THE USE OF REMOTE SENSING AS PRIMARY DATA TO ASSESS POST-DISASTER URBAN RECOVERY

ALEXANDRA COSTA VIEIRA

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SUPERVISORS:

Dr. N. Kerle

Ms. M. Kuffer, MSc

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ALEXANDRA COSTA VIEIRA

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SUPERVISORS:

Dr. N. Kerle

Ms. M. Kuffer, MSc

THESIS ASSESSMENT BOARD:

Dr. R. V. Sliuzas (Chair)

Dr. A. D. Hunka (External Examiner, University of Twente)

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ABSTRACT

Post-disaster urban recovery is a complex process that requires quick and systematic collection of information, to support stakeholders and decision makers to answer important questions addressing quality, speed and characteristics of recovery. The collection of necessary information to asses might be a challenge in post-disaster situation, due to poor accuracy of maps and blockage or lack of access to reach the affected area. Additionally, the absence of a comprehensive recovery framework causes people to work independently of each other and in different sectors of recovery. Finally, stakeholders and decision makers face challenges when planning and coordinating actions with limited resources.

Therefore, the main goal of this research is to assess post-disaster urban recovery by making use of geospatial data, in particular remote sensing. This study makes three primary contributions towards that goal. First, it investigates the literature for different indicators and variables (that are not only physical); identify important issues and ways they can be addressed in different sectors of society; and discusses the choices among the alternatives and approaches to measure recovery. Second, recovery is conceptualized through a geo-informatics context to support planners and stakeholders in monitoring and assessing recovery. Finally, the firework disaster that happened in May 2000 in Enschede, The Netherlands was used in as a case study to test indicators and features that could be extracted from geospatial data and remote sensing by the use of landscape metrics and GIS tools. The methods are tested examining high resolution aerial imagery from a time period of approximately 10 years. Although due to time constraints and data limitation, existing vector datasets (building footprints and road network) were adopted.

The analysis was structured broadly into two major parts. The first part measured two indicators from the built up sector: change in building morphology and road network. The first indicator is used to quantify changes in the total built-up area, average building density, shape and size. The second indicator is used to analyse the concentration of roads in an area. This measure can indicate how and where the road system modified the space. The second part measured the environmental sector using the indicator energy loss as a proxy variable to measure quality of housing.

Results indicate increase in density and urbanization, improvement in network function (traffic circulation and street connection) and change of urban function (now there is a presence of mix of uses; residential, home-business, commercial, etc.) indicating that the area is striving for a vibrant and attractive urbanity. More importantly the results showed that the use of remote sensing, landscape metrics and GIS analysis can support planners in the coordination, monitoring and assessment of recovery with information that goes beyond the use of physical features.

Keywords: recovery, remote-sensing, long-term reconstruction, landscape metrics, indicators.

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Alexandra Costa Vieira

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1. INTRODUCTION

1.1. Justification

A disaster is an interruption of a society, resulted by a hazard in combination with vulnerability conditions and low capacity to reduce negative consequences of risk. It causes major losses that surpass the ability of the affected people to cope using their own resources (UNISDR, 2011). Many researchers have studied disaster events through a continuous disaster cycle that is based on four components: mitigation, preparedness, response and recovery (Coppola, 2006).

In general recovery is seen as a process to restore a post-disaster situation, bringing back the community to a level of life acceptability (can be the same level as the pre-impact or not). Haas (1977) described recovery as predictable and ordered. More recently Coppola (2006) stated that recovery is a complex process that follows the emergency phase of a disaster. There are controversies in the literature about the definition of recovery, when it starts or ends and which phases are involved in the process. But, recovery is now seen as a dynamic process with no clear end point (Brown, Platt, & Bevington, 2010).

Although recovery is necessary and important for people's safety and wellbeing, and for planning purpose, it is considered the least understood phase of the disaster management cycle (Chang, 2010). This is because various roles involved in the recovery phases overlap, and interact with each other due to socio-economic and political aspects (Brown, Saito, Spence, & Chenvidyakarn, 2008).

According to Jha, Barenstein, Phelps, Pittet, and Sena (2010) reconstruction starts when a disaster happens. Thus, decision makers need to act quickly to define policies and get together with stakeholders to define reconstruction plan and necessary funds. But reconstruction is only a part of many other critical activities of the recovery process, such as the recovery of functions (residential, commercial, health, education, etc.).

The built up environment impacts social interactions and opportunities that may affect the disaster recovery rate (Carpenter, 2012). For example, a residential area can be totally rebuilt, but if there are no jobs or business to attend that population, residents would resist going back to the reconstructed area. Consequently, in this example, recovery would not be totally achieved once reconstruction is ready.

Measuring post-disaster urban recovery involves a complex integration of physical, social, economic, environmental and political aspects. Therefore, recovery is not easily capture by some existing methods such as: ground surveys, investigative interviews, census data or manual and semi-automatic computer programs (Rathfon, 2010). There is a need for measures that can be rapid applicable and transferable (Brown et al., 2010). However the desire for a systematic approach poses some limitations, once data are not always available or at consistent level of reliability across regions and time frame (Rathfon, 2010). Another challenge is the distribution of accurate information to the proper group of user at the right time (Sweta & Bijker, 2013).

Recovery process requires great financial support, project coordination and it might take years to be completed (Rathfon, 2010). The assessment and monitoring of recovery process are crucial to aid agencies, to promote transparency to the process and to ensure civil rights. It also helps decision makers and stakeholders to answer important questions addressing quality, speed and characteristics of recovery that can be used for risk mitigation and planning support (Brown et al., 2008).

The potential users involved in the recovery process vary depending of the type and level of disaster (Sweta & Bijker, 2013). Users who benefits of recovery information are planners (government and coordinating agencies), researchers (universities, institutes and research companies) and NGOs agencies. According to Sweta and Bijker (2013), planners are users present during all the phases of recovery and are responsible for the decision making and support during the different phases of recovery. The researches can use the products of this analysis to understand the event and to provide information to explain it. Finally, users from agencies as NGOs can have access to information about the infrastructure, transport, residential, etc. This type of information can be used to operate in the areas on their activities and to inform the community.

There are different methods to provide post-disaster recovery information for all different users. One of them is the use of remote sensing that has been widely used for change detection in a time series analysis to assess hazards. However, there are only few examples in literatures that explore its use to assess post-disaster urban recovery. To illustrate, Guo et al. (2010) used airborne optical images acquire during 3 years after the Wenchuan Earthquake, to assess and monitor restoration and reconstruction in the affected area. A visual interpretation and image pattern recognition was used to calculate the house collapse ratio. The results of the image analysis were used to support consultative services and decision makers. But the authors concluded that recovery analysis requires faster processing for multi-level remote sensing data, and the development of quantitative analyse technique for comparison.

In other hand, there are more literatures related to the measurement of urban form, using remote sensing, that could be implemented in a recovery assessment. For example, Hagelman, Connolly, Zavar, and Dahal (2012) used remote sensing imagery to perform a post-classification comparison to assess morphological changes of the town Greensburg, Kansas after a tornado. They detected urban expansion and changes in the footprint of the city, after the disaster event, which caused reduction of business number and a high percentage of business that changed location or type during the period of recovery. Urban form are features of development of an urban area (Zhang & Guindon, 2006) and comprises physical and non-physical aspects as: density, land use (residential, commercial, open spaces), transportation, building types, etc. (Jenks, 2009). Theory of urban form are part of a post-disaster event, because it can characterize urban structures, providing information on socio-economic aspects and supporting the understanding of the processes behind a post-disaster recovery that influences the city as a whole.

Remote sensing is a potential tool to map and monitor urban form and estimate socio-economic data. Satellite imagery as IKONOS, hyper-spectral sensors, Quickbird, Geoyey and Worlview-2 provide detailed and accurate data from urban areas at different spatial temporal scales (SIC, 2013). The strength of remote sensing relies on the consistency of data sets and the possibility to cover larger areas, with high detail and temporal frequency and historical data series. But generally the studies had focus in the physical aspects of recovery, for instance, in the detection of losses and reconstruction of structures (residential, commercial, industrial, infrastructure and services). The physical recovery is usually easier to detect and measure (Lindell, 2013). However to classify the complex urban systems from high resolution imagery is a challenge, due to their spectral and spatial heterogeneity (Taubenböck, Esch, & Roth, 2006).

This study provides a framework of disaster recovery and aim to assess the different types of recovery using geospatial data and remote sensing. At the moment there is no known standard remote sensing method to evaluate disaster recovery. However, landscape metrics and GIS Tools are examples that can be used to quantify and assess recovery in multi-temporal images.

Also objected-oriented analysis can contribute with a classification of an image object (extracting contextual information), rather than only pixels information (Bhaskaran, Paramananda, & Ramnarayan, 2010). The use of remote sensing combined with landscape metrics and GIS applications provides detailed information on urban structures and change. In addition, it improves map accuracy and facilitate the analysis of urban applications (Herold, Couclelis, & Clarke, 2005).

Nevertheless, there is a demand from planners and decision-makers to have up-to-date information. They require spatial and temporal information, not only from physical structure aspects, but a complete understanding of how the urban areas are changing, for the implementation of policies. Also, what are the resulting spatial-temporal and human-environment interactions that influence post-disaster urban recovery process (Blaschke, Hay, Weng, & Resch, 2011).

1.2. Research problem

After a disaster event, there is great pressure to governments to act quickly to rebuild communities, reduce risk and restore permanence. This urgent act to take difficult decisions can result in policies that might increase long term recovery and vulnerability of the affected people (Ingram, Franco, Rio, & Khazai, 2006).

In addition, a lack of comprehensive recovery framework and characterization of its different types make it difficult to assess recovery. Consequently, to monitor and identify the changes that happen in the space in a post-disaster situation becomes difficult for stakeholders and decision makers. In many cases the information needed to provide shelter, to assess people’s needs and to calculate the aftermath of the disaster may be limited by lack of access to roads, blockage of bridges, etc. In addition, stakeholders and decision makers face challenges when planning and coordinating actions with limited resources.

Post-disaster recovery phases, aim to re-establish the living conditions of the affected community. However, these phases can take many years. Remote sensing in combination with landscape metrics and GIS tools can be used to provide information about the physical damage, urban change processes, monitor reconstruction and trend analysis. Current technological developments have made geospatial information, especially remote sensing data, more accessible to users. Also, the output results have increased in quality and accuracy (Sweta & Bijker, 2013).

The assessment of post-disaster urban recovery is significant for the development and planning of a city or region. It provides information on how land use changes, how cities organize the urban space and creates opportunities for planning. Finally, it can provide information about how the recovery planning is being conducted, if the polices and reconstructions are being executed according to the proposed plan.

Therefore, the main problem discussed in this study is how remote sensing methods could be applied to measure variables that can explain the recovery process beyond the physical aspects?

1.3. Objectives

1.3.1. Main objective

The main objective is to assess post-disaster urban recovery employing elements of urban form, using geospatial data, in particular remote sensing techniques.

1.3.2. Sub objectives

1- To identify variables (that are not only physical) and features of urban forms that can be used to assess post-disaster recovery;

2- To create a conceptual framework of recovery;

3- To assess urban recovery using geospatial and remote sensing data;

4- To interpret recovery in terms of metrics and descriptors, and if those are accurate and true.

1.4. Research questions

This section shows in table 1 the research questions that will be addressed in this research according to each sub-objective.

Sub objective	Research questions
1	Which indicators or remote sensing based proxies can be used to describe recovery in terms of urban form and function (transport, economic, residential, etc.)?
	Which are the recent methods and tools used to describe and quantify recovery?
2	Can recovery and its different types and aspects be conceptualized though a geo-informatics context?
3	Which are the indicators, variables and data needed to assess post-disaster urban recovery?
	Can geodata based approaches characterize the complex recovery process, in a way that goes beyond the focus on physical features?
4	Can we test reliability of methods and results of the assessment of the case study: Firework disaster, using data derived from statistics, reports and current recovery plan of the study area?

Table 1 Research questions according to each sub-objective.

1.5. Expected outcome

Under ideal conditions, such as: participatory planning approaches, availability of funds and government support, it is supposed that post-disaster recovery will follow a plan. In the case of such conditions, the use of landscape metrics and remote sensing imagery methods should provide the basis to quantify variables that can characterize recovery and functions. The results derived from the variables measurement should be also useful to identify the different status of recovery development, which are: have not changed after the disaster, recovery led to a progress that increased or decreased development of the area.

1.6. Outline of thesis

This research is divided in 8 chapters and below a short outline per chapter is given.

Chapter 1

This first chapter introduces the main concepts of the research, the motivation for the topic, main problems, objectives and research questions and expected outcome.

Chapter 2

This chapter presents a conceptualization of post-disaster urban recovery, and its different types and aspects based on literature review. The overall theories and frameworks will be discussed in this chapter, including definition; components of recovery; a discussion of the recovery phases and differences between recovery and reconstruction. Section 2.4 will explain and describe the different types and elements of urban form. Also, how they can describe recovery process and be measured. And section 2.5 will discuss the previous attempts to measure recovery, the indicators and approaches. Based on information of the literature review the first sub-objective and the following research questions will be answered: I) which indicators or remote sensing based proxies can be used to describe recovery in terms of urban form and function (transport, economic, residential, etc.)? and II) Which are the recent methods and tools used to describe and quantify recovery?

Chapter 3

This chapter presents a recovery framework, its conceptualization and different types and aspects, through a geo-informatics context. The outcome of chapter 3 is a conceptual framework of recovery that fulfils the sub-objective 2, and the research question: Can recovery and its different types and aspects be conceptualized though a geo-informatics context?

Chapter 4

This chapter introduces the case study: a firework disaster in the neighbourhood of Roombeek, in the city of Enschede, the Netherlands. A brief description of the firework disaster and characteristics of the area is given. Also this chapter will investigate the disaster event that happened in the region and their inter-relations with the surrounding neighbourhoods.

Chapter 5

This chapter describes the method used to measure neighbourhood recovery, the sectors addressed and indicators. This chapter discusses the third sub-objective and answers the research question: which are the indicators, variables and data needed to assess post-disaster urban recovery?

Chapter 6

This chapter will discuss the results from the image processing and analysis of chapter 5. This chapter also addresses the sub-objective 3 and answer the following research question: can geodata based approaches characterize the complex recovery process, in a way that goes beyond the focus on physical features?

Chapter 7

This chapter presents the discussion of the results, verifying if the variables and methods used are accurate and true. This chapter uses reports, statistics data and the actual recovery plan of the area to prove the results veracity. In addition this chapter discusses the sub-objective 4 and answer the research questions: Can we test reliability of methods and results of the assessment of the case study: Firework disaster, using data derived from statistics, reports and current recovery plan of the study area?

Chapter 8

The final chapter of this thesis summarize the key conclusions, discussed the limitation encountered in this research and gives suggestions for future work.

2. UNDERSTANTING POST-DISASTER URBAN RECOVERY

2.1. Definition of recovery

In the existing literature, recovery has many definitions and different interpretations. This makes it difficult to fully comprehend the process and find agreement with an integrated and systematic framework. There are limited numbers of theories that explain recovery, compared with other phases of disaster management cycle (mitigation, response or preparedness). The assessment of recovery lack knowledge about how to exactly describe the characteristics of recovery and how it could be measured (Ruiter, 2009).

Definition of recovery is generally used in the sense of restoring the affected community to pre-disaster level as soon as possible. However, if assumed that recovery must restore the community to its previous condition; it would reproduce its previous vulnerability state (Lindell, 2013).

In the late seventies, Haas (1977), presented in his work a recovery framework containing four stages: I) emergency period, II) restoration period, III) replacement reconstruction period and IV) commemorative, betterment and developmental reconstruction. The three last stages would last approximately ten times longer than the first stage. This theory received many critics, due to assumptions that the sequence of events and process to recover is ordered by activities and occurs in regular time and space, instead of recognizing recovery as a process that contains uncertainties and its outcomes are influenced by socio-economic and political aspects. Recently recovery is seen as multidimensional, complex and non-linear process (Chang, 2010). Recovery phases comprises of many activities that can be implemented sequentially or simultaneously (Lindell, 2013). These phases may overlap and interact with each other and recovery is seeing as a process with no clear endpoint (Brown et al., 2008).

Recently definitions of recovery have focused on restoring and improving pre-disaster living conditions of the affected community, as well as encouraging people's participation in the process to facilitate necessary adjustments to reduce risk and vulnerability (Ruiter, 2009). Khan and Sayem (2013) argue that recovery involves more than the reconstruction of the physical environment. In conclusion, recovery process should address the impacts of disaster faced by the people (communities, organizations, families, government, etc.), the impacts on the physical infrastructure and natural system. As well as how these sectors would recover along time. This definition follows the principle of sustainability and also includes in the analysis socio-economic factors.

Disaster provides opportunities for a sustainable development. Community changes continuously, thus return to its previous situation is also not realistic. This is why decision makers and stakeholders should think about the speed and quality of recovery and include sustainability aspects (Rathfon, 2010). A sustainable recovery goes beyond repairing and reconstruction of the physical space, but it contributes also to reduce risk and vulnerability. Sustainable recovery should certify that future generation will not suffer by recovery efforts. Also recovery should leave room for technological improvements, increase of information and awareness. In addition recovery should promote accessibility and mobility, ensure building liveability and restore livelihoods (UNDP, 2011).

2.1.1. Short-term and long-term recovery

Recovery process comprises of many activities that acts in different aspects of the society. Many literatures divide the recovery activities into phases, sometimes with specific time length to start or end. However, due to the dynamic aspect of recovery Brown et al. (2008) state that the use of phases might simplify the process and mask in reality how some of these activities and aspects interact and overlap with each other. However, other authors argue that the knowledge of the activity and when it occurs is important to inform planners and decision makers (for pre-disaster mitigation actions), and to follow other actions during the recovery process. Also, the knowledge about phases and activities might help to identify the individual needs and explain variations across disaster and communities. For instance, to know which type of disaster may prolong the long-term phase and which type of community tends to recovery faster (Chang, 2010).

Although there is little agreement about the number and description of recovery phases, Lindell (2013), gives a good example of recovery process. Table 2 gives an overview of the many activities that are involved in the recovery process. The phases comprise many activities and can also happen in different times or simultaneously, it is divided in four phases: disaster assessment, short-term recovery, long-term reconstruction, and recovery management.

Disaster Assessment

- Rapid assessment
- Preliminary damage assessment
- Site assessment
- Victims' needs assessments
- "Lessons learned"

Short-term recovery

- Impact area security
- Temporary shelter/housing
- Infrastructure restoration
- Debris management
- Emergency demolition
- Repair permitting
- Donations management
- Disaster assistance

Long-term reconstruction

- Hazard source control and area protection
- Land use practices
- Building construction practices
- Public health/mental health recovery
- Economic development
- Infrastructure resilience
- Historic preservation
- Environmental recovery
- Disaster memorialization

Recovery management

- Agency notification and mobilization
- Mobilization of recovery facilities and equipment
- Internal direction and control
- External coordination
- Public information
- Recovery legal authority and financing
- Administrative and logistical support
- Documentation

Table 2 Recovery and reconstruction after disaster. Retrieved from (Lindell, 2013).

Disaster assessment should be part of the emergency response phase, because it will identify the damage impacts and act in the victims' needs as first activity. The short-term recovery focus on the immediate relief activities as securing the area, provide shelter and try to restore the "normal" community conditions (in terms of basic needs and infrastructure) (Lindell, 2013). One of the challenges in a large scale disaster is finding temporary shelter for many displaced families. This activity is important to give sense of security and safety to the population. Another important aspect is the restoration or rehabilitation of critical infrastructure, once population will require the continuity of good services as access to roads, water, sewer, public lighting, etc. Short-term recovery is the precursor to long-term recovery, the stability of infrastructure and services will lead to opportunity to development. The unconsidered development of short-term recovery may cause negative effects to long-term and influence the quality and speed of the process (Carlton, 2012).

Long-term recovery phase includes the reconstruction of the area and the social, psychological, demographic, economic and political impacts caused by the disaster. Residents will want amenities (groceries shop, banking centre, post offices, etc.) and other services to go back to its common routine. For a successful long-term recovery it is necessary to design a good planning strategy, significant amount of coordination and implementation of policies (Coppola, 2010).

