# A method for metropolitan landscape characterization; case study Rotterdam

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## Abstract

This paper presents a theoretical and methodological framework for a comprehensive landscape characterization, focussing on the largest and most complex urban realm: the metropolitan region. Landscape character has in recent years emerged as a new paradigm to understand, monitor and evaluate cultural landscapes undergoing change. The scope of characterization methods however, is by and large limited to the non-urban realm. In physical terms, the border between the urban and non-urban realms is becoming increasingly diffuse, particularly in metropolitan regions. Metropolitan regions thus conceptually challenge the scope of landscape characterization, as cities can also be understood to be in and of themselves a form of cultural landscape. Moreover, territories where urban and rural realms merge, result in new 'hybrid' types of space that fall outside existing characterization methods. The method developed and presented in this paper is aimed at producing a comprehensive landscape characterization tool for metropolitan regions in order to understand, evaluate and monitor their spatial form. The method developed combines elements from conventional landscape character assessment with urban morphology, mapping, and cluster analyses. The first version of the method was tested using the metropolitan region of Rotterdam and resulted in a preliminary categorization of thirty-six metropolitan landscape types. Twenty-four of the thirty-six types are defined as 'hybrid' or mixed landscape types, which occupy approximately 30% of the territory. Their make-up is determined by formal varying densities of topographic elements, land use categories, and heights. The hybrid landscape types that have emerged as a result of applying this method are of particular interest, as they were not recognized as a specific category by other classification methods. The extent and character of these landscapes is not yet fully understood and therefore not used in the landscape policy forming. The method also reveals a substantial disparity between the assumed threshold of city and countryside in the Rotterdam region, and the one that has resulted from this study. The distribution of hybrid landscape types also shows that patterns of dispersion, diffusion, periphery and fragmentation have exceeded what is considered the peri-urban area of Rotterdam in administrative and planning circles.

## Key words

landscape characterisation, metropolitan landscape, hybrid landscape, cluster analyse, landscape type

# 1. Introduction

Globalization and the networked society have far-reaching spatial implications, which in turn produce territorial rearrangements of urban regions (Pinzon Cortes, 2009). In recent decades, research into territorial transformations in metropolitan regions arising from these conditions have resulted in a range of new insights from varying perspectives on the form of the territory such as: 'citta diffusa' (Indovina, 1990), 'Tapijtmetropool' (Neutelings, 1994), 'middle landscape' (Rowe, 1991), 'edge city' (Garreau, 1992), 'exopolis' (Soja, 1992), 'Zwischenstad' (Sieverts, 2004) and 'tussenland' (Frijters and RPB, 2004). A common theme in these concepts is the shifting relationship between city and countryside.  In contrast to compact homogenous cities, metropolitan regions are characterized by an amorphous patchwork of urban fragments in which the distinction between rural and urban realms is dissolving. According to Castells (2010, p. 2739) "it includes in the same spatial unit urbanized areas and agricultural land, open space and highly dense residential areas […], it is a multi-centred metropolis that does not correspond to the traditional separation between central cities and their suburbs." In the European context 'dispersed urban regions' can be compared to urban areas with heterogeneous land use and fragmented structure, which is often referred to as Urban Morphological Zone or Urban Metropolitan Area.

The metropolitan region challenges morphological concepts such as 'urban periphery'. The term 'metropolitan' as used in this research broadens the meaning of what is usually understood under urban and peri-urban and includes the entire territory of the city-region, from the dense inner-city tissue and the vast sub-urban up to rural territories. In these areas, processes of urbanization  lead to 'hybridization' of landscape. The mixes of industrial, residential, infrastructural, recreational and other kinds of urban tissues which penetrate agricultural or nature areas are characterized by varying densities and forms of built and un-built space which differ markedly from that of compact (historical) urban spaces and open countryside. These hybrids challenge existing categorizations of the spatial disciplines, falling as they do outside both urban and non-urban qualification frameworks. The environmental, social, and economic challenges metropolitan regions face necessitate a comprehensive understanding of the interrelationship of the spatial form of city and countryside. The limitations of existing approaches to characterize and assess metropolitan spatial tissue restrict our comprehension of their physical extent and character and in turn our ability to plan and intervene in them. As conventional methods are not sufficient to understand the complex nature of the metropolitan landscape, a new comprehensive characterization method is needed. The motivation for this research is thus to expand the scope of existing characterization methods to include these metropolitan areas.  The paper elaborates on the results of the first implementation of the method in a case study of the Rotterdam metropolitan region.

## 1.1 Landscape Character Assessment (LCA)

The increasing scale and pace of spatial development affecting European landscapes in general has catalysed attention to methods that can aid in objectively understanding landscapes and help to monitor and manage change. Landscape Character Assessment (LCA) has thus become a key framework in recent years and now serves as a basis for landscape analysis, evaluation, policy development, and design concept development. In the LCA approach, Landscape Character is defined as a distinct, recognizable and consistent pattern of elements that makes one landscape different from another (Swanwick, 2002). Landscape Character is that which makes an area unique (Swanwick, 2002) and can be seen as an expression of the holistic nature of the landscape (Antrop, 2003; Jessel, 2006)  The process of characterization involves recognition of areas that have similarities, classifying them and mapping them. One of the most comprehensive and well-documented methods for Landscape Character Assessment can be found in the Guidelines for landscape character assessment developed in 2002 by the Scottish Countryside Agency. The Scottish approach is now widely practiced outside the UK (Swanwick, 2002; Wascher, 2005; Nogué and Sala, 2006; Van Eetvelde et al., 2006; Kim and Pauleit, 2007). The Swanwick guidelines also serve as a basis for the development of this method.

## 1.2 Landscape character assessment in metropolitan areas

Although etymologically the term landscape also applies to urban landscapes, most landscape characterization has focussed on cultural, natural or rural landscapes. The European Landscape Convention has broadened the concept of landscape character to include built components in the landscape definition. Nevertheless the tradition of seeing landscape as something outside the cities still dominates the landscape characterization practice and policy making. The intention of the Swanwick Guidelines is to be suitable for the character assessment of both rural and urban landscapes; nevertheless its application in urban landscapes is only just beginning (Swanwick, 2002). As a consequence, in the majority of classifications, urban areas typically remain categorized as one type, termed 'urban area' (as is for instance the case in Dutch classifications). Even in more elaborate classification, such as that prepared for Belgium by Van Eetvelde and Antrop (2009), urban landscapes are subdivided into only three principal categories: urban landscapes, suburban landscapes and industrial and harbour landscapes. Landscape characterization can form an important contribution to understanding urban landscapes, but to date neither landscape character assessment methods nor methods for urban space characterization have been able to sufficiently comprehend and catalogue their complex and composite nature.

# 2. Brief overview of classification methods

There are a number of different approaches to landscape typology and systems for landscape classification (Lipský, & Romportl, 2007). As a result, landscape can be categorized according to a wide number of classification variables ranging from climatic, cultural or land use. In the following text we present a short overview of existing methods for landscape classification.

