Urban and regional heat island adaptation measures in the Netherlands

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Foreword / Epilogue

The aim of this thesis is to propose urban design guidelines to positively influence the heat islands in Dutch cities and regions. As an architect and urban planner, the challenge was to provide a series of spatial planning guidelines that had to be open enough to be compatible with other urban planning priorities and accurate enough to mitigate the Urban Heat Island (UHI). This thesis is thus marked by this tension between a generic reflection on the integration of scientific findings within the vision of a larger urban planning and the need of specific scientific results for the Dutch context.

In that sense we can differentiate two parts in the research: the articles with a theoretical component and the articles with a practical approach.

- The articles with a theoretical component study the relevance of the phenomenon at a national and international scale, its implications (lack of comfort, increase of mortality, energy consumption…) and existing online tools to assess it (chap 2). They also investigate the relevance of the regional vision to prevent the formation of the urban heat (chap 3), and propose catalysing mapping strategies (chap 4).

- The articles with a practical approach specifically study the formation of the UHI in the Netherlands at different scales: they assess the phenomenom in the existing urban environment (chap 5 and chap 6), they develop urban design guidelines for the assessment of urban heat in future development areas (chap 6) and they propose spatial guidelines for the interventions at the landscape scale (chap 7).

The challenge of the 21st century urban planner´s work

I have the perception that the 21st century urban planners have to face two important challenges which are multi-scale and multidisciplinary projects. Both aspects imply an increase of complexity of our discipline, thus more than ever the nature of the urban and spatial planner´s work should be kept in mind to prevent it from being diluted in the new socio-economical context. The urban planner is above all a "vision generator" and an "integrator". The urban planner should be able to develop a multi-scale spatial vision, from which different priority levels will derive to address the numerous disciplines it should integrate. The growing availability of information and documentation that can be retrieved, systematically processed, shared, and enhanced, through mobile applications, online platforms, tablets, GPS, drones…may confuse us urban planners. The temptation is thus to overcome the data tide, with over-specialisation: to concentrate the efforts in identifying data gaps and aiming to fill them with scientific and empirical research. It seems that in our efficient and sometimes over-specialised society, the generation of necessary creative, intuitive and integrative visions is lacking. Urban planners have extensive accurate knowledge over specific elements (public transport calculations, pedestrian traffic in commercial streets for retailers' analysis, specific architectural elements...), and in turn often lack of long-term urban sustainbility analysis or an urban and regional vision coordinating the totality of urban actions. In our specialised society, the urban planners have to play an integrative role, while retaining the part of vision generators.

Multi-scale dimension of the urban planners' assignment:

Cities occupy only 3% of the earth's surface, however modern cities' operations affect more than 75% of the globe´s surface. The global cities are more interconnected than ever, with more than 100,000 daily flights. The relationship between world-oriented cities and regions has changed dramatically. Production and consumption patterns, population growth tendency and urbanisation dynamics are simply unsustainable. Urban planners, as designers of the built environment, need to take over. Urban planning is no longer about planning the urban, it should start dealing with planning the non-urban. The traditional urban rural contraposition is no longer applicable in the 21st century. One does not exist without the other. Urban should ventilate and incorporate greenery, and rural should start to get structured and organised, as it includes a wide variety of uses: semi-industrial, agricultural, landscape, recreational and infrastructural, which are all related to urban areas, not necessarily located in the vicinity. The scale at which the global approach overlaps with the urban approach, is the regional one. Since the 1920's several groups have claimed the importance of the regional vision. The article "Regional balance for UHI mitigation" (Echevarria Icaza & Van der Hoeven, 2017) reviews the importance of the regional approach to reduce the impact of the UHI.

Multidisciplinary approach of the urban planners' assignment:

Modern multidisciplinary space planning was somehow born with MacHarg in the 1970's with a multidisciplinary team of physicists, biologists, sociologists, architects, landscape designers, urban planners, and territory planners. Since then, technology has allowed a deeper and systematic analysis of a wide range of parameters: water flows, forest fragmentation, energy and moisture fluxes, anthropogenic heat emissions, imperviousness, energy consumption, waste emissions, mobility matrixes, and even crime rates, surveillance, traffic, light-switch activity, or mobile phone activity. One of the new sets of parameters to be considered are the ones related to the UHI. The UHI is one of the main climatological phenomena affecting cities nowadays. Even though it generated over 30,000 excess deaths across Europe in 2003, and over 55,000 in Russia only in 2010 (Barriopedro et al. 2011), it cannot be considered as the only priority of urban planners. In order to be able to play a role as “integrators”, urban planners need to first find ways of consolidating vast and varied amounts of data in their new plans. Precisely, the article “Integrating Urban Heat Assessment in Urban Plans” strategies (Echevarria Icaza et al., 2016c) explores mapping strategies to generate creative and harmonised urban proposals which allow for the consolidation of UHI-related parameters.

Leyre Echevarría Icaza

Contents

List of Figures 16
Glossary 21
Summary 29
Samenvatting 33
Resumen 37

1 Introduction 41

1.1 Background 41

1.2 Overall UHI analysis and mitigation strategies 46

1.2.1 References at neighbourhood scale 47
1.2.2 References of urban studies 48
1.2.3 References at regional scale 50
1.2.4 References of the use of remote sensing for UHI assessment 50

1.3 Systematic approach to the UHI assessment 51

1.4 The UHI in the Netherlands 52

1.5 Problem statement and objective 57

1.6 Research questions 57

1.7 Block scheme 58

1.8 Research Scheme 59

PART A Method

2 Impacts, strategies and tools to mitigate UHI 67

2.1 Introduction 68

2.2 Materials and Methods 70

2.3 Results 71

2.3.1 Trends on urban heat islands in cities round the world 71
2.3.2 Strategies to reduce heat islands 76
2.3.2.1 At building scale 77
2.3.2.2 At city scale 78
2.3.2.3 At regional scale 79
2.3.2.4 Raising awareness among residents 80
2.3.3 Systematising estimation and adaptation measures to UHI 81
2.3.3.1 The "Decision Support System" (DSS) 81
2.3.3.2 The CE Urban Heat Island Atlas 84
2.3.3.3 The STAR tools 85
2.3.3.4 The "London unified model" (Londum) 88
2.3.3.5 The ADMS model 88
2.3.3.6 The LSSAT 89
2.3.3.7 EPA Mitigation Impact Screening Tool (MIST) 90
2.3.3.8 The Urban Microclimate tool 93

2.4 Conclusions 96

3 Regionalist principles to reduce the urban heat island effect 103

3.1 Introduction 104

3.2 Materials and Methods 107

3.3 Results 110

3.3.1 Regional territory 110
3.3.1.1 Sense of Place/The Concept of Nature 110
3.3.1.2 Regional economy 111
3.3.2 Urban containment 112
3.3.2.1 City sizes and population densities for regionally balanced environments 112
3.3.2.2 Greenery Standards 116
3.3.2.3 The Neighborhood Scale 118

3.4 Discussion 120

3.5 Conclusions 122

4 Integrating urban heat assessment in urban plans 129

4.1 Introduction 130

4.2 Methodology: overview of the role mapping as a design tool 131

4.2.1 The nature of the urban planners' work 131
4.2.2 New parameters to be integrated in contemporary practice 132
4.2.3 Urban heat assessment 134

4.3 Results: Catalysing mapping strategies to suggest urban heat adaptation guidelines 138

4.3.1 Game-board: preliminary strategic analysis 139
4.3.2 Rhizome: integration schemes 140
4.3.3 Layering: physical overlap 143
4.3.4 Drift 150

4.4 Conclusion 151

4.5 Discussion 152

PART B Results

5 The urban heat island effect in Dutch city centres – Identifying relevant indicators and first explorations 161

5.1 Introduction 162

5.1.1 UHI studies despite the lack of micro-measurements 162
5.1.2 Bridging the gap between scientific and applied knowledge 163
5.1.3 Remote sensing as a tool to identify, mitigate and quantify urban heat. 163

5.2 Methodology 165

5.2.1 Research framework 165
5.2.2 Research methodology 166

5.3 Identification of UHI hotspots in areas with a lack of micro-measurements 171

5.3.1 Possible UHI indicators 171

5.4 Validation examples: comparing storage heat flux mapping with multi-day mobile observations for the cities of The Hague and Utrecht 173

5.4.1 The Hague 173
5.4.2 Utrecht 175

5.5 Heat mitigation strategies in Dutch cities: relevant parameters 177

5.5.1 Normalised Difference Vegetation Index (NDVI) 177
5.5.2 Land Surface Temperature (LST) 179
5.5.3 Sky View Factor (SVF) 181
5.5.4 Anthropogenic heat losses 183
5.5.5 Coolspots and cool wind corridors 183
5.5.6 Albedo 187

5.6 Quantification of heat reduction through roof mitigation strategies. 189

5.6.1 Increasing the albedo 189

5.7 Conclusions of UHI analysis of Dutch cities 196

5.7.1 General findings 196
5.7.2 Implications of the work 197
5.7.3 Replicability of the study 198

6 Surface thermal analysis of North Brabant cities and neighbourhoods during heat waves 203

6.1 Introduction 204

6.1.1 Heat islands and medium size cities 204
6.1.2 North Brabant: particular mosaic urban structure 205
6.1.3 Research questions 207

6.2 Methodology 207

6.2.1 Determining the role of different parameters in the formation of the UHI in the region of North Brabant 207
6.2.2 Night-time land surface temperature from July 2006 as a key UHI indicator 208
6.2.3 UHI-related parameters analysed 209
6.2.3.1 Parameters related the urban design 209
6.2.3.2 Parameters related to city size 211

6.3 Results 215

6.3.1 The role of different parameters in the formation of the UHI in the region of North Brabant 215
6.3.2 Redefining the “urban living environment” classification based on thermal surface cover criteria 217

6.4 Conclusions 226

6.5 Discussion 227

7 Using satellite imagery analysis to redesign provincial parks for a better cooling effect on cities – The case of South Holland 231

7.1 Introduction 232

7.1.1 The Urban Heat Island effect 232
7.1.2 Greenery as a cooling source 233
7.1.3 South Holland provincial parks 235
7.1.4 Research questions 235

7.2 Methodology 236

7.2.1 Definition of thermal behaviour of land use categories in South Holland provincial parks 236
7.2.2 Definition of design adaptation guidelines to increase the cooling capacity of Midden-Delfland provincial park 239

7.3 Results 242

7.3.1 Results of the analysis of night LST, day LST, NDVI, imperviousness, patch surface and patch shape index for six main land use categories in South Holland provincial parks. 242
7.3.2 Surface thermal classification 252
7.3.3 Defining the adaptation measures to improve provincial parks cooling capacity 255