During the long-term process changes in the environment are unavoidable. Recently, literature provides numerous researches that express the concern of stakeholders and decision makers about the speed and quality of recovery. Their concerns are related to issues for a sustainable development, economic growth, social inequalities and environmental resources. In the work of Carlton (2012) the new urbanism theory is introduced in the long-term recovery as a method to minimize these concerns. This theory is based on principles of sustainability, quality of life, smart transportation, etc. These new ideas come to reform the built environment, develop community sectors and providing quality of life (Elshater, 2012).

In the final phase recovery management has the following objectives: the administrative coordination of the other recovery phases, their activities and resources to achieve them. As well as provide outcomes to risk mitigation actions (Lindell, 2013).

2.2. Differences between recovery and reconstruction

Reconstruction and rehabilitation are part of the recovery process. Recovery in addition encompasses also non-physical aspects, as for instance: promotes security and safety, wellbeing, health care, engage psychological support for the people affected, etc. Also recovery activities comprises recovery of economy, business and many other socio-economic and political aspects that are not part of the reconstruction activities (Chang, 2010).

Rehabilitation can be considered as a transition phase between short-term and long-term phase. It focusses on assisting victims to repair physical damage, in order to stabilize systems to prevent second damage as fire due to leak of gas or structure collapses. After that the attention are driven to rehabilitate communication links, transport network, community infrastructure facilities, and rehabilitation of settlements (UNDP, 1993). These activities are important to enable the community to return to its normal activities.

Reconstruction is part of the long-term phase and encompasses the full reconstruction of all services, local infrastructure, housing/buildings and replacement of damaged physical structures (UNDP, 1993). A successful reconstruction requires planning and extensive coordination of the activities (Jha et al., 2010).

In this research, reconstruction will be investigated to provide indicators to assess post-disaster recovery using remote sensing as primary data source. Managing reconstruction as part of the long-term phase includes planning and implementation of policies. Some tools used in reconstruction phase are: regulations (land use control), building codes and program standards (technical construction assistance to people affected by disaster). Also, social policies as: self-resilience, empowerment (reconstruction in local level, with people participation), equity and relocation (TCGI, 2004).

Due to project complexity and long time to rebuilt critical infrastructure, the reconstruction of houses might take place earlier than infrastructure. Thus, it is common that some interventions need to be made to provide minimum standards for basic services for the population in the affected area (Jha et al., 2010). Many displaced residents will consider the availability of services to attend their everyday needs, before decide to return to their pre-disaster locations (Carlton, 2012).

Jha et al. (2010) describe some basic infrastructure interventions relevant to housing and community reconstruction to attend to peoples need. In table 3 there is a short description of few of infrastructure intervention actions.

Priority actions	**Infrastructure**	
Greater priority / least effort	**Intervention**	**Long-term**
	Essential facilities (police and fire stations, schools, hospitals)	• Develop construction plan to improve building quality and policies for risk mitigation. • Prioritize construction of schools to minimize family, life disruption.
	Transportation system (road segments, bridges)	• Provide access to deliver construction materials. • Plan to improve codes and standards. • Design roadway system to encourage walking and bicycling. • Plan for public transit access.
	High potential loss (dams, power plants)	• Plan to increase resilience to facilities and improve services. • Reconstruction of the rehabilitated system to higher and safer standards.
	Utility lifeline systems (power lines, sewers and water mains)	• Provide power to households and community facilities, for pumping water and for generators for reconstruction. • Consider alternative energy generation in the design of new houses and buildings. • Plan to improve power installations. • Design site for rainwater capture, maximize water infiltration, etc. • Plan for water installation and test for availability and quality of water.
Least priority /greatest effort	General building stock (number of buildings, occupancy and construction classification).	• Monitoring of recovery process. • Incorporate resilience and mitigation actions in city plan.

Table 3 Infrastructure intervention actions. Modified from (Jha et al., 2010).

2.2.1. Physical reconstruction vs. recovery of function

Urban function is composed by urban activities and communications that make the human relationships possible (Knox, 2010). Physical reconstruction includes buildings, places and streets, which induce changes in the physical space of a community, in the way people feel it and in the distribution of space and activities. Although, recovery of functions is associated to the reconstruction of the space, it does not mean they correlate with each other. These two concepts take place in different levels and they may vary in order of which one takes place first. But it is important to say that both follow the same path to recovery (Rathfon, 2010).

Residents might be ready to return to their neighbourhood or community, once basic infrastructure is restored, even if their house is damaged but yet habitable. In this case the function (provide shelter) is achieved, however not completed recovered. The recovery of function and reconstruction is fully completed, when household has shelter and the house is rebuilt in a permanent state. Another example is a store that is physically repaired, but the business is not functionally recovered, once consumers are not buying or supplies are not available (Rathfon, 2010).

There are few literatures that explored both, physical reconstruction and urban functions. Study the elements of a city and how they relate to each other may facilitate and provide significant information for the assessment of urban recovery.

2.3. Components of recovery

As mentioned in the previous sections, recovery is not only about the physical assets or providing welfare services. It is important to include many aspects of a society and people's need. In addition, recognize all the activities and functions to achieve a successful recovery. This is a long process that may take several months and even decades. The restoration of a society affected by a disaster, involves recover community functions, social structures and systems. The government of New Zealand created a holistic framework for recovery (figure 1) that illustrates the integration of different environments that must be addressed in the recovery process (CDEM, 2005).

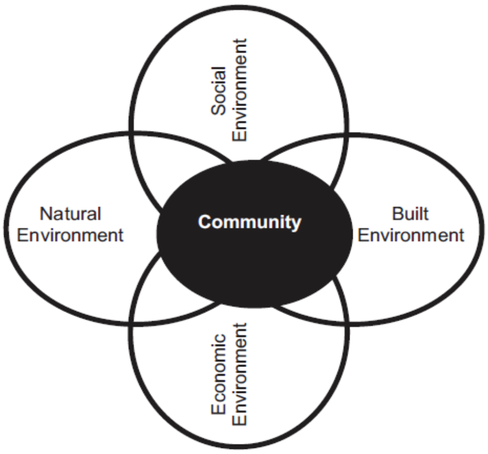


Figure 1 Components of community recovery. Retrieved from (CDEM, 2005).

According to CDEM (2005), social environment comprises of: safety and wellbeing, health and welfare. Safety and wellbeing, as the name suggest, guarantee safety to people that remains in the disaster area during the recovery process. Health recovery includes a range of activities to support the people affected (follow up care after emergency response, groups exposed to future hazards, trauma experiences, etc.). Finally welfare comprises of psychosocial support, care for individual's emotional, cultural, physiological and social needs.

Built environment is the most studied component in the recovery process. For commercial and industry, the repair and continuation of business is crucial rather than the achievement of recovery to 'pre-disaster' levels. An empirical study on how business responds after a major disaster was done in New Orleans after hurricane Katrina. The results of this research showed that business have reopened just after the assessment of the damages (LeSage, Kelley Pace, Lam, Campanella, & Liu, 2011). According to Khan and Sayem (2013) recovery of business includes: reopen of activity and profits doing as good as before the disaster, adaptation to the new post-disaster economic environment, business is running even if not totally viable and ability to maintain its own financial resources.

Other elements that belong to the built environment are: public buildings and assets (critical facilities with social value need to be identified as priorities), lifelines (restoration/reconstruction of utility services, transport and communication links) and housing (Ruiter, 2009). Housing refers to repair/rebuilt households' former residence or move to new ones in a permanent location. In addition, housing phase includes: sheltering and temporary housing (Ganapati, 2013).

CDEM (2005) had also described natural resources, amenity values, biodiversity and ecosystems, and waste and pollution as components of the natural environment. Amenities values are related to aspects of recreation, cultural or social importance. These aspects attracts people to occupy the space (Bryant & Allan, 2013). Also during a recovery process waste disposal activities must be addressed (sewage and garbage collection), once society continues to function (CDEM, 2005). Pollution also is an important aspect to control, for example: debris must be removed; sanitation monitored and in case of other pollutants (oil spill, radiation, etc.) affects the area, certain measures needs to be implemented, once it might affect the recovery process.

The economic environment illustrated in the figure 1 comprises of four aspects: individual, business, government and infrastructure. Individual economic recovery include: maintain livelihoods (employment, payment/salary, access to bank account, insurance). Business recovery actions should include: assistance to individual business, asset protection and availability of information. Also, during a recovery process, government should monitor the economic impacts, transmit confidence to stakeholders, provide information, etc. Finally, infrastructure recovery is important to maintain business continuity (communication links, access to transport, etc.) (CDEM, 2005).

There are various different ways to analyse and understand the components of recovery. Recently, other international frameworks also have adopted components of recovery in their analysis for a better understanding of the disaster event and how it affects the society. For instance, Brown et al. (2010) provided information on how to monitor and evaluate recovery and reconstruction after a disaster event. Brown et al. (2010) research worked in parallel to the Post Disaster Needs Assessment - PDNA and adopts a range of physical, environmental, social and economic aspects of the components of recovery. Many of these aspects were already described earlier with the literature of CDEM (2005). In addition, Brown et al. (2010) framework analysed how useful remote sensing is to monitor post-disaster recovery (see annex 1: framework for monitoring and evaluation methodology using remote sensing).

The main objective of Brown et al. (2010) was to identify the indicators to assess recovery using remote sensing imagery, internet-based statistics and field survey. After the Post Disaster Needs Assessment conference (PDNA) in 2008, Brown et al. (2010) prioritized several indicators that are distributed in the following six components of recovery: accessibility, buildings, population, services/utilities, environment and livelihoods.

Hence, recovery components are referred to by various names. In the next sections of this thesis, these components will be referred to by the term “sectors”.

2.4. The elements of urban form and how they relate with recovery

An effective recovery process should take into consideration the role of city’s form and its interactions. Some factors that influence urban recovery can be described by urban/city forms that are a description of a city’s characteristics; it is the morphological attributes of urban areas represented in different scales (Jenks, 2009). Features of urban form can be physical as: size, shape, land use, building type, urban block and distribution of open spaces. But, can also be non-physical, for instance: density, economic, socio and political process. It can be measured through different scales of individual buildings, street, urban block, neighbourhood, etc. Finally, they interact with each other, and influence sustainability and human behaviour (Jenks, 2009). The study of these features is important because recovery planning offers the opportunity to interact different professionals to re-design cities and regions in an intelligent and confident manner. This process should produce a transparent, functional, sustainable and equitable product. The recovery planning methodology should include smart growth, environmental protection, transportation planning, sustainable development and community revitalization (Ellis, 2005).

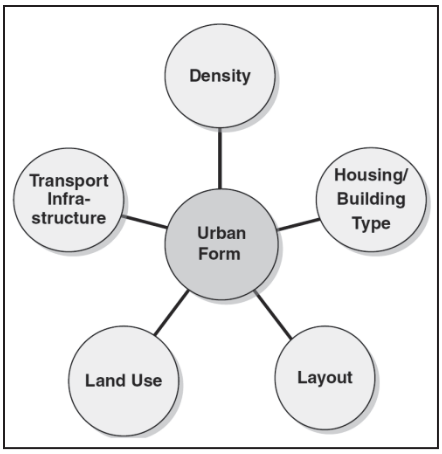


Figure 2 Elements of Urban Form. Retrieved from (Jenks, 2009).

This section explores the elements of urban form (figure 2) based on the literature of Jenks (2009), because it contains a clear and explanatory theory about urban form. Transportation as urban form is connected to accessibility and the way to reach places. It is not related only with proximity, but how well the transport system is connected and spatially distributed, as well as how people use the transport system. This urban form is linked with land use and layout (the means to get in a determined place or how the transport system is arranged will describe how accessible a place or service might be).

Housing and building characteristics are urban forms that influence recovery in terms of urban living. Some building characteristics as age, type and height might affect building efficiency. For example, building orientation and exposure to sun light affects building energy consumption. In addition urban form relates to function conversions from one building type to another, for example changes from housing to commercial (Jenks, 2009). Buildings can be monitored during the recovery process to track their construction and absence. To measure this urban form is significant to identify where these processes took place and what type of land cover has changed. These observations can describe how and why buildings varied after the disaster event, and how many buildings are needed in the affected area (Brown et al., 2010).

Furthermore, density as elements of urban form measures for example, the number of people living in a given area, roof coverage density, floor area ration, etc. However this measure might be relative and may differ from state to other state or country. Density is also associated to other urban forms like: land use and transport (for a service or facility to be accessible or feasible it will depend on the size of a population). In addition it is used to measure quality of urban life through provision of services and availability of public /private spaces. Layout of urban form is permeable and influences pedestrian movement and the way places and space are connected to each other. This connectivity determines the extent of routes and how well-used or connected a space is to reach a service or facility by pedestrians. The layout controls the access and influences other urban forms as land use and density. The configuration of urban layout, for instance street network (size of parcel, location, vehicular connection, etc.) can affect the intensity of activities (Jenks, 2009).

Finally, land use as an element of urban form describes the functions of the environment in an urban context. Generally, residential use tend to be predominant, however an urban area require also commercial, industrial, infrastructure, and other uses. An good understanding of land use patterns give planners and decision makers information about the efficiency of a city, the sustainability of a transportation system or the level of quality of life, for instance through the existence and distribution of green spaces. Land use patterns also influence and is influenced by market forces. The provision and availability of services are key components of land use form and are dependent of the population requirements and might vary from area to area (Jenks, 2009).

2.5. Measuring recovery

The assessment and monitoring of post-disaster recovery are crucial to aid agencies, to promote transparency to the process and to ensure civil rights. Recovery is expensive and in the past years the World Bank and other aid/donor agencies has financed billions in disaster activities. Also, numerous stakeholders and sectors get involved in the recovery process. Due to gap of information or means to develop a systematic and independent framework, it is difficult to answer questions about how much have being achieved so far or what should be done next? (Brown et al., 2008).

The need for information for relief and recovery phases are not the same, and professionals with different skills are involved in each of these phases (Brown et al., 2010). Therefore, the initiatives to collect the information face some challenges. For instance, how to collect data and attest its quality; how to present the data in a clear and understandable way to users and decision makers; which indicators could be transferable and so one (TRIAMS, 2009).

Because recovery is a dynamic process, the measurement of recovery will depended on many factors. The time frame of different processes and importance of indicators may vary depending of the disaster event and location (Brown et al., 2010). Other factors that influence recovery measurement are: type of disaster, level of damage and pre-disaster preparedness levels. Finally, it is important to take into consideration the geographic scale (individual, households, neighbourhoods, community, city or regions) and perspective of the evaluator when measuring recovery (Rathfon, 2010).

There are many methods and techniques to measure post-disaster recovery that vary in efficiency and type of information that is derived. Brown et al. (2010) discussed two tools to measure recovery: direct observation (using ground-based and remote sensing) and social-audit (focused on group meetings, household surveys and interviews). The following sections will give examples from the literature on how to measure recovery through direct observations.

2.5.1. Ground-based methods

A great number of researchers have developed case studies using data from interviews, surveys, archival documents, census data and observation to make comparison analysis of recovery processes (Chang, 2010). For a start, Webb, Tierney, and Dahlhamer (2002) predicted long-term business recovery using a large-scale mail survey as data source. The data was collected from business sector in Santa Cruz County, California. This study used ordinary least square (OLS) regression models combined with the questionnaire data that focused on issues of business vulnerability, direct and indirect impacts of disaster on business and level of preparedness. The results were used to compare recovery outcomes across two major disasters that occurred in California (the Loma Pietra earthquake and the Hurricane Andrew).

Next, Xu and Lu (2012) uses a theoretical approach and field investigation to create a meta-synthesis pattern (quantitative modelling-systematic planning) to provide a pathway for post-disaster recovery and reconstruction with an integrated solution, with the intent to reduce risk and increase preparedness. Ganapati (2013) discusses the importance of measures of housing recovery, using in-depth interviews, focus groups, participant observations and review of secondary sources. This study highlights how recovery organizations should conduct the measures and outcomes of housing recovery, taking into consideration (I) land on which the house is built, (II) who participates of the planning process (III) the coordination of the projects and agencies involved, (IV) people's satisfaction with the new houses and (V) equity issues.

Other example of ground-based methods is the research of Rathfon, Davidson, Bevington, Vicini, and Hill (2013) that used building permit, certificate of occupancy and property appraiser data for a quantitative assessment of housing recovery. This research created a conceptual framework to consider recovery not as an endpoint, but as a process that involves people and place. And, Wang, Chen, and Li (2012) researched the factors affecting earthquake recovery using surveys, logistic regression models and statistical analysis. These methods made an analysis of distribution of characteristics of household's economic costs and time costs recovery.

These growing bodies of recovery literature explain significant factors of the recovery process. Also stresses the complexity to measure recovery and its concern not only with the reconstruction of the built and infrastructure sectors, but also with the interactions between the city environment and people, community, business, organizations and society as a whole (Chang, 2010). But, the examples given in this section require great amount of data and up to date information. Other limitations of these approaches are: the availability of certain type of data, aggregated scale for analysis, quality and reliability of questionnaires, completeness and accuracy of data may also be questionable (Chang, 2010).

These limitations and uncertainties about recovery process emphasize the need of a systematic framework to monitor and assess recovery. These complex process needs to be transparent, operational and effective to provide a better understanding for stakeholders and decision makers when making decisions (Brown et al., 2010).

2.5.2. Remote sensing methods

Recently, remote sensing images capable of sub-meter (≤ 1 meter) spatial resolution have become more accessible to users (Carlton, 2012). For example, IKONOS sensor, its panchromatic images has a spatial resolution of 1 meter and QuickBird has a spatial resolution of 0.6 meter (Joyce, Belliss, Samsonov, McNeill, & Glassey, 2009). In addition, the sensor WorldView -2, launched October 2009, provides 0.46 meter panchromatic resolution and 1.85 meter multispectral resolution (SIC, 2013). High resolution images can be used in post-disaster surveys, making use of remote sensing images to analyse and monitor time series for a particular geographic area. Also it can be used to analyse urban areas in specific detail, once this type of images allows easy identification of objects as buildings, vehicles and other structures (Carlton, 2012).

There are few literatures that use remote sensing imagery to assess recovery processes, and in many researches the use of manual interpretation methods to achieve high accuracy is predominant. However this method faces disadvantages with process speed and reproduction. Joyce et al. (2009) attested the need to develop and test a more rapid and automatically implemented algorithm approaches for disaster detection and monitoring. But one needs to consider that many different techniques still need to explore the availability of images (Joyce et al., 2009). Some of the processes that are visible in satellite images during recovery are: debris clearance, building demolition, road rehabilitation, building and infrastructure reconstruction, tents and shelters, camp construction and removal and environmental recovery (Brown et al., 2010).

This section gives few examples of researches that explored the use of automatic and semi-automatic remote sensing methods for the assessment and monitoring of recovery. For example, Brown et al. (2010) identified indicators to assess recovery using high-resolution remote sensing imagery (IKONOS and

QuickBird), internet-based statistics and field survey. To analyse visible recovery characteristic a spatially tiered approach (per-building and community scale) was used. Also, image processing (combination of pixel and object-based) was used to quantify changes in the area, structural configuration and construction materials. Field surveys complemented the remote sensing methods (e.g. imagery analysis and mapping of key indicators such as: accessibility and reconstruction of buildings) by investigating the socio, physical and institutional achievements of recovery.

Other example is given by Wagner, Myint, and Cerveny (2012) that used remote sensing as a tool to capture the rate of recovery, after the tornado in 1999 Moore, Oklahoma. Medium resolution images were used in this research. A combination of vegetative and urban indices was used to assess tornado damage in recovery analysis, due the complexity to detect variability in the urban areas. The role of remote sensing in this research was to provide significant information for government and decision makers to be able to implement more resilient approaches for reconstruction. It also served as a cost-effective alternative for ground survey and aerial photography.

Curtis, Mills, McCarthy, Fotheringham, and Fagan (2010) that explore the case study of the Katrina hurricane and makes use of a spatial video acquisition system (SVAS) in the ongoing recovery phase of the disaster. The video reveals information about house condition and occupancy (or return to homes). SVAS data can easily be incorporated in GIS software while in the field (providing attribute information for each building). The SVAS may be considered similar to Google Earth Street View. However the data is not static, SVAS update the data regularly and can capture the dynamic recovery landscape. This method is considered an efficient tool for neighbourhood data collection in a post-disaster event.