## 2.1 Landscape classification methods

Depending on which elements are used to define the distinct types, landscape classification methods can be broken down into three main categories (adapted from Berendsen, 2000; Groom, 2005; Nijhuis, & Reitsma, 2011):

- **Biophysical landscape classification**: this category addresses the internal coherence between landscape factors focussed on key-aspects of form and functioning of the natural landscape, such as: soil, geomorphology, climate, vegetation and land cover. The typologies are usually monothematic in nature. European examples include: Geomorphological regions of Europe (Embleton, 1984), Ecological Regions in Europe (Painho and Augusto, 2001), the Soil Atlas of Europe (Jones et al., 2005), Environmental Zones of Europe (Metzger et al., 2005), CORINE Land Cover (Bossard, 2000). National examples include: Soil-based Landscape Typology of the Netherlands (Edelman, 1950; Jongmans et al., 2013), Flora Districts of the Netherlands (Van der Meijden, 1996), Geological Landscape Typology of the Netherlands (TNO, 2009).
- **Anthropic landscape classification**: this category addresses the specific structure and development (genetic succession) of the landscape, focussed on the human influence on the landscape form, such as: agriculture, forestry, recreational uses, mining and infrastructure. The typologies usually combine factors such as soil, climate, management system, historical aspects, and land use dynamics. European examples include: the pan-European landscape typology by Meeus (1988, 1993, 1995), ENVIP-nature map on landscape types (JRC, 2002), European Landscape Classification-LANMAP2 (Mücher and Wascher, 2007; Mücher et al., 2010), and the Map of European Leisure-scapes (Wascher et al., 2008). National examples include: Landscape Typology of the Netherlands (Piket et al., 1987; Visscher 1972; Zonneveld 1985; Berendsen, 2000), Landscape Atlas of Flanders (Antrop et al., 2010; Eetvelde and Antrop, 2003), and the Polder typology of the Netherlands (Steenbergen et al., 2009; Nijhuis and Pouderoijen, 2013).
- **Visual landscape classification**: this category addresses the visual appearance (physiognomy) and human experience of the landscape, focussed on landscape perception and preference exemplified by indicators such as: degree of openness, landscape attractiveness, scenic and aesthetic aspects, visual urbanisation and cluttering. The typologies usually combine formal, visual and psychological aspects of the landscape. Pan-European examples are not available. National examples include: Landscape Attractiveness Map of the Netherlands (Roos-Klein Lankhorst et al., 2002, 2011), Degree of Openness (Dijkstra, 2000; Nijhuis and Reitsma, 2011), Mapping Aesthetic Preference (Sevenant and Antrop, 2010), Visual Urbanization (Van der Hoeven and Nijhuis, 2012).

## 2.2 Urban space classification methods

There are similarly a number of different approaches to urban space classification and assessment. This overview has no intention to offer an extensive listing of existing methods but reflects on several examples that are relevant for the characterization of metropolitan space. Methods for urban space classification depend on the aims of the study they are implemented in, so they will differ when the city is viewed from different disciplines. Taking into account the type of data used for analyses, techniques implemented, and the ways of representation, two main groups emerge: form-related and function-related classification. Form related classification looks at the patterns and forms of urban elements by studying their morphological character; the representation of these studies is expressed in drawings and maps. Function-related

classifications start from land use, adding statistical data about densities of housing, jobs, inhabitants etc. These methods use computational techniques such as statistical calculations or clustering, and represent the results in the form of maps, which can be either grids or polygons.

- **Form related classification**: within the existing literature, there are two significant lines of studies on urban form. The first corresponds to the tradition of morphological studies, influential in the 1970s and 80s, and the second to more recent studies about the form of the landscape and the territory, which have been conducted since the 1990s (Pinzon Cortes, 2009). For both lines of studies, mapping and drawing are the most used techniques. Urban morphology deals with the knowledge of the logic of form, in this case, urban form. It is studied in several disciplines and involves looking at physical characteristics, structure, relations and transformations of things and their constituent elements. From the existing studies, the main three schools of typo-morphology can be distinguished: British, French and Italian along with studies conducted in the Dutch context (Pinzon Cortes, 2009).
- **Function related classification**: Here we are using two examples: 'Urban Environments' (Stedelijke milieus) Ritsema van Eck et al. (2009) and European Urban Atlas (http://www.eea.europa.eu/data-and-maps/data/urban-atlas). For their classification of 'Urban Environments' Ritsema van Eck et al. used statistical data on land use, density of housing, jobs, shops, percentage of high rise buildings, office and shopping floor areas. They applied a grid of 250 x 250 meters, covering all of the land area of the Netherlands and grouped it into 18 urban environments (and one non-urban environment) using cluster analysis. This was done for 2000 and 2006 using the same categorization so that the changes could be analysed. Another example of the functional analyses is the European Urban Atlas (http://www.eea. europa.eu/data-and-maps/data/urban-atlas), which is providing pan-European comparable land use and land cover data for Large Urban Zones with more than 100.000 inhabitants and uses images from satellites to create reliable and comparable high-resolution maps of urban land. The Urban Atlas has a legend designed to capture urban land use, including low-density urban fabric, and expressing it in a level of continuity with a resolution that is 100 times higher than CORINE land cover. The Urban Atlas provides a far more accurate picture of urban sprawl in the fringe of urban zones. It provides relevant data for analysis related to transport, environment and land use.

## 2.3 Emerging tools for metropolitan landscape characterization

As we can see from the overview of the landscape classification methods, they focus primarily on non-urban landscapes. Conversely, classification frameworks for urban space generally stop at the city border. Looking specifically at urban and peri-urban landscape classifications, the literature shows very few classifications that treat urban and rural landscape together. The most important exceptions are the landscape typology and characterization for the federal state of Belgium (Van Eetvelde, & Antrop, 2009) and the European Urban Atlas (http://www.eea.europa.eu/data-and-maps/data/urban-atlas). Although those tools can be implemented for metropolitan landscape categorization they are still insufficient for the comprehensive coverage of the variety of hybrid landscape types. Nevertheless they were used as a starting point and inspiration for the development of the new method, which will be described in the following paragraphs.

# 3. A method for the metropolitan landscape characterization

Given the nature of metropolitan territories, the tools and methods presented in paragraphs 2.1 and 2.2 are inadequate for comprehensive metropolitan landscape characterisation. For this research, characterization and classification tools for both rural and urban areas were merged into one new framework. This new framework has been sourced from both urban and landscape fields: morphology and mapping analysis from urban studies, and landscape character assessment from the field of landscape studies.

## 3.1 Case study area of Rotterdam

The first stages of the method discussed in this paper was developed and tested using the metropolitan region of Rotterdam as a case study. This region is situated in the south of the Randstad conurbation in the Netherlands, the so-called South Wing and is also called Rotterdam-Rijnmond (literally Mouth of the Rhine). It is an official region of the province of South-Holland and consists of 16 municipalities with a total population of approximately 1.3 million.

In order to effectively incorporate the entire metropolitan area, the study area was set as twice the extent of the existing urban area calculated on the basis of existing administrative, planning and geographic border data. The borders of the study area were furthermore set by a rectangular frame measuring 60 km x 30 km. No distinction was made between rural and urban areas, as municipal borders were not used for the calculations.
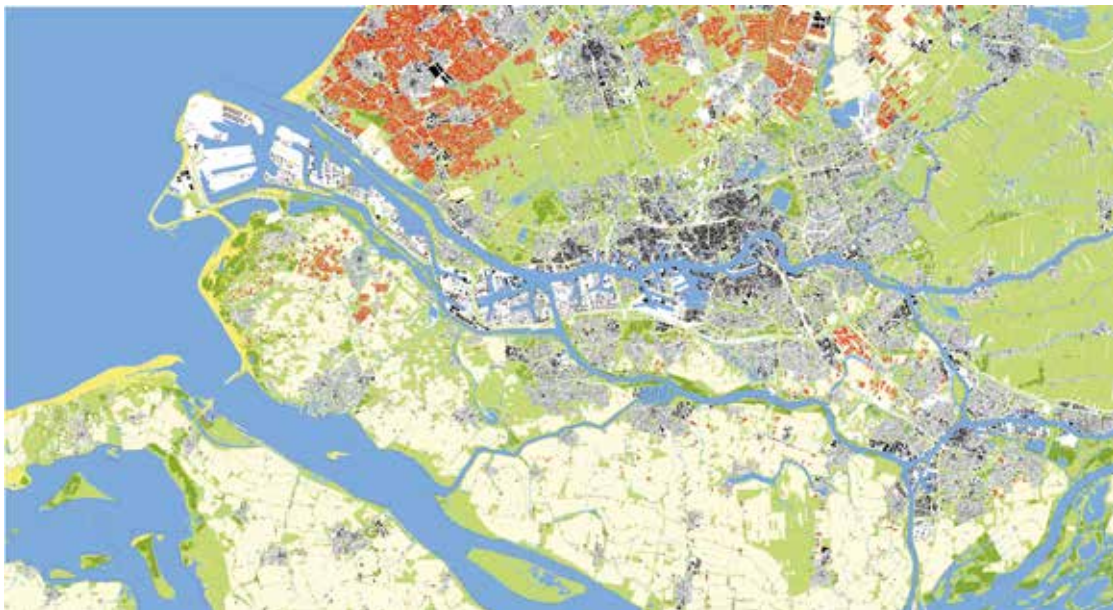