7.4 Conclusions 260

7.5 Discussion 260

8 Conclusions 271

8.1 Answering the research questions 271

8.1.1 SCALE. How would the implementation of the 1920´s regionalist premises of Geddes and Mumford affect the UHI phenomenom? 274
8.1.2 TOOLS. What satellite imagery and remote sensing processing techniques could be used for the heat island assessment at supra-urban scale? 275
8.1.3 STRATEGY. What representation and mapping strategies could we use to ensure the proposed measures are accurate enough to actually make a difference and open enough to be compatible with the rest of urban planning priorities? 278
8.1.4 Could the use of satellite imagery help analyse specifically the urban heat in the Netherlands and suggest mitigation actions implementable in the existing urban contexts of the cities, regions and provinces assessed? 278

8.2 Interpretation of the results and conclusions in a wider context 280

8.3 Discussion 281

8.3.1 Climatologist tools for the urban planning practice 281
8.3.2 Resolution limitations 282
8.3.3 Remote sensing limitations for UHI assessment 282
8.3.4 Replicability of the study 283
8.3.5 The challenge of redefining the regional scale balance nowadays 283

8.4 Outlook 284

8.5 Societal Impact 284

8.5.1 Reinterpretation of technology 284
8.5.2 Connection with existing realities 285

Acknowlegements 287
References 289
Curriculum Vitae 305

List of Figures

1.1 Graph showing the number of deaths/day related to the temperatures in Paris during the heatwave 2003 (Dousset, 2011) 42

1.2 Schematic of climatic scales and vertical layers found in urban areas. Planetary Boundary Layer (PBL), Urban Boundary Layer (UBL) and Urban Canopy Layer (UCL). (Oke, 1987). 44

1.3 Basic characteristics of Surface and Atmospheric Urban Heat Islands. Extracted from Reducing Urban Heat Islands: Compendium of Strategies (EPA, 2015). 44

1.4 Variations of Surface and Atmospheric Temperatures. Extracted from Reducing Urban Heat Islands: Compendium of Strategies (EPA, 2015). 45

1.5 Conceptual drawing of the diurnal evolution of the UHI during calm and clear conditions (EPA, 2015). 46

1.6 Schematic overview of the four KNMI'14 climate scenarios. (KNMI, 2015). 52

1.7 Global temperature rise relative to 1981-2010 based on climate model calculations performed for the IPCC 2013 report. Two different IPCC emission scenarios: RCP4.5 (stabilization) and RCP8.5 (high emissions). Coloured bands: model spread; lines: model means; dots: global temperature rise determined for the KNMI'14 climate scenarios for the Netherlands. 53

1.8 Average summer days per year (maximum temperature of at least 25 degrees °C) for the Bilt in the past (blue) and for the KNMI'14 scenarios, with natural variability between 30-year periods (gray). 53

1.9 Increase in Urban Heat Island effect per district in the Hague. Alterra Wageningen UR (De Groot, 2011). 54

1.10 Observed median and percentile values of AWBGT for thes tudied cities in the Netherlands. The roof level stations are shown in modified fill (Steeneveld et al.,2011).. 55

1.11 Block Scheme 58

1.12 Research Scheme 60

2.1 Overview of a set of literature on UHI distributed by country. 74

2.2 Screenshot of the interactive assessment configuration of the DSS tool. 82

2.3 Screenshot of the customised map output showing the change in annual mean temperature per decade for the city of Stuttgart. 82

2.4 Screenshot of the customised map output showing the projected changes in the annual near-surface temperature for the periods 2021-2050 and 2071-2100 for the city of Stuttgart. 83

2.5 Screenshot of the customised map output showing the heat wave frequency for the periods 1961-1990 and 2071-2100 for the city of Stuttgart. 83

2.6 Screenshot of the CE Urban Heat Island Atlas. 84

2.7 Screenshot of the input values that should be incorporated by the user, which refer to the land cover scenario for the selected area, the considered temperature scenario 86

2.8 Screenshot of the input values that should be incorporated by the user, which refer to the land cover scenario for the selected area, the considered temperature scenario 87

2.9 Screenshot of the output map of Londum model estimating the Urban Heat Island Intensity on May 2008 at 9.00 PM. 88

2.10 Screenshot of the output map of ADMS model estimating the temperature changes due to land use variations on the Olympic Parkland site development. 89

2.11 LSSAT model, fixed temperature stations along the 8 transects of the Greater London Area. Measurement locations are marked in squares. 90

2.12 Screenshot of the input values that should be incorporated by the user, which refer to the selection of the city, and the corresponding city parameters (which can be adjusted manually). 91

2.13 Screenshot of the mitigation strategy selected and its quantification. The mitigation strategy options are mainly albedo and vegetation modification or a combination of both. 92

2.14 Screenshot of the impact estimation for the selected city and mitigation strategy. 93

2.15 Overview of different digital UHI tools available 94

3.1 Methodology scheme 108

3.2 List of the references reviewed to complete the regionalist principles analysis and the Urban Heat Island related literature at the regional, urban, and neighbourhood scales. 115

3.3 Howard's Garden city proposal. Diagram of the municipality ground-plan (Office National Statistics UK, 2011). 117

3.4 Analysis of garden city and other regionalist model benchmarks for city size, density, and greenery standard. 118

3.5 Renovation proposal for the creation of a "community" within the post war residential blocks in The Netherlands. (a) original block elevation. (b) proposal (Echevarria Icaza, 2004). 119

3.6 Anthropogenic heat emissions: Annual averages with global coverage for 2013 (Dong et al., 2017). 121

3.7 Anthropogenic heat emissions: The percentage contribution of energy loss (loss), heating from commercial, residential, and transport sectors (CRT); heating from the industrial and agricultural sectors (IA); and heating from human metabolism (M). Bars represent the largest urban agglomerations. The dotted black line indicates the city-level gross domestic product in 2010 (Dong et al., 2017). 121

4.1 Densityscape, New York City, a three dimensional map depicting the super-dense residential population landscape of Manhattan Island. The exposed city: Mapping the urban invisibles. London: Routledge (Amoroso, 2010) 134

4.2 SMS activity at midnight, New Year´s Eve in Amsterdam (MIT, 2016). 135

4.3 Diagnosis and adaptation design for hotspots with an LST>42°C (Echevarria Icaza et al., 2016a). 140

4.4 Compilation of LST-related maps for Eindhoven metropolitan area:Surface cover clustering and "urban living environment" categories (Echevarria Icaza et al., 2016b). 141

4.5 Surface cover cluster proportions for each of the "urban living environment" categories in the analysed medium-size cities of the North Brabant region. Neighbourhoods 3 and 5 present similar cluster proportions, and thus could be grouped. Neighbourhoods 4, 6, 7, 8 and 9 present similar cluster proportions, and thus could be grouped (Echevarria Icaza et al., 2016b). 142

4.6 Modified from layers for the urban heat assessment of the city of The Hague (Echevarría Icaza et al., 2016 c) 144

4.7 Modified from layers for the urban heat assessment of the city of Delft (Echevarría Icaza et al., 2016 c) 145

4.8 Modified from layers for the urban heat assessment of the city of Leiden (Echevarría Icaza et al., 2016 c) 146

4.9 Modified from layers for the urban heat assessment of the city of Gouda (Echevarría Icaza et al., 2016 c) 147

4.10 Modified from layers for the urban heat assessment of the city of Utrecht (Echevarría Icaza et al., 2016 c) 148

4.11 Modified from layers for the urban heat assessment of the city of Den Bosch (Echevarría Icaza et al., 2016 c) 149

4.12 Comparative hotspot, coolspot, and wind corridor analysis for the Dutch cities of The Hague, Delft, Leiden, Utrecht, Den Bosch, and Gouda (Echevarria Icaza et al., 2016c) 151

5.1 Analysed cities. Google earth image. Data SIO, NOAA, U.S. Navy, NGA, GEBCO ©2015Google. Image Landsat ©2009 GeoBasis-DE/BKG 164

5.2 Size of the Landsat 5 TM image analysed. (image extracted from the USGS Global Visualization Viewer). Courtesy of the U.S. Geological Survey. USGS/NASA Landsat. 165

5.3 Hotspot identification process 167

5.4 UHI adaptation measures recapitulation chart 169

5.5 Night-time temperature in The Hague, the Netherlands. These maps (De Groot-Reichwein et al., 2014) are the result of a correlation between measurements of the UHI effect in the municipality of Rotterdam and parameters for the UHI, which are then extrapolated to spatial economic scenarios and climate scenarios. 174

5.6 Storage heat flux map for The Hague, 16 July 2006. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3 174

5.7 Spatial distribution of the maximum night-time UHI intensity for the city of Utrecht and its surroundings, from Brandsma & Wolters, 2012. 175

5.8 Storage heat flux map for Utrecht, 16 July 2006. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3 176

5.9 Normalised Difference Vegetation Index (NDVI) of the different Dutch cities. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3 178

5.10 Land Surface Temperature (LST) of the different Dutch cities. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3 180

5.11 Sky View Factor (SVF) of the different Dutch cities 182

5.12 Coolspot analysis (Storage heat flux map for The Hague, Delft, Leiden, Utrecht, Den Bosch and Gouda 16 July 2006. Landsat image courtesy of the U.S. Geological Survey. USGS/NASA Landsat. further processed with ENVI 4.7 and Atcor 2.3) and wind corridor analysis of the different Dutch cities. Right column google earth imagery. 185

5.13 Albedo of the different Dutch cities. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3 189

5.14 Albedo increase analysis of the different Dutch cities. 192

5.15 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of The Hague 193

5.16 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of Delft 193

5.17 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of Leiden 194

5.18 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of Gouda 194

5.19 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of Utrecht 195

5.20 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of Den Bosch 195

5.21 Analysis of storage heat flux hotspots in the cities of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch. It is important to highlight that the storage heat flux images and values might be distorted in areas covered by water, since the algorithm used by ATCOR for the storage heat flux calculation is based on Parlow´s equation G=0.4 Rn, which is a valid assumption for urban areas but not for water surfaces 197

6.1 Growth areas adjacent to medium-size cities (Province North Brabant. Spatial vision, 2010) 206

6.2 Average night-time LST urban areas of the province of North Brabant. LST values retrieved from Modis 11A1 imagery of the 23rd of July 2006. (Courtesy of the U.S. Geological Survey. USGS/NASA Modis) 209

6.3 Average albedo in urban areas of the province of North Brabant. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3. 210

6.4 Average NDVI in urban areas of the province of North Brabant. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3. 211