Another example is given by Ji, Ma, Twibell, and Underhill (2006) that calculated landscape metrics based on land cover data to characterize long-term trends and patterns of urban sprawl. This study identified different stages of urbanization and that changes in housing and commercial construction were the driving factors. Analysis like that, using urban form elements can help to explain how an area can recover after a disaster or which are the functions influencing changes in the urban environment.

Other change detection methods that might be used in the assessment of recovery are pixel-based methods and object based approach (Desclée, Bogaert, & Defourny, 2006). Because these methods comprises contextual information like: hazard information, neighbourhood characteristics, spectral signature, texture, shape, height, etc. (Walker & Briggs, 2007). Blaschke et al. (2011) cites in his article a number of authors and researches that successfully used object-based methods to evaluate for example: forest land use structure to assess environmental change, identify and quantify shelters, map urban land cover and burned areas, urban function types, damage analysis, risk analysis and landslide.

Although object based image analysis is a potential tool to assess recovery. This method faces some limitations with relative scale, context and fuzzy or smooth transitions. At the moment there are few software available to use object based methods, some of them are: eCognition/ Definiens Professional 8.87, InterImage 1.36 and Erdas Objective (Blaschke et al., 2011).

There is also an increase of published object based literature. However there is the necessity of significant contributions that will help remote sensing to answer more conceptual questions, related to environment, rational planning and decision making. More research is needed to acquire contextual information and to integrate object based methods with GIS applications.

2.5.3. Indicators

There is little literature available that uses remote sensing imagery to extract information to assess post-disaster recovery. This section gives examples extracted from the literature of some current methods used to assess post-disaster recovery. And address the first sub-objective of this research, answering the following research questions: Which indicators or remote sensing based proxies can be used to describe recovery in terms of urban form and function (transport, economic, residential, etc.)? and Which are the recent methods and tools used to describe and quantify recovery?

Indicators are an effective way to assess post-disaster recovery and can also be used for comparison between disaster events or communities affected by the same disaster (Chang, 2010). Indicators can develop baseline knowledge, test hypotheses, validate models and inform policy. However to address this issues it is necessary some levels of standardization and a systematic definition of recovery and sectors to be analysed (Rathfon, 2010).

Some examples are organized in the tables 4, 5, 6 and 7, which contain key indicators and features that can be analysed using remote sensing methods. The indicators are organized into four sectors: built up and infrastructure, environmental, economic and social. These sectors are based on the components of recovery theory explained in section 2.3, but were renamed to best cover a manageable number of indicators researched.

The first sector, built up and infrastructure, has indicators that comprises generally physical features visible by remote sensing imagery that can describe recovery processes. Some structural features are: location, stage of development, presence of garden, presence of cars in driveways, clean/dirty swimming pools, neat front yards, roads, bridges, roof colour, debris removal, etc. (Curtis et al., 2010).

Change in building morphology indicator is significant, once urban form is an important issue for urban planning. The urban form also influences in the building's light, noise and comfort level. This indicator can also be used as a proxy to measure living conditions (Brown et al., 2010). The indicator removal and reconstruction of buildings provide information about the speed progress in reconstruction and significant information on the type of reconstructed buildings in time period (Guo et al., 2010). House condition or building context indicator capture information on condition in the neighbourhood and can identify return of people to their homes (Curtis et al., 2010). Quality of dwelling reconstruction can be a proxy to measure occupant satisfaction. Features that can be detected are: garden, extension and driveways, changes in building (size, shape and colour, tone, pattern, texture, orientation) and vegetation density. The information extracted can also determine the rate and patter of reconstruction and changes in urban form (Brown et al., 2010).

Infrastructure indicators (accessibility analysis, presence of vehicles, road condition and bridges and public facilities) are important because aid agencies need access to service and facilities to attend people in the relief and long-term recovery phase. The key transport routes must be cleared and restored to ensure the coming and going of food and other resources. Presence of cars may suggest sign of recovery and vehicles can be identified by: size, colour and texture of the surface on which the vehicle is sitting. Another important service to measure is the supply of water. Remote sensing can monitor the distribution and connectivity of water points in the camps/shelters (Brown et al., 2010).

The second sector, environmental, has indicators that give an overview of land cover and green spaces change. For example, recovery of agricultural fields is essential for food security and open spaces can be a proxy indicator of quality of life (mental and physical wellbeing). Some studies also showed that open spaces affects house prices. Land cover features are: erosion and land degradation, deforestation and construction (Brown et al., 2010). Permeability of surfaces indicator is important to measure the degree of urbanization and environmental quality. For instance the increase of impervious surfaces can lead to increase of volume, intensity and duration of urban water runoff. Consequently increasing flood frequency and storm flows. The increase of floods direct impact the transportation system, increase pollutants levels and influence urban climate (Weng, 2012).

In the third sector, economic, the choices for indicators will depend on the region characteristics and need detailed analysis of the activities and business of the area. For example, the livelihood recovery indicator refers to the means to secure the necessities of life (employment, income). The recovery of livelihoods must happen quickly or households might rely only on aid support. Shops and local business also must reopen as soon as possible to support recovery of local economy and to provide services and products (Brown et al., 2010). Remote sensing can also be used to identify signs of industry recovery observing features as: cooling towers, presence of heavy vehicles, railroads, pipelines, roof colour and material and warehouse. Change in urban morphology as indicator can also indicate economic recovery. Reconstruction after a disaster may offer opportunities for development and business can move to areas designated in a recovery plan to better accommodate their activities. This change of areas influences transportation system and the way the city is organized. Also the change in business geography or availability of new areas for business, can serve as attractive to new type of business, increasing economy of the region (Hagelman et al., 2012).

The last sector, social, has a set of indicators illustrating how remote sensing can be used to monitor and evaluate social recovery. First, the temporary accommodation indicator measures the extent and distribution of tents, transitional camps and shelters, by using physical features as for example: building footprint. With this variable it is possible to delineate the extent and longevity of camps. Second, local facilities in use indicator can be displayed near the shelters by remote sensing using an up-to-date map. Finally, monitoring overcrowding indicator is important to control disease and to prevent overcrowding in camps during the recovery process. It can be measured for instance by the minimum covered living space per person and the minimum surface area per person (Brown et al., 2010).

Pedestrian access and mobility indicator are linked to transportation urban form. They refer to access of people to reach places and facilities. This indicator can also be a proxy for quality of life or population health, once encourage residents to walk (improving health) and lower vehicles mile travelled (Song & Knaap, 2004). This indicator can also indicate inequalities in access to physical and social infrastructure (Martínez, 2009).

Settlement types, topographic location and commercial development are proxy variables that can be used to assess social vulnerability. Proxy variables can be applicable when the parameters or indicators of interest are not directly assessed or observed (Ebert, Kerle, & Stein, 2009). According to Ebert et al. (2009) the mentioned proxy variables can provide characteristics of areas that would be less capable to coop in a disaster event and could be considered most socially vulnerable.

The choice of indicators may vary depending of many factors as described in section 2.5. They can also be grouped into different categories than the ones used in this research, to prioritize the indicators that are relevant to the case been studied. Users can choose each indicator and sector to monitor, according to their needs and data availability (Brown et al., 2010).

BUILT UP AND INFRASTRUCTURE

What are the key indicators?	Key Features	Remote sensing method	Reference
Change in building morphology (can be also used as a proxy for living conditions)	Building density Building extent Building shape Building size	Kernel analysis combined with change detection and landscape metrics (mean nearest neighbourhood and patch density) Landscape metrics (class area and number of patches) Landscape metrics (mean perimeter –area ratio and mean shape index) Landscape metrics (mean patch size and mean patch edge)	Brown et al., 2010
Extent of built environment	Impervious surface classification	Maximum Likelihood algorithm	Brown et al., 2010
House condition or Building context	Neat front yards Presence of trash bins Cars in driveways Number of abandoned homes	SVAS- Spatial video acquisition system	Curtis et al.,2010
	Driveways Parking place Clean/dirty swimming pools External buildings	Visual interpretation and supervised classification algorithm	Brown et al., 2010
Removal and reconstruction of buildings	Roof colour (blue tarps: structure under construction) House collapse ratio	Visual interpretation	Guo et al.,2010
	Monitoring removal, presence and absence of buildings and creation of new buildings.	Plot the patter of change (graphic) to see number of building over time and overall rate of reconstruction. Manual delineation of building points or supervised classification method	Brown et al., 2010
	Difference new building and rehabilitated	Rule-based change detection	
Building recovery score	Building foot print (location/dimension) Structure unchanged since disaster event Structure demolished Debris removal Structure rebuilt in same footprint Structure rebuilt different footprint	Visual change detection	Hill et al., 2011
Change in land use	Map of land use type	Visual interpretation	Yu et al., 2012
Quality of dwelling reconstruction	Structure attributes (size, shape, orientation and roof colour of building footprint) Stage of development (identification of land clearance and foundations)	Visual interpretation and supervised classification	Brown et al., 2010
	Proximity to services	Visual interpretation and traveling time analysis	
Road condition	Classification of roads (path, dirt track non-asphalt and asphalt road),	Visual interpretation and manual delineation of the transport network in GIS	
Accessibility	Shortest route distance Service area analysis Width of road	Visual interpretation and network analysis in GIS environment	
Bridges and public transport facilities (mobility)	Key public transport infrastructure Functionality of facility	Visual interpretation, but ground information might be needed	
Presence of vehicles	Traffic activity Human activity	Visual interpretation (identification and quantification of number of vehicles and location in the image)	
Water supply	Tanks and towers Dams Reservoirs Water body Distribution and connectivity of water points	Visual interpretation and image analysis	

Table 4 Remote sensing utility table: built up and infrastructure sector.

ENVIROMENTAL

What are the key indicators?	Key Features	Remote sensing method	Reference
Land-cover	Vegetative and urban recovery rate	Vegetation index (NDVI) Soil-adjustment vegetation index (SAVI) Urban index Short wave radiation index (SWIRI) Coupled vegetative urban index (CVUI)	Wagner et al., 2012
	Erosion Land degradation Deforestation	Vegetation index (NDVI), maximum likelihood supervised classification and change detection analysis.	Brown et al., 2010
Environmental restoration	Barrier lake Debris flow	Visual interpretation	Guo et al., 2010
	Post-fire recovery forest (classification: burnt forest, not burnt forest and bare soil)	Visual interpretation and pre-classification, followed by ground verification and change detection analysis (comparison between spectral signatures)	Sriboonpong, 2010
	Distribution of open spaces	Landscape metrics (Large patch index, mean nearest neighbour, patch density and total edge)	Brown et al., 2010
Access to recreation	Availability of land	Visual interpretation in combination with GIS statistical query and change matrix	Yu et al., 2012
Permeability of surfaces	Land use/land cover Buildings height and area Roads Parking lots	Automated extraction (object-based, multi-agent segmentation and classification, artificial neural network, linear spectral mixture analysis and maximum likelihood classifier)	Weng, 2012
Water contamination	Evidence of debris, mud or salt	Spectral analysis and visual interpretation	Brown et al., 2010

Table 5 Remote sensing utility table: environmental sector.

	What are the key indicators?	**Key Features**	**Remote sensing method**	**Reference**
ECONOMIC	Livelihood recovery	Presence of boats (fishery industry)	Visual interpretation and GPS photographs	Brown et al., 2010
		Arable land	Visual interpretation and change detection	
	Industry recovery	Chimneys Presence of heavy vehicles Warehouses railroads pipelines Roof colour and material	Visual interpretation, supervised classification and automated extraction (object-based analysis)	Brown et al., 2010
	Change in urban morphology	Business location Business type	Post-classification comparison	Hagelman et al., 2012

Table 6 Remote sensing utility table: economic sector.

	What are the key indicators?	**Key Features**	**Remote sensing method**	**Reference**
SOCIAL	Temporary housing (extent of tents, camps and shelters)	Building footprint (shape) Camp longevity location Road access Open spaces	Visual interpretation, manual delineating, landscape metrics (quantify the physical morphology of the camps) and change detection	Brown et al., 2010
	Monitoring overcrowding	Covered living space	Landscape metrics (density)	
	Pedestrian access/mobility	Number of street intersection Transport network data (size of network, routs, connectivity, etc.) Size of block parcel	Landscape metrics	Song & Knaap, 2004
	Local facility in use	Car parking Building size Main high street Garden Swimming pool Chimneys Playground	Visual interpretation and supervised classification	Brown et al., 2010
	Settlement type	Proportion of built up and vegetated area Road conditions	Landscape metrics	Ebert, Kerle, & Stein, 2009
		Roof type	Spectral analysis of roof material using object-oriented analysis and landscape metrics	
		Available infrastructure	Visual interpretation	
	Topographic location	Slop position	Position was calculated from a digital terrain model combined with a membership function to obtain slop information	
		Proportion of buildings in hazard zones	Manual delineation based on existing GIS hazard maps and statistical analysis	
	Commercial and industry development	Building heights	Manual delineation of building heights using lidar data. Buildings > 7 floors can be associated to commercial and industry developments	

Table 7 Remote sensing utility table: social sector.

3. RECOVERY CONCEPTUAL FRAMEWORK

This chapter is constructed base on the study of the literature review. The aim is to develop a framework that is efficient and can support planners to assess and monitor post-disaster recovery using geospatial data, in particular remote sensing methods. This chapter fulfil sub-objective 2, and answer the research question: Can recovery and its different types and aspects be conceptualized though a geo-informatics context?

Figure 3 illustrates the interaction between recovery, the use of remote sensing and urban form elements, and how this interaction is assumed to influences policies and other phases of the disaster management cycle. For example, remote sensing can be used to extract urban form information that can characterize recovery processes. In other hand the assessment of recovery through urban form might give better understanding of the functions that influences the recovery processes. The information generated from the recovery assessment can result in guiding, transparent and equitable policies. Those policies can influence the disaster management cycle and promote a sustainable risk/resilience management.

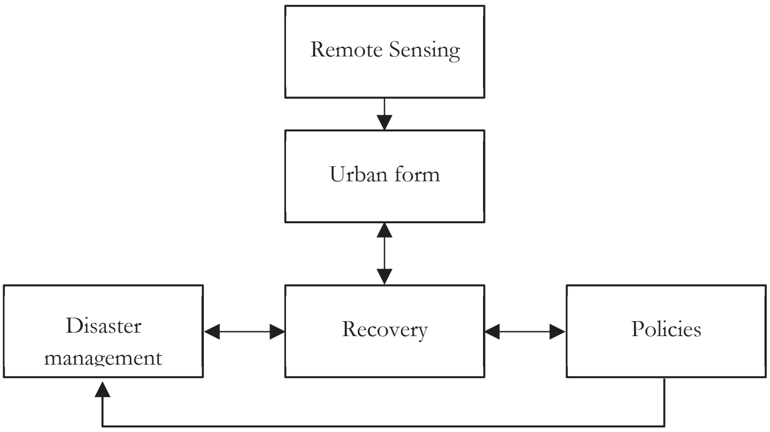


Figure 3 Conceptual framework.

Based on the assumption illustrated above, figure 4 conceptualizes recovery through a geo-informatics context. As mentioned in previous sections the monitoring of recovery will depend on the type of disaster and level of damage. Thus, the starting point of a recovery process is the planning process. This first stage would analyse the area condition and characterize the disaster and the scale to be measured (community, neighbourhood, local or regional). The geospatial data and time series of remote sensing imagery comprises for example of (I) raw remote sensing images, that provides an overview of the rapidly change in the area; (II) image analysis, that can combine manual and semi-automatic methods to extract important recovery features; and (III) change detection, that can extract spatial and time information over the recovery process (Brown et al., 2010). The first image analysis and/or pre-event data provide the bases for the recovery needs assessment. This concept identifies in the images the recovery needs, for example: bridges that collapsed and are blocking the access, facilities that needs to be reconstructed, shelter and available land for development of new houses, etc. (TRIAMS, 2009). However some needs and indicators might be dependent of the availability of the image. The indicators are derived from the recovery needs assessment (Brown et al., 2010). For a successful recovery, all sectors of the society must be incorporated in the analysis (CDEM, 2005).

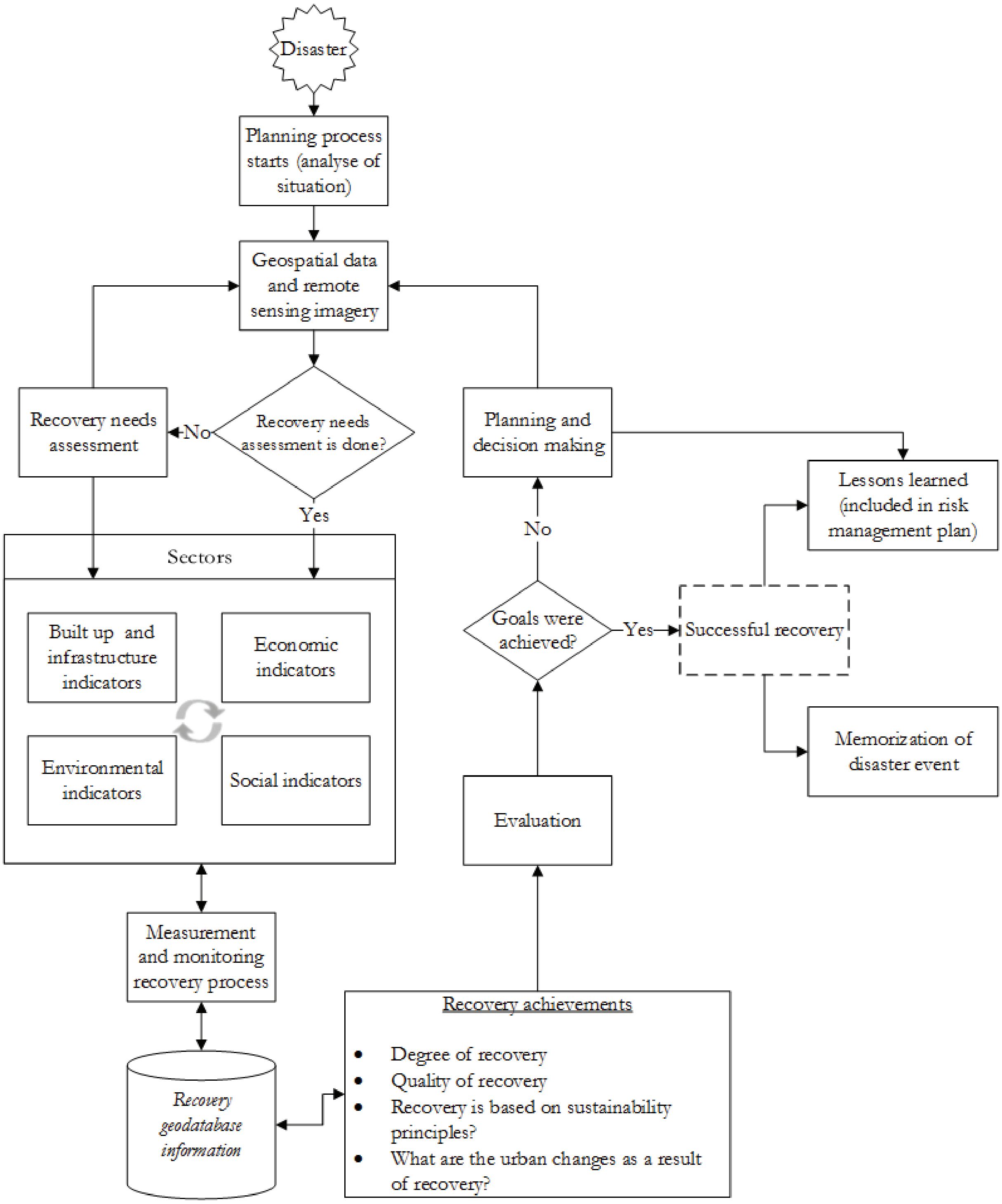


Figure 4 Conceptualization of recovery in a geo-informatics context.

For this research it was used the four sectors of society described in section 2.5.3, which are: built up and infrastructure, environmental, economic and social. The indicators are context dependent and may influence each other. The measurement and monitoring of indicators creates a recovery geo-database that combined with other geo-informatics methods, as GIS environment, can be used for further analysis. The recovery achievements are the results of the monitoring and measurement analysis. With this information it is possible to answer questions related to the degree, quality and speed of recovery (Brown et al., 2010). In addition, the results can show if the recovery achievements are based in the sustainable principles. Finally the changes in the spatial layout of a city can be identified, and the city functioning can be explained instead of seeing as a random event derived by recovery processes.