Figure 1
*Topographic map of the metropolitan region of Rotterdam*

Existing landscape classifications of Rotterdam area show the same lack of comprehensive landscape characterization as most of the other metropolitan regions. For the rural area the Province of South Holland developed a tool for policy-forming based on Area Profiles (Gebiedsprofielen www.zuid-holland.nl/documentenverkenner.htm?Gr=Ruimte&t1naam=Ruimtelijke%20kwaliteit&t2naam=Gebiedsprofielen). The

Area Profiles are comparable to landscape character types but are again only elaborated for rural areas. As a tool for urban landscape planning the Municipality of Rotterdam uses standard policy instruments such as Masterplan, Green space plan etc. that are only focusing on green spaces such as parks, playgrounds and other usual categores of public urban green spaces (see for instance http://stadsregio.nl/sites/stadsregio.nl/files/pagina-bestanden/RGSP 2011-12-14 RGSP 3.pdf; http://www.rotterdamvooruit.nl: http://www.polderdag-rhoon.nl/uploaded_files/DV_2008 Groenonderzoek Rotterdam Samenvattting.pdf etc.)

## 3.2 The model of the new method

The proposed model for the new method for metropolitan landscape characterization uses the basic structure of the Landscape character assessment of the Scottish Natural Heritage (2002) as an initial starting point. First their steps of the model focus on desk study on regional scale while the fourth and fifth step concern detailed field study of each of the preliminary developed draft character types.

One of the most important modifications to this model is the addition of mapping/morphology and cluster analysis in step 3 (figure 2). In the following text the five steps of the model will be described, using the case of the Rotterdam metropolitan region. It is important to note that later in this paper we present and discuss the results of the regional scale analyses, which produced the draft character types.
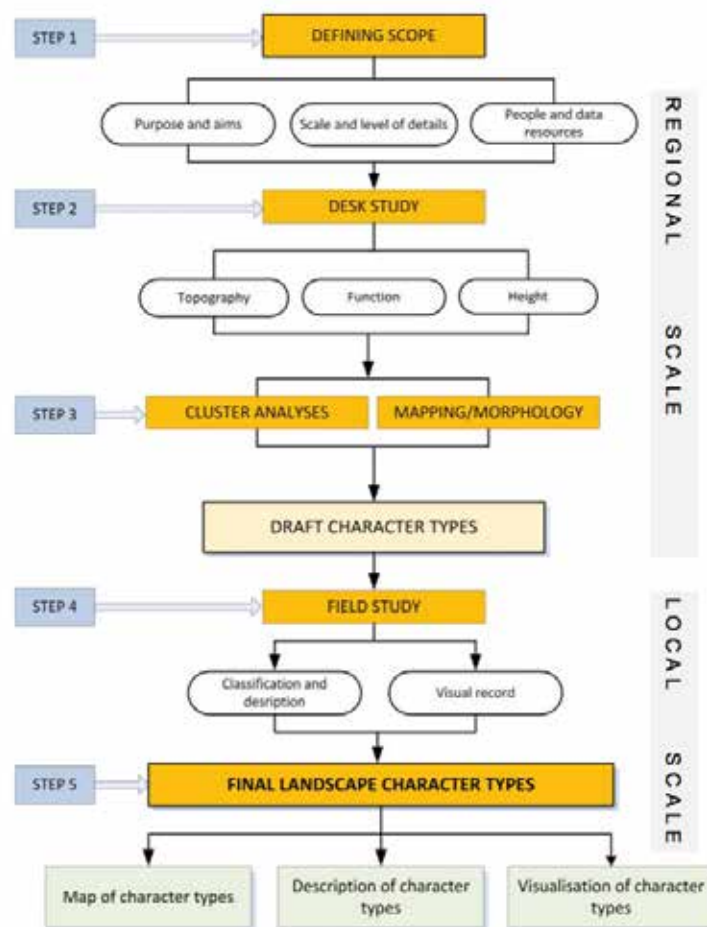


Figure 2
The structure of the Framework for Metropolitan Landscape Characterization

## Step 1. Defining the scope

The first stage of the method involved the definition of the scope of the research, which is explained in the first paragraph. The goal of the classification was to understand the character of heterogeneous metropolitan landscape so that it can be included in the policy forming or monitoring of the changes in these areas. In this stage we decided to work in two scales – regional (step 2 and 3) and local (steps 4 and 5).

## Step 2. Desk study

Desk study step involves a selection of elements that will be used to define a first stage spatial categorization, to serve as a basis for landscape character types. The choice of elements can vary because it is very strong related to the purpose of the characterization. The elements can be sourced from various datasets. As the purpose of this research was to focus on the physical and formal landscape characterization, we have decided to work with the datasets that are relevant for this purpose and that are as accurate as possible. Data were sourced from a highly detailed vector topographical database of the Netherlands (TOP10nl, 2011), Land Use Maps (BBG, 2008) and height maps of the Netherlands (Actueel Hoogtebestand Nederland, AHN-1, 1997-2003). The information in the AHN has been derived directly from aerial photos with a high positional accuracy, making it very suitable for statistical and spatial analysis. As original data are developed for the general purposes of various users they needed to be adjusted for the purpose of this landscape characterisation.

TOP10nl has been used to define a first stage categorization of four spatial categories (figure 3): green, blue (water), red (built-up) and grey (infrastructure). As these categories only cover half of the area of the TOP10 and the rest is unclassified – and in order to get 100% coverage of the study area – we reclassified the remaining area into four classes: in-between space residential area (mixed paved and green areas), in-between space business district (mixed paved and green areas), construction sites, and remaining areas. We then celled the layers using a resolution of one metre and made a mosaic of these cells with the dominant value on top, removing any overlapping areas. As a next step we aggregated each category in cells with a resolution of one hundred metres, resulting in eight cell layers with percentages of each of the eight categories (red, green, blue etc.) per hectare.

In order to analyse the degree of interspersion of urban and non-urban realms in the metropolitan region, we chose to reduce the spatial categories further to two: 'red' (urban) and 'green' (non-urban). Red comprises all categories of built-up space regardless of whether they are residential or industrial, and glasshouses. Green comprises non-built space, such as forests, heathlands, wetlands, dunes, beaches and recreation parks, as well as agricultural areas, such as orchards, croplands, nurseries, meadows, and urban spaces, such as parks and gardens, cemeteries, sports fields, allotment gardens and verges. Red and green layers were then classified and outputted as black and white morphology maps for visual assessment (table 1).