6.5 Analysis of surface and population of North Brabant medium-size cities. 212

6.6 Analysis of surface and population of North Brabant medium-size cities (ABF research, 2005) 214

6.7 Data list of the analysed medium size cities of the region of North Brabant. Parameters analysed: night-time LST, albedo, NDVI, imperviousness, distance to nearest town and surface. 215

6.8 Analysis of the relationship between the different parameters and night-time average LST, for each of the analysed medium size cities in the region of North Brabant. 216

6.9 Average albedo, NDVI, imperviousness and night LST values for each of the 6 clusters resulting from the unsupervised classification of the albedo, NDVI and imperviousness maps of the analysed medium-size cities of North Brabant. 218

6.10 Scatterplots of night LST and albedo, for each of the different surface cover clusters. 219

6.11 Scatterplots of night LST and NDVI, for each of the different surface cover clusters. 220

6.12 Scatterplots of night LST and imperviousness, for each of the different surface cover clusters. 221

6.13 Spatial distribution of surface cover clusters in Eindhoven metropolitan area. 222

6.14 Compilation of LST-related maps for Eindhoven metropolitan area: Albedo, NDVI, imperviousness, surface cover clustering and "urban living environment" categories. 223

6.15 Surface cover cluster proportions for each of the "urban living environment" categories in the analysed medium-size cities of the North Brabant region. Neighbourhoods 3 and 5 present similar cluster proportions, and thus could be grouped. Neighbourhoods 4, 6, 7, 8 and 9 present similar cluster proportions, and thus could be grouped. 224

6.16 Average night LST for each of the "urban living categories". Neighbourhoods 3, 4 and 5 present similar night LST, and thus could be grouped. Neighbourhoods 6, 7, 8 and 9 present similar night LST , and thus could be grouped. 225

7.1 South Holland provincial parks (Province of South Holland, Spatial Planning and Housing Department, 2011) 236

7.2 Land surface temperature image retrieved from Landsat 5TM 240

7.3 Land surface temperature differences in Midden-Delfland 241

7.4 Average night LST, day LST, NDVI, imperviousness, patch surface and patch shape index for the six main land use typologies of South Holland provincial parks. 243

7.5 In red, forest patches of Duin, Horst en Weide provincial park, with small surfaces and numerous narrowings. In blue, analysed forest patches 244

7.6 Analysis of the relationship between the different parameters and daytime LST for forest patches with surfaces above 1 ha in South Holland provincial parks. 245

7.7 Analysis of the relationship between the different parameters and daytime LST for cropland patches in South Holland provincial parks. 246

7.8 Analysis of the relationship between the different parameters and daytime LST for grassland patches in South Holland provincial parks. 247

7.9 Analysis of the relationship between the different parameters and daytime LST for water surfaces in South Holland provincial parks. 249

7.10 Analysis of the relationship between the different parameters and daytime LST for built patches with surfaces below 250 m² in South Holland provincial parks. 250

7.11 Analysis of the relationship between the different parameters and daytime LST for warehouse patches with surfaces below 1,000 sqm in South Holland provincial parks. 251

7.12 Unsupervised classification clusters from day LST, NDVI and imperviousness layers. The greenhouse areas are classified either in the same cluster as water or on the same cluster of forested areas. Due to their small presence in the parks, they are grouped with categories with similar thermal behaviour. 253

7.13 Unsupervised classification clusters from day LST, NDVI and imperviousness layers. The bare soil areas of the coast are classified in the same cluster as the built up areas, since they have a similar thermal behaviour. 254

7.14 Average day LST, night LST, NDVI and imperviousness for the five different clusters produced by the unsupervised classification of the day LST, NDVI and imperviousness maps. 254

7.15 Cluster composition of the different land use present in South Holland provincial parks. 255

7.16 Midden-Delfland hotspots with and LST>41°C surrounding the park. 256

7.17 Midden-Delfland hotspots with 41°C>LST>36°C surrounding the park. 256

7.18 Diagnosis and adaptation design for hotspots with an LST>41°C. 258

7.19 Diagnosis and adaptation design for hotspots with an LST ranging from 36°C to 41°C. 259

7.20 Midden-Delfland analysis schemes 262

7.21 Duin, Horst en Weide analysis schemes 263

7.22 Wijk en Wouden analysis schemes 264

7.23 Bentwoud/Rottemeren analysis schemes 265

7.24 Hollands Plassengebied analysis schemes 266

7.25 Isselmonde analysis schemes 267

8.1 Overall thesis structure 272

Glossary

DEFINITIONS	
Absolute atmospheric humidity	The absolute atmospheric humidity is the amount of water vapour per volume of air.
Adaptation	Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation (Adapt, 2015).
Albedo	Albedo is an index that represents surface reflectance. It indicates the fraction of short-wave radiation that is reflected from land surfaces into the atmosphere. When a surface has an albedo of 0, it means that it doesn´t reflect any radiation whereas an albedo of 1 means that all the incoming radiation is reflected by the surface to the atmosphere.
Anthropogenic heat	Heat released to the atmosphere as a result of human activities. Anthropogenic heat discharge in a city contributes to the UHI effect. Sources of anthropogenic heat include cooling and heating buildings, manufacturing, transportation, and lighting (Shahmohamadi, 2011).
Approximated wet bulb globe temperature (AWBGT)	Human comfort is influenced by temperature, humidity, air movement, radiant temperature, clothing and metabolic rate. $\mathrm{AWBGT} = 0.567T_a + 0.393e + 3.94, \quad (2)$ where Ta is the air temperature and e is the water vapor pressure (hPa). AWBGT threshold is the value above which preventive action should be undertaken to prevent heat stress. This threshold depends on the person´s activity and clothing. For moderate activity AWBGT < 27.7°C represents conditions without heat stress.
ATCOR 2/3	Atmospheric & Topographic Correction for Small FOV Satellite Images. Software used to perform atmospheric and geometric correction of satellite imagery, and to map albedo and surface heat flux maps (Richter & Schlapfer, 2013).
Brabantstad (Brabant City)	Urban network comprising the cities of Tilburg, Breda, ´s-Hertogenbosch, Eindhoven and Helmond.
Catalysing mapping strategies	Mapping procedures used to trigger urban change through the representation of “driving forces” as in a game-board, or through the representation of a network of interrelated abstract considerations capable of producing the systems for the development a new urban core as in a rhizome, or through the overlap of different layers of urban information (layering), or through the representation of urban thematic routes (drif).
Climatope	Climate class which integrates the following layers of infromation: air temperature, airflow, land use, land cover, building structure, surface relief and population density (Ng and Ren, 2015).

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DEFINITIONS	
Climatotope	Climatic component (air temperature, sunlight, wind...) of the environment, characterised by specific ecotopes (homogeneous landscape functional unit).
Cooling degree day (CDD)	The number of degrees that a day's average temperature is above the base temperature (Outside temperature below which a building needs no air conditionning). The base temperature may be defined for a building, a country or for a region. The base temperature in the EU is 15,5°C (EEA, 2016).
Cool roof	Flat and sloped roofs finished with high albedo materials, which prevents the rise of the roof surface temperature.
Cool wind corridor	Paths that allow the circulation of cool air from coolspots towards hotspots.
Coolspot	Areas which remain cooler than their surroundings during heatwaves. They present lower night land surface temperature and lower day storage heat flux values than their urban and rural surroundings.
Downwelling radiance	Radiant flux received by the analysed surfaces.
Drift	Catalysing mapping strategy which maps itineraries across the cities to guide pedestrians with a specific theme. Here, drift is used as a mapping strategy to guide citizens to fresher areas during heat waves. The concept of drift was originally introduced by the situationists and the main driver of this mapping category was a political one, which aimed at actually empowering the working class to promote a revolution.
ENVI 4.7	ENVI is a software for the visualization, analysis, and presentation of all types of digital imagery. ENVI's image-processing package includes spectral tools, geometric correction, terrain analysis, radar analysis, raster and vector GIS capabilities. Here ENVI 4.7 (Exelisvis, 2015) was used for the analysis and enhancement of the images previously processed in ATCOR 2/3.
Game-board	Catalysing mapping strategy which aims at mapping hidden driving forces which "strongly affect physical states and behaviour" of urban areas and which are actually manifestations of global influences on local environments (Bunschoten, 1996).
Geographic Information System (GIS)	System designed to capture, store, manipulate, analyse, manage, and present spatial or geographic data. Here GIS is used as analysis software for the systematic calculation of imperviousness percentages, distances between urban areas, landscape shape index of specific land use patches, or for the creation of systematic land use classifications.
Heating degree day (HDD)	The number of degrees that a day's average temperature is below the base temperature (Outside temperature above which a building needs no heating. The base temperature may be defined for a building, a country or for a region). The base temperature in the EU is 15,5°C (EEA, 2016).
Heat wave in The Netherlands	Heat waves are long periods of excessively hot weather. In The Netherlands, the KNMI defines a heat wave as a situation of at least five consecutive days on which the maximum temperature is 25.0 ° C or superior; wherein the maximum temperature is 30.0 ° C or superior for at least three days.
Hotspot	Areas which concentrate more heat than their surroundings during heatwaves. They present higher land surface temperature and higher storage heat flux values than their urban and rural surroundings.

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DEFINITIONS	
Imperviousness	Percentage of water capable of penetrating a surface, here pavement, roofs, vegetated surface, bare soil…Imperviousness makes a strong contribution to urban heat. Imperviousness seals the surface preventing water evaporation and thus preventing solar radiation from being converted into latent energy. The energy is thus stored during the day and released into the atmosphere at night.
Koninklijk Nederlands Meteorologisch Instituut (KNMI)	Royal Netherlands Meteorological Institute or the Dutch national weather forecasting service, which has its headquarters in De Bilt, in the Netherlands. The primary tasks of KNMI are weather forecasting, monitoring of climate changes and monitoring seismic activity. KNMI is also the national research and information centre for climate, climate change and seismology.
Landsat 5TM	Landsat is the world's longest continuously acquired collection of space-based moderate-resolution land remote sensing data. The Landsat project is a joint initiative between the U.S. Geological Survey (USGS) and NASA and the data it collects supports government, commercial, industrial, civilian, military, and educational communities throughout the United States and worldwide. Landsat 5TM was launched on March the 1st 1984. Landsat 5TM has a resolution of 30 m for all its bands, except for band 6 which has a resolution of 120 m resampled to 30 m. It has a temporal frequency of 16 days and the scene size is 170 km x 185 km.
Landscape shape Index (LSI)	Index defining the compacity of a land use patch. $\mathrm{LSI} = \frac{P_t}{2\sqrt{\pi \times A}}$ Where LSI is the Landscape Shape Index Pt is the perimeter of the patch and A is the area of the patch.
Latent Heat flux (LE)	Latent Heat flux is the energy flux available of evapotranspiration.
Layering	Catalysing mapping strategy consisting of the physical overlap of different structures over a common territory.
Letchworth	Garden city built case study. Letchworth was founded in 1905, and is actually the first garden city built in the world, covers 5500 acres (22.3 km^2) and has a population of 33,249 inhabitants (Office National Statistics UK, 2011), thus presenting an average density of 1,491 inhabitants per sqm, similar to the ideal model defined by Howard.
Mitigation	An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies and measures to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks. Examples of mitigation measures are renewable energy technologies, waste minimization processes and public transport commuting practices, etc. (Adapt, 2015).
Modis 11A1	The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument is operating on both the Terra and Aqua spacecraft. It has a viewing swath width of 2,330 km and views the entire surface of the Earth every one to two days. Its detectors measure 36 spectral bands and it acquires data at three spatial resolutions: 250 m, 500 m, and 1,000 m. Modis 11A1 product has a resolution of 1 km, and screens the surface of the earth on a daily basis. The scene size is 1,100 km x 1,100 km. It maps Land Surface Temperature and Emissivity providing per-pixel temperature and emissivity values.

