satisfied using the *Aggregate* operator in setting a minimum hole size which will be removed.

Constraints to preserve minimum distances (7 - 11): Constraint 7, a minimum distance of 10 meters between buildings, is preserved with the *Resolve Building Conflict* operator. However, the defined minimum distance of 10 meters was adjusted to 11 meters during the test process with agreement of the experts from swisstopo. **Constraint 8**, where the distance between buildings and black traffic signatures is defined, was fulfilled using again the *Resolve Building Conflict* operator. This operator offers the possibility to define features to which the buildings can *snap* to. Once more it should be stressed at this point that adjustments were made in advance to the road symbolisation to account for the snap feature. This is necessary because the buildings are overlapped by the roads for a predefined distance (see chapter 4.2.1). Due to time restraints this adjustment was however not possible for **constraint 9**. Here the distances between the buildings and red traffic signatures as well as between the buildings and the water features are defined. Technically this constraint was not fulfilled within this research but can be correlated to constraint 8. **Constraint 10 and 11** may only be verified per visual examination, conducted during the expert evaluation. This is because there is no known technical way to prove the minimum distances within densely built-up areas.

Constraint to preserve the positional accuracy (12): Objects with special feature types need to retain a high positional accuracy. This may be reached by *assigning these features a hierarchy attribute value* of 0. This value will result in these features being excluded from the displacement operations. One known drawback is that this can cause topological errors such as features are being placed upon the wrong side of a road or even under a road. Due to this drawback it was decided to handle these features as all other features in order to retain the topology. This point is however still open for discuss and a final decision will have to be reached before continuing with this research.

Constraints to maintain shape (13 - 16): Particular shapes of building footprints have to be retained as defined in **constraint 13**. This is fulfilled with the *Simplify Building* operator which simplifies buildings whilst maintaining the main characteristics. The operator *Aggregate* is necessary to achieve **constraint 14** which states that buildings are only to be merged when not separated by a road axis. **Constraint 15** defines that buildings which are closer together than 1m can be merged under special rules. This could only be partly fulfilled. With the *Aggregate* operator it is possible to merge buildings which are within a specific distance. However, it is not possible to do this under the consideration of defined rules, such as; only features of the same object type are to be aggregated. An option to satisfy these special rules within the *Aggregate* operator would be to run this as a loop function within the *ModelBuilder*. As the exact definitions for these special rules for all building classes were missing it was decided to handle all classes identically. For any further research it would be definitely necessary to consider this limitation. **Constraint 16** defines that special settlement structures need to be maintained. This also cannot be technically proven and needs to be given a special weighting during the expert evaluation.

Constraints retaining density (17 – 23): Of special importance whilst retaining the building structure is the maintenance of the black-white ratio as defined in **constraint 17**. The thinning value within different settlement areas such as fine, dense, sparse, coarse, and widely dispersed is defined as a percentage within **constraints 18 – 22**. Due to the fact that the different densifications of settlement areas are not defined it is not possible to proof this exactly. In this case, once again, it is necessary to verify this by the visual examination. **Constraint 23** is that the size of any settlement must not be changed by the generalisation, which also means that peripheral buildings should not be displaced into free space. This constraint is satisfied by the operator *Resolve Building Conflict* where barrier features, such as the outline of a big settlement area, may be defined.

Constraints retaining the differentiations of building sizes (24 – 28): To verify if the size differences have been preserved, **constraint 24**, it was necessary to set a special focus upon on this as part of the expert survey. **Constraints 25 – 28** defines how the different sized buildings, small, medium and large, should be exaggerated. Unfortunately with the *Resolve Building Conflict* operator it is only possible to define a minimum size for buildings. There is, as yet, no way to define how every individual classification of building should be handled. This is a major restriction and might result in the differentiation of buildings getting lost.

Constraints retaining the orientation of buildings (29 – 32): Constraint 29 – 31 define that the orientation of buildings must be obtained and that in two ways. Fist, the orientation of buildings to their neighbouring buildings and second, the orientation of buildings to the road network. This parameter can be set in the *Resolve Building Conflict* operator. However, only one of those two parameters can be set. In this research the decision was made for the orientation towards the roads because the orientation of the other buildings inside building blocks was kept automatically from the input data. If the orientation has been obtained successfully needs to be verified in the expert evaluation. **Constraint 32** is also from high importance in order to keep the structure. Roads which are no longer shown are to be implied using the orientation of the buildings. So far there is no specific tool available for this. However, the *Resolve Building Conflict* operator handles this issue quiet well.

Constraints retaining the arrangement of buildings (33 – 34): Those two constraints define how the arrangement of buildings should appear. Firstly, rows of houses should be preserved and secondly, the difference between regular and irregular building arrangement must be maintained. Both are handled by the *Resolve Building Conflict* operator and need to be evaluated in the following expert survey.

5 The evaluation: assessing the cartographic quality

The evaluation of generalisation results and its quality have been discussed for several decades within the field of cartography. Until today this topic has not yet been conclusively determined (Bard (2004); Burghardt et al. (2008); Ehrliholzer (1996); Shea and McMaster (1989). The fundamental problem being that, for the evaluation of generalisation results there does not exist a generally accepted set of reference data, against which a result may be compared (Bard, 2004). Another problem of a reference data set is that in itself can never be objective due to the reason that all cartographers have differing ideas and perceptions about how to generalise. This is underlined by the fact that no two cartographers would generalise the same map the same way.

The following two chapters state how the evaluation criteria have been defined. Also the evaluations format and the definition of the participating expert groups are also explained in detail. After the conclusion of the survey the results of the evaluation were analysed in detail and a conclusion about the quality of the generalised result extracted in order to answer the questions posed during the research.

5.1 Defining the evaluation criteria

In this research the focus lies on the qualitative evaluation of the generalised results accomplished by the developed workflow. This evaluation is highly significant and allows a general statement regarding the quality of the generalized result to be formulated. To facilitate this, an expert survey to verify the cartographic quality according to the formulated cartographic constraints was developed. In formulating the expert survey it was also necessary to consider which user groups would be questioned.

In order to assess and to evaluate the results qualitatively the final solution was presented to an expert panel consisting of individuals directly involved with the subject of generalisation and represented by three distinctly different users groups. The following user groups were chosen: Software specialists from Esri, cartographers from swisstopo and experts in the theory of generalisation, mostly within higher education. The motive leading to these three different user groups was to hopefully reach a more valuable evaluation of the generalised result.

The research was conducted at Esri and using Esri technology and commissioned by swisstopo. It was deemed for the research very important, not only to receive feedback from within these two participating groups but also from a third, and perhaps more “Neutral” group, an external panel of theoretical experts.

The project used a convenience sample of 33 test persons, all with a background in cartography and over half of those participating are also specialists in the field of generalization. Each group contained the following number of experts: Swisstopo = 7, Esri = 8 and Externs = 18.

The experts received a questionnaire (Appendix D) to evaluate the generalised results for a given test area. The evaluation has been based on the guidelines of Mieg and Näf (2005) and consisted of three main parts. The questionnaire explains the meaning and purpose of this research as an introduction. Information about the accompanying documents and how to conduct the survey were also given. In the first questionnaire block, three short initial questions are asked in order to receive knowledge about the technical background and how much experience the participant has in the field of cartography and generalisation. Block two contains specific questions concerning the quality of the building generalisation. The questions asked are based on the considerations when generalising buildings as introduced in chapter 2.6.2. For each question an option of assigning one quality criteria was given. The quality criteria in this research are based on the classification of Ehrliholzer (1996) and are enhanced for this questionnaire by swisstopo (table 5.1). The enhancement was to allow for an outstanding good result to be recognised.

Quality criteria by Ehrliholzer	**Quality criteria enhanced**:
Good	Very good
Acceptable	Good
Bad	Bad
Unusable	Very Bad

Table 5.1: Quality criteria for the evaluation

Finally, block three consisted of an open questionnaire about the generalised results and can be seen as an addition to the second question block in order to be able to analyse the results more precisely. The participants were asked to mark and explain areas which they considered to be the most successful and the most problematic. During the following analysis the focus is set upon those areas designated as problematic because these are undoubtedly the most important when considering further research.

5.2 Results of the questionnaire

To assess the cartographic quality of the generalised results these have been qualitatively evaluated by experts. The results are given as a percentage related relatively to the number of participants of each group. Due to this it is possible to draw direct conclusions between the results of the three groups. For each question the average is calculated to indicate the general trend of the quality. The participants were further asked to mark areas directly in the supplied plots which have been generalised most and least successfully and to explain their decisions. These answers are used to further support the statements for each individual question. The answers to the open questions are analysed per user group and summarised visually in map and table form in Appendix E. In the following sections the results of the questionnaire regarding the considerations when generalising buildings (the settlement structure, the shape- and graphic generalisation, the selection, and general questions) are discussed and evaluated. The analyses of the graphs are complemented by the individual perception about the very successful and problematic areas.

5.2.1 Retaining the settlement structure

As pointed out in chapter 2.6.2 the most important goal during building generalisation is to retain the settlement structure. To verify if this goal has been reached, six questions were given. The resulting graphs are listed and explained into detail below.

The first main question to answer is **how the building density has been preserved**. To refer back to chapter 2.6.2 it is very important to keep the black white ratio in order to retain the density. The results, as shown in the following figure 5.1, indicate that the building density has been perceived to be preserved either **very good or good**. It is significant to note that the participants in the *extern* group had a 50% split between the rating **good and very good**. The *swisstopo* group rated almost about the same with the difference that 14% assessed the result as being **bad**. With over 50% giving a **very good** rating for the results, the *esri* group gave by far the best average rating in this category. *Swisstopo* group argued that the building density and open spaces can be interpreted well and that the black-white ratio is very good whereas the *esri* group commented that the overall look and feel of the density pattern of buildings is maintained: dense areas still look dense, while the sparse areas have remained sparse. Through about is that homogenous and industrial areas with less dense character are handled the best. There are a few areas where the density was considered as problematic, especially in the area within and around the historic old town.

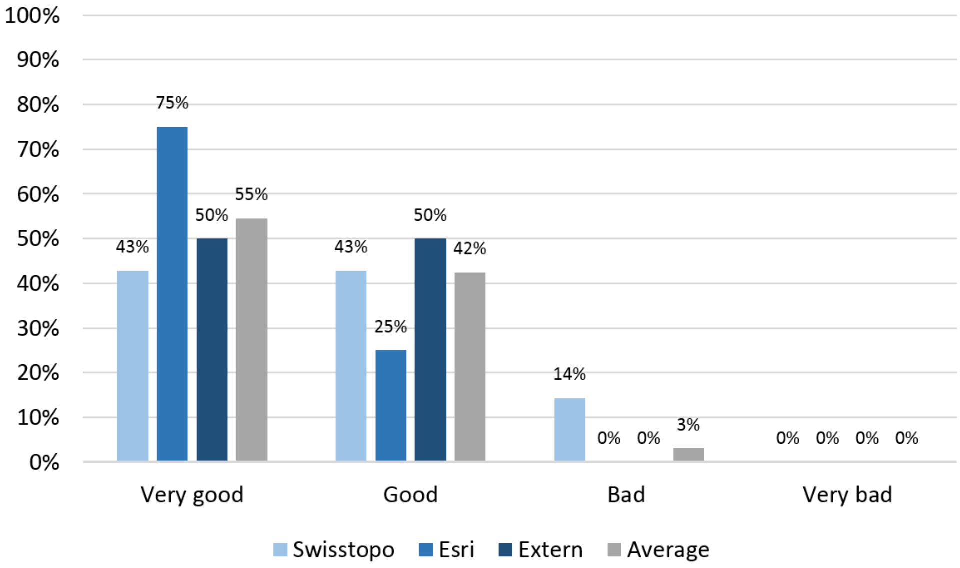


Figure 5.1: Evaluation of the results: preservation of the building density

Secondly, it is important for the typical settlement structure **to preserve the relative building size differences**. The following figure 5.2 indicates that the overall perception of this requirement is fulfilled to 64% with a **good** rating. Significantly here it is only participants of the *esri* and the *extern* groups which rated a few areas as **bad**. This is reflected in the comments, where it is stated that the smallest buildings do have an artificial look because they all appear to have the same size. Another important comment is that it might be only necessary to distinguish between only two size categories among all buildings instead of making a distinction between small and medium sized buildings.

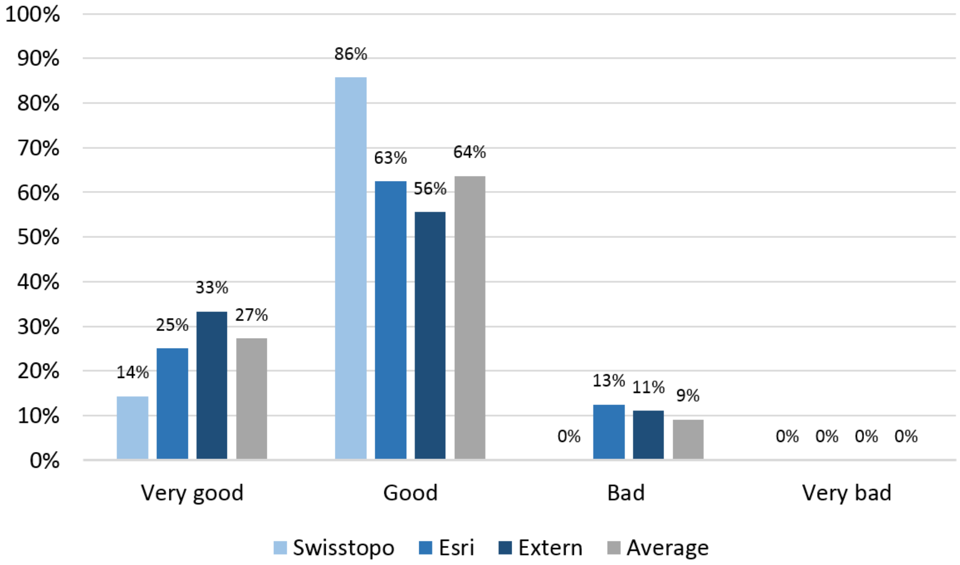


Figure 5.2: Evaluation of the results: preservation of the relative building sizes

Another important point to consider is the **orientation of buildings, either from one to another or to streets**. The following graphs 5.3 and 5.4 show a strong correlation. Both results are **good** by more than 50%. By the orientation of buildings to the streets, 14% of the *swisstopo* group considered a rating of **bad** to be appropriate. However, the *extern* group commented that the orientation of buildings along the road network is very well maintained and *esri* group maintained that the building alignment is well done.