The second input was the Land Use Map (BBG, 2008). Here we reduced the thirty-eight categories in the dataset to ten: residential, infrastructure, services, industry and offices, functional green, agriculture, glasshouses, nature, water and remaining area. These data has been celled with a resolution of one hundred metres; the value of the largest combined surface of the ten categories has been assigned to the grid cells, resulting in a map with the dominant function per hectare. With the combination of the two input layers the share of green and share of red per land use category have been calculated, and visualised as the two images on the bottom of figure 3.
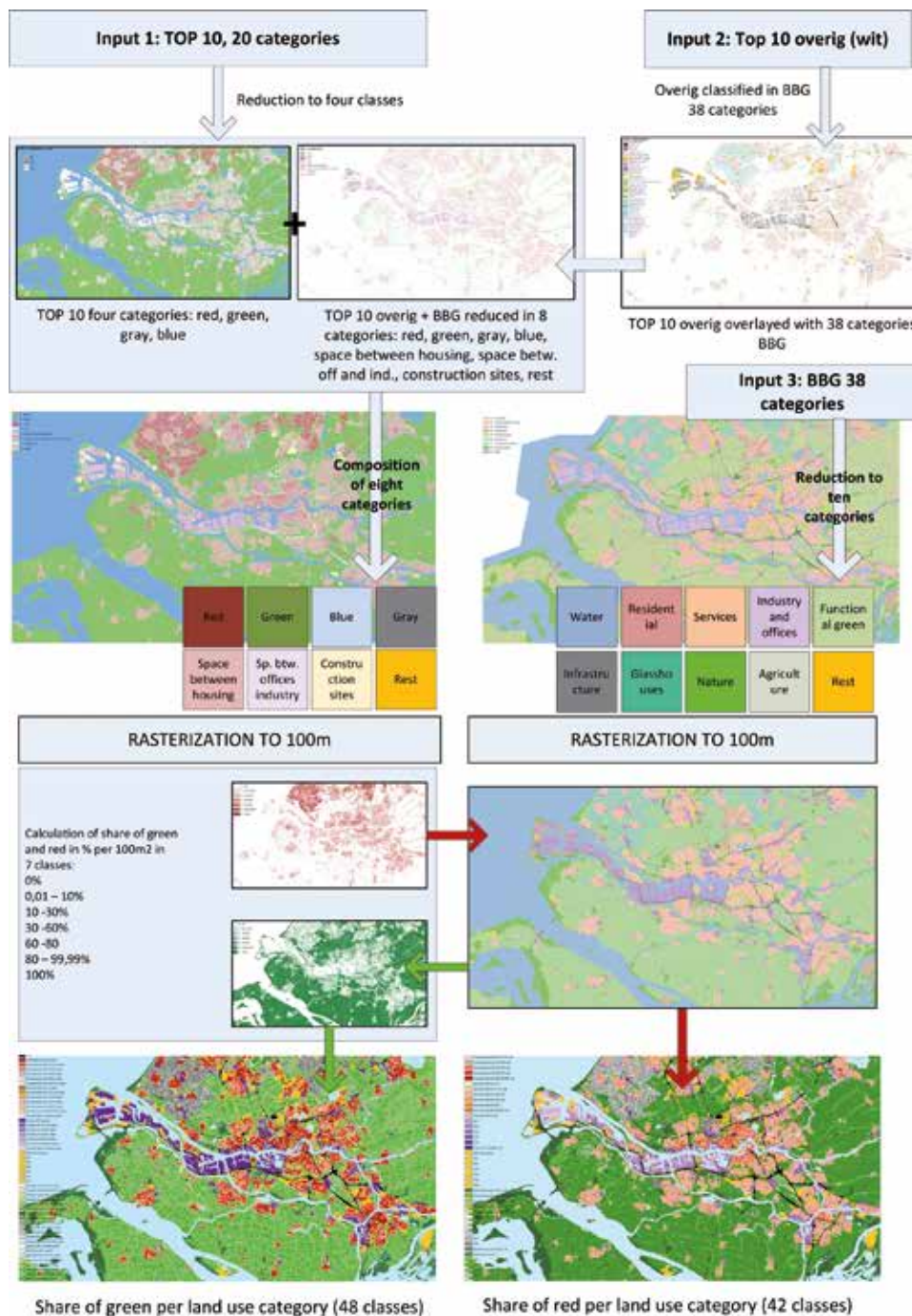
*Process of selection and modification of datasets*

The third input is the height of topographic elements such as buildings and vegetation. The definition of height in terms of under or above eye-level (1.60 m) addresses the potential of 'being able to see' in a particular situation, and is related to the definition of space by means of spatial boundaries (Nijhuis, & Reitsma, 2011). Space-defining elements are surfaces, screens and volumes that reach above eye level (Thiel, 1961; Curdes, 1993). The actual heights were derived from a high-resolution digital elevation model (DEM), the Actueel Hoogtebestand Nederland (AHN-1, 1997-2003), which is precise to about 15 centimetres per square metre. The DEM's density, distribution and plani-metric accuracy is such that topographic objects

with a size of two by two metres can be identified clearly and with a maximum deviation of 50 centimetres (AHN, 2010). The model has been supplemented with recent topographic data: the digital topographic map at a scale of 1:10.000 (TOP10nl, 2009). All legend items were selected that were higher than eye-level (including ascending elements, buildings and trees and/or shrubbery) based on the definitions of the Topographical Service of the Land Registry.

## Step 3a. Morphology and mapping

Morphology is a well-known method used to study urban form. It involves looking at physical characteristics, structure, relations, patterns and transformations of things and their constituent elements. Mapping is about the "acts of visualizing, conceptualizing, recording, representing and creating spaces graphically" (Cosgrove, 1999). By the evolution of GIS-techniques, application of mapping in the studies of the form of the territory and the landscape became one of the most popular techniques. After we prepared the data we subsequently looked firstly at the patterns of red and green by mapping the distribution of cell percentage categories across the territory. This was followed by the analysis of the percentage of red or green per cell, which was then used to define continuity (more than 80% red or green) or discontinuity (les than 10% of red and green spaces). Following this, the analysis of the share of red and green per land use category gives insights into penetration of red into green space and of green into red space. Discussion of the morphology and mapping analyses of the Rotterdam metropolitan region are presented in paragraph 4.1, 4.2 and 4.3.

## Step 3b. Cluster analyses

When there are many layers of spatial information it is difficult to handle them and draw conclusions by simple overlay methods using GIS. Cluster analysis involves grouping a set of elements in such a way that cells in the same group (called a cluster) are more similar (in some sense or another) to each other than to those in other groups (clusters). It is a common technique for statistical data analysis, used often in landscape analyses for classification (see for instance Ritsema van Eck et al., 2009 and Van Eetvelde and Antrop, 2009) or pattern recognition. In the case of MLC for Rotterdam we have chosen to apply cluster analyses using the same data layers as for the mapping, but adding extra information about heights. This stage of the method resulted in 42 clusters which where afterwards manually regrouped in 36 clusters – draft character types for the metropolitan region of Rotterdam. Discussion of the morphology and mapping analyses of the Rotterdam metropolitan region are presented in paragraph 4.4.

## Step 4. Fieldwork

This phase of the method concentrates on the local scale by establishing properties of the character types such as shape, pattern, height, coverage, openness-enclosure, etc. The results of the desk-study analysis are to be verified by doing spot-checks on different typologies to check a) the location and makeup of cells from the TOP10 and BBG, and b) verification of heights. This work is yet to be carried out.

## Step 5. Finalization of landscape character types

In this phase the desk-study and fieldwork verification are synthesized in a definitive list of landscape character types. The bulk of the work involves a detailed description of the character types and a visualization of their principal characteristics using diagrams and photos. This work is yet to be carried out.

# 4. Discussion

This section discusses the first preliminary findings of the testing of the method on the case of the city-region of Rotterdam. In the following paragraphs we discuss the results of the morphology and percentile analyses (paragraphs 4.1, 4.2, 4.3), followed by the results of the cluster analyses (4.4).

## 4.1 Morphology of cells using different percentages of red and green

A first outcome of the method is a detailed indication of the pattern of green and red using different percentage categories of red and green per cell. These patterns indicate firstly the degree of hybridization of cells per percentage group, and where these are located, indicating the morphological extent of the merging of urban and rural realms in the study area. Patterns of red and green were analysed by means of the distribution of cells with different percentage of red and green taken from the 1:10.000 map (figure 3).



| Morphological patterns of urban and non-urban space in varying percentage groups of 'red' and 'green' | | |
|---|---|---|
| **%** | **Green** | **Red** |
| **0 %** |  0 |  Disregarding the water bodies, areas with 0% red-in-cell cells are more extensive than 0% green-in-cell cells. |
| **0.01 - 10 %** |  Low concentrations of green mainly occur in cells in urban areas and glasshouses. |  0,01-10% red-in-cell cells are scattered throughout the territory. The patterns of ribbon buildings, villa districts, nature areas and industrial areas are partly visible. |
| **10 - 30 %** |  10-30% green-in-cell cells are scattered throughout urban areas, glasshouses and in large parts of rural areas. |  Patterns of 10-30% red-in-cell cells clearly show low-density housing areas on the periphery of Rotterdam, Delft and Dordrecht and other smaller settlements. |

Table 1

*Morphological patterns of urban and non-urban space in varying percentage groups of 'red' and 'green'.*

**Tisma, A., van der Velde, R., Nijhuis, S., & Pouderoijen, M. (2013). A method for metropolitan landscape characterization; case study Rotterdam. SPOOL, 1(1). doi:10.7480/spool.2013.1.637**