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DEFINITIONS	
Neotechnics	Idea of restoring nature through the adaptation of new technologies (Luccarelli, 1995). The neotechnics premises strongly connect the natural and the built environment.
Normalised Differential Vegetation Index (NDVI)	Vegetation index used to density of green on a patch of land. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 µm). The more leaves a plant has, the more these wavelengths of light are affected, respectively. NDVI = (NIR-VIS)/(NIR+VIS). Where NDVI is the Normalised Difference Vegetation Index, VIS is the surface reflectance in the red region (650 nm) and NIR is the surface reflectance in the near infrared region (850 nm) (US EO).
Organicism	The principle of restoring the nature´s influence on culture through literature, architecture, and the built environment. The Organicism premises strongly connect the natural and the built environment (Luccarelli, 1995).
Radburn	Experimental urban development, developed by the United States Federal Housing Administration in the 1920´s as an alternative to the traditional suburbs of the end of the 19th century. The Radburn superblock clearly translated the principles of the European Garden Cities (such as Letchworth). The superblocks were characterised by their interior greenery and the underpasses.
Radiant Energy (Rn)	The energy balance equation for radiant energy absorbed by heat fluxes can be written as (Asrar, 1989): Rn = G + H + LE. Where Rn is the net radiant energy absorbed by the surface.
RCP4.5: IPCC stabilisation emission scenario	Representative Concentration Pathway (RCP) 4.5 is a scenario that stabilises radiative forcing at 4.5 W/m² in the year 2100 without ever exceeding that value. Simulated with the Global Change Assessment Model (GCAM), RCP4.5 includes long-term, global emissions of greenhouse gases, short-lived species, and land-use-land-cover in a global economic framework (Thomson A.M. et al., 2011).
RCP8.5: IPCC high emissions scenario	Representative Concentration Pathway (RCP) 8.5 combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and GHG emissions in absence of climate change policies. Compared to the total set of Representative Concentration Pathways (RCPs), RCP8.5 thus corresponds to the pathway with the highest greenhouse gas emissions (Riahi K. et al., 2011).
Regional balance	Here, balance between compactness and sprawl, which should ensure that cities are green enough to prevent them from overheating but still dense enough to ensure efficient transportation and infrastructural systems. In order to reach a regional balance, 1920´s regionalists suggested not only guidelines at the regional scale, they also envisioned the materialization of the smaller (neighbourhood) and larger (supra-regional/infrastructural) scales guidelines.

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DEFINITIONS	
Regionalism	Mumford L. developed in the first half of the 20th century the concept of regionalism to ensure a rational, balanced, and sustainable urban development (Luccarelli, 1995). A region is actually defined by geographical factors (terrain, climate, and soil) (Mumford, 1927). Regionalism revolves around three concepts: the idea of restoring nature through the adaptation of new technologies (neotechnics), the principle of restoring the nature´s influence on culture through literature, architecture, and the built environment (organicism) and the concept of recovering the human-scaled, civic-minded social order through the community.
Remote Sensing	Remote sensing is the retrieval of information without physical contact, and generally refers to sensor technologies (on board aircrafts or satellites) to detect and classify objects on Earth.
Relative atmospheric humidity	The relative atmospheric humidity is the amount of water vapour in the air compared to the maximum amount of water vapour the air can contain. As opposed to the absolute atmospheric humidity, the relative atmospheric humidity depends on the air temperature; air with a higher temperature can contain more water vapour (CPC, 2014).
Rhizome	Catalysing mapping strategy which aims at representing a network of interrelated abstract and physical urban considerations capable of producing the systems for the development a new urban core. This mapping strategy is inspired in the botanical definition of rhizome, which is actually a horizontal underground plant stem which is capable of producing the shoot and root systems of a new plant.
Sensible heat flux (H)	Energy flux dissipated by convection from a surface into the atmosphere (its behaviour varies depending on whether the surface is warmer or colder than the surrounding air).
Sky view factor (SVF)	The sky view factor (SVF) was defined by Oke as the ratio of the amount of the sky seen from a given point to that potentially available (Oke, 1987). Its values range from 0 for full obstruction, to 1 for completely open areas. The average SVF in central parts of European cities ranges from 0.40 to 0.75.
Storage heat flux (G)	The energy flux dissipated by conduction into the ground or into the building materials.
Sunnyside	One of the garden city models proposed by Mumford as examples for the use of new technologies of that time (hydro-generated electric power and automobiles) to revert the harm done by the industrial cities to the environment (Mumford, 1925; Mumford, 1963). In Sunnyside, streets and grids were already developed, and in order to create the communities a mix of housing typologies was proposed, ranging from row houses to apartment blocks with important interior gardens (Wright, 1935).
Surface energy balance	The energy balance equation established how net radiation is balanced by sensible, latent and conduction heat fluxes.
Surface thermal classification	Here it refers to the classification of urban surfaces in different clusters depending on their thermal behaviour. Here it is calculated performing unsupervised classifications of the surfaces using as inputs UHI-related parameters (such as albedo, imperviousness, NDVI, ...)

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DEFINITIONS	
Unsupervised classification	In order to perform an unsupervised classification in GIS, first it is necessary to determine the amount of classes and the input bands (here UHI-related parameters). The software then clusters pixels into the set number of classes.
Upwelling radiance	Radiant flux emitted by the analysed surfaces.
Urban Boundary Layer	The urban boundary layer is situated directly above the urban canopy layer. This is a local or mesoscale concept referring to that portion of the planetary boundary layer whose characteristics are affected by the presence of an urban area at its lower boundary (Oke, 1976).
Urban Canopy Layer	The urban canopy layer consists of the air contained between the urban roughness elements (mainly buildings). The urban canopy is a microscale concept, its climate being dominated by the nature of the immediate surroundings (especially site materials and geometry)(Oke, 1976).
Urban containment	Urban planning policies and regulations which aim at limiting urban sprawl.
Urban heat island	Temperature difference between the city and its inmediate surroundings.
"Urban living environment" categories	In the Netherlands there are two main "urban living environment" classification systems. One was developed by ABF (ABF research, 2005) and the other one is RIGO-typology for neighbourhoods built before and after the war (RIGO 1995; RIGO, 1997). Both analyse physical characteristics of housing and urban equipment but Rigo classification also takes into consideration socio-economic factors (Planbureau voor de leefomgeving, 2006).
Urban Sprawl	Non-structured urban spreading in the city outskirts (typically monofunctional, low-density and car-dependent developments).
Vulnerability	Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (Adapt, 2015).
Welwyn	Built garden city case study. Welwyn´s construction began in 1919 and occupied 2,377 acres (9.6 km²) and until 1956 housed less than 19,000 inhabitants, far below the maximum population planned which was 50,000 inhabitants. Thus the actual density of Welwyn was 1,979 inhabitants/km² for decades, below the level established as a reference of 5,200 inhabitants/km².

ACRONYMS	
AWBGT	Approximated wet bulb globe temperature
CDD	Cooling degree day
CHC	City Housing Corporation
DSS	Decision support system
HDD	Heating degree day
KNMI	Koninklijk Nederlands Meteorologisch Instituut
LSI	Landscape shape Index
LST	Land Surface Temperature
MIST	Mitigation Impact Screening Tool
NDVI	Normalised Differential Vegetation Index
PAA	Park adaptation areas
US EPA	United States Environmental Protection Agency

Summary

The urban planner´s role should be adapted to the current globalised and over-specialised economic and environmental context, envisioning a balance at the regional scale, apprehending not only new technologies, but also new mapping principles, that allow obtaining multidisciplinary integral overviews since the preliminary stages of the design process. The urban heat Island (UHI) is one of the main phenomena affecting the urban climate. In the Netherlands, during the heat wave of 2006, more than 1,000 extra deaths were registered. UHI-related parameters are an example of new elements that should be taken into consideration since the early phases of the design process.

Problem statement

Thus, the development of urban design guidelines to reduce the heat islands in Dutch cities and regions requires first an overall reflection on the heat island phenomenom (relevance of the large scale assessment, existing tools, instruments) and proposal of integrative and catalysing mapping strategies and then a specific assessment of the phenomenom at the selected locations in The Netherlands (testing those principles).

Main research question

Could the use of satellite imagery help analyse the UHI in the Netherlands and contribute to suggest catalysing mitigation acions actions implementable in the existing urban context of the cities, regions and provinces assessed?

Method

The development of urban design principles that aim at reaching a physical balance at the regional scale is critical to ensure a reduction of the UHI effect. Landsat and Modis satellite imagery can be analysed and processed using ATCOR 2/3, ENVI 4.7 and GIS, allowing not only a neighbourhood, city and regional scale assessment, but also generating holistic catalysing mapping typologies: game-board, rhizome, layering and drift, which are critical to ensure the integration of all parameters. The scientific inputs need to be combined not only with other disciplines but often also with existing urban plans. The connection between scientific research and existing agreed visions is critical to ensure the integration of new aspects into the plans.