After the recovery achievements analysis an evaluation can be done to check if the goals were achieved. In a positive case, recovery is successfully finalized and the disaster event can be memorialized and the lessons learned can be used for planning purpose and for risk/mitigation plans. In case the goals were not achieved, the recovery process needs to pass for a planning phase. Decision makers and stakeholders in this phase review the results and decide the next actions. For example: the acquisitions of new imagery, creation of policies, starting of new reconstruction phase, manage financial aid support, etc. In some cases the decision makers might agree to stop the recovery process. It can be due for example: lack of finances, failure of methods and lack of imagery or data. If this happens, the results and negative experiences should be implemented in the lessons learned, for future corrective initiatives and reinforcement of positive experiences.

For an on-going recovery process it is advised to acquire images few weeks after the disaster and in intervals from 6 to 12 months, until the process is finalized (Brown et al., 2010). Because recovery is dynamic and nonlinear, the analysis will travel the cycle every time a new image is acquired. However the recovery needs assessment does not need to be done again. The indicators are measured again and the information containing the changes is stored in the recovery geo-database.

Finally, for comparison of projects only two images can be used, a pre-project image and a post-project image (Brown et al., 2010). In this case during the evaluation phase, the projects can be compared and the goals can be achieved or not. In a negative case factors that influenced an incomplete recovery need to be further analysed.

4. CASE STUDY: FIREWORK DISASTER, ENSCHEDE

The study is carried out in the neighbourhood of Roombeek, in the city of Enschede in the Netherlands (figure 5). This neighbourhood was selected due to the severe damage caused by the explosion and fire leaving a large empty space. Therefore, the features of recovery would be easier to capture using remote sensing imagery than in the surrounding affected areas, where the destruction caused broken windows, removal of roof tails, damages in the house structure, etc. Those damages were with a relative short period of time restored.

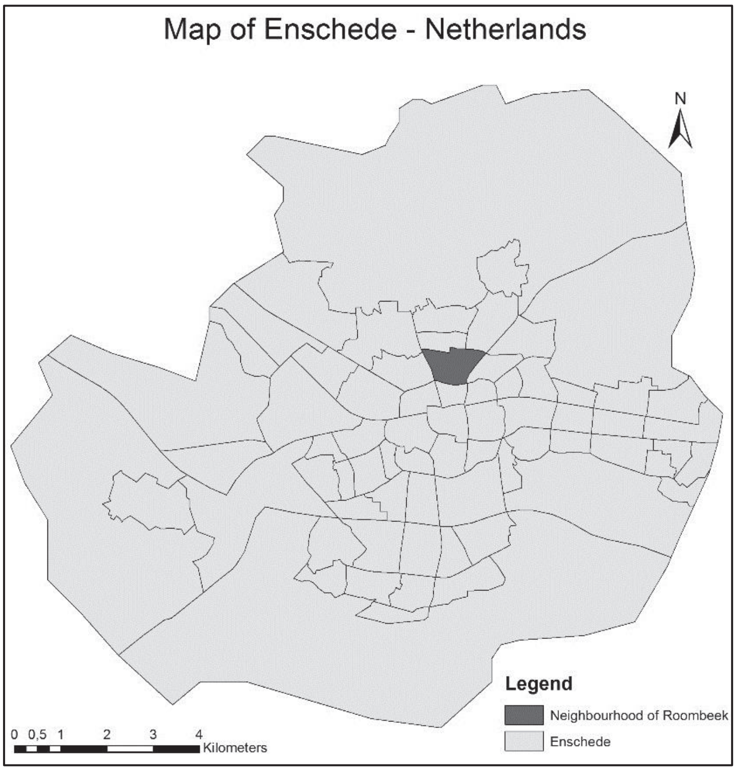


Figure 5 Map of Enschede locating case study

The study area is relevant to the research problem, because a significant planning and recovery process was conducted, for example the developing plan of the region, in Dutch: “Ontwikkelingsplan Roombeek: De Stad Voortgezet”(Enschede, 2003a). The policy process was well documented and had a high participation of the community. This collection of informations can assist the interpretation and validity of the measurement results. In addition, it could be used to identify if the variables and indicators that are used in the assessment of this case study could explain the complex process of recover and the status of development achieved in the time period studied.

4.1. History

In the late eighteen century, Enschede was a centre of textile production. This contributed to a large increase in population and leading to further development of residential areas, concentrated around the neighbourhood of Roombeek (Visitenschede.nl, 2010). But around 1960 a crises hit the textile industry and the companies began to stop their activities. Following that period, a new zoning was planned for the area, which was already focusing on the environment (COT, 2000). Some industries were relocated to the eastern part of Enschede and many vacant factories were demolished. But in the Roombeek area many factories remained, for example the Grolsch beer factory, S.E. Firework and the Bamshoeve (Lugt, 2000).

One of these buildings was the S.E. Fireworks company, specialized in professional firework shows. On May 13, 2000, a fire started in the warehouse of the factory, where 900kg of fireworks was stored. The fire hit the containers placed illegally outside of the building. Circa 177 tons of firework exploded and an approximate area of 300 meters was severely affected (Visitenschede.nl, 2010).

The firework disaster killed 22 and injured about 950 people. The damage was enormous, circa 200 houses were destroyed, and another 300 homes were severely damaged. As the result of the disaster, about 1.250 people lost their homes and a number of inhabitants had all their belongings lost. The aftermath of the disaster includes also: fifty commercial buildings that were heavily or irreparably damaged and workshops of artists were destroyed. It was estimated by the municipality of Enschede that in the outer ring (see figure 6) of the actual disaster area, around 1.500 houses were damaged, from these 50 were condemned. Approximately 10.000 people have to spend at least one night outside of their homes. The total damaged was estimated to exceed one billion dollars (Oosting, 2001).

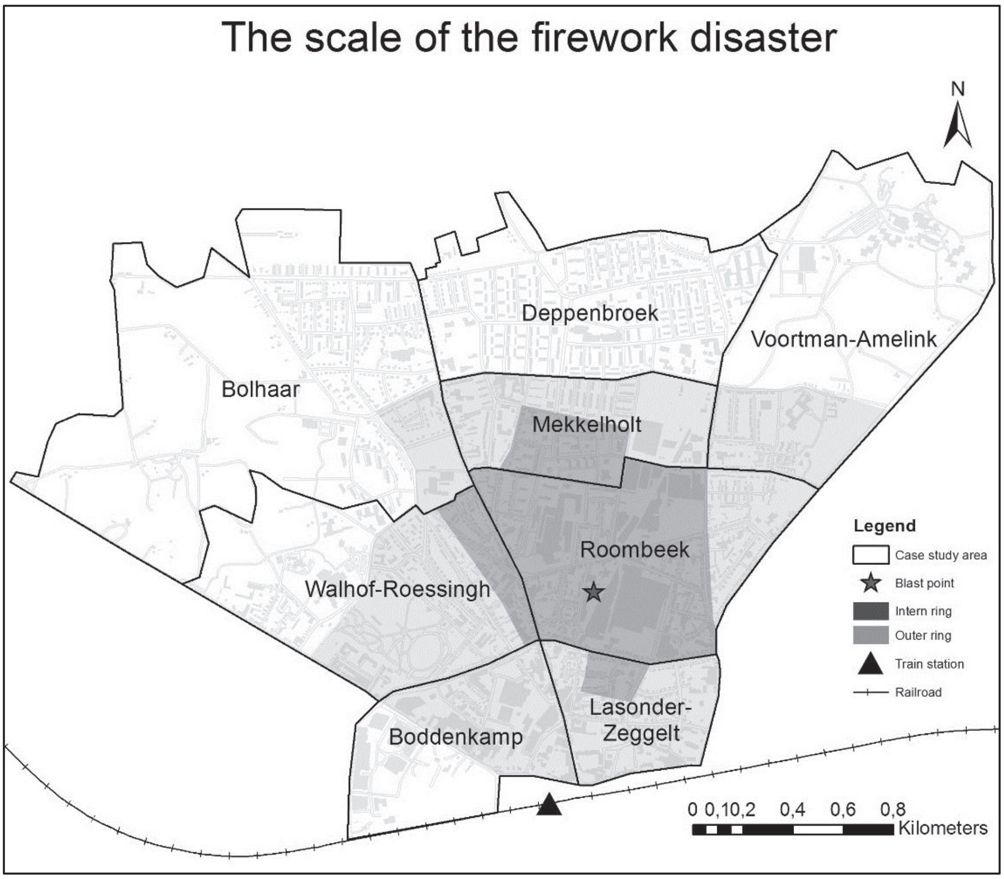


Figure 6 Overview of the area affected by the firework disaster in Enschede.

The explosion destroyed an area of approximately 74 hectares (Oosting, 2001). In 1997, it is estimated that 3.320 people lived in the Roombeek neighbourhood. In table 8, it is possible to observe that after the disaster the total population decreased circa 58%. The neighbourhoods that surround the Roombeek are: Mekkelholt, Lanonder-Zeggelt, Deppenbroek, Walholf-Roessingh, Boddenkamp and Voortman-Amelink, these areas were also damaged by the disaster, as shown in figure 6.

Years	Roombeek	Mekkelholt	Deppenbroek	Walhof-Roessingh	Boddenkamp	Lasonder-zeggelt	Voortman-Amelink
1997	3320	2110	5120	2230	600	1390	1420
2001	1940	2170	4440	2190	520	1350	1400
2005	2760	2110	4640	2360	510	1370	1340
2010	3875	2340	4720	2470	505	1295	1180

Source data retrieved from (CBS, n.d.).

Table 8 Total population in the study area since 1997 to 2010.

According to Oosting (2001) Roombeek had circa 1.400 houses, on January 1, 2000. From these total amounts of houses, 580 were occupied by owners, the same amounts were for social housing and 240 were rented by private landlords. At the time of the disaster these houses were on average 50 years old. These houses were characterized by detached and semi-detached houses and high-rise buildings.

Two buildings that stand out in the total affected area are the Grolsch beer factory and the Rijksmuseum Twente. The Grolsch factory had about 640 workers and it was considered the largest employer in the Roombeek. The industry was heavily damaged, but the beer production was rapidly restored. The old textile company Bamshoeve, not operating since 1990, was used as a workshop for artists and small business (around 150 people). Besides that Roombeek had more than 100 business places (general services, repair and trade). These companies had an average of less than four people employed (Oosting, 2001).

After the firework disaster, the media characterized the Roombeek as a social problem area (Oosting, 2001). However, after a research about neighbourhood's level of wellbeing and quality of housing, the municipality of Enschede concluded that the Roombeek did not rank an exceptional position compared with the other city's neighbourhoods. But compared with the surrounding neighbourhoods, Mekkelholt, Walholf-Roessingh and Lasonder-Zeggelt, it received lower scores for wellbeing and quality of housing (Oosting, 2001).

4.2. Development of the area before and after the disaster

After the textile companies moved or closed its business, a developing plan for the area called Groot Roombeek (Great Roombeek in English) was created. The plan consists of the rehabilitation of approximately 33 hectares, where around 1.100 houses would be built. The aim was to integrate living and business in an environmental friendly way (Oosting, 2001)

Between 1989 and 1990 a feasibility study in the area considered the housing along the street Tollenstraat a good option. At the time the proposition was to develop a line of housing and a new road access to give room to a transitional zone with business development. However, the feasibility was limited, due to high costs related to expansion and renovation of the site, relocation of existing houses and business, demolition and new plots acquisition. Because of that the developers considered the street Bamshoeve (where the S.E. fireworks building was located) the most suitable area for the construction of the new houses. Once the S.E. fireworks had the desire to expand, a proposal for relocation was seen as a good alternative (COT, 2000).

In 1998 the Groot Roombeek plan still needed to be approved, the constructions were expected to start in the early 2000 and there were still concerns about the relocation of the S.E fireworks industry (COT, 2000).

Because of the disaster in May, 2000 the Groot Roombeek plan could not be executed and in the following two years, other 2 plans were developed for the neighbourhood and surrounding affected area. Both plans had intensive participation of stakeholders, residents, business, associations, artist, and more (Oosting, 2001). This was because the government wanted to regain people's trust and gave the residents more power to make decisions in corporation with project bureau and supervision by planners. The recovery plan called Ontwikkelingsplan Roombeek: De Stad Voortgezet (in English Development plan Roombeek: The City Continues) received national and regional support for additional budgets. In addition, the government had low supervision on type of building, area specification, height and location. Because of this the residents had freedom to design and build their "dream house" (Klok, 2013). These factors contributed to the recovery plan design and to the actual urban form of the area. Also, it contributed for a different developing line than the one planed if the disaster did not occurred.

The recovery development provided the opportunity to build a unique living environment. The houses have a special typology that was not planned for the Groot Roombeek and the area has a mix of dwellings that includes: detached, semi-detached, terraced, apartment blocks and residential units (Enschede, 2003b).

Another differences between the development of the Groot Roombeek and the Ontwikkelingsplan Roombeek: De Stad Voortgezet are the amount of area constructed and number of houses. The old development plan proposed a revitalization of about 33 hectares and the construction of 1.100 houses. While after the disaster the area that needed to be developed was about 62 hectares (Enschede, 2003b). The developers planned the construction of around 1.500 houses, where 400 were designated to social housing (including 60 units for students). The other 1.100 were planned for ownership. A new traffic situation was created to prevent congestion and guarantee the quality of the services and safety of people (Enschede, 2003b).

Roombeek has now a mixing function of living and working. The Grolsch factory gave space to new business activities and in the post-disaster area the land use became less restrictive than in the rest of the city. This means a wider admission of policies that include professions at home (dentist, doctors, physiotherapists, etc.). But also it includes other services once they meet the appropriate conditions, for example, activities that cannot interfere with the liveability and characteristics of the neighbourhood (Enschede, 2003b).

4.3. Overview of recovery process

This section shows a time series imagery of the pre- and post-disaster situation. The aim is to illustrate using remote sensing imagery the process of recovery in the area where the explosion took place. Figure 7 shows the presence of the Bamshoeve and S.E. firework industries before the disaster. It is possible to observe in the image the blast point and the great damage of the explosion. In 2002 the area is already clean and the reconstruction process seems to start. The images show the process of recovery until 2011, those are the years used for the analysis in chapter 5.

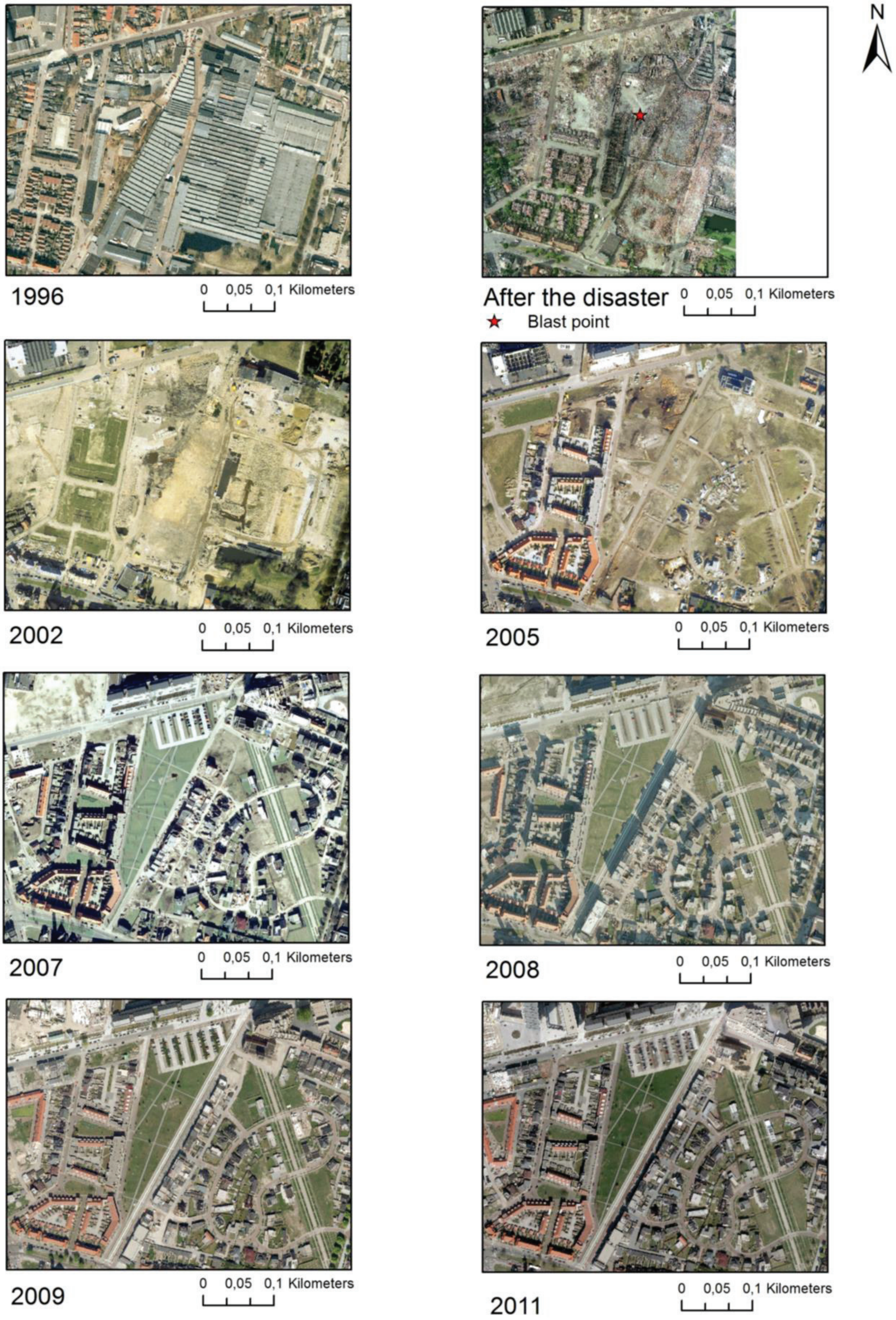


Figure 7 Time series of pre- and post-disaster to illustrate the process of recovery.

5. DEVELOPING MEASURES OF NEIGHBORHOOD RECOVERY

This section fulfils sub-objective 3 of this research, answering the following research question: which are the indicators, variables and data needed to assess post-disaster urban recovery?

In this research a visual interpretation of the collected time series imagery was performed to identify the features of recovery. The observations showed features such as: demolishing/cleaning of debris, removal/reconstruction of houses, removal of industries, improvement of landscape (creation of open spaces), operation of public transportation, use of facilities and services, creation of new business, etc. These features showed that the neighbourhood has a varying range of recovery needs and therefore this methodology uses the four key sectors as mentioned in section 2.5.3. These four sectors are: built-up and infrastructure, environmental, economic and social.

The purpose of this analysis is to interpret recovery in terms of metrics and descriptors, and if those are accurate and true, instead of using remote sensing only to identify if recovery took place. There are many possible methods to measure recovery changes, but the aim of this analysis is to identify which variables (direct or indirect) actually explain the recovery status of development. The status of development can be interpreted as a comparison over time with the condition of the area before the disaster. So it shows if the condition of the area after the disaster is equal or if recovery led to a progress that increased or decreased development of the area. With that information it is possible to know if geodata-based approaches can indeed characterise the complex recovery process, in a way that goes beyond the traditional focus on physical features.

The list of indicators presented in table 9 offers few examples that can be useful in representing the main features of neighbourhood recovery. They were developed based on a review of previous recovery studies and are organized according to the sector that it represents. In the table the indicators used in the analysis are highlighted. It shows that some features of urban form (e.g. building, size, shape, density) are being used in the analysis. In this research two sectors are selected. For the first sector, built up and infrastructure, the following indicators will be measured: change in building morphology and road network. For the second sector, environmental, the indicator energy loss is used as a proxy variable to measure quality of housing.

The sectors and indicators were selected due to data availability and the intent to test landscape metrics to assess recovery using elements of urban form. Besides, the analysis of all sectors and indicators is a complex process that would last longer than the available time to conclude this research.