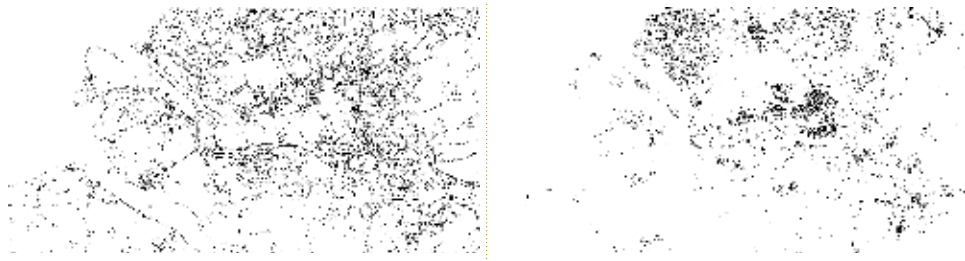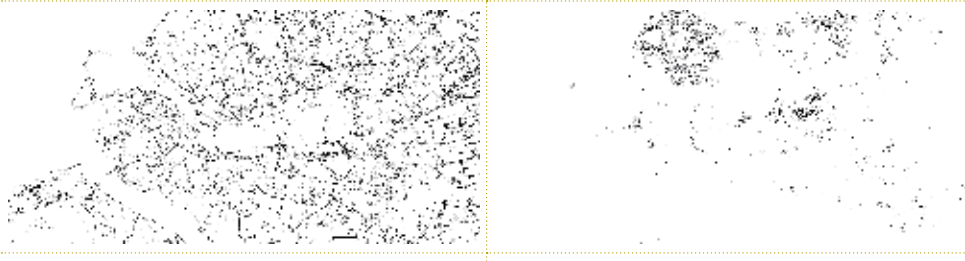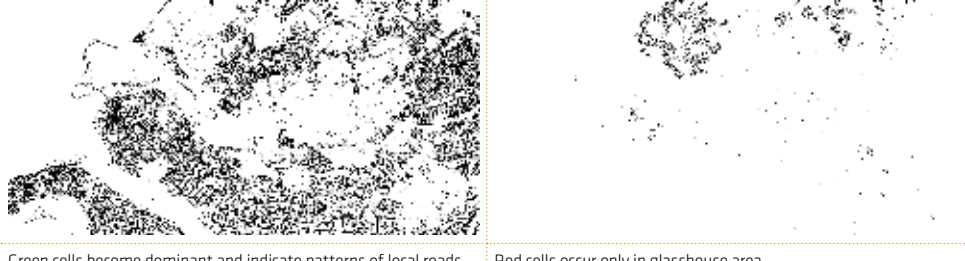| Morphological patterns of urban and non-urban space in varying percentage groups of 'red' and 'green' | | |
|---|---|---|
| **30 - 60 %** |  |  |
| | 30-60% green-in-cell cell patterns indicate a city fringe, and green cells along larger waterways and infrastructure. | Cells occur primarily in the CBD of Rotterdam; glasshouses also dominant. |
| **60 - 80 %** |  |  |
| | 60-80% green-in-cell cell patterns indicate a city fringe, and green cells along larger waterways and infrastructure. | Cells indicate the contours of the CBD of Rotterdam; glasshouses also dominant. |
| **80 - 99.99 %** |  |  |
| | Green cells become dominant and indicate patterns of local roads and larger natural areas and forests. | Red cells occur only in glasshouse area. |
| **100 %** |  |  |
| | 100% green cells are mainly present in agricultural areas, as well as some forests and natural areas | 100% red cells are only present in glasshouse areas. |

Table 1

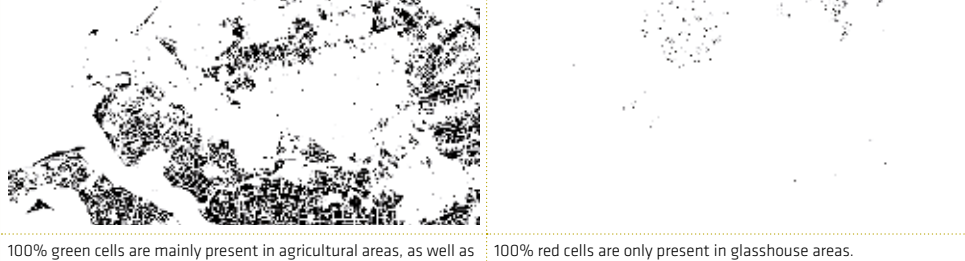*Morphological patterns of urban and non-urban space in varying percentage groups of 'red' and 'green'.*

Of note are the extensive variations in patterns of cells depending on which percentage is isolated. Excluding water bodies, 0% green-in-cell cells are limited to glasshouse areas and some downtown urban tissue, while 0% red-in-cell cells still occur in large areas of the territory. These patterns correspond to conventional urban-rural morphology patterns, with a clear spatial definition of urban areas and countryside. This pattern continues in the category 0.01%-10% green-in-cell cells, with low concentrations of green occurring typically in urban areas and glasshouse zones. From this point however, there is a shift in morphology patterning away from typical conditions towards hybrid patterning of built-up and non built-up areas. 0.01%-10% red-in-cell cells for instance, are scattered throughout the territory, including areas on the limits of the study area. This pattern continues up until the 30-60% category, revealing little or no morphological definition of 'city' and 'countryside', aside from low-density residential areas visible in the 10-30% red-in-cell category.

In the 60-80% green-in-cell cell patterns a city fringe begins to appear, along with cells along larger waterways and infrastructure. Nineteenth century urban expansion areas are also revealed in the 60-80% red-in-cell categories. Categories above 80% begin to display the morphological patterns visible in the lower percentage categories, although not as well defined.

The extent of green-in-cell and red-in-cell morphology in the categories between 10% and 80% indicate the degree of heterogeneity and discontinuity of city and countryside in the study area. At the same time, the analysis shows that the study area still has a relatively high percentage of continuous green (80-100%) cells. This is partly, due to the size of the study area frame, but also demonstrates the legacy of the stringent planning culture in the Netherlands which has until recently been able to maintain a relatively distinct division between urban and non-urban realms. In addition, as shown in the absolute percentage distribution maps, areas with no red occupy a much greater area than those with no green. Low concentrations of green-in-cell cells occur mainly in urban areas and glasshouses while low concentrations of red-in-cell cells are scattered throughout the whole area. Additionally, patterns of ribbon development, villa districts, nature areas and industrial areas are partly visible in the 0-10% and 80-99.99% categories.

## 4.2 Percentile analysis of cells and hybridization

In a graph illustrating the percentages of red or green per cell in the study area (figure 4 / table 2), we can see that the total area of 100% red-in-cell cells is very low (only 0,2%) compared with 20,1% for 100% green-in-cell cells. Cells with some percentage of red however, can be seen to be present throughout the whole area in different densities and concentrations. This penetration of 'red' results in a large amount of 'hybrid' spaces where green and red mix (categories 10 to 80%). This pattern is discussed further in 4.3.
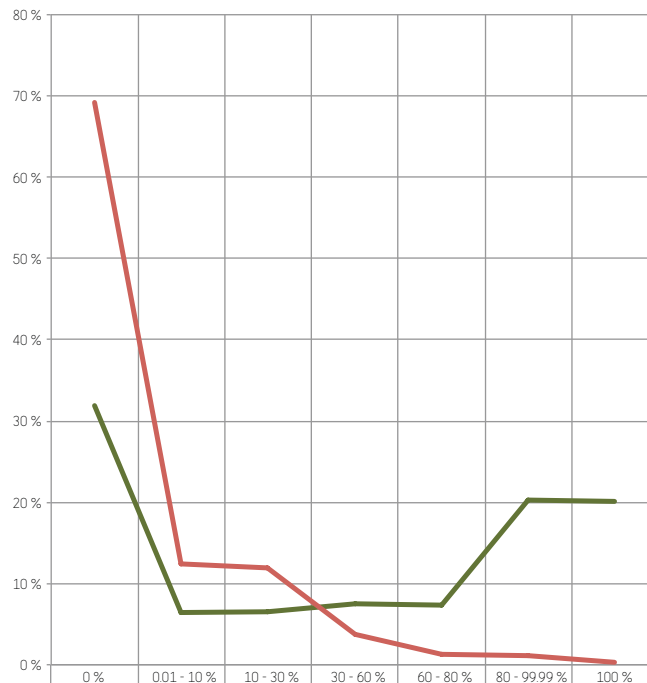