Results

At the neighbourhood level the areas that have a greater heat concentration in the cities of Delft, Leiden, Gouda, Utrecht and Den Bosch are the city centres characterised by their red ceramic roof tiles, brick street paving, and canals. Several mitigation strategies could be implemented to improve the UHI effect in those areas; however, since the city centres are consolidated and listed urban areas, the mitigation measures that would be easier to implement would consist in improving the roof albedo. A consistent implementation of albedo improvement measures (improving the thermal behaviour not only of flat roofs, but also of tiled pitched roofs) of all roofs included in the identified hotspots (with an average storage heat flux greater than 90 W/m²) would help reduce the temperatures between 1.4°C and 3°C. Pre-war and post-war compact and ground-based neighbourhoods present similar thermal behaviour of the surface cover, and green neighbourhoods and small urban centres also present similar thermal behaviour.

At the city scale the analysis of 21 medium-size cities in the province of North Brabant, which belongs to the South region of the county -in relative terms the most affected by the UHI phenomenon during the heat wave of 2006-, reveals that albedo and normalised difference vegetation index (NDVI) are the most relevant parameters influencing the average nightime land surface temperature (LST). Thus, imperviousness, distance to the nearest town and the area of the cities do not seem to play a significant role in the LST night values for the medium-size cities analysed in the region of North Brabant, which do not exceed 7,700 ha in any case. The future growth of most medium-size cities of the regions will not per se aggravate the UHI phenomenon; in turn it will be the design of the new neighbourhoods that will impact the formation of urban heat in the province.

The average day LST of provincial parks in South Holland varies depending on the land use. The analysis of the average night LST varies depending of the land use of the patches. The following surfaces are arranged from the lowest to the highest temperatures: water surfaces, forests, cropland, and greenhouse areas. For each of these land uses, NDVI, imperviousness and landscape shape index (LSI) shape index influence the thermal behaviour of the patches differently. NDVI is inversely correlated to day LST for all categories, imperviousness is correlated to day LST for all areas which do not comprise a significant presence of greenhouses (grassland and built patches) and inversely correlated to LST for areas with a high presence of greenhouses (cropland and warehouses). Greenhouse surfaces have highly reflective roofs, which contribute to the reduction of day LST. Finally, landscape shape index varies depending on the nature of the surrounding patches, especially for small patches (built areas, forests and greenhouse areas). When the patches analysed are surrounded by warmer land uses, slender and scattered patches are warmer, more compact and large ones are cooler. In turn, when they are surrounded by cooler patches it is the opposite: slenderer and scattered patches are cooler and more compact and larger ones are warmer. In Midden-Delfland (1 of the 6 South Holland provincial parks), most of the hotspots surrounding the park are adjacent to grassland patches. The measure to increase the cooling capacity of those patches would consist in a change of land use and/or an increase of NDVI of the existing grassland patches.

Conclusions

Satellite imagery can be used not only to analyse the heat island phenomenom in Dutch neighbourhoods, cities and regions (identify neighbourhoods with highest surface temperature, identify impact of city size and morphology in surface temperature, calcuate average surface temperature for different land uses...), but also to suggest mitigation actions for the areas assessed. Moreover, satellite imagery is here used to generate catalysing mapping typologies: game-board, rhizome, layering and drift, ensuring that the measures proposed remain accurate enough to actualy be efficient and open enough to be compatible with the rest of urban planning priorities.

Samenvatting

De rol van de stedelijke planner moet worden aangepast aan de huidige mondiale en specifieke economische en milieucontext, waarbij een evenwicht op de regionale schaal wordt uitgewerkt. Daarbij worden niet alleen nieuwe technologieën aangepakt, maar ook nieuwe karteringsprincipes, die het mogelijk maken multidisciplinaire integrale overzichten te verkrijgen vanaf de voorlopige stadia van het ontwerpproces. Het urban heat island (UHI, stedelijk hitte-eiland) is een van de belangrijkste fenomenen die het stedelijke klimaat beïnvloeden. Tijdens de hittegolf van 2006 werden in Nederland meer dan 1.000 extra sterfgevallen geregistreerd. UHI-gerelateerde parameters zijn een voorbeeld van nieuwe elementen die vanaf de vroege fasen van het ontwerpproces in overweging moeten worden genomen.

Probleemstelling

De ontwikkeling van richtsnoeren voor stedelijke ontwerpen om de warmte eilanden te verminderen in Nederlandse steden en regio's vereist dus eerst een algehele reflectie op het fenomeen van het hitteiland (relevantie van de grootschalige evaluatie, bestaande instrumenten, instrumenten) en het voorstel van integratieve en katalyserende mappingstrategieën en Dan een specifieke beoordeling van het fenomeen op de geselecteerde locaties in Nederland (het testen van die principes).

Belangrijkste onderzoeksvraag

Zou het gebruik van satellietbeelden de UHI in Nederland kunnen analyseren en voorstellen dat katalysatiewerkzaamheden worden uitgevoerd die in de bestaande stedelijke contexten van de steden, regio's en provincies kunnen worden beoordeeld?

Methode

De ontwikkeling van stedenbouwkundige principes die gericht zijn op het bereiken van een fysiek evenwicht op de regionale schaal is van cruciaal belang om UHI-effecten te verminderen. Landsat en Modis satellietbeelden kunnen worden geanalyseerd en verwerkt met behulp van ATCOR 2/3, ENVI 4.7 en GIS, waardoor niet alleen een buurt-, stads- en regionale schaalbeoordeling wordt geanalyseerd, maar ook holistische katalyserende karteringstypologieën wordt gegenereerd: bordspel, rhizoom, layering en drift, die van cruciaal belang zijn voor de integratie van alle parameters. De wetenschappelijke inputs moeten niet alleen gecombineerd worden met andere disciplines, maar ook vaak met bestaande stedelijke plannen. De verbinding tussen wetenschappelijk onderzoek en bestaande overeengekomen visies is cruciaal om de integratie van nieuwe aspecten in de plannen te waarborgen.

Uitslagen

Op buurtniveau zijn stadscentra in de steden Delft, Leiden, Gouda, Utrecht en Den Bosch, die gekenmerkt worden door hun rode keramische dakpannen, stenen bestrating en grachten, gebieden met een grotere warmteconcentratie. Verschillende mitigatiestrategieën zouden kunnen worden geïmplementeerd om het UHI-effect in deze gebieden te verbeteren, maar aangezien de stadscentra geconsolideerd zijn met veel beschermde monumenten, valt onder de mitigatiemaatregelen die gemakkelijker kunnen worden uitgevoerd: het albedo van daken verbeteren. Een consistente implementatie van albedo-verbeteringsmaatregelen (verbetering van het thermische gedrag van niet alleen platte daken maar ook hellende daken met dakpannen) van alle daken inbegrepen in de geïdentificeerde hotspots (met een gemiddelde opslagwarmteflux groter dan 90 W/m²) zou helpen om de temperaturen met 1.4°C tot 3°C te reduceren. Vooroorlogse en naoorlogse compacte en grondgebaseerde wijken tonen een gelijkwaardig thermisch gedrag van het oppervlak, en groene buurten en kleine stedelijke centra gedragen zich ook op soortgelijke wijze.

Op stadsschaal blijkt uit de analyse van 21 middelgrote steden in de provincie Noord-Brabant, die behoort tot de zuidelijke regio van het graafschap - in relatieve termen het meest getroffen door het UHI-fenomeen tijdens de hittegolf van 2006 - dat albedo en de genormaliseerde verschil-vegetatie-index (NDVI) zijn de meest relevante parameters die van invloed zijn op de gemiddelde nachtelijke oppervlaktetemperatuur van het land (LST). De permeabiliteit, de afstand tot de dichtstbijzijnde stad en de oppervlakte lijken derhalve niet een belangrijke rol te spelen in de nachtelijke LST-waarden voor de geanalyseerde middelgrote steden in Noord-Brabant, die in elk geval niet groter zijn dan 7.700 ha. De toekomstige groei van de meeste middelgrote steden in de regio zal het UHI-fenomeen op zijn beurt niet verergeren, het zal de vormgeving van de nieuwe wijken zijn die de vorming van stedelijke warmte in de provincie zal beïnvloeden.

De gemiddelde LST overdag van Zuid-Hollandse provinciale parken varieert afhankelijk van het landgebruik. De analyse van de gemiddelde nachtelijke LST varieert afhankelijk van het landgebruik. Van de laagste naar de hoogste temperatuur hebben we: wateroppervlakken, bossen, akkerland en kassengebieden. Voor elk van deze typen grondgebruik beïnvloeden de NDVI, ondoordringbaarheid en patch shape index het thermische gedrag van de gebieden op andere wijze. Voor alle categorieën is de NDVI omgekeerd gecorreleerd met de LST overdag, ondoordringbaarheid is gecorreleerd met de LST overdag voor alle gebieden die geen significante aanwezigheid van kassen bevatten (grasland en gebouwen) en omgekeerd gecorreleerd met de LST voor gebieden met een grote aanwezigheid van kassen en loodsen. De oppervlakken van kassen hebben zeer reflecterende daken die bijdragen aan de vermindering van de LST overdag. Tenslotte varieert de LSI afhankelijk van de aard van de omliggende gebieden, vooral voor kleine gebieden (gebouwen, bossen en broeikasgassen). Wanneer de geanalyseerde gebieden omringd zijn door warmer landgebruik geldt: hoe slanker en verspreider de gebieden, hoe minder warm ze zijn, en hoe compacter en groter hoe koeler. Omgekeerd, wanneer ze omgeven zijn door koelere gebieden geldt het tegengestelde: hoe slanker en verspreider hoe koeler en hoe compacter en groter hoe warmer. In Midden-Delfland (een van de zes Zuid-Hollandse provinciale parken) grenst het merendeel van de hotspots rondom het park aan grasland. Een maatregel om de koelcapaciteit van die gebieden te verhogen zou bestaan uit een verandering van het landgebruik en/of een toename van de NDVI van het bestaande grasland.

Conclusies

Satellietbeelden kunnen niet alleen gebruikt worden om het fenomeen van het hitteiland in Nederlandse wijken, steden en regio's te analyseren (identificeer buurten met de hoogste oppervlaktetemperatuur, identificeer de impact van stadsgrootte en morfologie in de oppervlaktetemperatuur, bereken de gemiddelde oppervlaktetemperatuur voor verschillende grondgebieden ...) Maar ook aan te bevelen mitigatieacties voor de beoordeelde gebieden. Bovendien worden satellietbeelden hier gebruikt om catalyserende mappingstypologieën te genereren: game board, rhizome, layering en drift, zodat de voorgestelde maatregelen nauwkeurig genoeg blijven om efficiënt en open genoeg te zijn om compatibel te zijn met de rest van de stedenbouwkundige prioriteiten.