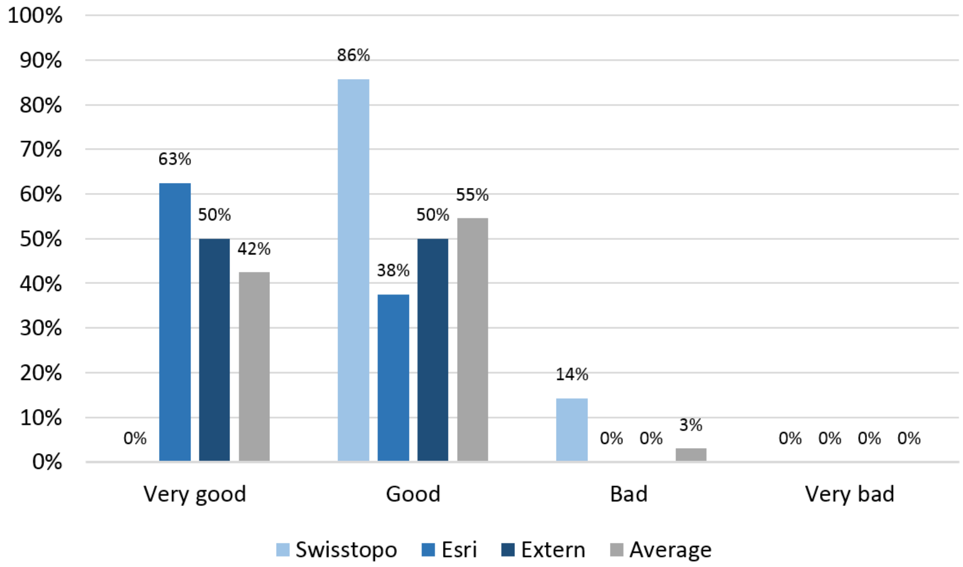


Figure 5.3: Evaluation of the results: preservation of the building to street orientation

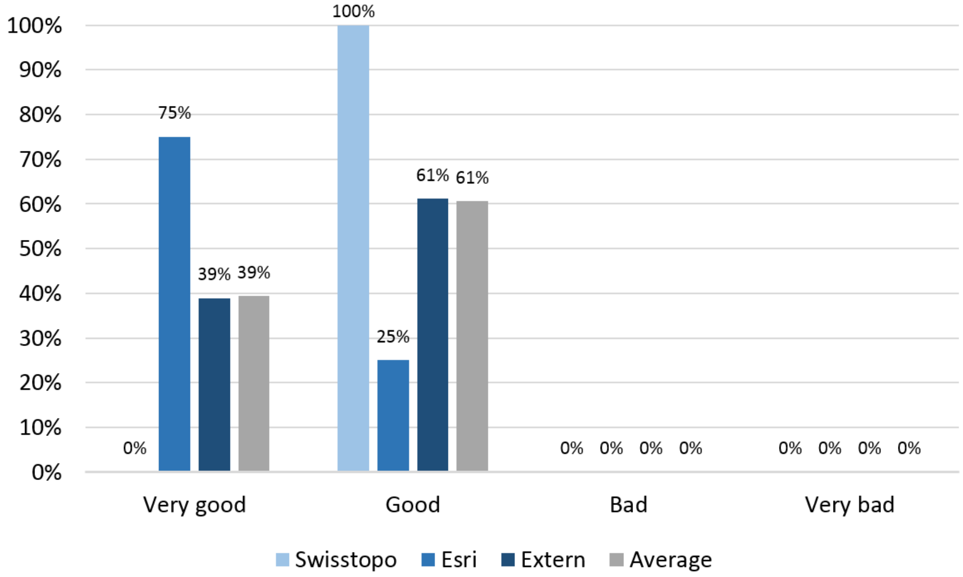


Figure 5.4: Evaluation of the results: preservation of the building to building orientation

As stated in chapter 2.6.2 it is from significant importance **to preserve the differences between regular an irregular building layouts** in order to retain a settlements structure. Especially for the reasons of good orientation this is important. The following graph 5.5 shows very clearly that the visual perception vary a lot when answering this question. This variation might result from the fact that there has been already a problem of pattern recognition due to missing relative building sizes and the pattern preservation. The analysis of the graph shows that 43% from the *swisstopo* group ranked this as being **bad**. Surprising, is that the *expert* group opinion differs very much. Besides the 72% **good** rating there are also ratings varying from **very good to very bad**. The graphs analysis is further confirmed by the open comments where the *swisstopo* group identified some areas where very homogenous single house settlements are displayed too arbitrarily. The *expert* experts identified areas where the structure has been not well preserved especially in areas where there is a dense irregular and regular pattern. However the overall opinion is still ranked for **good**. The general positive impression is that the regular settlement structures are handled well. There are many areas where the building distribution and the settlement pattern is very well preserved as stated by all expert groups (see Appendix D).

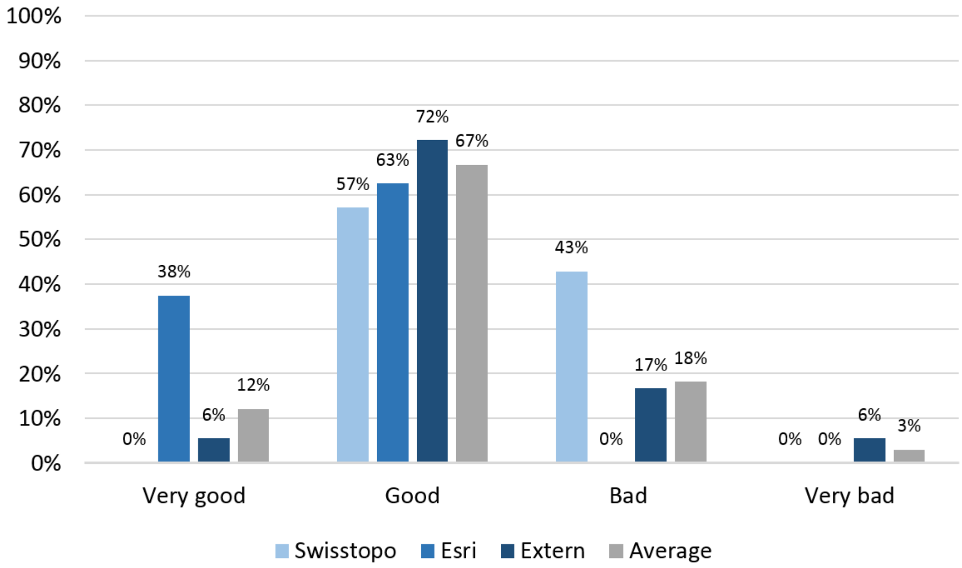


Figure 5.5: Evaluation of the results: preservation of building arrangement

The last very important point in order to retain the settlement structure is that **the original extent of the settlement has to be preserved**. The test persons stated that the representation of the overall built-up area footprint is well maintained. This is true throughout. Also, the extent of settlement is corresponding to the scale from which it has been generalised. Through the results displayed in the following graph 5.6 it becomes clear that there is a strong correlation between the open comments and the analyses. Overall 64% gave a rating that the extent of the settlement had been preserved **very good**.

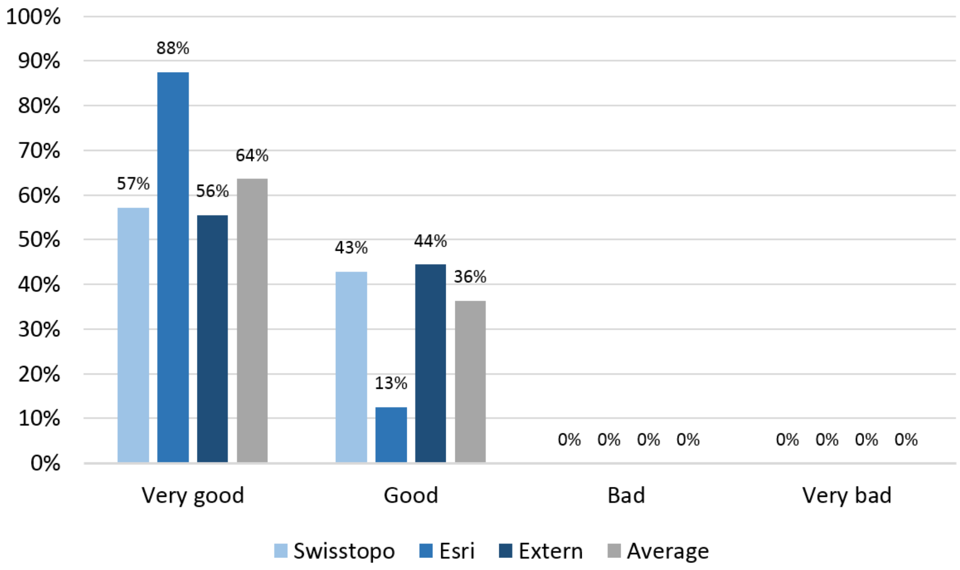


Figure 5.6: Evaluation of the results: preservation of settlement extent

5.2.2 Generalising the shape

Another important goal to achieve during building generalisation is to generalise the shape correctly. To verify if this has been achieved the following four questions were asked:

- Has the original form of the settlement been preserved?
- Has the special character of the historic old town been maintained?
- Have the characteristic shapes of the buildings been retained?
- How have the smallest details of individual buildings been generalized?

The following four graphs show the quality perceived to have been reached the resulting data.

Firstly, it is very important that **the original form (the main type) of the settlement has been preserved**. Once again there is a large deviation between the opinions of the experts (figure 5.7). It might be that this question was misunderstood and as such the results were interpreted differently. This sentiment was also mentioned as a feedback. In a future questionnaire this question would be further clarified. The only comments from *extern's* experts were that the settlement is very well preserved and that the original form is depicted very well. Overall it can be still stated that there is a correlation between **very good and good**. However 15% gave a **bad** rating.

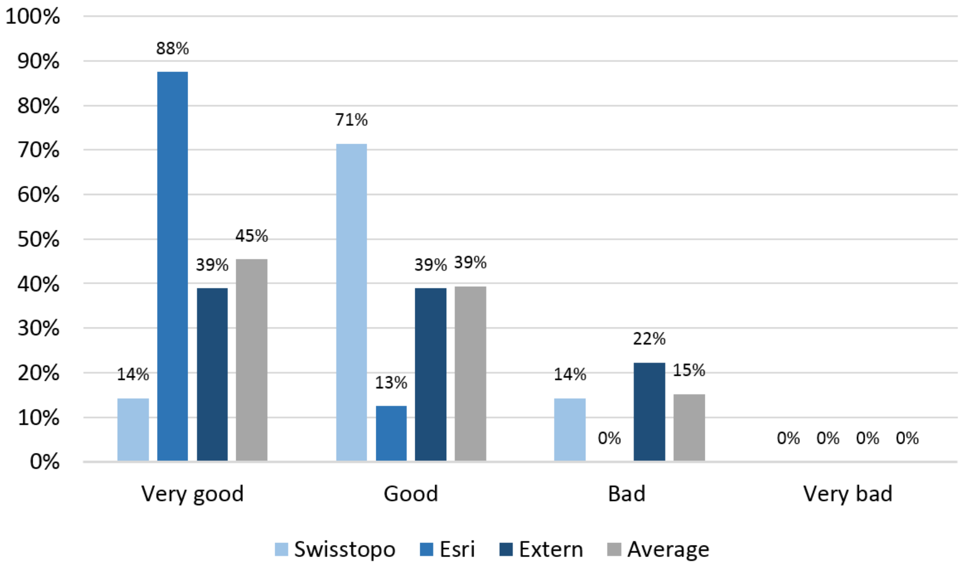


Figure 5.7: Evaluation of the results: preservation of the original form

Secondly, one of the main goals of shape generalisation is to preserve the special character of the settlement. A speciality of the test area is the historic old town. **It is important to maintain this special character of the historic old town**. The graph 5.8 indicates conclusively that preserving the historic old town's character is highly problematic. The overall rating is 45% **bad** as well as 9% **very bad** which total's more than 50%. This is also reflected in the open comments where it is stated that the character of the historic old town is lost and hand editing is hence unavoidable. Another important point recognised is that it appears that the roads in this area have not been generalised that well. An improvement here would of course also have a direct impact upon the generalisation of buildings. Going into more detail about the original form it becomes clearer why the previous question was rated so differently. Apart the matter of the historic old town there are also positive remarks about other settlement structures. The street village and the industrial characters are maintained very well. The results are overall really good both for the generalisation of the single buildings as for the generalisation of big settlement areas. Linear structures are also rated as good.