Figure 4
*Percentage of green and red cells in the total area of the Metropolitan Region Rotterdam*

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| Percentage of green and red cells in the total area of the Metropolitan Region Rotterdam | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 % | 0.01 - 10 % | 10 - 30 % | 30 - 60 % | 60 - 80 % | 80 - 99.99 % | *100%* |
| % of green cells in city region | 32 | 6 | 7 | 7 | 7 | 20 | **20** |
| % of red cells in city region | 69 | 12 | 12 | 4 | 1 | 1 | **0** |

Table 2

*Percentage of green and red cells in the total area of the Metropolitan Region Rotterdam*

The method of calculation of percentage of green or red per 10.000 m2 cell results in overlapping cells, as each of the cells can have a certain percentage of red or green, which are not complementary. Therefore the combination of the two maps can result in various other images, depending on the questions we want to answer. Figure 5 is one example of these possibilities. It represents a combination of all cells that have both red and green in them, in total 19 categories.



Figure 5

*Combinations of all cells that have red and green in them*

This map shows the extent of hybridization of red and green in the Rotterdam metropolitan region. These hybrid cells occupy 26% of the study area (figure 6). These results are comparable with the study of Slak and Lee (2003), who have analysed the heterogeneity and homogeneity (the term Slak and Lee use for what is in our paper pattern analyses) of the rural landscapes in France. Their results have shown that the heterogeneity occurs in 35% of the grid cells covering the whole territory of France (in total 15.700 grids). The difference between the methods used in our study and the study of Slak and Lee is that the pattern analyses in our study were done by using expert visual assessment, while in the texture indicator used by Slak and Lee an algorithm is developed to simulate visual perception.
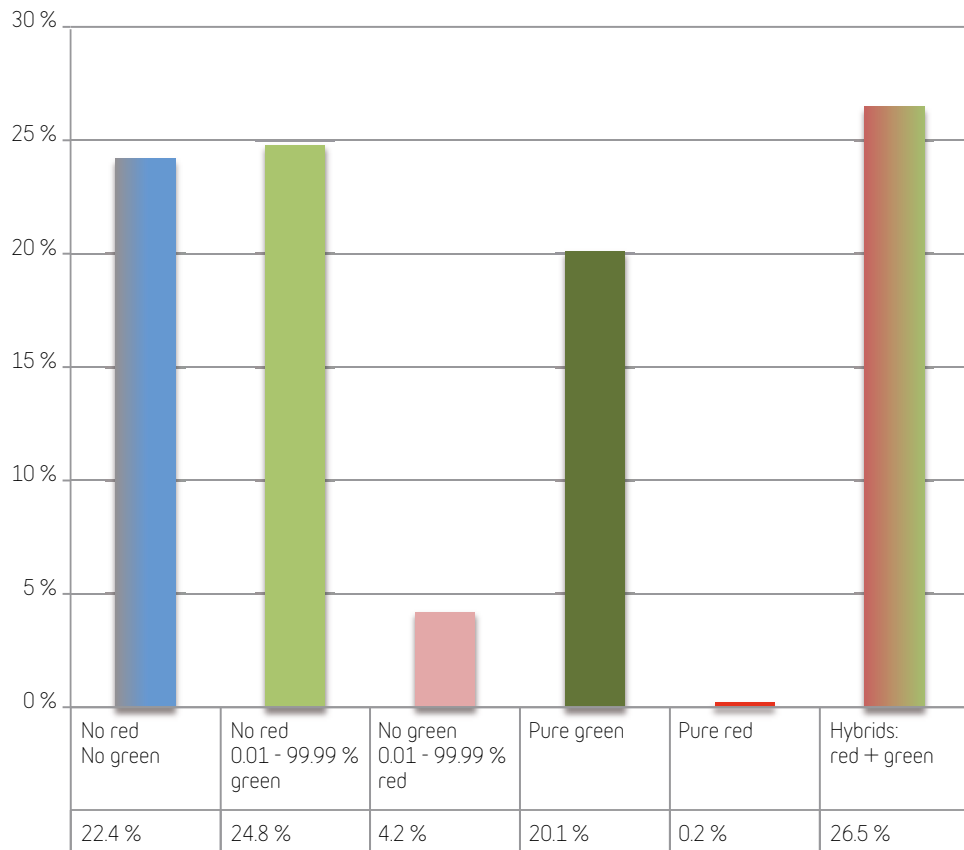
| No red<br>No green | No red<br>0.01 - 99.99 %<br>green | No green<br>0.01 - 99.99 %<br>red | Pure green | Pure red | Hybrids:<br>red + green |
|---|---|---|---|---|---|
| 22.4 % | 24.8 % | 4.2 % | 20.1 % | 0.2 % | 26.5 % |

Figure 6

*Percentage of hybrid landscapes in the metropolitan area*

Figure 6 illustrates that pure red areas are very low qua surface (0,2%) while 'pure green' takes ' takes up 20,1% of the territory. Red areas without any green present are below 5% while green areas without any red are below 24,8%. It is important to note that aside from the large percentage of hybrid landscapes we also detected considerable areas of green space. This pattern originates from agricultural land, which is still a dominant 'green' element that defines the Rotterdam metropolitan region. This is an interesting discovery because the landscape policy evaluation (PBL, 2009) and perception studies (PBL, 2008) argue that the perception of this area as cultural landscape is fragmented by disturbing built-up elements such as industrial, agricultural and infrastructural objects.

## 4.3 Mix of red and green – hybrid landscapes

We also looked at the share of green and share of red per land-use category. This resulted in the two maps (at the bottom of the figure 3) showing respectively the penetration of red in green space and the penetration of green in red space. The colours representing housing, industry, services, and glasshouses are ordered so as to become darker when less green or more red is present in the cells, and lighter when more green and less red is present in them. In the green categories (functional green, agricultural and nature areas) the colours are ordered the other way around – the more green or the less red they have the darker they are. The image presented on the map 'share of red' appears much darker than the image of 'share of green'. The largest intact dark green colour represents agricultural land with some scattered lighter green elements in it. The darkest colour represents natural areas, which is almost 100% green (contains a very few red cells).  For the share of red it was interesting to look at the presence of built-up elements in the

spaces that are used for leisure and recreation (which we named functional green), nature and agricultural area. Statistics shows that there are no extremely red cells present in these categories, but very low concentrations of red (0,01-10%) are very much present in the whole rural area, mainly in agricultural area and functional green areas, and in very few cases in natural areas.

The image on the map 'share of green' is still very dark, but much lighter than the first one. The agricultural area is not so compact as in the 'red' map anymore, because the pattern of local roads is visible. Dominant green are now only natural areas, but we see a lot of 'hybrid' categories in the city fringe and within urban green spaces. For the share of green it is interesting to look at 'urban' functions such as housing and services, and then at industry and glasshouses. The majority of housing areas and services are in the 'hybrid' category, while the majority of industrial area and glasshouses have a very little amount of green or no green (0-10%). The 'hybrids' can be a mix of different spatial entities and combine various spatial functions.

## 4.4 Cluster analyses

In the last step of the desk analyses we conducted cluster analyses. For each cluster we had as input eight categories from the Top10 map, ten categories of land use and two categories of height, below and above eye height. The cluster analyses resulted in three variants: 39, 42 and 49 clusters. By looking at the underlying topographic data we concluded that 42 clusters best represent the situation in the Rotterdam metropolitan region. Afterwards we manually adjusted the clusters merging a few that were similar, which resulted in a total of 36 clusters. Looking at the table with the statistic on minimum, average and maximum values and standard deviations for each cluster, we selected those that have more than 80% of all these values as continuous, the rest as discontinuous. Between the discontinuous clusters we noticed the patterns of larger patches and smaller – 'edge' – cells. Finally we can say that there are 12 continuous and 24 discontinuous or 'hybrid' landscape types. Of the discontinuous types half are larger patches and half 'edge' types. Figure 7- 11 list the preliminary character types and their location.