Resumen

El papel del urbanista debe adaptarse al actual contexto económico y medioambiental globalizado y sobre-especializado. Deberá buscar un equilibrio a escala regional, haciendo uso no sólo de las nuevas tecnologías, sino también de nuevos principios cartográficos, que permitan la integración de todas las disciplinas desde las etapas preliminares del proceso de diseño. La isla de calor urbano (ICU) es uno de los principales fenómenos que afectan al clima urbano. En los Países Bajos durante la ola de calor de 2006 se registraron más de 1.000 muertes extra. Los parámetros relacionados con ICU son un ejemplo de nuevos elementos que se deben tener en cuenta desde las primeras fases del proceso de diseño.

Planteamiento del problema

Por lo tanto, el desarrollo de directrices de diseño urbano para reducir las islas de calor en las ciudades y regiones holandesas requiere primero una reflexión general sobre el fenómeno de las islas de calor (relevancia de la evaluación a gran escala, herramientas existentes, instrumentos) y la propuesta de estrategias cartográficas integradoras y catalizadoras. Y a continuación, una evaluación específica del fenómeno en los lugares seleccionados en los Países Bajos (prueba de esos principios).

Pregunta de investigación principal

¿Es posible utilizar imágenes satélite para analizar y sugerir medidas catalizadoras para la reducción de las islas de calor en los Países Bajos, que además tengan en consideración los contextos urbanos y espaciales de las ciudades, regiones y provincias analizados?

Método

El desarrollo de principios de diseño urbano que buscan alcanzar un equilibrio físico a escala regional es fundamental para asegurar una reducción del efecto de la ICU. Las imágenes satélite de Landsat y Modis pueden ser analizadas y procesadas utilizando ATCOR 2/3, ENVI 4.7 y GIS, permitiendo no solo una evaluación de barrios, ciudades y regiones sino también generando tipologías cartográficas catalizadoras holísticas: tablero de juego, rizoma, capas y deriva, que son fundamentales para asegurar la

integración de todos los parámetros. Los insumos científicos deben combinarse no sólo con otras disciplinas sino también con los planes urbanos existentes. La conexión entre la investigación científica y las visiones existentes es fundamental para asegurar la integración real de nuevos aspectos en el planeamiento.

Resultados

A escala de barrio, las zonas que tienen mayor concentración de calor en las ciudades de Delft, Leiden, Gouda, Utrecht y Den Bosch son los centros de la ciudad caracterizados por sus tejas de cerámica roja, pavimentos de ladrillo y canales. Se podrían implementar varias estrategias de mitigación para mejorar el efecto ICU en esas áreas, sin embargo, como los centros urbanos son áreas urbanas consolidadas y protegidas, las medidas que serían más fáciles de implementar estarían basadas en la mejora del albedo de las cubiertas. La mejora del albedo de todas las cubiertas (no solo de las cubiertas planas, sino también de las cubiertas inclinadas) de los edificios situados dentro del ámbito de los hotspots identificados (con un flujo medio de almacenamiento de calor superior a 90 W/m^2) reduciría la temperatura media de los mismos entre 1,4°C y 3°C. Los barrios de tipología compacta construidos antes y después de la segunda mundial presentan un comportamiento térmico superficial similar y los barrios verdes y pequeños centros urbanos también presentan comportamientos térmicos superficiales similares..

A escala de la ciudad, el análisis de 21 ciudades de tamaño medio en la provincia de Brabante Septentrional, que pertenece a la región sur del país -en términos relativos la más afectada por el fenómeno ICU durante la ola de calor de 2006-, revela que albedo y el índice de vegetación de diferencia normalizada (NDVI) son los parámetros más relevantes que influyen en la temperatura media de la superficie terrestre durante la noche (TS). Por lo tanto, la impermeabilidad, la distancia a la ciudad más cercana y la superficie de las ciudades analizadas no parecen desempeñar un papel significativo en los valores nocturnos de TS para las ciudades medianas analizadas en la región de Brabante Septentrional. El crecimiento futuro de la mayoría de las ciudades de tamaño mediano de esta región no agravará per se el fenómeno ICU. Será el diseño de los nuevos barrios, el que influirá en la formación de calor urbano en la provincia.

El valor medio de la TS de los parques provinciales de Holanda del Sur varía dependiendo del uso del suelo. Enumeramos a continuación los distintos usos de suelo presentes, ordenados de TS más baja a la más alta: superficies de agua, bosques, tierras de cultivo y áreas de invernadero. Para cada uno de estos usos, el NDVI, la impermeabilidad y el factor de forma del parche influyen de manera diferente en el comportamiento térmico de los parches. El NDVI está inversamente correlacionado con la TS diurna para todas las categorías, la impermeabilidad se correlaciona con la TS diurna para todas las áreas que no comprenden una presencia significativa de invernaderos (pastizales y zonas construidas) e inversamente correlacionadas con TS para áreas con alta presencia de invernaderos y almacenes). Las superficies de los invernaderos tienen cubiertas altamente reflectantes que contribuyen a la reducción de la TS diurna. Por último, el factor de forma varía dependiendo de la naturaleza de los parches circundantes, especialmente para pequeños parches (áreas construidas, bosques y zonas de invernadero). Cuando los parches analizados están rodeados por usos más cálidos, cuanto más delgados y dispersos los parches, mayor TS. A su vez, cuando están rodeados de parches más fríos es lo contrario, cuanto más delgados y dispersos menor TS. En Midden-Delfland (uno de los seis parques provinciales de Holanda del Sur), la mayoría de los puntos calientes que rodean el parque son adyacentes a parches de pastizales. La medida para aumentar la capacidad de enfriamiento de esos parches consistiría en un cambio en el uso del suelo y / o en un aumento del NDVI de los parches de pastizales existentes.

Conclusiones

Las imágenes satélite pueden utilizarse no solo para analizar el fenómeno de las islas de calor a escala de barrio, ciudad y región en Holanda (permiten identificar los barrios con mayor temperatura superficial, estudiar el impacto del tamaño y la morfología de la ciudad en la temperatura superficial, calcular la temperatura media superficial dependiendo del uso del suelo…), sino también para sugerir acciones de mitigación para las áreas evaluadas. Por otra parte, las imágenes satélite se utilizan aquí para generar estrategias de mapeado catalizadoras: juego, rizoma, estratificación y deriva, que permitan que las medidas propuestas sean lo suficientemente precisas como para ser efectivas y lo suficientemente abiertas como para ser compatibles con el resto de prioridades urbanas.

1 Introduction

§ 1.1 Background

Extreme summer temperatures can be as dangerous as extreme winter temperatures. More than 30,000 excess deaths were registered across Europe between June and September 2003 (Robine et al., 2008) (Figure 1.1). Besides, there is scientific evidence proving that extreme summers, far from being isolated phenomena, will become more frequent, more intense and they will last longer (Meehl & Tebaldi, 2004; Karl & Trenberth, 2003).

After the heatwave of 2003 (Robine et al., 2008; Dousset, 2011) several studies were conducted to analyse and quantify the effects of Urban Heat Islands on the health and mortality of citizens.

– The World Health Organisation Report "Improving Public Health Responses to Extreme Weather/Heat-Waves, EuroHEAT" (Meeting Report Bonn, Germany, 22-23 March 2007) highlights the fact that hot weather can kill and cause illness.
– Within the CANICULE project more than 30,000 excess deaths were observed between June and September 2003 (Robine et al., 2008).
– A ten-year analysis of 15 European cities, carried out in the PHEWE4 project, estimated a 2% increase in mortality in northern cities, and a 3% in southern cities for every 1°C increase in apparent temperature above the city threshold level.

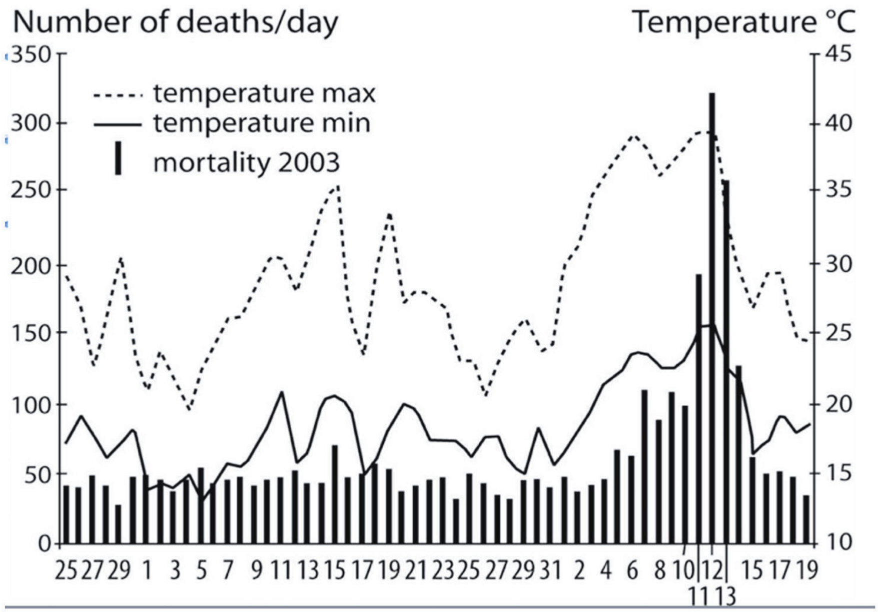

FIGURE 1.1 Graph showing the number of deaths/day related to the temperatures in Paris during the heatwave 2003 (Dousset, 2011)

Heat waves wreak havoc especially in cities, where the Urban Heat Island effect increases the daily average temperature and prevents them from cooling down during the nights. Urban Heat Islands are caused by the changes human constructions introduce in the radiative and thermal properties of the environment. The annual mean air temperature difference between the city and its rural environment ranges from 1 to 12°C (EPA, 2016).

The most appropriate tool for the systematic assessment of heat islands at city and regional scale is remote sensing, which allows for analysing surface temperature maps and for producing images revealing the distribution of other parameters influencing UHI (imperviousness, greenery, etc.).

Although there are many scientific peer-reviewed journal articles studying the Urban Heat Island effect in depth for different case study cities around the world from a climatological perspective (Dousset, 2007; Yang Lui, 2009), there seems to be a gap between the sophisticated available technologies (remote sensing), and the local UHI policies for the vast majority of medium-size to large cities. Urban planners punctually use images processed by remote sensing, but our discipline has not appropriated such a powerful tool yet.

The objective of this research is to explore the potential of the use of remote sensing technology for urban planners to be able to analyse the thermal behaviour of cities, in order to generate action plans for thermal masterplanning at the scales of the region and the city.

There are two main heat island types: the surface UHI and the atmospheric UHI, and they have different behaviours and different identification methods.