The table 9 also shows potential techniques to measure each indicator by its feature to be assessed. The potential techniques, as mentioned in the table, focus on the use of remote sensing imagery, object-oriented based and landscape metrics. The advantages and use of object-oriented base methods were discussed in the literature review in chapter 2. It is know that object-oriented approaches provide high accuracy in the extraction of for example, building features (Herold, Scepan, & Clarke, 2002). However this research does not explore this method. Due to time constraints existing vector datasets (building footprints and road network) were adopted for the measurement of the indicators: change in building morphology and road network. The results of this research supports the users involved in a post-disaster recovery to answer questions related to: changes in land use, relocation and creation of new business, housing, etc. (Brown et al., 2010).

Key indicators	Features	Potential technique	Output
BUILT UP AND INFRASTRUCTURE			
Change in building morphology	**Building density** **Building extent** **Building shape** **Building size**	**Delineation of building footprint and application of landscape metrics**	**Are the new houses the same size as those that existed before? Did building density changed?**
Removal and reconstruction of buildings	Creation of new buildings Difference between new building and rehabilitated Presence and absence of buildings	Membership function classification and object classification comparison based (using object-oriented)	How fast were households built in the area? Which buildings are new and which ones are the same?
Change in land use	Map of land use types	Land cover classification (object –oriented) and landscape metrics	There were changes in the land use?
Road network	**Road density**	**Line density calculation using GIS**	**What were the changes in the morphology of landscape?**
ENVIRONMENTAL			
Environmental restoration	Distribution of open spaces	Membership function classification to create a vegetation map, landscape metrics and object classification comparison based (using object-oriented)	Are the open spaces well distributed?
Permeability of surfaces	Parking lots Roads Building area Land cover (bare soil, urban, grass and thick vegetation)		There was increase or decrease of impervious surfaces?
Energy loss (proxy of quality of housing)	**Temperature of houses**	**Visual interpretation of thermo scan map**	**Are the new houses good insulated?**
ECONOMIC			
Change in business	Business location and type	Post-classification comparison	How many business have been built and in use?
SOCIAL			
Pedestrian access	Size of block parcel Number of street intersection Transport network	Landscape metrics and network analysis	How far are households from services and facilities? Are sufficient schools available?
Local facilities in use	Car parking Playground Main high street Building size	Visual interpretation and change detection	Are facilities reopened? How many facilities were created?

Table 9 List of potential indicators to measure post-disaster recovery after the firework disaster, in Enschede.

5.1. General approach

The following sections will describe the types of data used in this research, the method for image pre-processing, limitations and the methodology to measure the indicators selected.

5.1.1. Data source and requirements

The choice of images is an important step for recovery assessment, but it depend on the imagery availability, resolution and what can be affordable. Table 10 shows the images that were acquire for the case study. These images were used for visual interpretation 1) for damage interpretation; 2) buildings reconstruction and typology; 3) identification of recovery features; and 4) for comparison between neighbourhoods, through the identification of socio-economic similarities using physical features.

Year	Timeline	Resolution	Spatial reference
1996	-48 months	0,16 meter	Undefined
May 1998	-24 months	1 meter	Amersfoort_ITC_Coordinate_Frame_Double _Stereographic
May 2000	After disaster	0,12 meter	Amersfoort_ITC_Coordinate_Frame_Double _Stereographic
2002	+2 years	0,2 meter	WGS_1984_UTM_Zone_1N
2005	+ 5 years	0,2 meter	Undefined
2007	+7 years	0,16 meter	Undefined
2008	+8 years	0,10 meter	Amersfoort_RD_New (Stereographic projection)
2009	+9 years	0,10 meter	Amersfoort_RD_New
2011	+11 years	0,10 meter	Undefined

Source: images from 1996 and 2002 onwards were provided by ©Municipality of Enschede, The Netherlands Centre for Information services (ISC).

Table 10 List of remote sensing data used to assess post disaster recovery after the firework disaster, in Enschede.

The images from May 1998 and 2000 were provided by the Faculty of Geo-information Science and Earth Observation (ITC), and are raster format, obtained by a multispectral sensor (camera). It contains 3 bands (red, green and blue) and has a large scale, which means many details on small areas. The remaining images were obtained by an airborne camera and were provided by the ©Municipality of Enschede. They are also raster images, containing 3 bands (red, green and blue); they have very high resolution and were delivered in TIFF and ECW formats.

Data	Type	Years				Source
Building footprint	Geodatabase polygon feature class	Before May 2000	2002	2005	2011	ITC and DANS
Road network	Geodatabase polygon feature class	Before May 2000	-	-	2011	DANS

Source: the building footprint vector data from 2011 and the road network vector dataset were provided by ©DANS (Data Archiving and Networked Services).

Table 11 Vector dataset used to assess the indicators: changes in building morphology and road density analysis.

Table 11 shows the type of vector dataset used in the assessment of neighbourhood recovery. They are a geodatabase polygon feature class, the unit is in meters and the geo-reference is Amersfoort_RD_New (Stereographic projection). The vector dataset was used to measure the following indicators:

- Change in building morphology (uses the vector file of building footprints from before the disaster, 2002, 2005 and 2011);
- Road network (uses the vector file of road feature class from before the disaster and 2011)

The accuracy of the vector dataset will have influence on the analysis of the landscape metrics. It is important to state that the data from ITC has limitations in the accuracy (some building footprints are not extracted) and the exact reference date is unknown. The adjustments in the dataset were seen as not viable. Because it would require: a great amount of time, expertise to add the missing buildings and to test accuracy of the building extraction for the past years.

5.1.2. Image pre-processing

To evaluate recovery, observe and compare the ongoing changes over time, the images from table 9 should be in the same spatial framework. The georeferencing was done using AutoSync tool in ERDAS Imagine 2013. When creating a new project in AutoSync the following parameters were used:

- Project option: Georeferencing
- Properties of the output: resample (nearest neighbours)

The image from 2008 was selected as the reference image (containing the coordinates and projection information to be used). This means that it will serve as the base layer for the rest of the images that present a different georeference. Circa 10 points (using ground control point tool) were identified. This process required attention to find the exact point in the reference image (2008) and in the image from the year that was being analysed. To facilitate the process it was chosen clear points such as road intersections or sharp angular edges.

After the manual identification, AutoSync can automatically identify tie points using image matching. The program calculates a model (using statistical correlation) to best fit the unreferenced image to the reference image, in this case the 2008 raster data.

Once the model was run and the results were accepted, a calibration/resample process was done automatically by the program and the images were than georeferenced to 2008. This georeferencing process was chosen because it is a simple and straightforward method. However it is important to check erroneous points to avoid distortions in the final image output.

5.2. Measuring built up and infrastructure sector

This section explains the methodology used to measure the two indicators chosen for the analysis of the built up and infrastructure sector. The first indicator is change in building morphology and is measured by the use of landscape metrics. The second indicator is road network and will be measured using GIS tools.

5.2.1. Indicator: Change in building morphology

5.2.1.1. Review of landscape metrics

Landscape metrics are spatial statistics that allows quantitative analysis to describe the habitat composition and configuration of a landscape pattern (Herold, 2001). They are generally used to measure biodiversity conservation and habitat fragmentation, but can also be used to detect natural or anthropogenic changes over time (Loraam, 2011). This method also applies to building footprints and urban maps (Brown et al., 2010). In this study, landscape metrics are used to quantify changes in the total built-up area, average building density, shape and size using the indicator retrieved from Brown et al. (2010). The authors mention in their research that this indicator was designed to be transferable and non- country or hazard specific. This research aims to test if the same indicator, using a similar approach, could be applied for a well-developed area with different characteristics than the Eastern countries (Pakistan and Thailand), where the research was conducted.

Building morphology indicator represents one element of urban form (section 2.4); housing and building type. This is an important indicator for the study area, because it allows the understanding of how densely built up areas redevelop after a disaster event. It is assumed that the built environment and morphology can affect the area in terms of its attractiveness and vibrancy.

Landscape metrics can quantify changes over space and time on three scales: patch, class and landscape (Herold, Goldstein, & Clarke, 2003).

- Patch: is defined as homogeneous regions of a landscape and describes the individual unit of interest;
- Class: represent all patches that share a common class;
- Landscape: it is the whole unit, encompassing all classes and all collection of patches.

In this research landscape metrics were calculated using the public domain Fragstats 4.2 program, where eight metrics were selected for the analysis (see table 12). The input data is a binary vector map (buildings and non-buildings) from the years: before the disaster event, 2002, 2005 and 2011. This analysis focus on the building footprints, thus the metrics were calculated for class and landscape levels.

Indicator: Change in building morphology

Feature	**Spatial Metric**	**Description**
Building extent	Class area	Equals the sum of the areas of all patches (m²), divided by 10.000(to convert to ha). It is the total area of patches
	Number of patches	Equals the number of patches in the area of interest
Building shape	Mean shape index	Equals patch perimeter (m) divided by the square root of patch area, adjusted against a standard square
	Mean perimeter-area ratio	Sum of each patch perimeter/area ratio divided by the number of patches
Building size	Mean patch size	Measures the average patch size
	Edge density	Equals the sum of the length of all edge segments of patch, divided by the total area of interest (m²), multiplied by 10.000 (to convert to ha)
Building density	Mean nearest neighbour	Equals the mean distance in meters to the nearest neighbouring patch, based on shortest patch edge-to-edge distance from cell centre to cell centre
	Patch density	Equals the number of patches divided by the total area of interest (m²), multiplied by 10.000 and 100 (to convert to 100 ha)

Table 12 Description of metrics used to measure change in building morphology indicator, (Brown et al., 2010).

Class area measures the landscape composition, in the purpose of this study it will measure the percentage of Roombeek that is comprised by the total buildings. Also it can measure the extent of the damaged area. This metric is measured in hectares and the class area is equal to the sum of the areas (m^2) of the building footprints, divided by 10,000 (to convert to hectares). The number of patches corresponds to the total number of patches in the area (McGarigal, Cushman, & Ene, 2012). With this metric it is possible to observe the extent of the buildings before and after the disaster. In addition this metric suggests the progress of reconstruction.

To measure building shape two metrics were chosen: mean shape index and mean perimeter-area ratio. These metrics measure the complexity of the building shape, whether they tend to be simple and compact, or irregular and convoluted. However the perimeter-area ratio as a measure of shape varies depending of the size of the patch. So using a shape index the complexity of patch shape is compared to a standard shape (square or circle) diminishing the problem of size dependency of perimeter-area. The index will be equal to 1 for square patches of any size, and higher (without a limit) as the patch becomes more geometrically complex (McGarigal et al., 2012). Building shape analysis can be an indicator of change in building type and could also indicate changes in the land use. Building size metrics can provide important information on the dimensions of the reconstructed buildings.

The mean patch size represents the average condition, and at building level is a function of number of patches in the class and the total class area. Edge density is a measure of total edge length of a patch type (building). It takes the patch shape and complexity into consideration and can be an expression of the heterogeneity of the landscape (McGarigal et al., 2012). In the context of this study, these measures can tell if the buildings had increased or decreased in size after the disaster, showing insights of changes in building design and construction and thereby influencing the occupant's life.

Patch density equals the number of patches of the building class divided by the total area of interest (McGarigal et al., 2012). This measure analyses how dense is the patch class (buildings) and it gives an overview of the changes in the built environment over the recovery process. Using a moving window analysis it is possible to identify new building areas that were developed and areas that were not yet rebuilt. Patch density has a great effect on the residents life, and using other analysis tools as interviews and questionnaires it can determine if the residents houses were better off or worse off than before the disaster (Brown et al., 2010).

5.2.1.2. Effect of changing scale on landscape metrics analysis

It is important to define the level of metric that is being analysed and the scale of the phenomenon studied. Otherwise the landscape metrics are meaningless and the results might lead to incorrect interpretations. For this study the buildings are the objects of consideration, so it will not be significant for example, to define a scale that is too big to represent the object (McGarigal et al., 2012).

In order to run Fragstats, it was necessary to convert the vector file into raster. The rasterization process may cause the join of disjunct patches or vice versa. This happens because in a raster image the level of detail is dependent of the cell (pixel) size or spatial resolution. To investigate the effects of changing cell size, the spatial resolution of the vector dataset from before the disaster was systematically changed from 10x10 meters to 8x8 meters, 5x5 meters, 3x3 meters, 1x1 meter and 0,5x0,5 meter. In figure 8 it can be observed that the smaller cell size of 1 meter or 0.5 meter can better represent the original image. However one must take into consideration that smaller cell size results in larger raster datasets, leading to longer processing time.

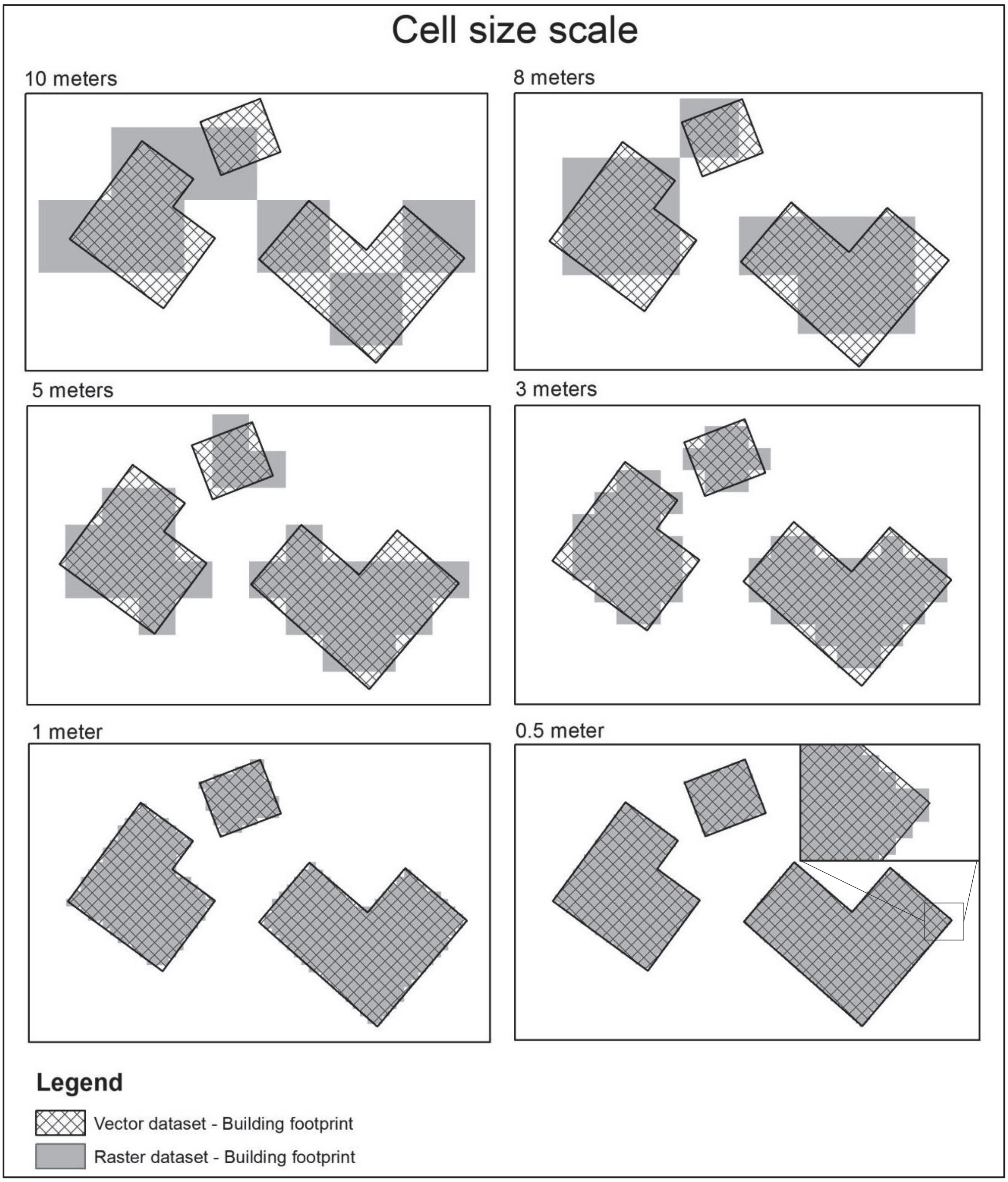


Figure 8 Effects of changing cell size resolution when converting vector data into raster images.

The cell size scale can have influence on the value of many metrics, specially metrics involving edge and perimeter. The cause is that raster formats represent lines differently than vector. Therefore, edge lengths will be biased because of the "stair-step outline". The bias will vary in relation to the cell size of the image. Generally the finer the resolution more detailed the edges are delineated, leading to an increase on edge length (McGarigal et al., 2012). This research adopts 1 meter cell size because it preserves the shape of the majority of the objects. Because the area analysed is not large, in Fragstats it has an acceptable processing time of 40 minutes to 1 hour to generate moving window analysis and few seconds to produce the no sampling statistics. With regards to the use and interpretation of the results, it is important to know that the edge indices are expected to be biased upward, as consequence of the stair-step outline effect.

5.2.1.3. Methodology to measure change in building morphology indicator

Figure 9 shows a flowchart of the methodology used to assess the indicator change in building morphology. The analysis was performed with GIS techniques and Fragstats through the use of landscape metrics using a binary vector map containing two categories: 1- non-buildings and 2- building footprints. The building footprint vector files are dated before the disaster (May 2000), 2002, 2005 and 2011. The building footprint dataset were clipped into the neighbourhood of Roombeek.

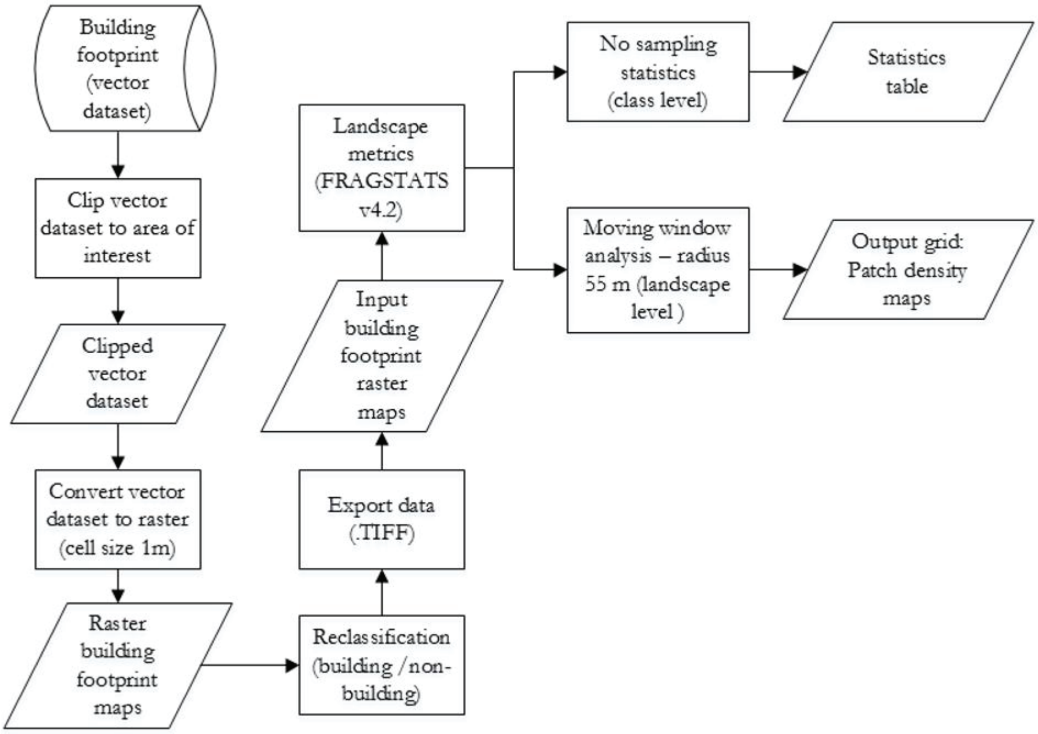


Figure 9 Flowchart: methodology to assess changes in building morphology indicator.

The clipped building footprint dataset was converted into raster using the conversion tool (polygon to raster). It was adopted cell size of 1 meter resolution to create the raster maps. Then using spatial analyst tool in GIS to reclassify the maps in two categories: 1- non buildings and 2- buildings. After exporting the reclassified map into TIFF file, the data was used as input for Fragstats v4.2.