The statistics of the results of the cluster analyses (table 3) shows that almost 70% of the territory of the metropolitan region of Rotterdam is covered by continuous and 30% by discontinuous spatial types. The dominant types in the continuous category are agriculture (26%) and water (24%). None of the discontinuous spatial types shows a particular domination; the most represented types range between 2 and 6%. Those can be found in the mixed low-density residential areas and as edges along the water and next to the smaller roads in agricultural area.
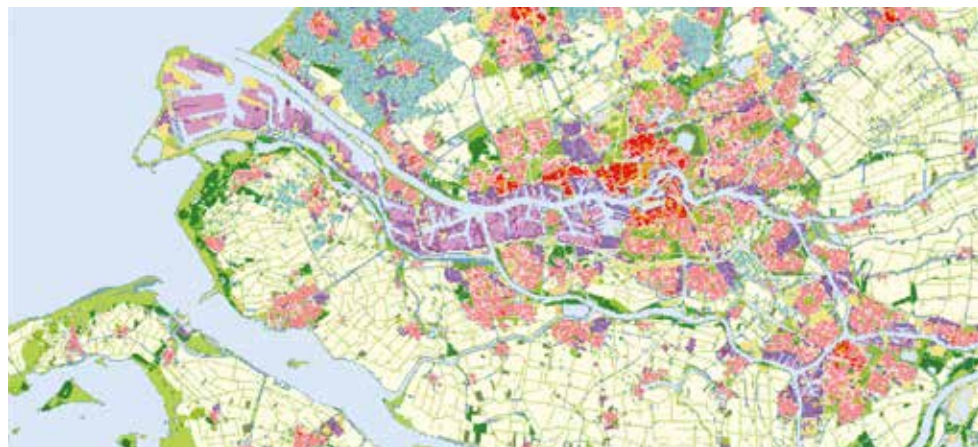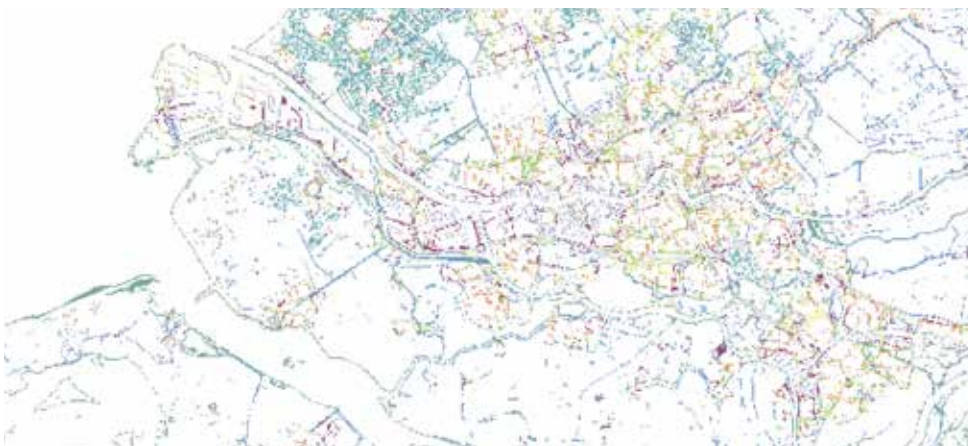


Figure 7
*36 Clusters*

 **Tisma, A., van der Velde, R., Nijhuis, S., & Pouderoijen, M. (2013). A method for metropolitan landscape characterization; case study Rotterdam. SPOOL, 1(1). doi:10.7480/spool.2013.1.637**

Figure 8
*12 Continuous clusters*



Figure 9
*12 Edge clusters*
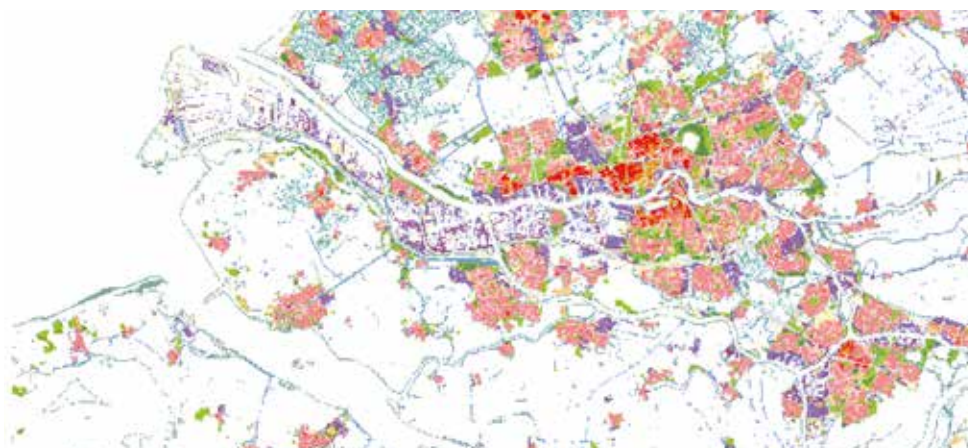


Figure 10
*12 Patch clusters*

**Tisma, A., van der Velde, R., Nijhuis, S., & Pouderoijen, M. (2013). A method for metropolitan landscape characterization; case study Rotterdam. SPOOL, 1(1). doi:10.7480/spool.2013.1.637**

| Cluster | Preliminary description | % |
|---|---|---|
| | **Continuous** | |
| 10 | 10 - in-between industrial with some grey, low | 1,60 |
| 104 | 104 - 11+26 - glasshouses | 1,54 |
| 105 | 105 - 15+23 - construction and remaining, low | 0,83 |
| 14 | 14 - agriculture, low | 26,14 |
| 31 | 31 - agriculture, with some grey, low | 6,90 |
| 1 | 1 - agriculture, with some grey or high red elements | 2,97 |
| 21 | 21 - green agriculture, predominantly high | 0,49 |
| 2 | 2 - green remaining, low | 0,61 |
| 29 | 29 - green nature, mostly low | 2,62 |
| 22 | 22 - green nature, mixed high/low | 1,13 |
| 7 | 7 - green nature, high (forest) | 1,35 |
| 103 | 103 - 9+12+40 - water | 24,40 |
| | | 70,58 |
| | **Disontinuous - patch** | |
| 39 | 39 - red residential, in-between residential and grey, mixed high/low | 0,68 |
| 16 | 16 - red residential, lots of in-between residential, predominantly low | 5,62 |
| 27 | 27 - residential with some in-between, grey and green, predominantly low | 2,69 |
| 28 | 28 - buildings, urban services, mixed high/low with grey | 0,30 |
| 101 | 101 - 4+18 - services mix | 0,58 |
| 35 | 35 - in-between industrial with buildings, predominantly low | 1,46 |
| 41 | 41 - red, industry/offices, mixed high/low | 0,74 |
| 20 | 20 - functional green (bungalow park) | 0,15 |
| 38 | 38 - functional green, mixed high/low with some grey elements (park) | 0,85 |
| 19 | 19 - functional green, predominantly low (recreational area, park) | 1,98 |
| 36 | 36 - construction green, remaining, predominantly high | 0,11 |
| | | 15,15 |
| | **Disontinuous - edge** | |
| 3 | 3 - green residential, grey, predominantly low | 0,96 |
| 33 | 33 - in-between industrial with grey infrastructure, green, predominantly low | 1,11 |
| 37 | 37 - industry/office water, low | 0,50 |
| 42 | 42 - grey with urban services, mostly high | 0,41 |
| 30 | 30 - grey infrastructure with surrounding green, mostly low | 1,38 |
| 106 | 106 - 17+25 - glasshouses mix | 1,20 |
| 32 | 32 - glasshouses with some in-between industrial | 1,11 |
| 6 | 6 - blue in green, agricultural areas, some grey, low | 2,76 |
| 34 | 34 - green grey, functional green, predominantly low | 0,98 |
| 24 | 24 - green grey, infrastructure remaining, low | 0,50 |
| 102 | 102 - 8+13 - green/blue edges, low | 2,81 |
| 5 | 5 - construction remaining, with some green, grey, low | 0,57 |
| | | 14,28 |
| | TOTAL | 100 |