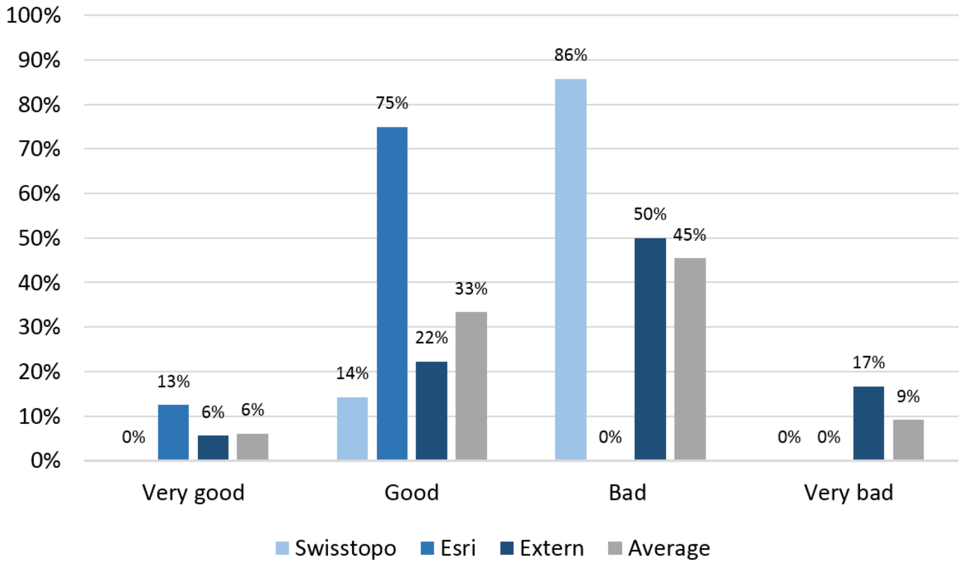


Figure 5.8: Evaluation of the results: special character of historic old town

Thirdly, it is from high significance that **the characteristic shape of the buildings has been retained**. It appears that the structures of very large building complexes and industrial buildings have been generalised very well and receive a **good**. The main characteristics of the buildings are maintained very well. This is also reflected in the following graph 5.9. Besides this there were also comments that the large building boundaries could be simplified even further and that in some areas the separation of buildings has not been maintained. It was also noted that previously rectangular buildings were ending up with curves after the generalisation, which is of course an unacceptable change in shape.

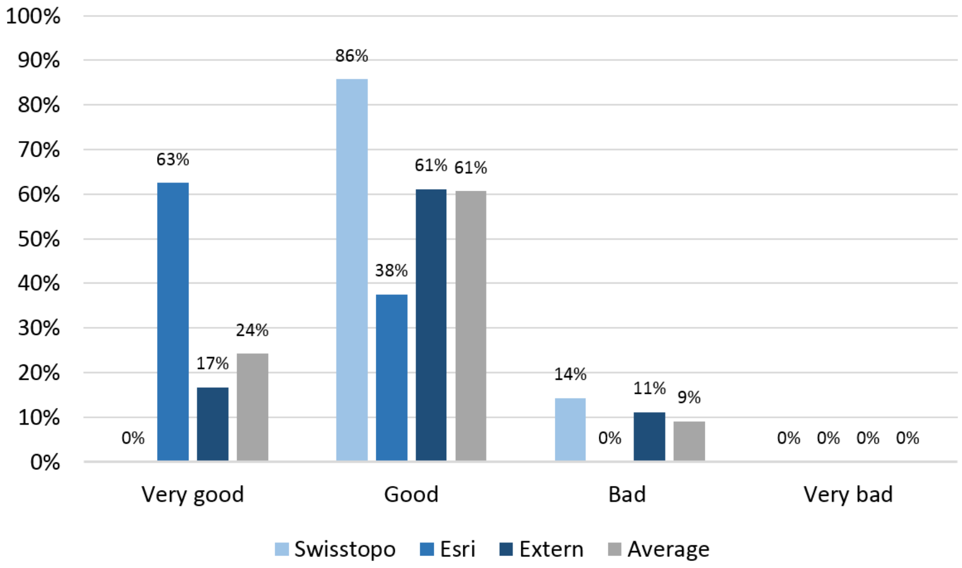


Figure 5.9: Evaluation of the results: characteristic shapes of buildings

Last but not least it is important that **the smallest details of individual buildings must be generalised properly** to the corresponding scale. Beside the fact that 14% of the *swisstopo* group gave a **very bad** rating the overall result is still **good** with over 50%. Between the three groups there was a high correlation. Significant is also that 39% of the *extern* group rated the result as **bad**. The reasoning given for this is that large buildings have too little generalisation as already mentioned in the previous question. Small extrusions or recesses have not been removed or completed resulting in a more squared result. Therefore a larger generalisation degree for large buildings is recommended. The small generalisation degree used generates so-called unrest in the map image and is badly interpretable.

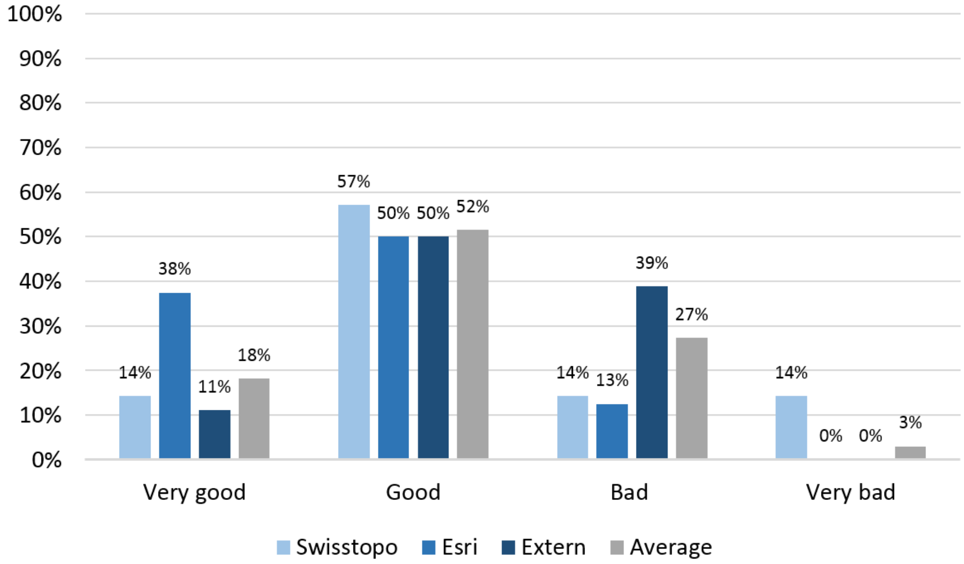


Figure 5.10: Evaluation of the results: smallest details of buildings

5.2.3 Graphic generalisation

Graphic generalisation is a key role in the automated generalisation and guarantees that the legibility of the map is preserved. As already introduced in chapter 2.6.2 the minimum dimensions as well as the spacing between buildings are from high significance and have to be observed. Also shifting and displacement of features is a key word within the graphic generalisation.

Firstly, it is very important that **the minimum dimensions have been preserved**. According to the experts this is fulfilled to 61% with a **good** rating. Here again it becomes clear that the visual perception differs. 14% of the *swisstopo* and 28% of the *extern* group rated this as **bad** and 14% of *swisstopo* as even **very bad**. An important comment is that bigger buildings appear too small due to the fact that they could not be shifted away or are partly overlapped by road symbols. Graph 5.11 illustrates this result.

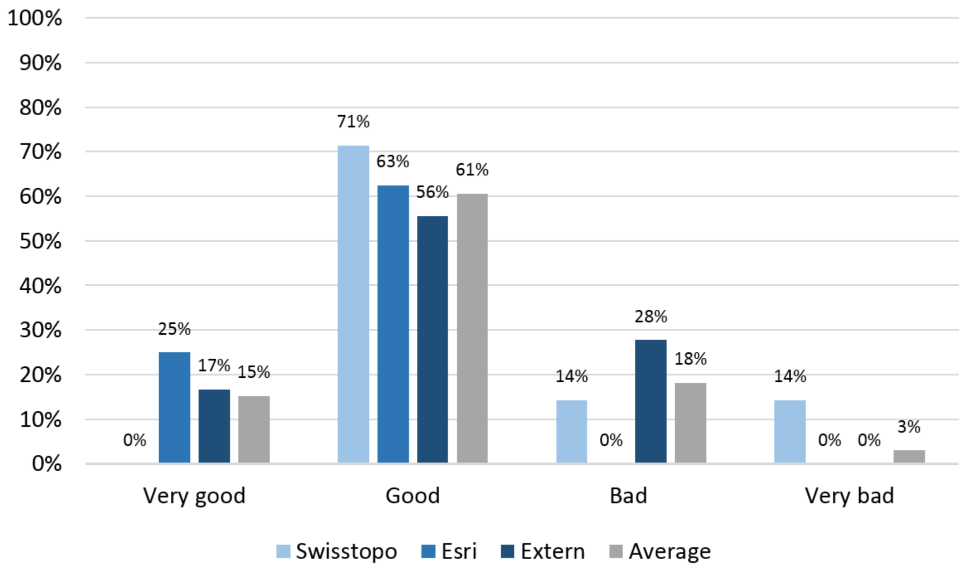


Figure 5.11: Evaluation of the results: minimum dimensions

Secondly, **the minimum distances need to be preserved**. As stated by the experts the minimum distances are very well preserved for the scale of 1:50‘000 which also corresponds to the following graph 5.12. The results for the minimum distances are almost the same as for preserving the minimum sizes. However, it has a higher rating of **very good** which results in an overall value of 27% besides the **good rating** of 55%. The rating for **very bad** is due to the fact that the minimum distances are not observed within the historic old town.

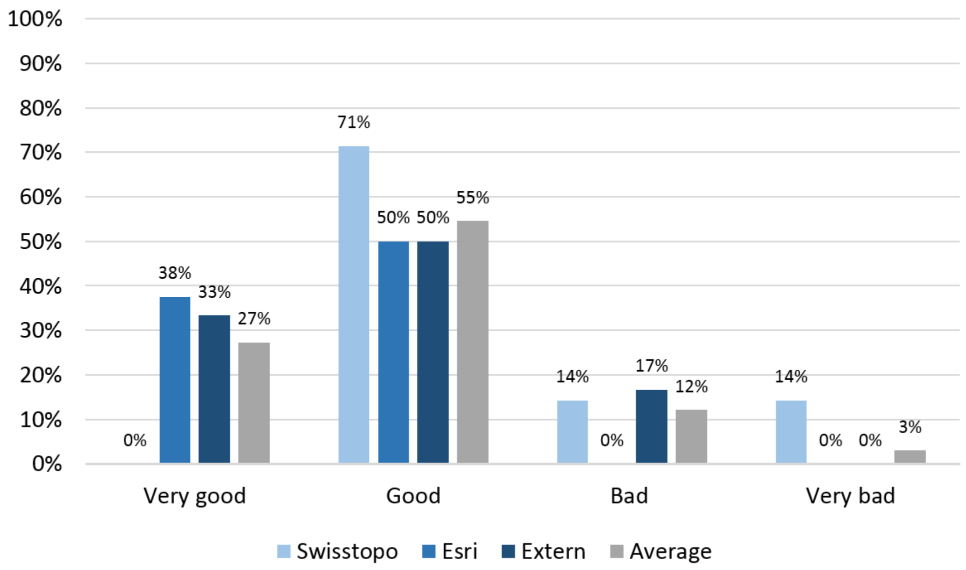


Figure 5.12: Evaluation of the results: minimum distances

5.2.4 Results of Selection

The selection of buildings is very important for generalisation to retain the settlement structure. Therefore it has been asked **how the individual buildings selections for the target scale of 1:50‘000 has been assessed**. Again the result is **good** with an overall value of 61% and **very good** with 27% (graph 5.13). A few ranked **bad and very bad** which is reflected in the comments. A significant discovery is that buildings are sometimes missing between roads. This is a direct result from less space being available after the road generalisation. In some cases small buildings outside of the settlement have disappeared which is totally wrong. Another important comment is that buildings at street corners are often eliminated in the generalised result which makes it more difficult to recognise and orient. Corner features are very important features to preserve.

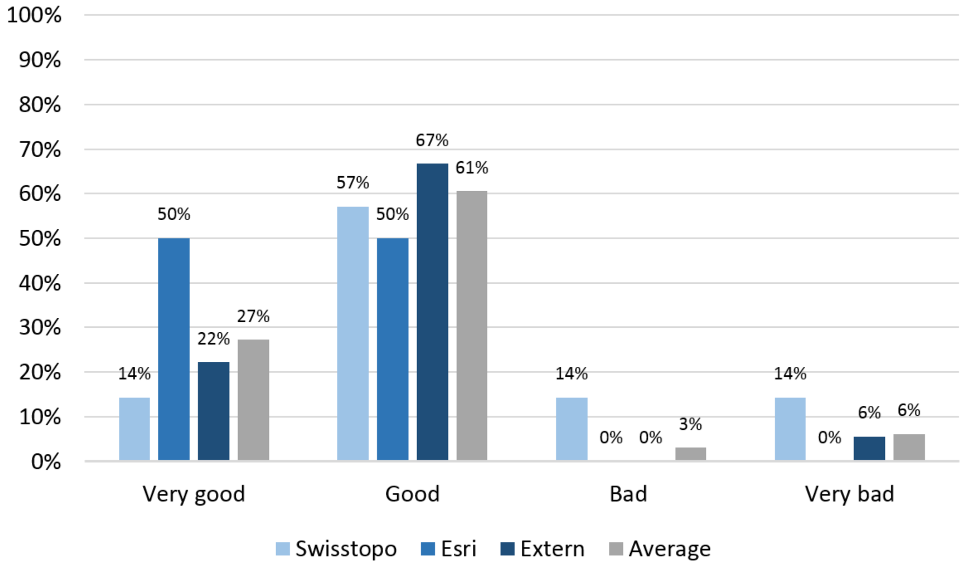


Figure 5.13: Evaluation of the results: individual building selection

5.2.5 Results in general

The last important question of the evaluation was **how the overall level of generalization for the target scale 1:50‘000 has been assessed**. After already having analysed all other questions it comes as no surprise that almost all were rated **good** (61%) or **very good** (33%). Only 6% rated the overall level of generalisation as **bad** but there was no clear reason in the open comments as why this was the overall impression.