An important limitation to consider when measuring this indicator is that the digitalization of the building footprint dataset grouped multiple houses as one block, instead of one unit per building. Because of this, some landscape metrics (e.g. class area and number of patches) might underestimate the real process of reconstruction. The underestimation is explained by the fact that the vector dataset, needed to undergo vector-to-raster conversions. Besides using a cell size of 1 meter resolution this process may have compromised the data integrity due to generalizations.

For the landscape metrics analysis it was taken two approaches: no sampling statistics and moving window analysis, both using 8 cell neighbourhood rule. The no sampling statistics was conducted at class level, the metrics used were: class area, number of patches, mean shape index, mean perimeter-area ratio, mean patch size, mean patch edge, mean nearest neighbour and patch density. And, the output was a table contain the values for each metric selected.

To visualize the patch density, a moving window analysis was conducted. In the moving window analysis the shape (square or round) and size (radius) of the window must be specified. However, most landscape metrics are sensitive to changes in scale or extent (Kong, Yin, & Nakagoshi, 2007). This indicator focuses on the morphological characteristics of the buildings and how they are distributed in the area. Because the analysis is at neighbourhood level, the rational choice for the radius is the half of the length of the smallest urban block in the area. The urban block contains buildings and its boundary is defined by the surrounding streets. Therefore a few trials (with 33, 55 and 75 meters radius) were conducted to test the impact of changes in the window size on the estimated results. The metrics were calculated based on a raster map of 1 meter cell size; it was proved that the 55 meters radius was more appropriated to capture the building footprint aggregation in the neighbourhood.

5.2.2. Indicator: Road network

This indicator uses the feature road density to analyse the concentration of roads in an area. This measure can indicate how and where the road system modified the space. The analysis compares the road density before the disaster and in 2011, showing how fragmented (more or less) the landscape became. The impact of road density is important in several aspects. First, it relates to environmental pollution and noise. Second, road density associated to centrality can have a large impact on whether people drive to work. Finally, the changes in the morphology of the space created by the road network might influence the distribution and amount of open spaces, increasing impervious surfaces (Bento, Cropper, Mobarak, & Vinha, 2005). However this analysis does not reflect the character of individual roads.

Figure 10 shows the methodology used to measure road density. The analysis was performed in GIS using road vector files, as mentioned in table 11. The dataset from before the disaster was clipped to the road delineation of 2011 provided by ©DANS to create a map of road density in the area affected by the disaster.

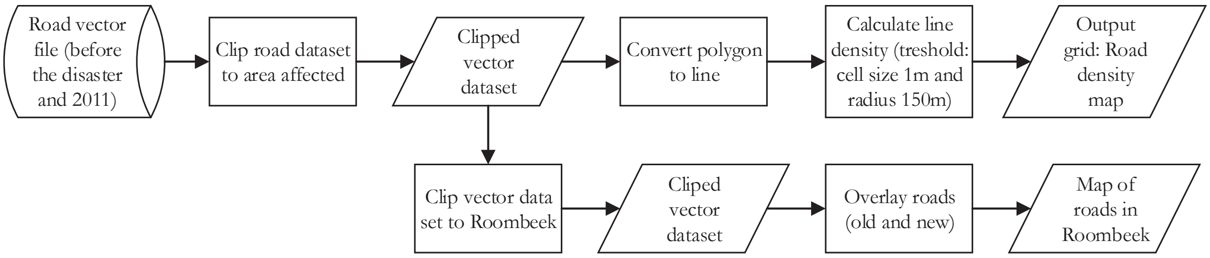


Figure 10 Flowchart: methodology to assess road density indicator.

The clipped files were converted from polygon to lines and the line density was calculated for both years. Line density calculates the magnitude per unit area from the polyline feature that fall within a radius around each cell. The radius was defined based on what was going on in a total study area (e.g. neighbourhood blocks within the area). Few trials were conducted (500 meters, 250 meters, 150 meters, 100 meters and 60 meters) to identify which radius would best fit in the observation. It was understood that the larger the search radius the broader the pattern, and the smaller the search radius the more detailed the density surface is. Therefore the radius of 150 meters suited best to analyse neighbourhood road density, using 1 meter cell size (same resolution used to calculate the building morphology indicator). For a visualization of the main roads and new roads created in Roombeek after the disaster, the clipped vector dataset was clipped to the neighbourhood of Roombeek and the main roads and new roads were overlaid.

5.3. Measuring environmental sector

This section will explain the methodology used to measure the indicator chosen for the analysis of the environmental sector. The indicator energy loss can serve as a proxy variable to measure quality of housing.

5.3.1. Indicator: Energy loss

To measure energy loss it was used a thermo scan picture retrieved from Enschede (2014). The thermal survey was done on winter days on 1 and 10 of February 2012 at approximately 23:00 and 6:00 hours to better capture the energy loss of the houses. During this period the average temperature was < 5 degrees Celsius, dry and with not much wind. Thermal scan uses a camera installed to an aircraft to create infrared images based on temperature measures.

In the thermo scan all the heat radiation of the houses are measured from above and this indicator shows the isolation quality of a roof or house. Because most of the heat disperses from the roof (circa 30% of loss), it is assumed that investments for a better isolation would increase quality of housing (Enschede, 2014).

This analysis is a visual comparison between house settlements in the Roombeek, one area that was reconstructed (block C) and two areas that remained the same since the disaster (block A and B). Block A is located between the streets H.B. Blijdensteinplaan and Jacob van Lennepstraat. Block B is situated between Deurningerstraat and Beekstraat. Finally, block C is located between Dr. J. van Damstraat and Putterstraat.

In addition, a comparison between Roombeek and the neighbourhood of Twekkelerveld. The area selected for Roombeek is located in the settlement block between the streets Stroinksbleekweg and Merelstraat, and the area analysed in Twekkelerveld is situated in the settlement block between the streets Weegschaalstraat and van Limborchstraat.

This neighbourhood was selected due to its similarities to Roombeek before the disaster. In Twekkelerveld the buildings are also from around the 30’s and 50’s, the house value and income were also similar in 1999 (Roombeek had an average of house value of €55.000 and Twekkelerveld around €43.000) (CBS, 2014). The type of houses present in both neighbourhoods are detached, semi-detached and terraces. Twekkelerveld is situated near a complex of industries, fact that characterized the neighbourhood of Roombeek before May 2000. Finally, in the research called Buurt Atlas, done by the municipality of Enschede to compare neighbourhoods and define actions for development; Roombeek held the rank of number 17 before the disaster, while Twekkelerveld was rank 15 in 2002 (I&OResearch, 2002). The results are expected to show that the new houses in Roombeek, rebuilt or reconstructed after the disaster would present better isolation as an indication of better quality of construction of the houses.

6. ANALYSIS OF RESULTS

This chapter will analyse the results derived from the measures of the built up and infrastructure sector using the following indicators: change in building morphology and road network. In addition, the measurement of the environmental sector using the indicator energy loss as a proxy variable to measure quality of housing. This chapter addresses sub-objective 3 and answer the following research question: can geodata based approaches characterize the complex recovery process, in a way that goes beyond the focus on physical features?

6.1. Results for built up and infrastructure sector

6.1.1. Indicator: Change in building morphology

The change in building morphology indicator was used to assess the building changes of an area affected by a firework disaster. The results in table 13 show that the building area (CA) and number of patches (NP) in Roombeek decrease drastically from before the disaster to 2002. However in the following years we can observe the gradual increasing in the area and in the number of buildings, indicating that recovery is taking place. But until 2011 the number of patches did not yet reach the level of built up before the disaster. With this information it can be concluded that the reconstruction is progressing and might exceed the built up level before the disaster.

Year	Class	CA (ha)	NP	PD (ha)	ED(m/ha)	AREA_MN (ha)	SHAPE_MN	PARA_MN	ENN_MN (m)
Before the disaster	Buildings	23,1	476	460,3	409,6	0,04	1,29	4326	5,41
2002	Buildings	10,73	287	283,6	249,64	0,03	1,32	4319	6,69
2005	Buildings	13,2	364	359,2	314,9	0,03	1,3	4138	6,27
2011	Buildings	16,5	434	464,2	519,1	0,03	1,48	4288	5,24

Source: building footprint data from 2011 was provided by © DANS (Data Archiving and Networked Services).

Table 13 Landscape metrics to measure change in building footprint morphology in the neighbourhood of Roombeek

The mean patch size metrics (AREA_MN) shows that the values did not differ so much across the years, expect for before the disaster and 2002. We can assume that this difference is due to the presence of the industries that have larger shape areas that might be influencing the mean value. Than in 2002 when the value decreases we can assume that the industries were removed.

To support the assumption that the industries are being removed from the area, a boxplot analysis was done to visualize the shape area distribution in the data. In figure 11 we can see few outliers that are bigger than almost all of the other areas. Some of the extreme outliers (illustrate as * in the graphic) were identified in the dataset as the industries. We can see in the figure that they are decreasing, which suggests that the industries are indeed being removed; as it was assumed with the results of the landscape metrics.

In figure 11 we can also see that the interquartile in 2011 has more area variety than the previous years, especially in the third quartile. This major difference is also caused by the digitalization of the building footprint dataset. The buildings in the 2011 dataset are digitized with more detail and sometimes buildings are grouped as a single block, instead of a single unit (see annex 2 Digitalization limitations of building footprint).

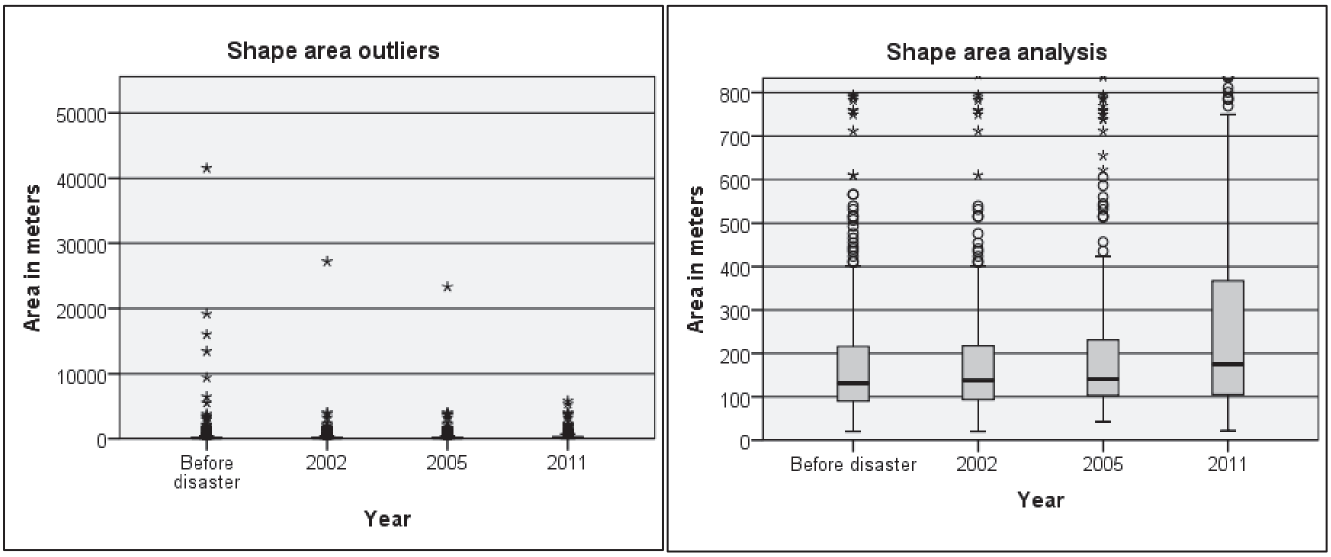


Figure 11 Boxplot analysis of the shape area data.

The area variety shown in the boxplot analysis also supports the results for the edge density metrics (ED). The metrics has shown an increase in the values indicating that the area is now composed of more patches of different characteristics and more complex shapes. But it is important to take into consideration the limitations regarded the bias present in the edge indices, due to scale dependency (as discussed in section 5.2.2) and limitation of buildings digitalization.

The table 13 also shows that was a significant change in building density suggesting an intensive building deconstruction in the area. The area was built denser, showing that its increase have reduced the distance between buildings. This decrease explains why the distance of neighbouring buildings (EM_NM) had increased in the year of 2002. But, in 2005 and 2011 with the increase in patch density (PD) we can observe that the building distance reduces.

Patch density (PD) maps show the concentration of buildings in the study area and give an overview of the changes in the built environment. Figure 12 shows the visualization of the patch density metrics derived by a moving window analysis in Fragstats. The areas in red mean high density and indicate more spatial heterogeneity, which means higher concentration of smaller urban units. It can be concluded that the area is still witnessing a developing process. It is assumed that these areas are new residential buildings, and they are being distributed in the space differently than the way they were before the disaster. This change in the morphology of space can be explained by the fact that people participation in the recovery plan showed their preference in relation to the way the space was organized. In addition, these maps can identify the hot-spot areas for development. The identification of the hot spot areas are significant to recovery if the target is towards a sustainable future, that means the efficient use of the area, build more compact, integration of open spaces and mix of uses.

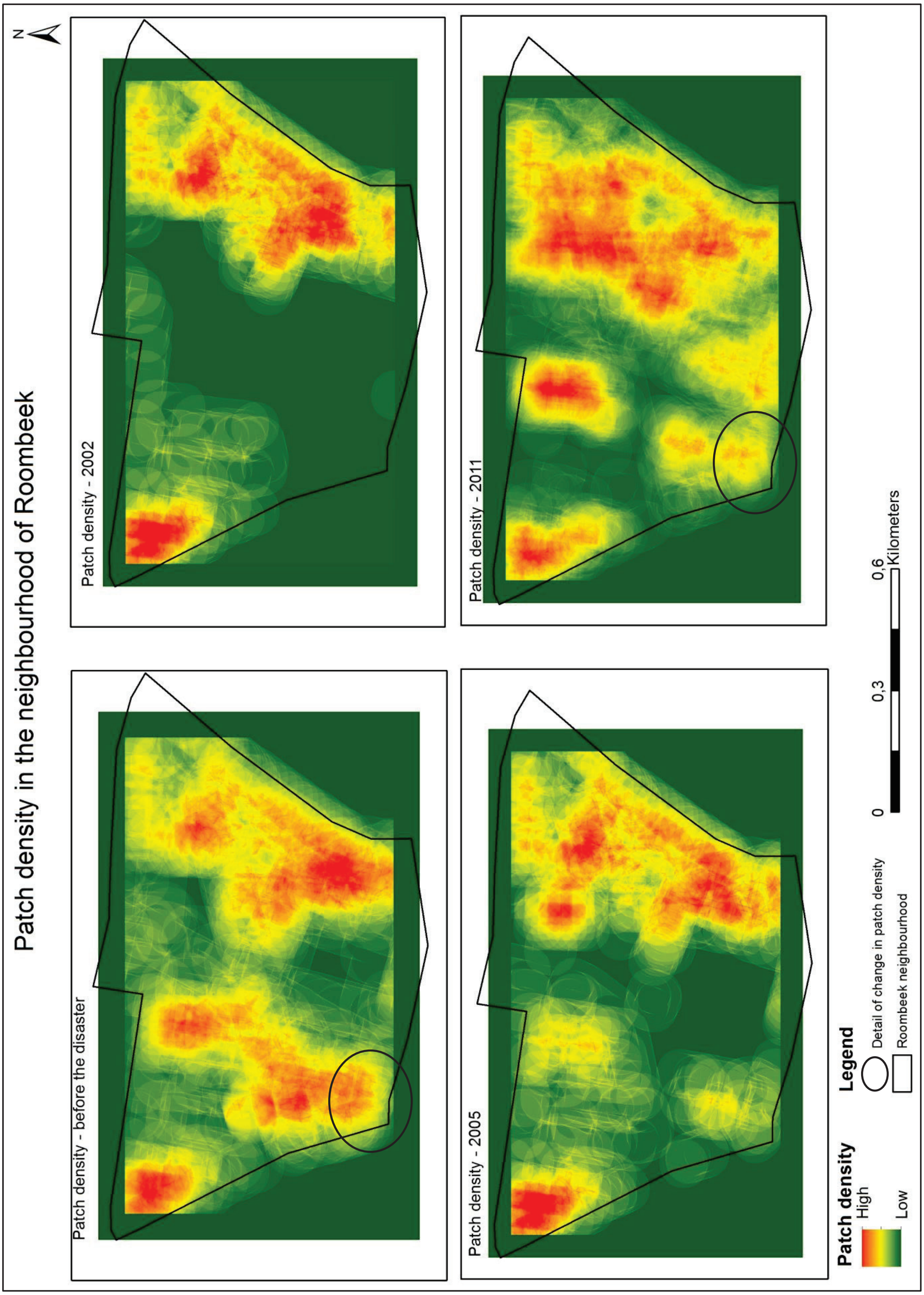


Figure 12 Patch density maps of the neighbourhood of Roombeek

Figure 13 shows the zoom of the detail of change in patch density seen in the previous image (figure 12). The image before the disaster shows that there was more building heterogeneity before the disaster compared with 2011, indicating change in building type. The results from shape metrics (SHAPE_MN and PARA_MN) also suggested changes in building type during the recovery process. In table 13 the metrics shows an increase in the value. This means that the buildings are becoming more complex in shape.

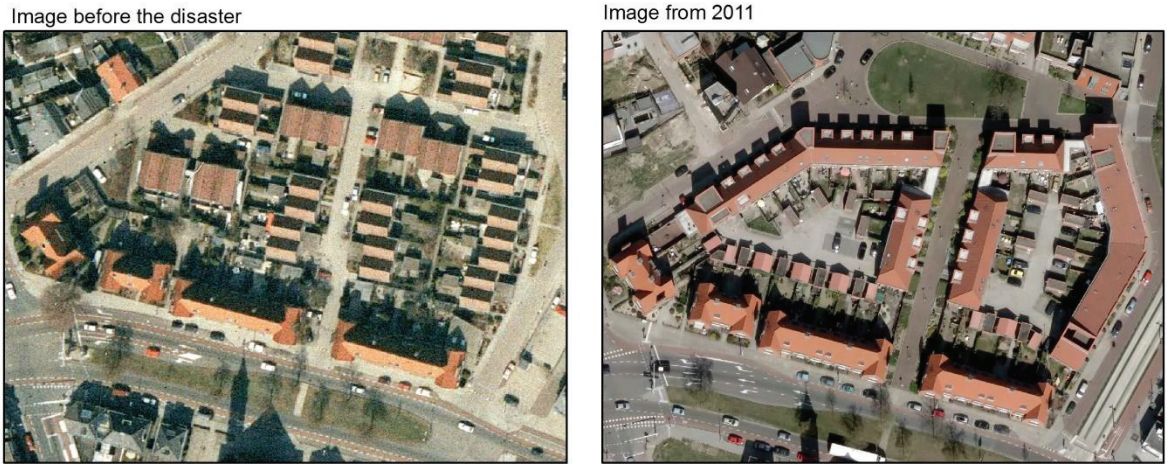


Figure 13 Residential block in the neighbourhood of Roombeek from before the disaster and from 2011.

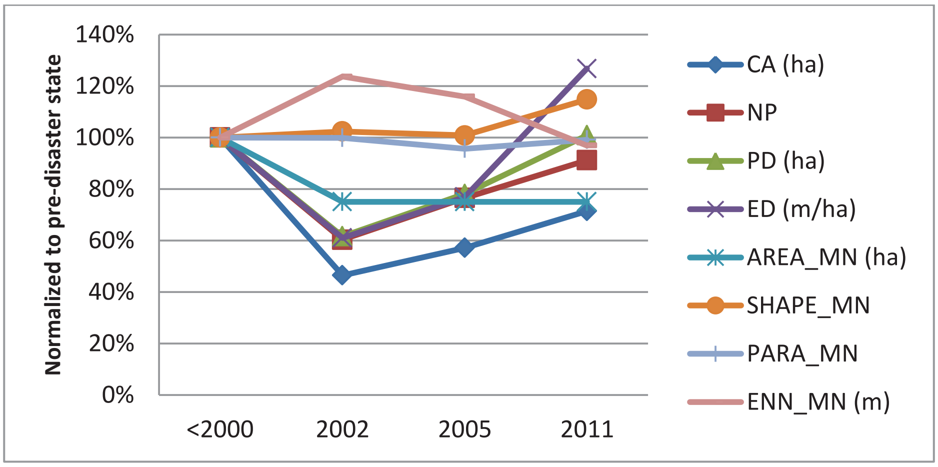


Figure 14 Landscape metrics applied to identify change in building morphology in Roombeek.