Table 3

*Percentage of landscape type per total area of the urban region of Rotterdam*

 Tisma, A., van der Velde, R., Nijhuis, S., & Pouderoijen, M. (2013). A method for metropolitan landscape characterization; case study Rotterdam. SPOOL, 1(1). doi:10.7480/spool.2013.1.637
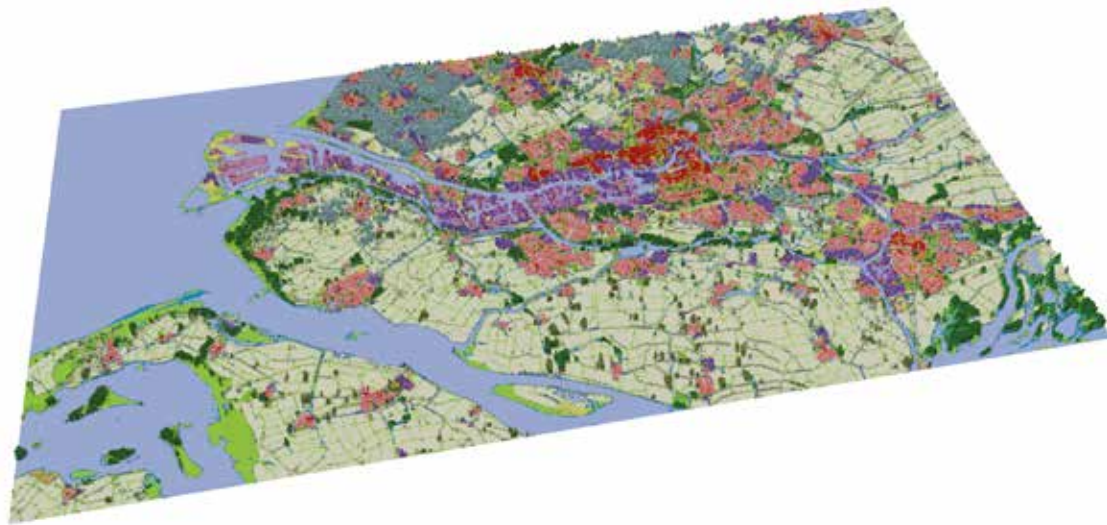
As can be seen from the diagrams presented in this paragraph, mapping and morphology analyses have shown different statistics about the percentage of hybrid landscapes than cluster analyses. This can be explained by the essential difference in the two methods. In the case of mapping the grid cells shown on figure 4 / table 2 contain only red and green elements, while blue (water) and grey (infrastructure) and all of the rest of 16 elements were not taken into analysis. In the cluster analyses all twenty elements play a role in the aggregation of the cells. Nevertheless, each of the two methods has its strengths and weaknesses; it is a combination that makes them stronger. The mapping method simplifies the spatial image and shows how the patterns are distributed in space in a more clear way then clustering. On the other hand mapping lacks in capturing the complexity of each of the cells. Therefore the combination of the two methods gives better insights in the composition, interaction, overlap, fragmentation, and distribution of hybrid cells.

When one wants to create homogenous regions from a classification there are generally a lot of small clusters that must be suppressed. A classical problem dealing with generalizations is to decide where to draw the boundary. In the landscapes where humans manage the land, the borders can show both sharp and gradual transitions between the different landscape types. The common way to display a border is with a sharp boundary that not really corresponds to the real world. To soften the borders, an often-used method is fuzzy sets. Fuzzy sets are sets or classes without sharp boundaries. Fuzziness is considered by many authors (Arnot and Fisher, 2007; Hall and Arnberg, 2002) as a way to handle uncertainty, complexity and vagueness in the class membership of objects.  In this perspective the typology resulted in our research needs one more adjustment step to soften the boundaries between the landscape types.

The hypothesis of our research started from the 'dispersed cities' theory with the intention to discover the occurrence of landscape hybridization. As these processes occur in small patches the method for quick scan of large regions had to be sensitive for the small-scale heterogeneities which occur on the 100m pixel level. At this stage of the research we stayed at the crisp classification, which is the product of the cluster analyses. Soft classifications which can be achieved with fuzzy sets were not yet applied in this stage of the research. Whether we will go on with 'fuzzification' in the sense of Hall and Arnberg (2002), will depend on the further applications of the method.

 **Tisma, A., van der Velde, R., Nijhuis, S., & Pouderoijen, M. (2013). A method for metropolitan landscape characterization; case study Rotterdam. SPOOL, 1(1). doi:10.7480/spool.2013.1.637**

# 5. Conclusions

A review of the extent of existing landscape characterization studies shows their scope to be largely limited to non-urban space. Heterogeneous metropolitan landscapes consisting of both urban and rural elements and hybrids of both fall outside existing methods for landscape characterisation.

The research started with the supposition that the existing landscape characterisation methods typically used in European practise are not sufficient to fully understand the landscape character of metropolitan areas. To answer this, we propose a new method for metropolitan landscape characterization which combines tools for rural and urban characterization in one framework.

The first application of the method for Metropolitan Landscape Characterization (MLC) for the study of Rotterdam metropolitan area resulted in thirty-six landscape types, twelve continuous and twenty-four hybrid. Several morphology and mapping analyses have confirmed presupposed fragmentation of traditional urban-rural patterns and diffuse spatial form. Statistical analyses gave additional insight in the extent of these transformations.

The morphology and mapping analyses have shown that the mixed green-red cells in the category of 10% to 80% indicate a large degree of heterogeneity and discontinuity of city and countryside in the study area, pointing to dissolution of periphery, peri-urban and hinterland definition. At the same time, the analysis shows that the study area still has a relatively high percentage of continuous green (non built-up) cells, partly due to the dominance of agriculture, but also demonstrating the legacy of the stringent planning culture in the Netherlands. In addition, as shown in the absolute percentage distribution maps, areas with no red also occupy a much greater area than those with no green. We can rather describe these phenomena in terms of gradation: a gradation of green begins in rural areas and dissolves gradually through the fringe and periphery towards the city centre. At the same time a gradation of 'red' starts from glasshouses and the urban centre of Rotterdam and other cities in this region and gradually dissolves in pure 'green' through peripheral housing districts, and city fringe. At the confluence, a series of hybrid landscapes emerge.
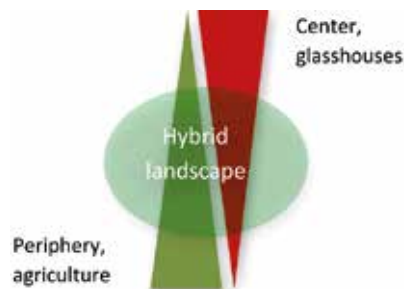


Figure 12
*Flow of green in red and red in green*

Cluster analysis revealed 24 discontinuous or 'hybrid' types which are new categories not occurring in existing characterization and classification methods described in paragraphs 2 and 3.1. Hybrid landscape types are present throughout the whole of the territory, in different configurations and concentrations covering 30% of the region in the form of larger or smaller patches and edges. Nevertheless, 70% of the area is still occupied by entities of continuous, mostly "green" landscape types. Looking at the results provided by combination of mapping and cluster analyses which we applied in step 3 of the MLC method we can conclude that the method fully satisfies in detection of heterogeneity and dispersal for the large scale regional characterization.

The results of the study presented in this paper refer to the regional scale and detailed field studies of the preliminary discovered 36 landscape types still need to be done. It is important to recognize and understand the precise physical character of these landscapes, the way they are perceived and valued, and the way they can be used in planning and improvement of the general environmental and living conditions of metropolitan regions.

The characterization of non-urban landscapes is already established tradition in most European countries, but the results of this study indicate a shift of focus needed towards the characterization of hybrid landscapes types in metropolitan regions. The physical amount of space they take up in the metropolitan region of Rotterdam, and most probably in other metropolitan regions, requires more attention, as they can become an important arena of planning, policy and design praxis.

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         Rotterdam. SPOOL, 1(1). doi:10.7480/spool.2013.1.637