The surface heat island refers to the surface temperature difference between the rural and the urban environment, which has its greatest intensity during summer days, ranging between 10 and 15°C. The surface temperature difference during night-time ranges between 5 and 10°C. Remote sensing is the usual tool for surface temperature estimation (EPA, 2016).

The atmospheric heat island refers to the air temperature difference between the rural and the urban environment. Peak intensity occurs after sunset (due to the release of heat stored in the built environment). There are two types of atmospheric heat islands (Figure 1.2 and Figure 1.3):

- Canopy layer urban heat islands exist in the layer from the ground to below the tops of trees and roofs. It is the most common one when speaking about UHI.
- Boundary layer urban heat islands start from the rooftop and treetop level and extend up to the point where urban landscapes no longer influence the atmosphere.

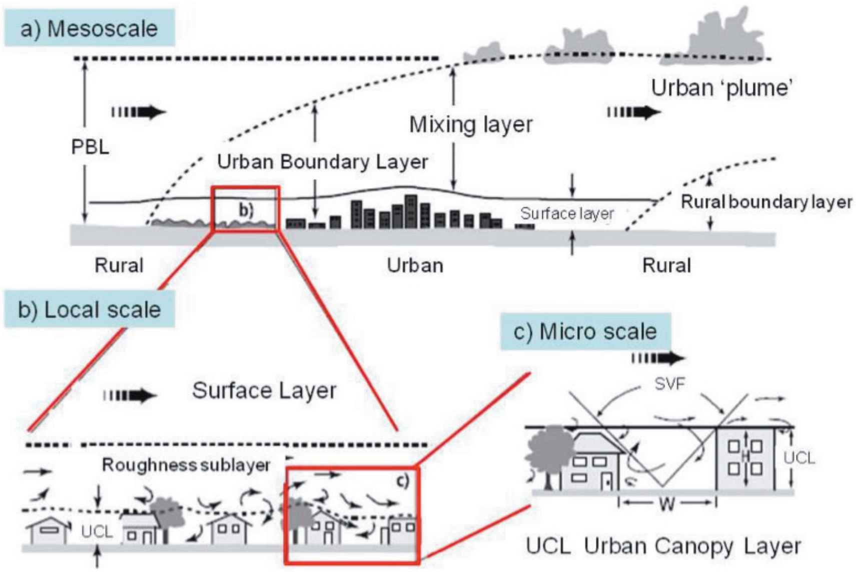

FIGURE 1.2 Schematic of climatic scales and vertical layers found in urban areas. Planetary Boundary Layer (PBL), Urban Boundary Layer (UBL) and Urban Canopy Layer (UCL). (Oke, 1987).

Feature	Surface UHI	Atmospheric UHI
Temporal Development	• Present at all times of the day and night • Most intense during the day and in the summer	• May be small or non-existent during the day • Most intense at night or predawn and in the winter
Peak Intensity (Most intense UHI conditions)	• More spatial and temporal variation: ▪ Day: 18 to 27°F (10 to 15°C) ▪ Night: 9 to 18°F (5 to 10°C)	• Less variation: ▪ Day: -1.8 to 5.4°F (-1 to 3°C) ▪ Night: 12.6 to 21.6°F (7 to 12°C)
Typical Identification Method	• Indirect measurement: ▪ Remote sensing	• Direct measurement: ▪ Fixed weather stations ▪ Mobile traverses
Typical Depiction	• Thermal image	• Isotherm map • Temperature graph

FIGURE 1.3 Basic characteristics of Surface and Atmospheric Urban Heat Islands. Extracted from Reducing Urban Heat Islands: Compendium of Strategies (EPA, 2015).

Although surface and atmospheric temperatures are different, there is a significant influence of the surface temperature on the canopy air temperature, especially by night. During daytime there are large differences between air and surface temperature behaviour, while in the evening they tend to behave similarly. At night there are large differences between the city core and the countryside temperatures (Figure 1.4 and Figure 1.5).

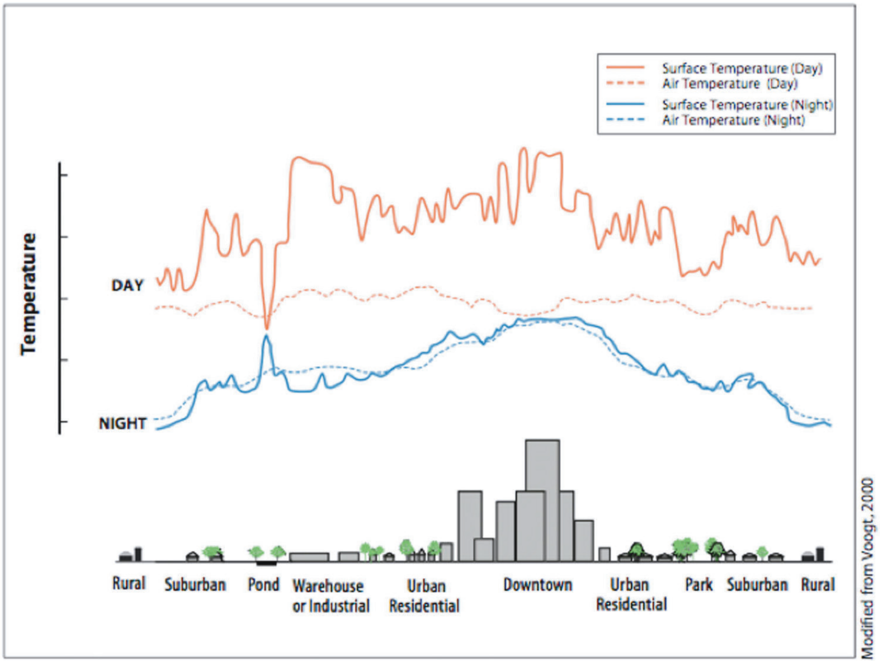

FIGURE 1.4 Variations of Surface and Atmospheric Temperatures. Extracted from Reducing Urban Heat Islands: Compendium of Strategies (EPA, 2015).

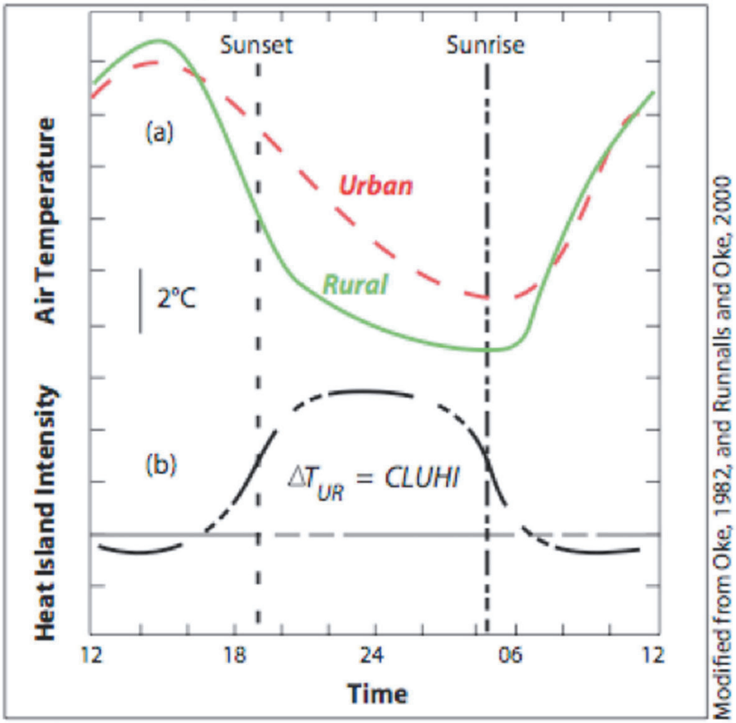

FIGURE 1.5 Conceptual drawing of the diurnal evolution of the UHI during calm and clear conditions (EPA, 2015).

§ 1.2 Overall UHI analysis and mitigation strategies

There are certain generic validated conclusions referring to UHI mitigation, however these are often not site specific, and thus should often be complemented by the use of tools to customise the assessment.

There are three types of mitigation actions to reduce UHI, at neighbourhood, city and regional scales. These will be discussed here.

§ 1.2.1 References at neighbourhood scale

- Climate zones London (Chandler, 1965).
- Meteorologically significant land uses in St Louis (Auer, 1978).
- Urban terrain zones Ellefsen (1990).
- Climatotopes in Metropolitan Hannover (Wilmers, 1991).
- Climatope classification of the region of Basel (Scherer, 1999).
- Urban climate zones (Oke, 2004).
- Local climate zones (Stewart & Oke, 2012).
- Remote sensing to define urban climate zones of Toulouse (Houet & Pigeon, 2011).
- Remote sensing for the definition of urban structure types in the city of Munich (Heiden et al., 2012).
- Object based classification to map urban structure typologies in Munich (Wurm et al., 2010).
- Remote sensing to define land-use classification produced for metropolitan Atlanta (Tang, 2007).
- The New Köppen-Geiger map created by the Council for Scientific and Industrial Research (CSIR) in South Africa (Conradie, 2016) divides the country in climatic zones (Köppen-Geiger) and suggests specific passive design strategies for each of them.

§ 1.2.2 References of urban studies

- Greenery (roof and pavement):
  - Publications that study the relationship between Normalised Difference Vegetation Index (NDVI) and other UHI-related parameters:
    - For fully vegetated surfaces NDVI is approximately 0.78, partially vegetated surfaces 0.33, dark asphalt areas 0.09, and bright concrete areas 0.07 (Richter & Muller, 2005).
    - Several studies (Kurn et al. 1994; Sailor 1995) estimate that the near-surface air temperatures over vegetated areas were 1°C lower than background air temperatures.
    - Imperviousness coefficient has a stronger linear relationship with land surface temperature (LST) values than with NDVI (Yuan and Bauer 2007), particularly in bare soil locations (Carlson et al. 1994).
    - The difference in urban and rural NDVI is linearly related with the difference in urban and rural minimum air temperatures (Gallo et al. 1993).
    - The heat fluxes can be expressed as a function of the vegetation indexes in rural environments (Choudhury et al., 1994; Carlson et al., 1995).
  - Studies that analyse the factors influencing the cooling effect of urban parks:
    - The size of the parks (Von Stulpnagel et al., 1990; Upmanis, 1998; Cheng, 2014).
    - The height and structure of the surrounding constructions (Upmanis et al., 1998; Jauregui, 1975, 1990-1991; Spronken-Smith, 1994).
    - The design of the parks. During daytime the local cool island intensity is related to the area of trees and shrubs inside the park (Cao et al., 2010; Potcher et al., 2006; Yu et al., 2006; Zhou, 2011). During night-time the coolest parks are those without trees (Chang, 2007; Taha, 1991).
    - Vegetation reduces the near-surface air temperature on average by 1 to 4.7°C, particularly during night-time when the UHI intensity is high (Kleerekoper et al., 2012; Li & Norford, 2016).
    - Assessments of the thermal load in terms of surface temperature in Tel Aviv demonstrated that the relatively low vegetation cover to free space ratio decreases the cooling effect of residential areas (Rotem-Mindali et al., 2015).
- Albedo. Albedo is the index representing the surface reflectivity. It indicates the fraction of short-wave radiation that is reflected from land surfaces into the atmosphere. When a surface albedo is 0 it doesn’t reflect any radiation, and when it is 1 all the incoming radiation is reflected to the atmosphere.
  - Most US and European cities have albedos of 0.15–0.20 (Gao et al., 2014; Prado & Ferreira, 2005; Akbari et al., 2001; Taha, 1997).