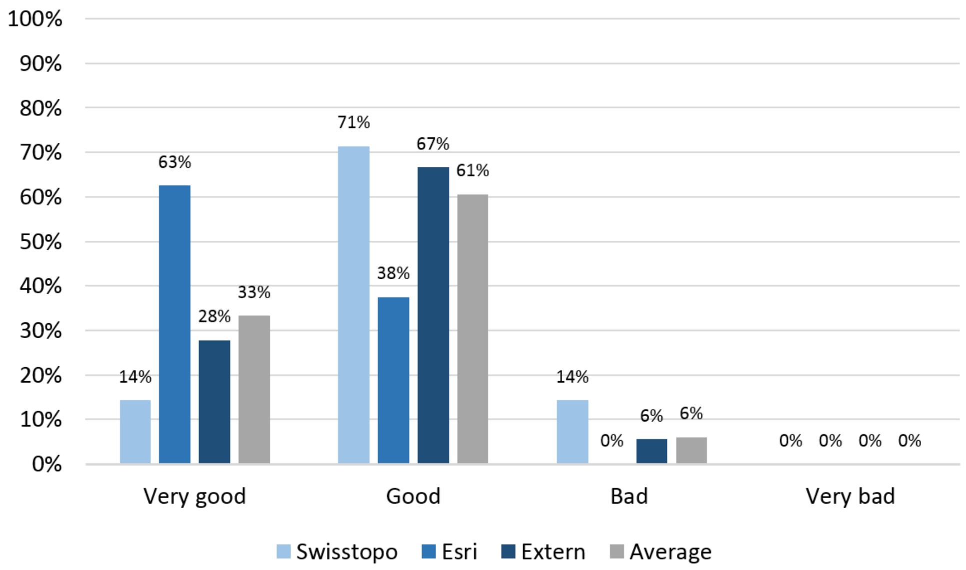


Figure 5.14: Evaluation of the results: overall level of generalization

5.3 General results and discussion

At this point, now that all results have been analysed in detail, there remains the need to verify the remaining constraints whose verification can only be achieved by visual examination and hence were not answered in Chapter 4.3.

The most important part regarding the settlement structure is to retain the building density which is defined in the constraints retaining density 17 – 22. The maintenance of the black-white ratio as defined in constraint 17. The thinning value within different settlement areas such as fine, dense, sparse, coarse, and widely dispersed is defined as a percentage within constraints 18 – 22. These constraints can be seen as successfully resolved as most of the ratings given were either **very good or good**. However, a small percentage rated **bad**. This hints that further adjustments may have to be made in the generalisation process to further improve on these results. Another focus was to prove if the differentiation of building sizes had been retained (constraint 24). As already stated in the previous chapter this received to 64% a **good** rating. Nevertheless it once more should be pointed out that 9% have the perception that this constraint could only be rated as **bad**. Further improvement is definitely required here in order to achieve a better result. The challenge is to find a way to the various building sizes and so be able to handle these differently during the process of graphic generalisation. Constraints 29 – 31 define how the orientation of the building footprints should be maintained, either from building to building or from building to street. Taking into account the results of the expert survey these constraints can be seen as being successfully resolved. Last but not least it is of special importance that the arrangement of buildings is preserved (constrain 33 – 34). According to the expert survey there is certainly a need for further investigation to reach a better result. Even though over 60% rated the result as **very good**, significantly over 20% rated it as either **bad** or even **very bad**. After analysing all questions regarding the preservation of the settlement structure it can be stated that an overall positive result has been achieved, this is confirmed by (figure 5.15) and it becomes very clear that an above average result has been achieved.

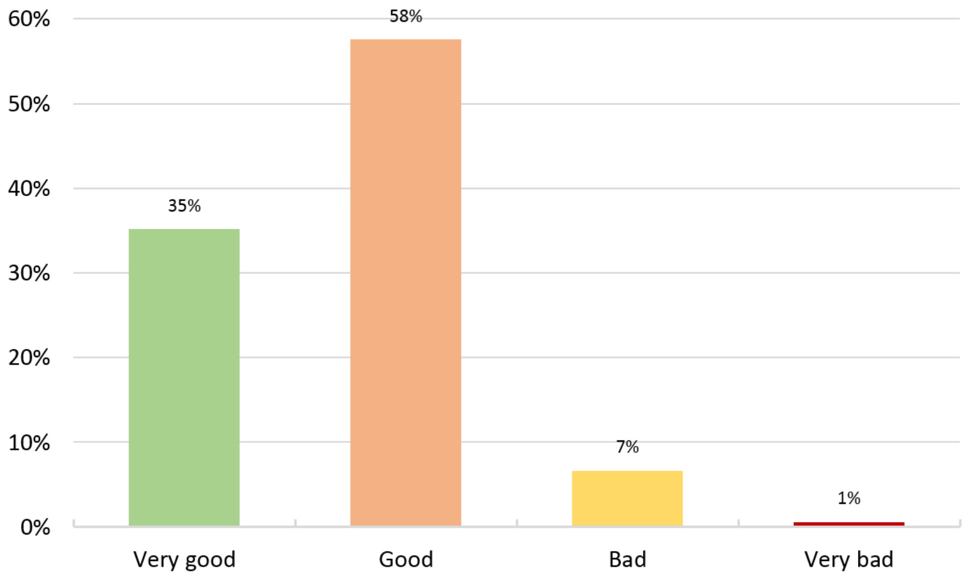


Figure 5.15: Overall result retaining the settlement structure

Another special characteristic which has to be reviewed carefully is generalising of shape. The constraints 13 – 16 are concerned with the generalising of shape and the constraints 13 – 15 have been already analysed in detail in chapter 4.3. Let us look at constraint 16 which defines that special settlement structures have to be preserved. As the analysis has shown this was not the case for the historic old town. The expert survey has been shown that 45% think the result is **bad** and 9% that it is even **very bad**. However, the overall result for generalising the shape (figure 5.16) is still rated with 24% as **very good** and 48% as **good**. But this unbalanced result shows that further development is definitely needed within very dense town centres.

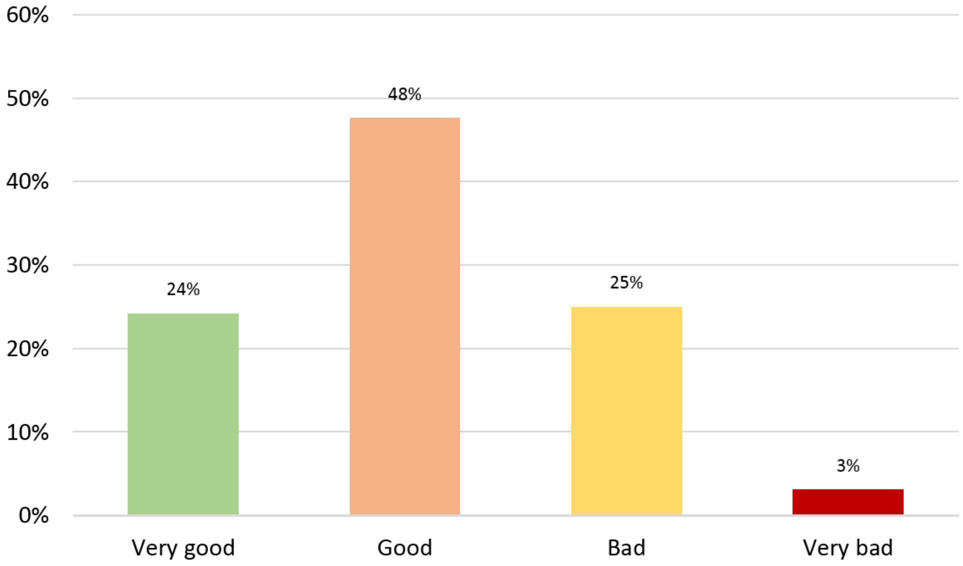


Figure 5.16: Overall result generalising the shape

The last cartographic constraints which need to be reviewed are those of the graphic generalisation. Constraints 5, 10 and 11, the minimum dimension for the simplification of buildings, the maintenance of the minimum dimension in dense settlement areas and a less dense settlement which must be represented by correspondingly larger distances. During the analysis of the results it became obvious that there was no clear opinion about whether the minimum dimensions have been met or not. This is also reflected in the overall result of the graphic generalisation (figure 5.17). However, the overall result for the graphic generalisation is rated with almost 22% as **very good** and 60% as **good**. Nevertheless, the expert survey has been also shown that the overall impression is with 25% **bad** and with 3% **very bad**. Especially the minimal dimensions and minimum distances are based on a very individual perception. For this it would be more suitable to find a more technical way, beside the visual evaluation, to measure if those constraints have been fulfilled.

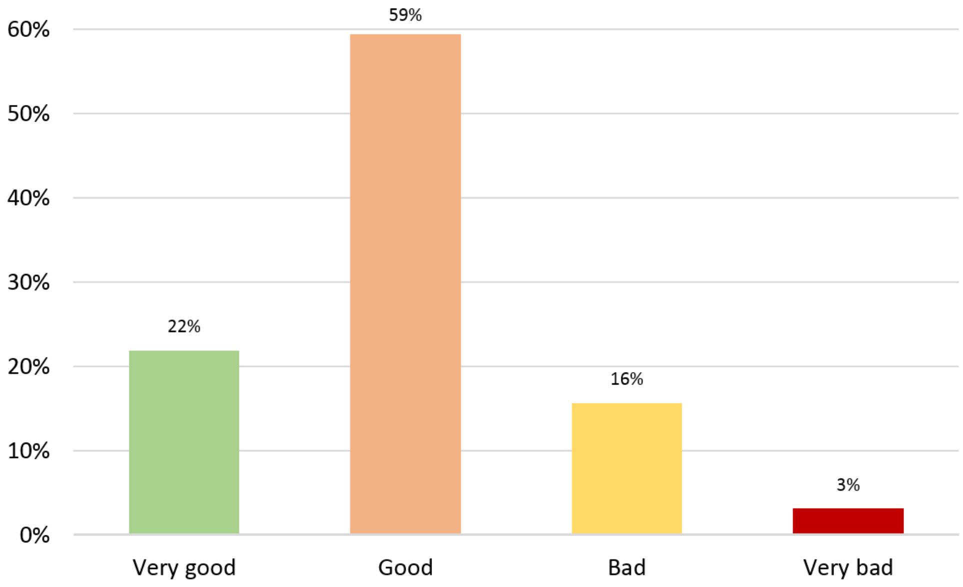


Figure 5.17: Overall result graphic generalisation

6 Conclusion and outlook

The main aim of this research was to investigate whether it is possible to automatically generalise the buildings for the scale 1:50‘000 under the requirement of keeping the existing settlement structure with ArcGIS out-of-the-box generalisation operators. For this purpose, a workflow within the ModelBuilder tool of ArcGIS was developed which must satisfy a set of predefined cartographic constraints as set by swisstopo. As a base dataset for the development a test area, encompassing different Swiss settlement structures was identified. All the available tools which are necessary for the generalisation of buildings have also been specified. The preliminary reduction of data was achieved through a model generalisation. Cartographic conflicts where then solved by performing the graphic generalisation. Through intense testing, verifying the workflow at different stages and adaptation where necessary it was possible to develop an appropriate workflow for the generalisation. Finally it was necessary to evaluate the quality of the results accomplished by the developed workflow by conducting an expert survey. This was significant as it allowed a statement to be formulated whether the main aim of this research has been accomplished or not.

With the developed workflow it has been shown that there are great opportunities for automated generalisation within ArcGIS when perceived through proof plots. However, there was the need to verify which cartographic constraints have been successfully resolved by the generalisation operators in order to know where the special focus needs to be in the expert evaluation. The operators resolved most of the constraints, which did not require a visual verification. Nevertheless, technical gaps were identified which limited the possibilities when aggregating buildings and no way was found to keep the positional accuracy under consideration of the topology accuracy. Another further drawback is that no way could be identified to handle the different buildings sizes during the graphic generalisation. But this raises the question if there is indeed the need to keep this differentiation or if this factor does indeed play a significant role when trying to preserve a settlements structure.

The final solution was presented to an expert panel consisting of individuals directly involved with cartography and the subject of generalisation and represented by three distinctly different users groups (cartographers, software specialists and higher education). The results of the questionnaires supply an interesting insight into the individual perception of generalisation. Especially for this research it is from significant importance that the experts had a very good impression about preserving the settlement structure. During the analysis it was possible to point out that most problems encountered lay either in maintaining the special character of the historic old town and that the smallest details of individual buildings have been generalised insignificantly. A further problem was that the minimum distances and dimensions had not been observed that well. Apart from perhaps the issue with the historic old town all other shortcomings can be overcome with further fine adjustment of the generalisation parameters within the model.