To support the metrics interpretation figure 14 was produced to visualize the changes in building morphology. By normalizing the pre-disaster state it is possible for example, to monitor the speed of recovery. And to understand the reconstruction of new buildings, for instance, the metrics for class area (CA) shows that 54% of the built up area is removed and later rebuilt by 11% in 2005 and 14% in 2011. With available data (building footprint) of a comparable neighbourhood that contains the same characteristics of the pre-disaster area and a normal building development, it is possible to compare trends. Trends can explain the development trajectory of the affected area compared with the trajectory of an area that was not affected by the disaster.

This indicator showed three important primary measures of recovery process. First, recovery is progressing to exceed the built up area before the disaster. Second, the metrics have shown that function in the urban area changed from industrial to residential. However, the collection of data available for this case study did not presented information on the building activity. Detail information about the building activity allows further analysis on how these changes in function will influence the recovery process. For example, using diversity metrics it is possible to obtain data on the variety and conversion of building activities (a building that was residential becomes commercial or vice versa). This information permits decision makers to implement policies to support or constrain certain building activities in a way that those would fit better with the existing neighbourhood character. Finally, the landscape metrics have shown changes in function of building type. The area now changed from small semi-detached units to multi-family terraces buildings. The change in building type gives insights about the quality of living conditions. The same area in figure 13 looks and feels different; liveability is better addressed in the renovated area form 2011. For instance, it has the presence of better organizational planning of the space (design), circulation, private parking, more green areas and sidewalks.

6.1.2. Indicator: Road network

This indicator uses the feature road density to measure how the line features are concentrated in the affected neighbourhoods. The road density measures the utility line in the area. The figure 15 shows that in 2011 there is a high concentration of roads in the neighbourhood of Roombeek in comparison with before the disaster.

The increase in density in the zoomed area may explain the fact that the area has passed by a process of development after the industries were removed. The visual interpretation of roads and buildings in the zoomed area (Deurningerstraat Oost/Talma and Bamshoeve) confirmed that the area in development was destined to residential houses. In result the area became more fragmented after the disaster due to the presence of transportation network to attend the residents.

Road density is a variable that could show that the area was indeed recovered, but not in the same manner. This is an indicator that recovery happened, but did not go back to its original situation. A reason is that the area was developed with a different use, indicating that land use has changed from industrial to residential.

Figure 16 shows the overlay of the new roads that were created in Roombeek after the disaster explaining the increase of density in the area. The road length increased approximately 14 km after the disaster. However the main streets remained the same. After the disaster the municipality made use of the old railroad and the cleared area to create a bus line as intended in the Groot Roombeek plan (section 4.2). This cleared space was used to build a high quality public transport (HOV) from the north of the city directly to the central train station of Enschede. In addition, a path only for bicycles was created to shorten the travel time and improve safety of people traveling from the north to the central station of Enschede. The street design is integrating walking, bicycle path and open spaces. This is an indicator that recovery is seeking a sustainable development, engaged in the space organization and interaction, bringing residents together in an attractive public space, making the area more appealing.

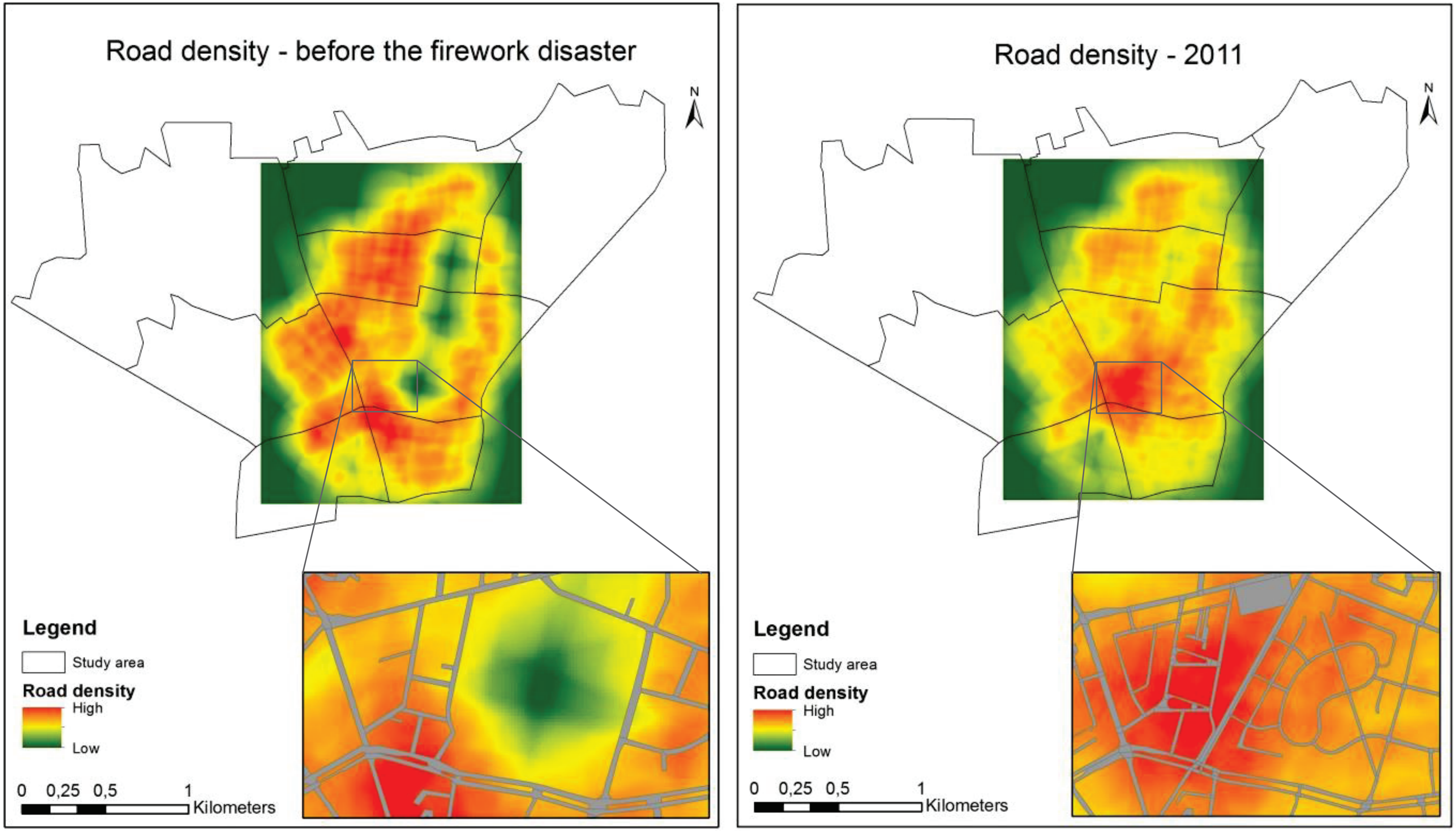


Figure 15 Road density map of the area affected by the firework disaster, in Enschede, The Netherlands

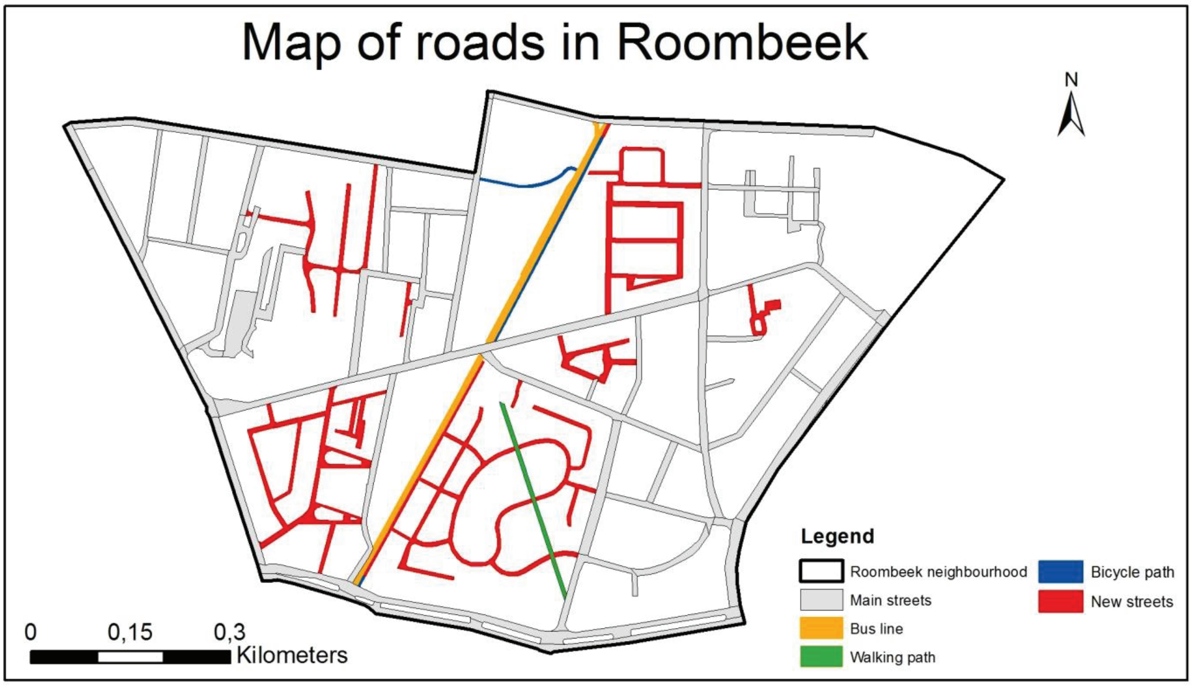


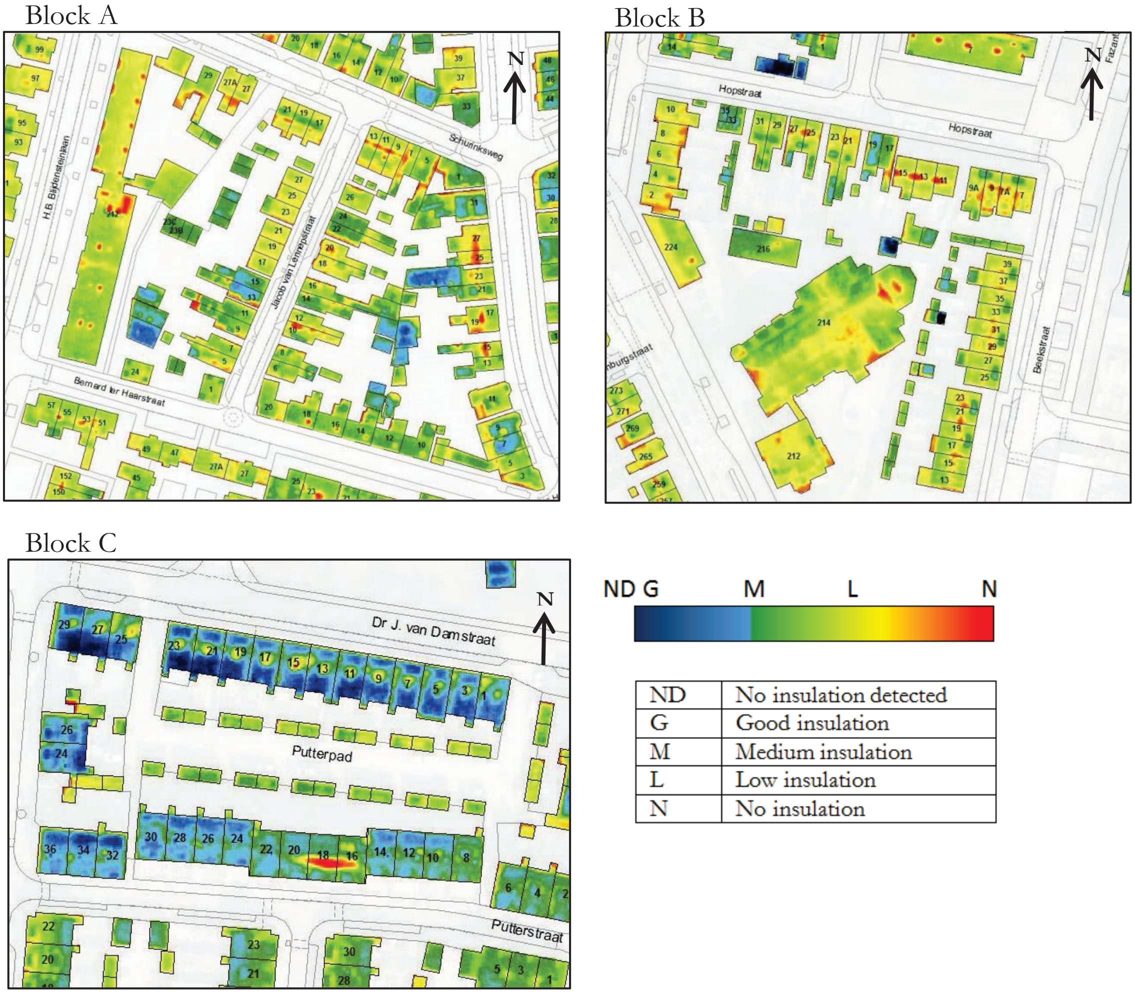
Figure 16 Map of main roads in Roombeek and the new roads created after the disaster.

Generally transportation studies had focus on model the physical part of infrastructure and traffic. But this indicator demonstrated that the use of density that is not a physical feature, could give important insights about the recovery process. First, the function of traffic circulation has changed with the creation of local streets to attend the residents. Second, the function of street connection also changed with the creation of the bus line and bicycle path. Finally, as the indicator in change in building morphology, this indicator has also shown the change in urban function, from industrial to residential.

6.2. Results for environmental sector

6.2.1. Indicator: Energy loss

The renovation or reconstruction of the houses after the disaster would provide an opportunity for reduction of energy consumption and an increase in the comfort level of residents. Therefore, energy loss indicator can be used as a proxy variable in the measurement of housing quality. Figure 17 compares three blocks in the Roombeek neighbourhood; block A and B containing houses that remained the same after the disaster and block C containing houses that were renovated or reconstructed. The houses present similar characteristics, for example: size and type (detached, semi-detached and terraces houses). In addition, a visual interpretation of remote sensing imagery of both areas (using features as: presence of cars, size of house and condition of garden, etc.) indicates that they have a similar socio economic level. It is verified that the houses from block C present better insulation scores than those that remained the same after the disaster.



ND	No insulation detected
G	Good insulation
M	Medium insulation
L	Low insulation
N	No insulation

Source: Images retrieved from ©ThermoScan, municipality of Enschede (image scale unknown).

Figure 17 Thermo scan image from the neighbourhood of Roombeek.

In general Roombeek has a medium to low score for insulation. But to know if the recovery process could have brought a better quality of housing, this research makes a visual comparison between Roombeek and the neighbourhood of Twekkelerveld to identify differences between both areas in terms of heating efficiency. These neighbourhoods present resembling characteristics, as described in section 5.4. Even though both areas present similarities in insulation characteristics (for complete visualization of neighbourhood, refer to Enschede (2014)); it is possible to observe that some houses present a very low level of insulation in comparison with the new settlement in Roombeek as shown in figure 18.


Twekkelerveld

Roombeek

Source: Images retrieved from ©ThermoScan, municipality of Enschede (image scale unknown).

Figure 18 Thermo scan image comparing the neighbourhoods of Twekkelerveld and Roombeek.

Cutting energy consumption by improving energy efficiency is a key commitment for a sustainable plan. Improving the thermal insulation of the building envelope leads to energy savings and also increases the indoor comfort (Gagliano, Nocera, Patania, & Capizzi, 2013). Based on the images above it can be concluded that the restored and reconstructed houses indeed present better insulation and consequently the quality of the house will increase. However, not all the restored or constructed houses from the recovery process present good levels of insulation. Some factors might influence the level of the insulation, for example the presence and absence of people in the house can affect the accuracy of the outcome of the thermo scan. With a person absence, the results might show little or no heat loss in the building. In addition, the type of roof may distort the results, for instance, a flat roof with presence of water or a metal roof cannot be measured. Thus, for these types of roof a dark colour will show which means the insulation is not detectable. Finally, the recovery of houses in the Roombeek area had the support of different housing corporations, which can explain the variation in quality insulation from the reconstructed houses. Some European countries require a minimum quality level of insulation. But it is possible that some housing corporation may install a more effective insulation than the minimally required. The main differences rely on the type of construction in terms of quality of thermal insulation, ventilation, airtightness and solar gains through windows (ISOVER, 2008).

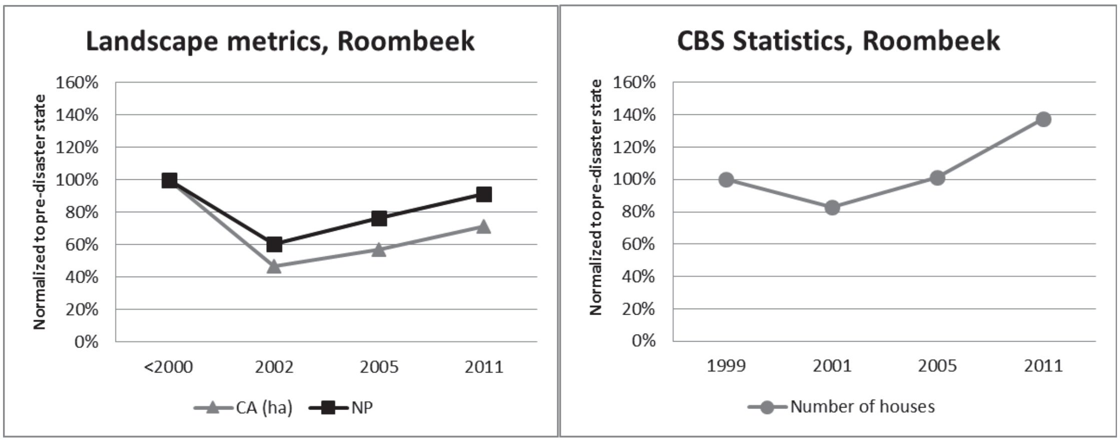
It is necessary further studies to define the type of construction plan and design that each corporation developed with the participation of residents; to determine if the characteristics chosen influenced the choice for type of roof and insulation, characteristics that can ascertain quality of housing. One might take into consideration some limitation when applying this indicator such as:

- This indicator alone cannot identify the quality of housing it would be good to use with interviews or questionnaires;
- Building construction type and human behaviour need to be accounted for;
- This type of data is not common and widely available.

7. DISCUSSION

This chapter discusses the results of the variables and indicators presented in chapter 6, and compares them with reports, CBS (Centraal Bureau voor de Statistiek, The Netherlands) data and actual recovery plan of the post-disaster in the neighbourhood of Roombeek. It is assumed that this information accumulate enough evidence to support the interpretation and validity of the results. The aim is to identify if the variables and indicators used could explain the process of recovery and the change in function in a time period of approximately 10 years.

The metrics for building extent showed that the process of reconstruction was progressing as seen in figure19, but yet have not reached the level of built up before the disaster. The number of houses could be used as a variable to show the trend of reconstruction growth. In figure 19 it indicates that the metrics for number of patches and class area were true. And reconstruction was indeed progressing, indicating that recovery might exceed the level of built up than before the disaster. This can also be confirmed by Roombeek (n.d) that states that already in March 2011, 80% of the actual reconstruction plan was executed.



Source: CBS statistics from Roombeek, Esnchede. retrieved from (CBS, 2014).

Figure 19 Trend of built up progress, comparison between the results of landscape metrics for class area and number of patches (indicator change in building morphology) and CBS statistics.

An important limitation to consider when measuring some landscape metrics (e.g. class area and number of patches) is the digitalization of the building footprint dataset. In this study the digitalization grouped multiple houses as one block, instead of one unit per building. Because of this, the result might have underestimated the real process of reconstruction in Roombeek. The underestimation is explained by the fact that the vector dataset, needed to undergo vector-to-raster conversions. Besides using a cell size of 1 meter resolution this process may have compromised the data integrity due to generalizations.