The most challenging part within this research was the adaptation of the parameters to meet the cartographic requirements and to concatenate everything in the right order to build a suitable workflow. However, not only was the development of the workflow important to reach the set goal but also to be able to reach a conclusion about the quality of generalisation. The expert survey supported and promoted the knowledge about the quality of the generalised results significantly.

The research question asked in the beginning, is it possible to automatically generalise buildings for the scale 1:50‘000 under the requirement of keeping the existing settlement structure with ArcGIS out-of-the-box generalisation operators, can now be answered as followed. The generalization tools in ArcGIS are very suitable for the generalization of buildings as well as fulfilling the rather special requirement of preserving the existing settlement structure. A few problem areas have been identified where further research is required.

In further research the presented workflow can be used and further adapted as well as testing each of the many parameters in more detail. Especially the rules for aggregation require further exploration. Due to time constraints and the lack of cartographic constraints stating how the features need to be aggregated exactly, these aspects were not considered in this research, however possibilities within the ModelBuilder do exist. In this research only the generalisation of buildings was taken into account. It should be mentioned that when considering the problem of generalisation, individual feature classes should never be seen and handled in isolation but rather within the context of the many different objects within a topographic map with which they interact with. Always consider the “Big Picture”. This is a challenge and requires further research.

List of Abbreviations

DCM50	Digital Cartographic Model 1:50‘000
DLM	Digital Landscape Model
Esri	Environmental System Research Institute
EuroSDR	European Spatial Data Research Network
GIS	Geographic Information System
MRDB	Multi-representation data base
NMAs	National Mapping Agencies
SGK	Schweizer Gesellschaft für Kartographie
SQL	Structured Query Language
TLM	Topographic Landscape Model

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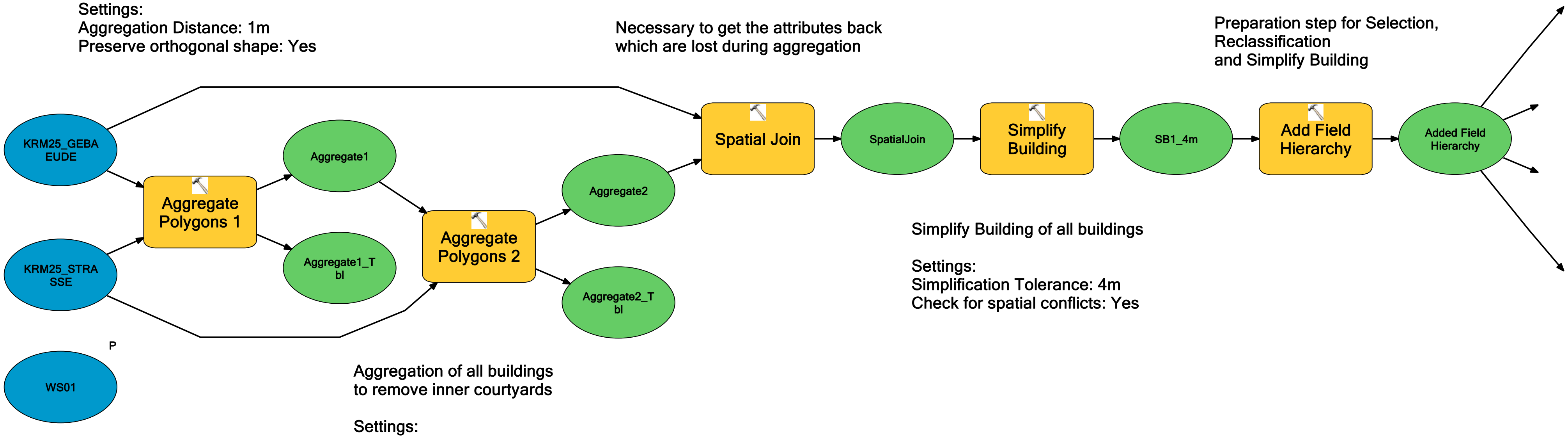
Appendix A: Automatic generalisation models

Model 1 - Part 1



Aggregation of all buildings

Settings:
Aggregation Distance: 1m
Preserve orthogonal shape: Yes

Aggregation of all buildings
to remove inner courtyards

Settings:
Aggregation Distance: 1m
Preserve orthogonal shape: Yes
Minimum Hole Size: 400 sqm

Spatial Join

Necessary to get the attributes back
which are lost during aggregation

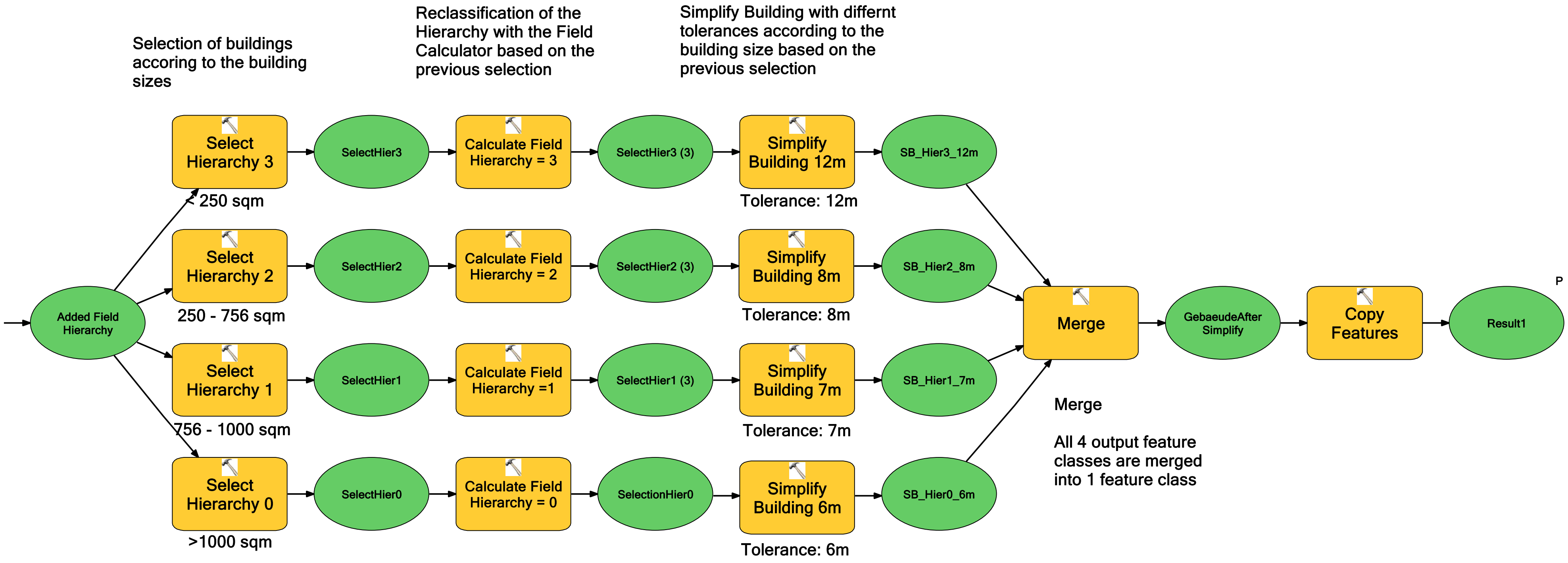
Simplify Building of all buildings

Settings:
Simplification Tolerance: 4m
Check for spatial conflicts: Yes

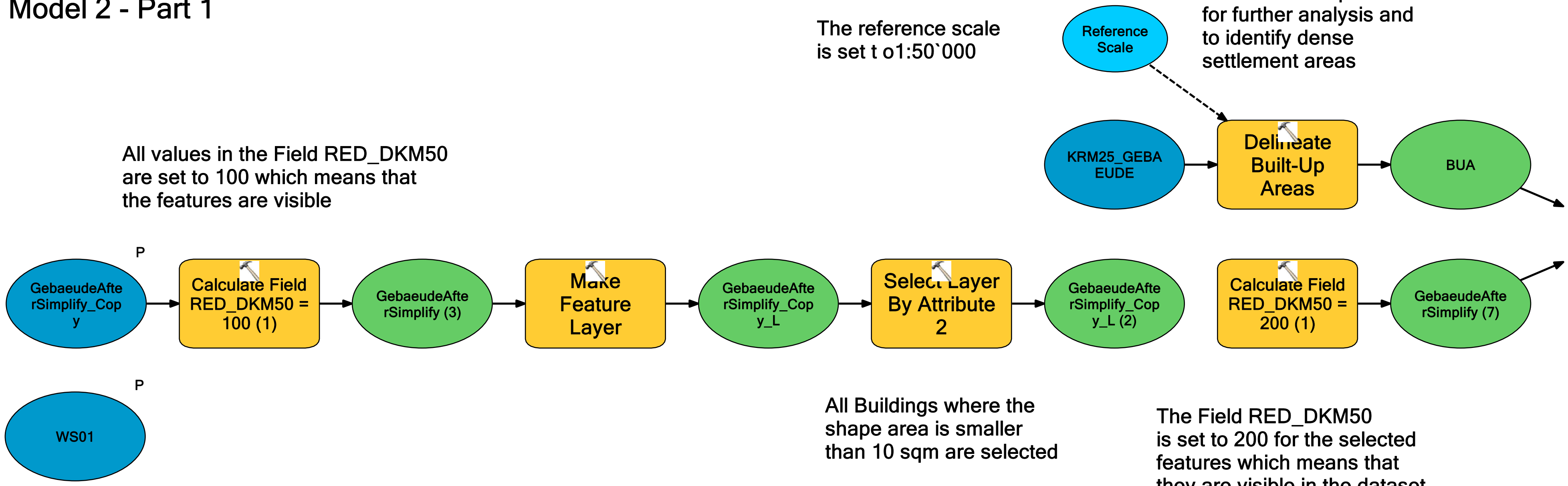
Add Field Hierarchy:

Preparation step for Selection,
Reclassification
and Simplify Building

Model 1 - Part 2



Model 2 - Part 1



All values in the Field RED_DKM50
are set to 100 which means that
the features are visible

The reference scale
is set t o1:50`000

Create Build-Up-Area
for further analysis and
to identify dense
settlement areas

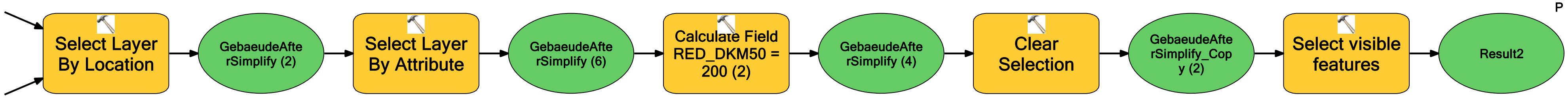
All Buildings where the
shape area is smaller
than 10 sqm are selected

The Field RED_DKM50
is set to 200 for the selected
features which means that
they are visible in the dataset

Model 2 - Part 2

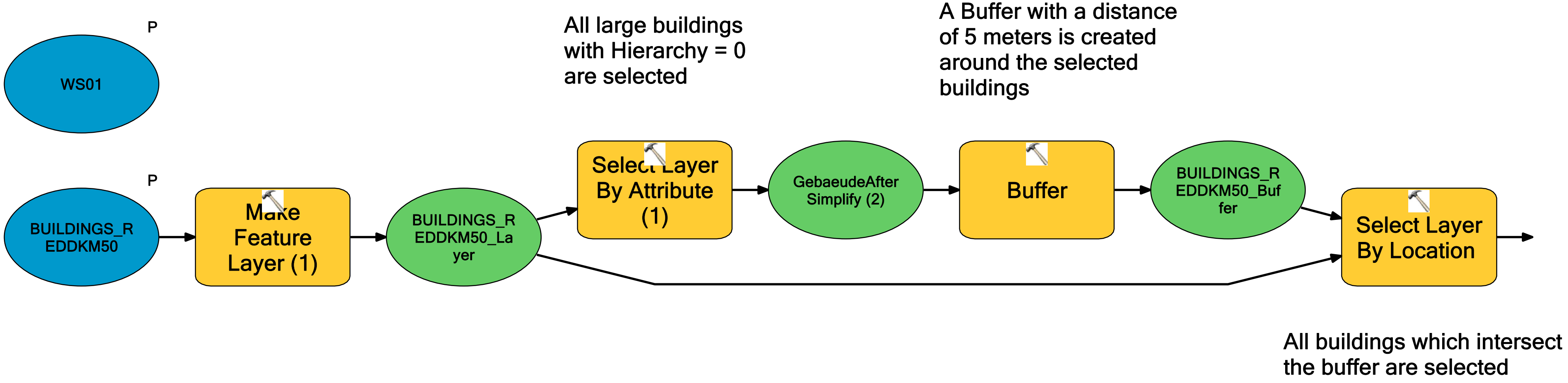
All buildings which intersect
the built-up area are selected

The Field RED_DKM50
is set to 200 for the selected
features which means that
they are visible in the dataset



A subset selection is made
on the previous selection.
All Buildings where the shape
area is smaller than 60 sqm
are removed within BUA

Model 3 - Part 1



All large buildings with Hierarchy = 0 are selected

A Buffer with a distance of 5 meters is created around the selected buildings

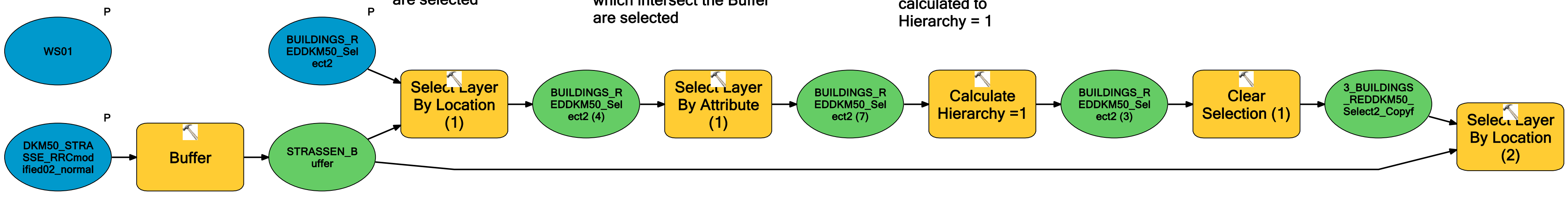
All buildings which intersect the buffer are selected

Model 3 - Part 2

A subset selection is made
on the previous selection.
All Buildings with a Hierarchy 3
which intersect the Buffer are selected

The Field RED_DKM50
is set to 200 for the selected
features which means that
they are visible in the dataset

Model 4 - Part 1



All buildings which intersect the buffer are selected

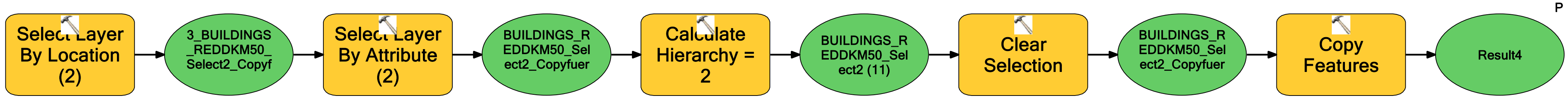
A subset selection is made on the previous selection. All Buildings with a Hierarchy 2 which intersect the Buffer are selected

The Hierarchy of the selected buildings is calculated to Hierarchy = 1

Input is the generalised road network

A Buffer is calculate arround the streets with a distance of 20 meters

Model 4 - Part 2



All buildings which
intersect the buffer
are selected

A subset selection is made
on the previous selection.
All Buildings with a Hierarchy 3
which intersect the Buffer
are selected

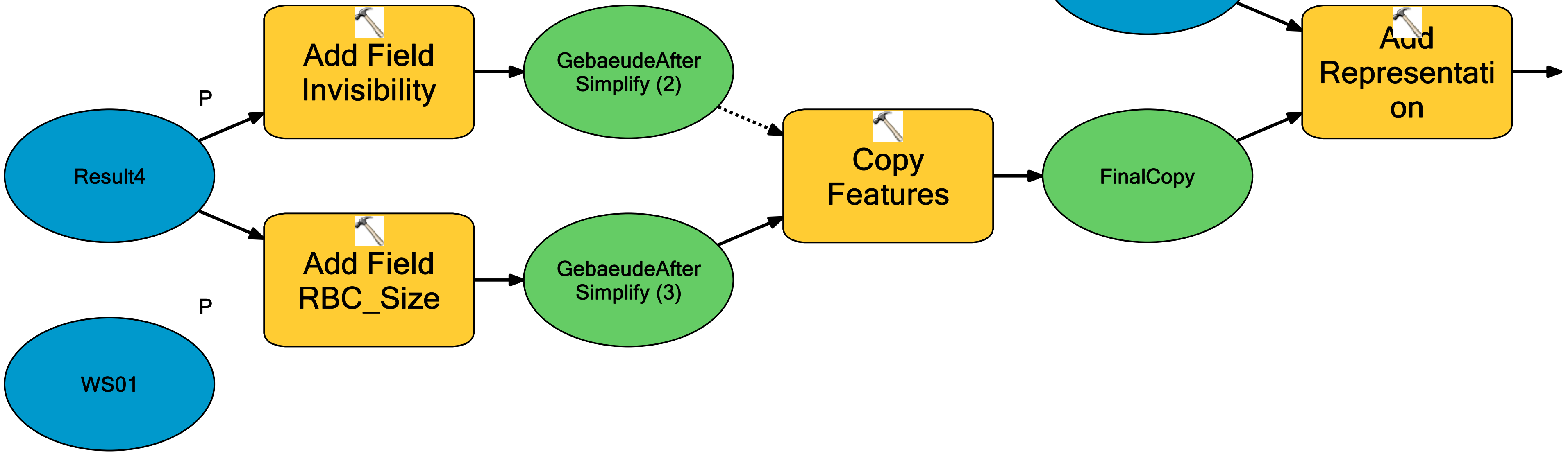
The Hierarchy of the
selected buildings is
calculated to
Hierarchy = 1

Model 5 - Part 1

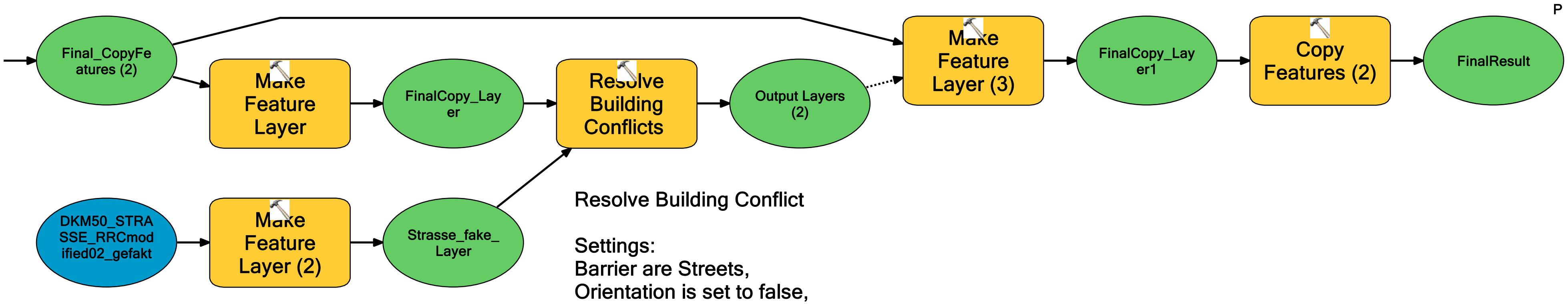
Fields Invisibility and RBC_Size are added
those are filled when the tool
Resolve Building Conflict runs

Symbology of buildings
is added

Representation is
added/created



Model 5 - Part 2



Selection Invisibility = 0 which means
that only buildins which are visible
are represented

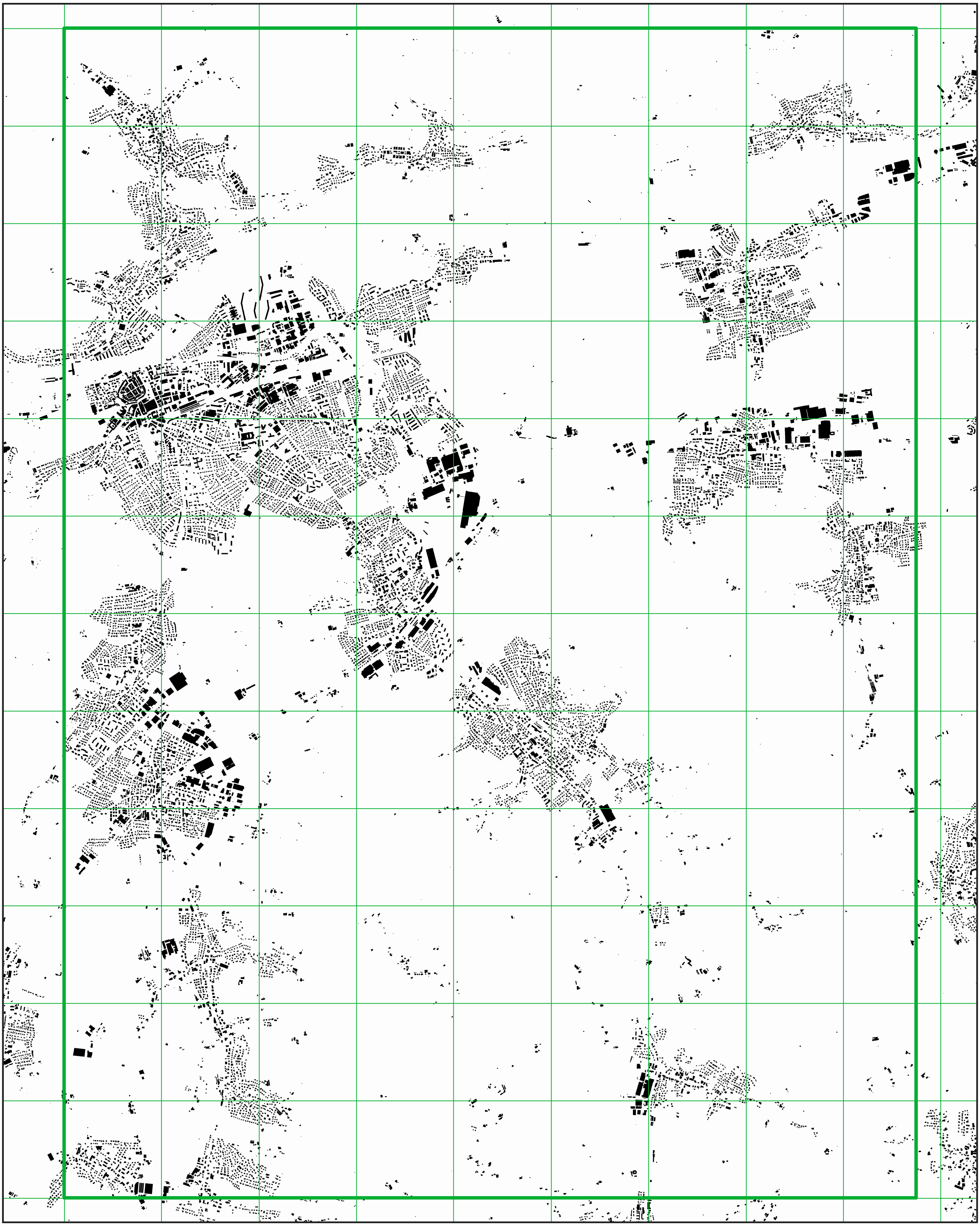
Resolve Building Conflict

Settings:
Barrier are Streets,
Orientation is set to false,
Building gap is 11,
Min. allowable building size is 20

Road class with manipulated sizes

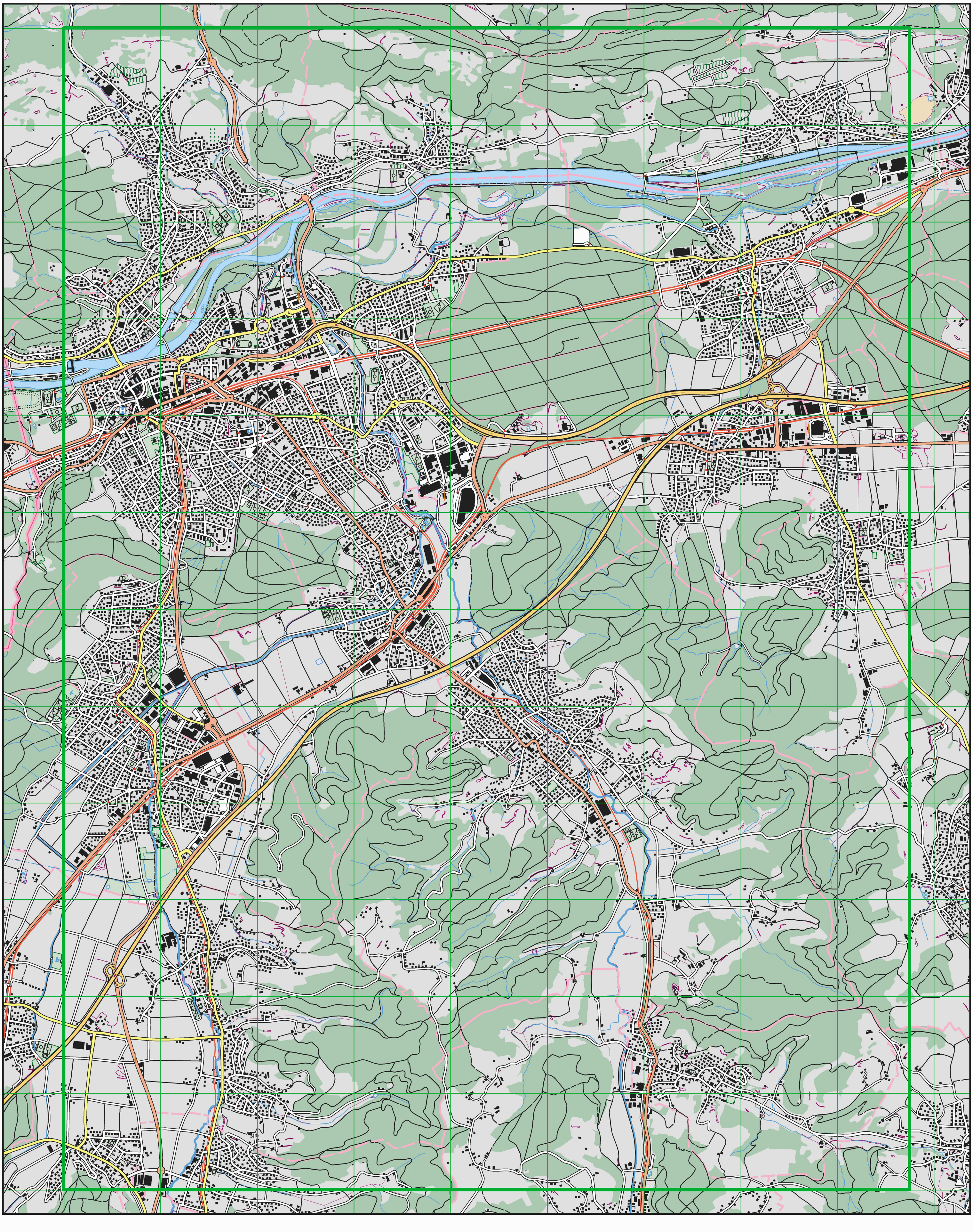
Appendix B: Ungeneralized data KRM25

swisstopo-0306, CMYK, 1016dpi
Date Saved: 31.07.2014 08:01:56
1:50'000



Appendix C: Result DKM50

swisstopo-0306, CMYK, 1016dpi
Date Saved: 13.08.2014 15:34:23



Appendix D: Questionnaire expert survey

Expert survey

Conducted by Anna Vetter, August 2014

The topic I have chosen for my Master's Thesis is "Automatic generalization of buildings whilst maintaining the existing settlement structure using Esri standard tools on the example of the Swiss national maps 1:50'000". This expert survey is an integrated part of the Thesis, through which I am hoping to gain a Professional opinion of the results achieved and provide me with a deeper insight into the quality of the workflow I have chosen.