The results for the metrics of building density and shape showed that the area present more spatial heterogeneity and concentration of smaller urban units. In addition, there was a change in the function of building type.

Enschede (2003a) proved that the reconstructed area will contain urban plots with a mix of different type of houses (terraces and semi-detached buildings, apartments, detached houses and luxury houses) than before the disaster. This might be caused by the high participatory planning process during the reconstruction of the affected area. The population could advise on various issues, especially in the design of the type of buildings (Denters & Klok, 2010). According to FEMA (2011) recovery of housing function involves the implementation of adequate housing solutions that supports the needs of the affected community. Remote sensing could support the analysis of these metrics showing insights of improvement of liveability, shown in section 6.1.1. However, the variables do not give significant information if the new building type fulfilled the need of the resident. Methods as surveys, interviews and questionnaires can be used to monitor living conditions and resident's perception of recovery to see if houses are better or worse off after the disaster.

Table 14 confirms that density have increased in the area. Urbanization density have changed from urbanized (1.500 – 2.500 addresses per km²) to very urbanized (>= 2.500 addresses per km²). In addition population density has increased by 27% from before the disaster until 2011.

Year	Urbanization	Population density per km²	Population density per km² in % compared with 1999
1999	2	4416	100%
2001	2	2693	61%
2003	2	2634	60%
2005	2	3883	88%
2011	1	5599	127%

Table 14 Table showing urbanization levels and population density in Roombeek, Enschede.

Road density results showed that the area became more fragmented after the disaster due to the presence of transportation network to attend the residential area. According to Enschede (2003a), the authorities wanted to stimulate mix of function of living and working in the area of Roombeek. Thus, the authorities have changed the environmental category of activities to limit industry operations. After the disaster, home-offices and business environmental category 1 and 2 (e.g. dentist, furniture shop, gym, bicycle shops, supermarket and retail, etc.) are allowed and category 3 (e.g. printer and graphic companies, storage and transport, swimming pools, auto repair shops, etc.) allowed with exceptions of the authorities.

For example, in the area of Bamshoeve, where an industrial complex was situated, a new luxury residential area was created. This residential area is characterized by its large plots and villa park environment, this design is reinforced by a winding ring road. In addition, the Grolsch beer factory area became a mix of different functions (retail, facilities, residential, commercial, etc.)(Enschede, 2003a).

These facts prove that the metric was efficient to show important primary information about the landscape and change in urban function. However, availability of information on services and facilities would have improved the recovery analysis on logistics (serviced and served) in the area (Berghauser Pont & Haupt, 2009). This information could be gathered and mapped for example, by crowd-sourcing methods and sources like OpenStreetMap (Brown et al., 2010).

Areas of high density can spread their benefit to other areas; this is made through corridors and nodes to link places, for example street connections. This is another insight in the way the neighbourhood functions (Steffen, 2011).

The bus line north (HOV-North) leading through Roombeek (figure 20), is an example of how the area improved its connectivity function. This bus line was finished between 2007 and 2010 providing better mobility and increase of public transport. They also connected a P+R (Park and Ride) from the edge of Enschede to the city centre with the intention to reduce traffic jam and amount of cars circulating in the centre. The construction of the Roombeek bus line made it possible to connect the north axis with the centre and other axis (west, east and south) improving the cities network. (Dubbeldam, 2007).

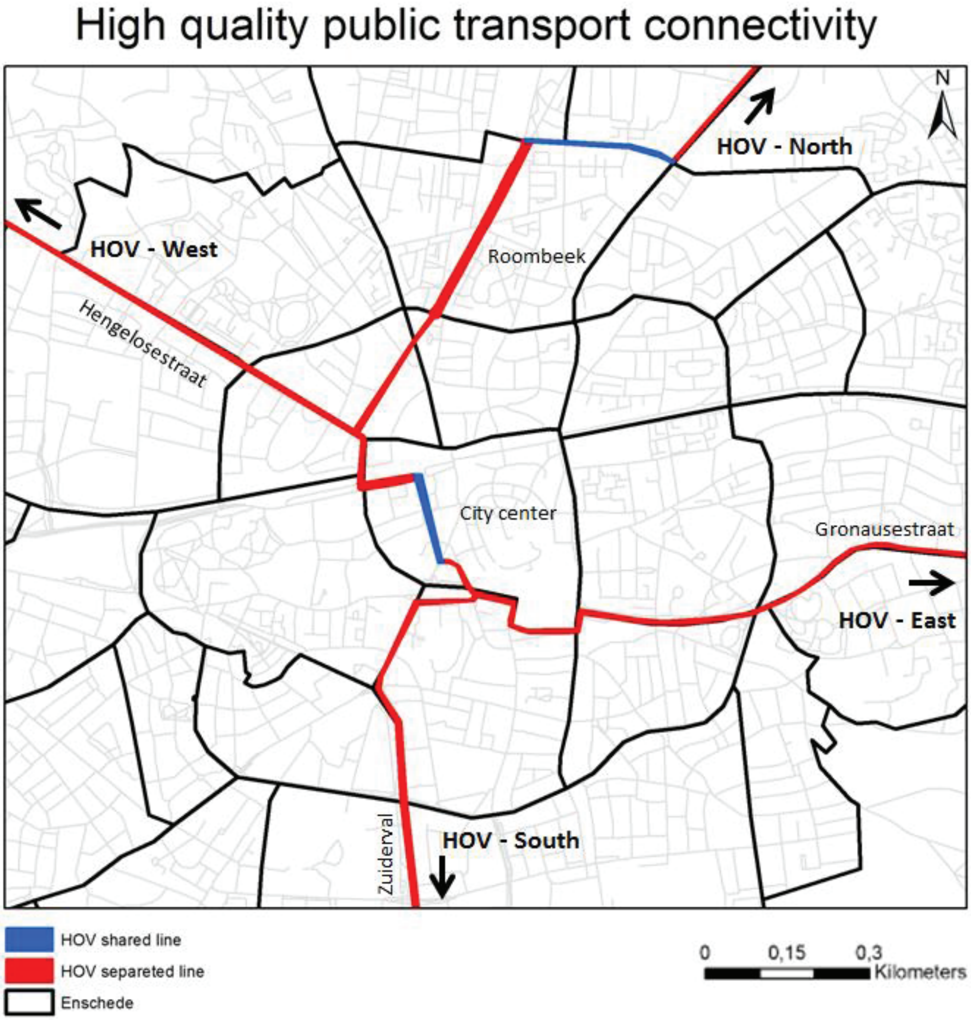


Figure 20 Map showing the high quality public transportation route and how it is connected in Enschede.

The concentration of urban function and the increase in urbanization may have leaded the neighbourhood to a sustainable mobility. Based on the actual recovery plan, results and discussion of road density, it can be concluded that road network planning was concerned with the concentration of urban function and distribution of public space. Therefore the bus line and bicycle path were created to integrate functions.

Finally, energy loss results have shown that some areas presented better insulation compared with other settlements that were not restored or reconstructed in the neighbourhood of Roombeek. Due to many factors that need to be considered for this indicator, it is hard to confirm that the houses in Roombeek increased in quality after the disaster. An investigation of CBS data about the energy usage was conducted to try to explain if the houses have become better insulated and consequently improving their quality. Data before the disaster it was not found during this research. In table 15 shows that between 2004 and 2011, average gas consumption indeed decreases. However this reduction might have been influenced by the percentage of houses using city heating. In conclusion, the energy loss indicator was not efficient to measure quality of housing, based on the information available for this research.

Year	Average usage gas in m³	Percentage of houses using city heating
2004	1200	25
2006	900	40
2008	800	48
2009	750	48
2010	1000	44
2011	750	46

Table 15 Table indicating average usage of gas and percentage of people that uses a city heating in Roombeek, Enschede.

In this discussion a number of indicators contributed to explore in more detail the use of remote sensing as a method to collect primary data to assess post-disaster recovery. As mentioned in previous sections, there are many methods to measure recovery. But, the aim of this research was to test features that could be extracted from geospatial data and remote sensing by the use of landscape metrics and GIS tools. For a complete overview of the recovery assessment, all sector of society (see table 9) should be addressed. However for the purpose of this study, the research was reduced in scope and discussed only two sectors and three indicators.

In general the indicators results have shown significant primary information about the landscape and the changes in recovery functions. Except the indicator energy loss; besides being an interesting indicator, it was not able to explain quality of housing based on the improvement of housing insulation. Availability of this type of data and issues related to building construction that must be taken in consideration when making use of this indicator, are just few of the limitations encountered in the testing of this variable.

The firework disaster devastated great part of the neighbourhood of Roombeek and damaged considerably the adjacent areas. In both analysis of the indicators change in building morphology and road network, the results showed recovering taking place differently than the previous disaster state. Although results showed improvements in recovery, data from the municipality of Enschede confirmed that by 2011, recovery was not concluded.

Results of this study support the idea that geodata based approaches can characterize the complex recovery process. In addition, it can give significant insights of recovery of function, going beyond the analysis of the physical features. Utilizing data derived from statistics (CBS), reports and the current recovery plan of the study area showed support in the testing of the reliability of the methods and results. However, many of the documents were not found in English that might be a great limitation for those that do not know the local language. In addition, the statistics (CBS) data from previous years differs in amount of available variables on neighbourhood level. This might be due to improvement of technology to collect and present data. This fact makes it difficult to collect and investigate historical data for time series analysis.

8. CONCLUSION

This thesis showed that the use of remote sensing as primary data to assess post-disaster urban recovery is a complex task. Section 1.3.2 in the introduction establish four sub objectives for this research: 1) identify features of urban form and variables (that are not only physical) that could be used to assess post-disaster urban recovery; 2) create a conceptual framework of recovery; 3) assess urban recovery using geospatial and remote sensing data; and 4) interpret recovery in terms of metrics and descriptors, to attest if those used in the assessment of recovery are accurate and true.

The conceptual recovery framework created in chapter 3 contributes to a comprehensive analysis of how geospatial data could be applied to quantify indicators in the different sectors and to assist planers in the monitoring of recovery processes. Planners and decision makers main concern relies on the understanding of the physical environment and in how to shape it to attend population needs (Lynch & Rodwin, 1958). In a post-disaster situation, the study of how the physical environment may change is one approach. However, the understanding of the conditions associated to the built up changes such as: social, economic and political aspects, permits the analysis of different functions and which alterations in space are taking place.

This thesis focuses on the long-term reconstruction recovery and uses Roombeek as a case study. It is used to explore in details the image analysis methods, and use of indicators and features that were extracted from literature review, which might be efficient in the assessment of post-disaster urban recovery. The tables created in section 2.5.3 were key contributions from this research, because the tables identify significant indicators, features and methods using remote sensing.

The results of the indicators: change in building morphology and road network, showed that remote sensing and landscape metrics produced significant primary information about the changes in the landscape and in recovery of functions. The values indicate increase in density and urbanization, improvement in network function (traffic circulation and street connection) and change of urban function (now there is a presence of mix of uses; residential, home-business, commercial, etc.) indicating that the area is striving for a vibrant and attractive urbanity.

However the proposed indicators to assess recovery in an urbanized area may require further modification. One significant modification to the proposed measures is extending the analysis to account for the other sectors of community (economic and social). This extension would provide a complete view of the recovery process and functions. The interaction of all sectors of society may need the implementation of other indicators and methods, according to the case studied (peoples need, the scale measured, the type of disaster and damage).

8.1. Recommendations and future work

The proposed measures of post-disaster urban recovery provide opportunity for future studies. A recommendation for further researches would be the application of the proposed indicators and features to other sectors of society, and to other various types of disasters (e.g. earthquakes or tsunamis), and to different scale (e.g. local, regional, and national).

The case study used in this research may differ drastically from other cases in terms of culture and economies. In this thesis the indicator change in building morphology was retrieved from Brown et al. (2010) and tested to see the transferability. The case studied demonstrated that the same indicator could be applied even in a different situation than the one presented by Brown et al. (2010). However it is necessary further studies to explore and test the indicators and features using geospatial data and remote sensing, to attest the transferability of similar approaches in different situations. The main objective is to determine potential measures, indicators and features that could be transferable and help communities to recover faster and more resilient.

Availability and accuracy of data is still a limitation in the analysis of recovery. Remote sensing imagery might be costly, but can be used for multiple indicators. Many sensors such as: Worldview-1, Worldview-2. Quickbird, IKONOS and Geoeye-1 provide very high resolution images that are more accurate and facilitate interpretation, besides the advantage to create opportunities for automatic pattern recognition. In addition, other technology innovations have helped to track and monitor the progress of recovery more rapidly and efficient. For example, the use of crowd-sourcing methods and open sources such as OpenStreetMap (Brown et al., 2010). Finally, the accuracy and quality of the information produced may be dependent of the level of expertise to deal with GIS tools, remote sensing and geospatial data approaches.

In summary, the use of remote sensing, landscape metrics and GIS analysis using the indicator, features and techniques presented in this research, will support planners in the coordination, monitoring and assessment of recovery with not only quantitative data. However, remote sensing should not be seen as a method to replace ground base methods. The main conclusion of this research, therefore, is that geospatial data and remote sensing in combination of methods, including ground base can be more effective to provide useful, accurate and quality information for the assessment of recovery.

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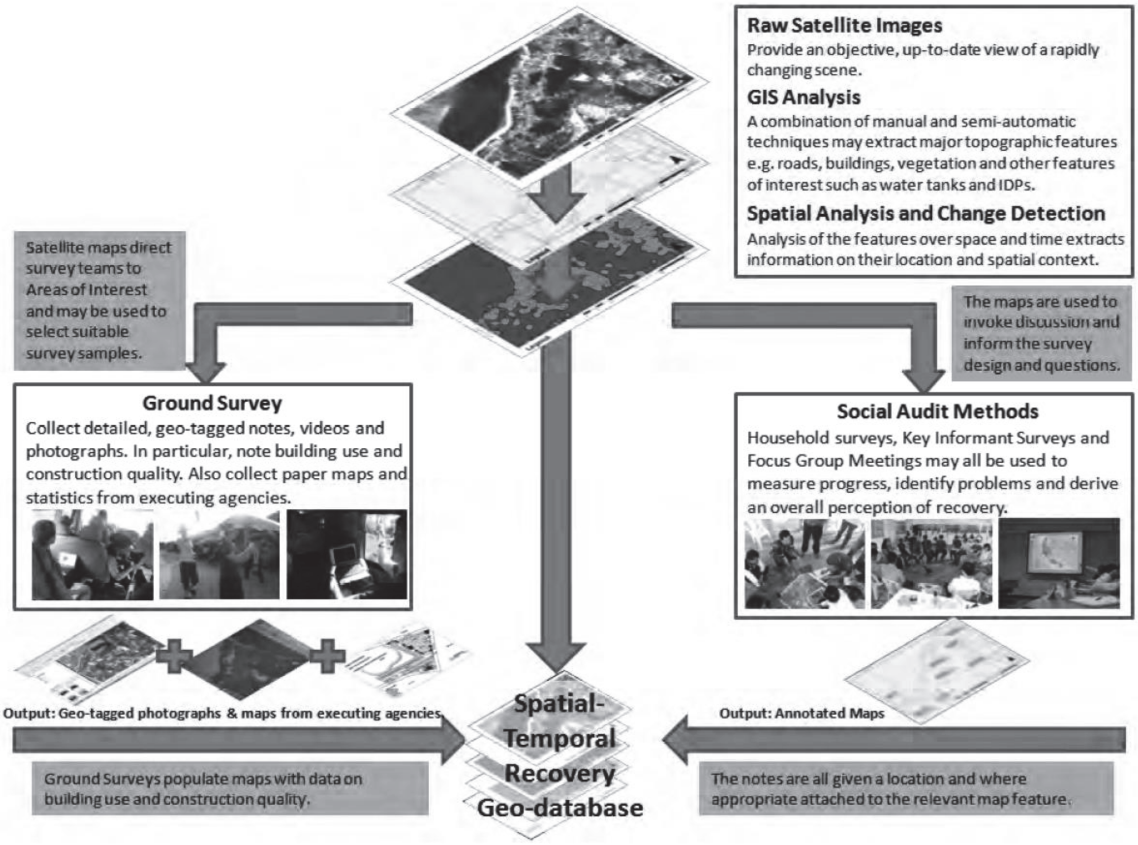
ANNEX

Annex 1: framework for monitoring and evaluation methodology using remote sensing. Retrieved from (Brown, 2010)



Raw Satellite Images
Provide an objective, up-to-date view of a rapidly changing scene.

GIS Analysis
A combination of manual and semi-automatic techniques may extract major topographic features e.g. roads, buildings, vegetation and other features of interest such as water tanks and IDPs.

Spatial Analysis and Change Detection
Analysis of the features over space and time extracts information on their location and spatial context.

Satellite maps direct survey teams to Areas of Interest and may be used to select suitable survey samples.

The maps are used to invoke discussion and inform the survey design and questions.

Ground Survey
Collect detailed, geo-tagged notes, videos and photographs. In particular, note building use and construction quality. Also collect paper maps and statistics from executing agencies.

Social Audit Methods
Household surveys, Key Informant Surveys and Focus Group Meetings may all be used to measure progress, identify problems and derive an overall perception of recovery.

Output: Geo-tagged photographs & maps from executing agencies

Output: Annotated Maps

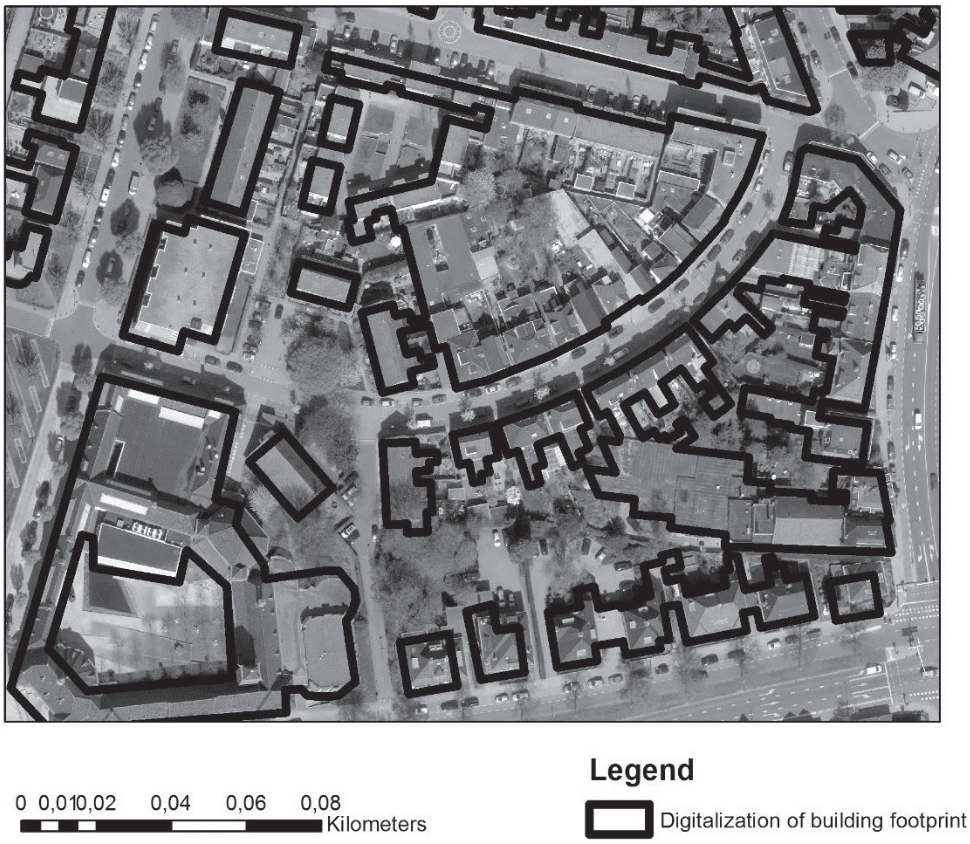
Ground Surveys populate maps with data on building use and construction quality.

The notes are all given a location and where appropriate attached to the relevant map feature.

Annex 2: Digitalization limitations of building footprint

Image before the disaster

Image of 2011



Annex 3: Overview of actual recovery plan of Roombeek (Ontwikkelingsplan Roombeek: De Stad Voortgezet)

Source Rene Kuiken Urbanism http://www.renekuiken.nl/portfolio/roombeek-enschede/