Information to the accompanying documents:

- Appendix 1: Original data derived from the topographic landscape model (TLM) of swisstopo. Scale of capture approximately 1:10'000. Print 1:50'000.
- Appendix 2: 1:50'000 building generalization results.
  - The representation of the digital cartographic model (DCM) does not correspond to that of the final Swiss National Map! The road network has been automatically generalized but not manually revised. The building generalization was based upon the generalized road data network and any features shown in addition to the buildings should only be used to help evaluate the building generalization and are not part of the actual review!
  - All Buildings have been symbolized identically. The specialized symbolization of buildings such as churches, guest houses and buildings with single-pitch roofs are not a part of this thesis.

Information regarding the methodology of the survey.

- The original data can be used as a comparison for the generalized results
- Please evaluate only the building generalization, all other content is not part of the review.
- Please answer the questions in block 2 with either very good, good, bad or very bad.
- Block 3 contains open questions. Please mark the relevant locations in Appendix 2 and give an explanation as to why you have made this decision.
- Please return the questionnaire and all documents together with your review before the 15.09.2014. A self-addressed envelope has been enclosed.

Block 1: Initial questions

1. **How long have you been working in the area of cartography?**

2. **In which branch of cartography are you in and what is your main job?**

3. **How much experience do you have in the field of generalization?**

4. **Would you be available for further questions?**

   ☐ Yes

   ☐ No

5. **Would you like to receive a digital copy of the completed Thesis?**

   ☐ Yes

   ☐ No

   Contact E-mail Address:

Block 2: Specific questions concerning the quality of the building generalization

1. **How has the building density - the ratio between built-up and undeveloped areas - been preserved?**

   ☐ very good ☐ good ☐ bad ☐ very bad

2. **How have the relative building sizes been preserved?**

   ☐ very good ☐ good ☐ bad ☐ very bad

3. **How is the orientation of the buildings in relation to:**

   a) **Streets?**

      ☐ very good ☐ good ☐ bad ☐ very bad

   b) **Buildings?**

      ☐ very good ☐ good ☐ bad ☐ very bad

4. **How have the differences between regular and irregular building layouts been preserved?**

   ☐ very good ☐ good ☐ bad ☐ very bad

5. **Has the original extent of the settlement been preserved?**

   ☐ very good ☐ good ☐ bad ☐ very bad

6. **Has the original form of the settlement been preserved?**

   ☐ very good ☐ good ☐ bad ☐ very bad

7. **Have the minimum dimensions been preserved?**

   ☐ very good ☐ good ☐ bad ☐ very bad

8. **Have the minimum distances been observed?**

   ☐ very good ☐ good ☐ bad ☐ very bad

9. **Has the special character of the historic old town (marked in Appendix 1) been maintained?**

   ☐ very good ☐ good ☐ bad ☐ very bad

10. **Have the characteristic shapes of the buildings been retained?**

    ☐ very good ☐ good ☐ bad ☐ very bad

11. **How have the smallest details of individual buildings been generalized?**

    ☐ very good ☐ good ☐ bad ☐ very bad

12. **How do you assess the individual buildings selection for the target scale of 1:50‘000?**

    ☐ very good ☐ good ☐ bad ☐ very bad

13. **How do you assess the overall level of generalization for the target scale 1:50‘000?**

    ☐ very good ☐ good ☐ bad ☐ very bad

Block 3: General questions

1. **Which areas of the generalized result would you consider to be the most successful? Please mark these areas with green directly on the print and explain your decision.**

2. **Does the result contain areas which you would describe as problematic? Please mark these areas with red and explain your decision.**

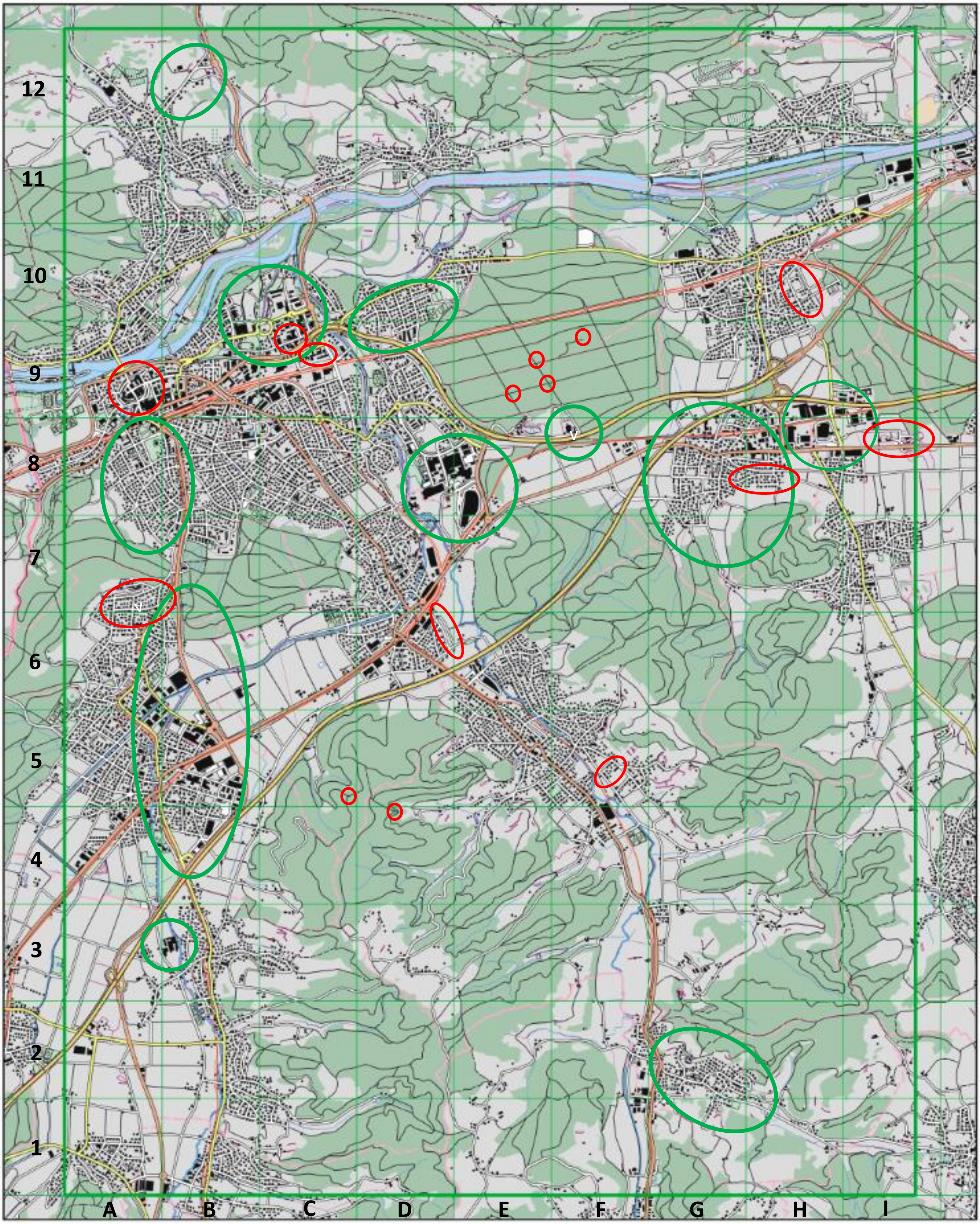
3. **Additional remarks.**

Thank you very much for your valuable time in completing this review and your help with my Master's Thesis!

Appendix E: Results Questionnaire: successful and problematic areas

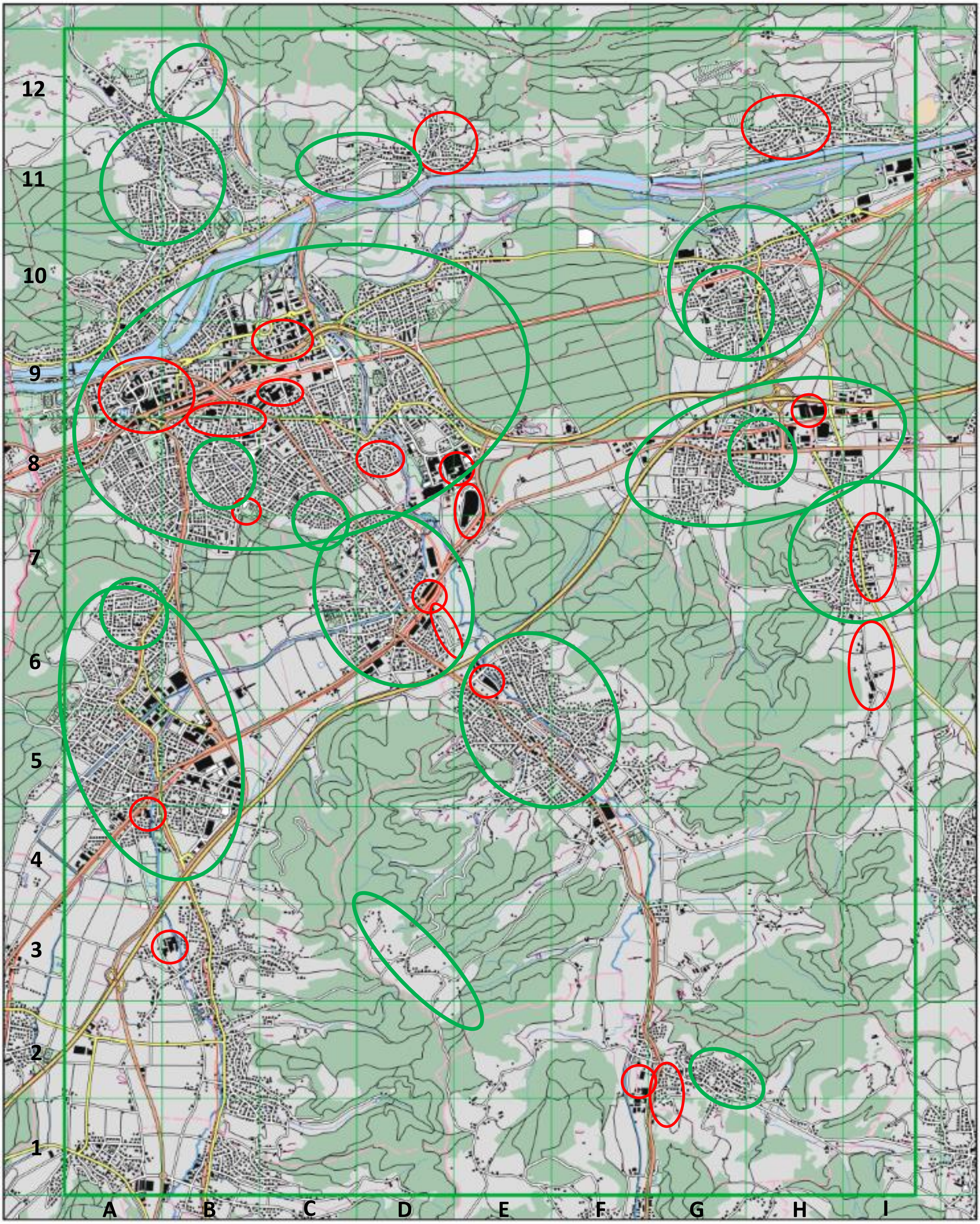
swisstopo-0306, CMYK, 1016dpi
Date Saved: 13.08.2014 15:34:23

Most successful and problematic areas by swisstopo



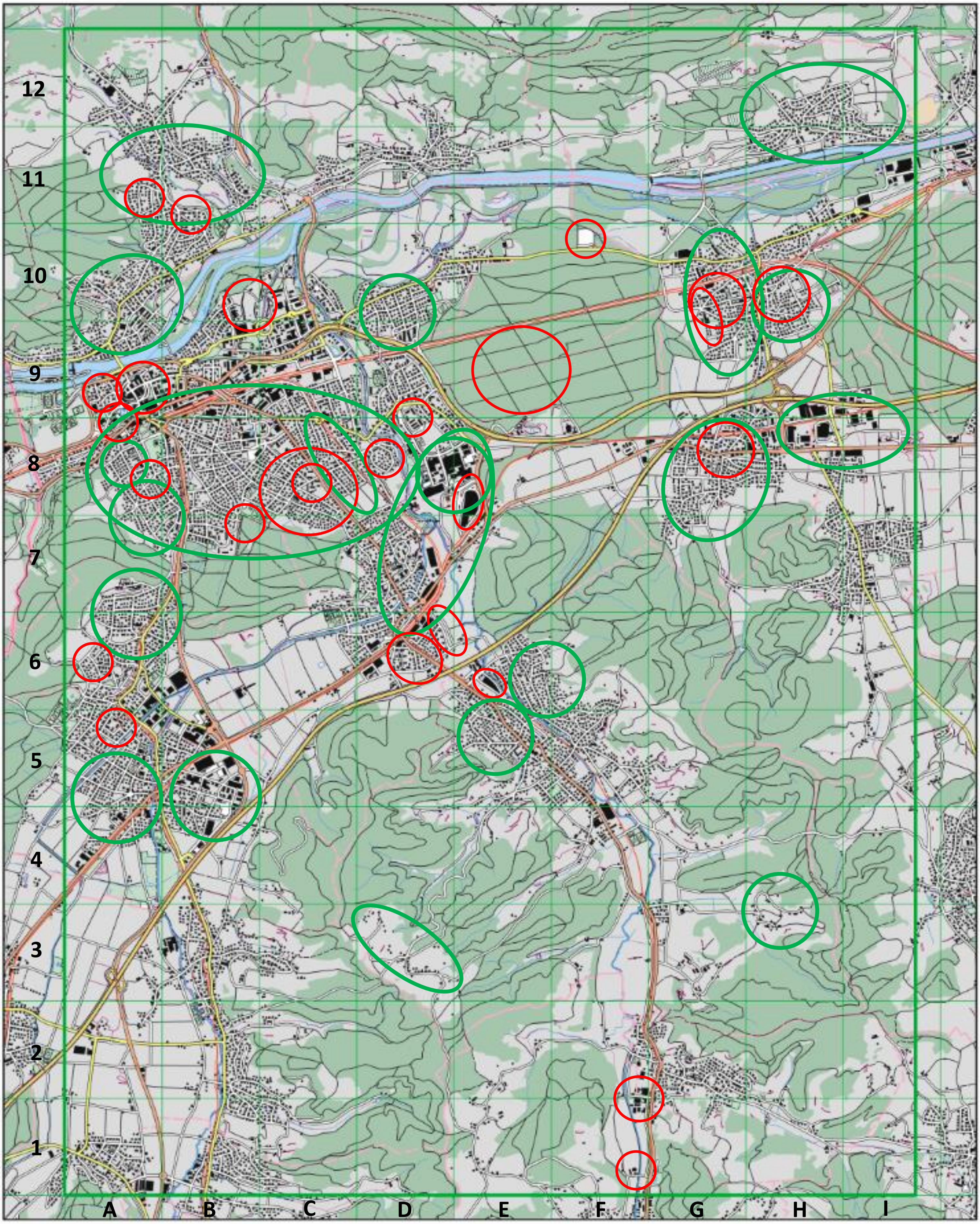
swisstopo-0306, CMYK, 1016dpi
Date Saved: 13.08.2014 15:34:23

Most successful and problematic areas by Esri



swisstopo-0306, CMYK, 1016dpi
Date Saved: 13.08.2014 15:34:23

Most successful and problematic areas by Externs



Listing of the most successful- and problematic areas with the comments of the test persons according to the questions in the expert survey and the considerations when generalising buildings

Settlement structure – Retaining density

Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
G2, G8, A8	Building density and open spaces can be interpreted well	G/H8, D6/7	Representation of the building density is well maintained. This is true throughout.	E5, F6	Not too dense single family housing zones are well generalised
D10	Black-white ratio is very good	G/H10	Maintaining the overall appearance, density	A/B/C/D8	The Density of the buildings are balanced.
B12	good density	I7, A5/6	The general density was maintained very well	General	Settlement density is very well preserved
		D3	Density well retained	General	Density of loose settlements and industrial areas is very well maintained
		General	Maintaining the overall look and feel of the density pattern of buildings	General	The settlement density is retained well.
		General	Dense areas still look dense, while the sparse areas have remained sparse		
		General	Areas of homogeneous, less dense character seemed best handled		
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	B8/9, C9	Density to sparse	A9	Density variations not well preserved
		I7	Higher density along street not well retained	A9	Building density to less
		A8/9	Character and density of historic old town lost		

Settlement structure – Preserving size differences

Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
D8 B3	Really good size relationships of buildings in industrial areas	-	-	H/I8, B4/5, D6/7/8	Good mix of different building sizes and types
B12	Consistent size relationships				
D10	Relative building sizes are very good preserved				
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	D11	Artificial look to the smallest buildings, all of the same size	A5	Difference from small to big buildings is lost
				G10	Size contrast not well preserved
				G9/10, A11	Relative size presentation of buildings not preserved
				General	Small buildings look all the same
				General	Showing size differences between very small and medium buildings is a choice. Possible to maybe distinguish only between two categories of sizes among all buildings. But this can certainly be discussed.

Settlement structure – Retaining orientation

Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	A/B/C/D11, G8, C8, E6	Relative building positions are well preserved.	H3	Clear orientation of buildings along the street

		General	Building alignment is well done	General	Orientation of buildings along the road network is very well maintained
		E5/6	Easy to still see town/road pattern through orientation of buildings	General	Orientation of buildings along the streets is very well done
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	-	-	D6	Regular and irregular orientation not well preserved

Settlement structure – Preserving regular and irregular building layouts (distribution of buildings)

Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
D10	Rows of houses are very good preserved	I7 A5/6	The general pattern of the area was maintained very well.	A8	Grid structure very well preserved
D10	Structure remains very well preserved	G2, G9/10, C7, F5/6, B8, A6/7, D3, H8	Pattern well retained	G9/G10, C8	Settlement structure very well represented
B5, C9/10, H8	very well preserved settlement pattern	A/B/C/D11, G8, C8, E6	Building distribution patterns are well preserved.	A/B/C/D8	The distribution and density of the buildings are balanced.
General	Regular settlement structures are well handled	General	Building pattern is well done	A11/B12	Overall settlement structure very well generalised
		E5/6	Maintains distribution of individual buildings and polygon buildings.		
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
F5, H8	Very homogeneous single house settlements are displayed sometimes arbitrarily	D8, G1/2:	Pattern lost	D8/9	Structure not very well preserved
A7	Houses are too arbitrary. Should be more in rows.			H10, A6	Problems with preservation of irregular/regular pattern
H10	Completely wrong picture of the distribution			C8	to uniform ground plans, too little differentiation
				C8, G8	Problem of pattern recognition due to missing relative size and irregular/regular pattern preservation.

Settlement structure – Preserving settlement extent

Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	G/H8, D6/7	Representation of the overall built-up area footprint is well maintained. This is true throughout.	General	The extend of the settlement is very well preserved
				General	Extent of settlement is corresponding to the scale from which it is generalised
				D9/10 H/I12	Good overall representation of the area. Original extent is depicted very well.
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	-	-	-	-

Shape generalisation – Preserving form (main type)

Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	-	-	General	The form of the settlement is very well preserved
				General	Form of settlement is corresponding to the scale from which is generalised

				D9/10, H/I12	Good overall representation of the area. Original form is depicted very well.
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	-	-	-	-

Shape generalisation – Preserving the special character of settlement (e.g. historic old town)

Area	swisstopo	Area	Esri	Area	Extern
D3	The street village character comes out very well	A/B/C/D11, G8, C8, E6	medium and small building areas are generalized well because they are showing adequate typification and exaggeration	B4/5	Very good preservation of industrial areas
D10	Settlement character is very well reproduced in this area			General	Most of the town areas are professionally generalised
				D3	Scattered settlement and street village are very well preserved
				B4/5, H/I8, D/E8	Good generalisation of areas with large buildings – character is retained
				A6,7, A7/8, H9/10	General single house representations are represented very well
				General	The results are overall really good both for the generalisation of the single buildings as for the generalisation of big settlement areas. Linear structures retain remarkable good.
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
A9	character of historic old town is lost, hand editing unavoidable	A9	Within the historic old town to much character lost due to the roads!	A8	Neighbourhood outside the historic old town difficult to recognise
		A9	Historic centre, buildings overlapped by roads	A9	Character of historic old town is lost, hand editing unavoidable, roads destroy the character of the historic old town as well.

Shape generalisation – Retaining characteristic building shapes

Area	swisstopo	Area	Esri	Area	Extern
B5 B6	Really good generalisation of the very large buildings	General	Maintaining large building shapes	A9/10 G8 A4/5	Characteristic of buildings are very well maintained.
C9/10	Structures of the big buildings are preserved very well			B4/5	Industrial buildings are very well retained
F8	Building complex very well generalised			General	Large building shapes are very well preserved
General	Large building complexes are well handled				
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	H9, A4	Large building boundaries could be simplified more	E6/8	Rectangular houses should not have curves after generalization, unacceptable change in shape
		D8	Separation of buildings not maintained	F1	Building with hole inside not recognisable, generalised wrong
				E8	The generalized shape is not desirable
				A9	No inner courtyards represented at the historic old town buildings (to similar to other big buildings)

				F1/2	Characteristic of the large buildings is lost
				General	Generalization of large buildings is too less
Shape generalisation – Generalisation of smallest building details					
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	-	-	-	-
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
C9, I8	Smallest details of buildings to less generalized which generates unrest und is badly interpretable	C9, B3	Details of some large buildings can be further generalized	General	Large buildings have too little generalisation. Small extrusions or recesses have not been removed or completed to produce more squared generalised buildings.
A9	Smallest details to less generalized within the historic old town			General	Larger generalization degree for large sized buildings recommended (applying aggregation and simplification more often.
				A9	details to less generalized within the historic old town
				General	Small details of buildings are to less generalised
Graphic generalisation – Preserving minimum dimensions					
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	-	-	A9/10, G8 A4/5	Minimal dimensions are very well maintained.
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	-	-	B10	Buildings to narrow
				A8/D8	Minimal dimension not preserved
				General	Sometimes bigger buildings appear to small (due to the fact that they could not shifted away or are partly overlapped by road symbols)
				A9	Minimum distances are not observed within the historic old town
Graphic generalisation – Preserving minimum distances					
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
D10	Spacing between buildings is very well preserved	General	Building spacing is well done	General	The minimum distances are for these scale very well.
				A6/7, A7/8, H9/10	General single house representations are represented with preserving the minimum distances
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
A9	Minimum distances are not observed within the historic old town	A9	Minimum spacing between large buildings not always met	-	-
		A9, E8, D7, E6, H9	Buildings are drawn under the road and due to that the minimum distances are not preserved		
Selection of buildings					
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**
-	-	I7, A5/6	Very good generalisation. Larger, distinct buildings were maintained and although the buildings, especially the smaller ones, were thinned.	General	The rural areas are most successfully generalised (partly because the generalisation decision is relative simple there, only the selection is activated)
Area	**swisstopo**	**Area**	**Esri**	**Area**	**Extern**

D6	Loss of buildings within the two roads	D6	Row of significant buildings missing	F10	Big building have disappeared
D5, E9	Buildings are completely lost	B8	Significant building missing	E9	Small buildings have disappeared
General	Sometimes too many buildings are represented. Especially buildings outside of the settlement area.	F2	Large buildings are missing	D6	Buildings have disappeared
		General	Buildings at corners of street intersections are often eliminated in the generalised result which makes it more difficult to recognise and orient. Corner features are very important features to preserve!	F1	Industrial buildings generalized missing, significant issue that large building is missing
		H11/12, I6	Area seems overgeneralized (too much selected/eliminated?)	B7	Missing building
				General	Sometimes big buildings are eliminated completely
				B11	To many buildings selected/eliminated

General comments

swisstopo	Esri	Extern
The overall results are very good and a promising basis for further development	Very successful result using automated tools for building generalisation	Overall the results are promising and appears to give an acceptable building output for the use in the Swiss national map.
Overall a really positive result. It would still be worth to compare the TK50 to the generalised results. That is what the customers perceive. How has the picture changed, is that bad or acceptable for the customer?	At this scale, what is the purpose of the buildings? On a map of this scale the buildings define the urban area of cities, and draw attention to the centre of the towns. The generalised buildings produced satisfy these user requirements.	Interesting and encouraging result obtained by the automated generalisation
The research and results are very promising	Overall result very good	The generalisation of buildings is very well performed with tools from ArcGIS
Even when there are negative points the overall result is good to very good. It is encouraging to see what is possible already with an automatic generalization.	This is an interesting and valuable study. The feedbacks would be very helpful to further enhancements of the automated generalization	
Overall a really encouraging result	The overall automatic generalization from 1:10`000 to 1:50`000 seems a bit on the conservative side, but the result seems mostly acceptable even with a few imperfect areas, which is expected. Manual editing would be necessary in a few key areas.	

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Declaration of Originality

I hereby declare that the submitted master thesis entitled **"The automatic generalisation of buildings whilst maintaining the settlement structure: A case study based on the 1:50‘000 Swiss National Map Series"** is my own work and that, to the best of my knowledge, it contains no material previously published, or substantially overlapping with material submitted for the award of any other degree at any institution, except where acknowledgement is made in the text.

Zürich, 28. November 2014

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