    - A white surface with an albedo of 0.61 is only 5°C warmer than ambient air whereas conventional gravel with an albedo of 0.09 is 30°C warmer than air (Taha et al., 1992).
    - Increasing the surface albedo from 0.25 to 0.40 could lower the air temperature as much as 4°C (Taha et al., 1988).
    - An increase of 0.1 of the hotspot overall albedo reduces the UHI by 1°C (Sailor, 1995).
    - The finishing materials of urban ground surfaces also have a major impact on the UHI effect (Gago et al., 2013).
    - Replacing materials with new surface cover reduces the radiative heat gain in the material and improves evaporative properties of the urban surface (Roth, 2013).
    - The current research trends in the field are focused on the development of highly reflective pavements and permeable pavements that use the cooling evaporation capacity of water (Santamouris, 2013).
    - Studies in Singapore demonstrated that the city-scale deployment of cool roofs can greatly reduce the near-surface air temperature and surface skin temperature during daytime (Li & Norford, 2016).
- Imperviousness:
    - A strong correlation was also found between paved surfaces and LST (Zhou et al., 2011; Li et al., 2011).
    - Diurnal LST is correlated with the largest patch size of the urban land use type (Cheng et al., 2014).
    - The same impervious surface produces a smaller UHI effect when it is spatially distributed (Li et al., 2011).
- Urban water surfaces and surface watering:
    - These have an average cooling effect of 1–3°C to an extent of about 30–35 m. Such functions of water are already applied in Dutch cities (Kleerekoper et al., 2012).
    - Positive thermal effects of pavement-watering in Paris during the summers of 2013 and 2014. The maximum reduction of 0.79°C, 1.76°C and 1.03°C for air, mean radiant, UTCI-equivalent temperatures and UHI-mitigation of -0.22°C have been recorded during the day (Hendel et al., 2016).
- Sky view factor. The sky view factor (SVF) was defined by Oke as the ratio of the amount of the sky seen from a given point to that potentially available (Oke, 1987). Its values range from 0 for full obstruction, to 1 for completely open areas. The average SVF in central parts of European cities ranges from 0.40 to 0.75.
    - Some studies reveal a strong relationship between the SVF and the nocturnal UHI in calm, clear nights (Svensson, 2004; Unger, 2009).
    - However, other studies reveal that the nocturnal UHI is not only affected by the horizon obstructions (SVF) but also by the thermal properties of the materials, and they do not find a correlation between the UHI and the SVF (Blankenstein & Kuttler, 2004).
- Size of the cities (Oke, 1973; Park, 1986; Fujuoka,1983; Hove, 2011).

§ 1.2.3 References at regional scale

- Cooling properties of natural landscape elements:
  - Hilly forests. Climate Analysis Map for the Stuttgart region (City of Stuttgart, 1977, 2008).
  - Parks and forests outside the city. Climate maps of Arnhem in The Netherlands (Burghardt et al., 2010).
  - Bays. Tokyo Bay, the renovation plans of the Tokyo Station vicinity aim at maximising the cool wind paths connecting the cool bay breeze with the urban hotspots (JFS, 2016).
  - Water surfaces. The role of water surfaces is unclear, but appears to depend on the size and depth of the body of water. Some studies revealed water had a positive effect on local cool island intensity (Saaroni and Ziv, 2003), while others have suggested its contribution is negligible (Cao et al., 2010).
- Cool wind corridors
  - Rivers. Often act as the best wind paths to channel sea breeze into cities (Yamamoto, 2006).

§ 1.2.4 References of the use of remote sensing for UHI assessment

- References of studies using Landsat 5TM for UHI assessment:
  - UHI analysis (Bechtel, 2011; Liu & Zhang, 2011; Rajasekar & Weng 2009; Cao et al., 2008).
  - Mitigation strategies (Rosenzweig et al., 2006; Baudouin & Lefebvre, 2014).
  - Estimation of the heat mitigation effect (Odindi et al., 2015; Onishi et al., 2010).
- Systematic analysis and mapping several UHI related parameters:
  - Surface heat fluxes (Parlow, 2003).
  - Land surface temperatures (Dousset et al., 2011).
  - Albedo (Taha, 1997; Sailor, 1995).
  - Vegetation indexes (Yuan & Bauer, 2007; Gallo et al., 1993).

§ 1.3 Systematic approach to the UHI assessment

Some researchers have attempted to create online tools to produce systematic and customised UHI assessment to analyse and develop mitigation action to palliate the effect of the UHI effect.

- The Decision support system (DSS) covers 8 metropolitan areas in the Central Europe Region (Bologna/Modena, Venice/Padua, Wien, Stuttgart, Lodz/Warsaw, Ljubljana; Budapest and Prague). Assessment of the UHI at building and the urban scale (Urban Heat Island project, 2014).
- The CE Urban Heat Island Atlas is actually an interactive digital map which allows to overlap layers of parameters which play a role in the formation of the UHI phenomenon in the Central Europe region. The different layers available are: location of the project partners, air temperature, digital elevation model, land surface temperature (day and night), normalised differential vegetation index, land cover (corine), and urban atlas land use.
- The STAR tools have been developed for the North-West region of England and they include a surface temperature tool and a surface runoff tool, which allow to estimate the impact on surface temperature and surface runoff for several land use scenarios under different temperature and precipitations scenarios (STAR tools, 2016).
- The "London unified model" (Londum) is a city-wide climate model. It has been developed for the city of London and it estimates the impact of the volume on long and short wave radiation (reflection, shadow, conduction of heat into the building and calculation of the flux into the atmosphere (Hamilton et al., 2012; University College London, 2012).
- The ADMS model was also developed within the Lucid program for the city of London, and is a neighbourhood scale model which allows to estimate the temperature and humidity depending on the building volume and surface covers (it considers albedo, evapotranspiration and the thermal admittance of surfaces) (Hamilton et al., 2012; University College London, 2012).
- EPA Mitigation Impact Screening Tool (MIST) (EPA, 2016) is a software tool developed by the US Environmental Agency to provide an assessment of the impacts of several UHI mitigation strategies (mainly albedo and vegetation increase) on the reduction of the urban air temperatures, ozone and energy consumption for over 200 US cities (Sailorand Dietsch, 2007).

These are interesting attempts to provide customised UHI assessment; however, these initiatives remain isolated examples, for specific geographical areas, analysing different indicators.

§ 1.4 The UHI in the Netherlands

The KNMI (Royal Netherlands Meteorological Institute) 2014 climate scenarios (KNMI´14) for 2050-2085 translate the research results on the global climate in the IPCC report (2013) to the Netherlands. The KNMI climate scenarios cover the vertices of likely changes in the climate of the Netherlands. The four KNMI'14 scenarios differ in the extent to which the global temperature increases ('Moderate' and 'Warm') and the possible change of the air circulation pattern ("Low value" and "High Value") (Figure 1.6) (KNMI, 2015).The global temperature rise will continue increasing in any of the four scenarios (Figure 1.7) and the amount of summer days (maximum temperature equal or above 25°C) per year will also continue rising in any of the four scenarios (Figure 1.8).

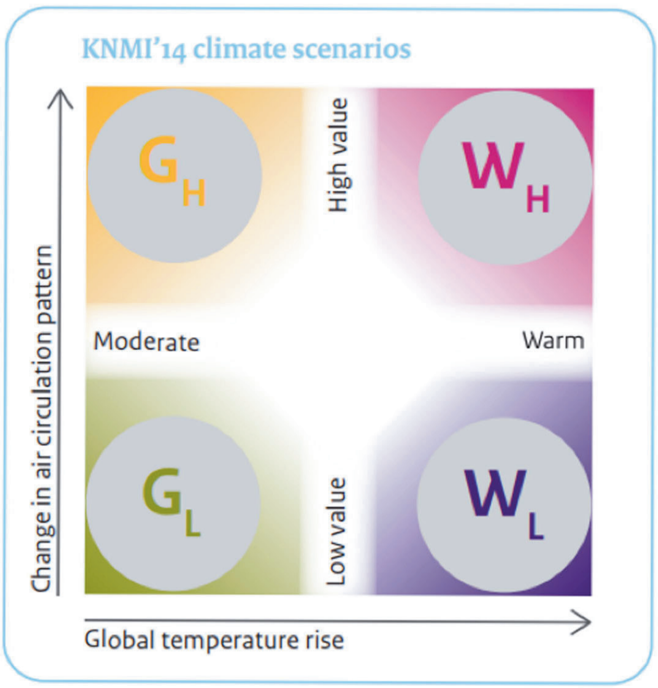

FIGURE 1.6 Schematic overview of the four KNMI'14 climate scenarios. (KNMI, 2015).

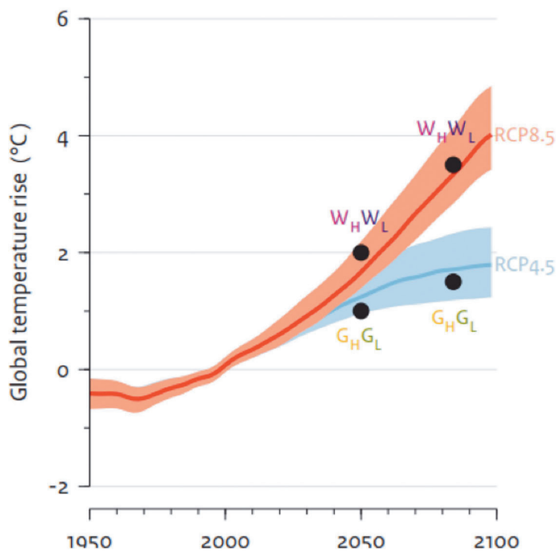

FIGURE 1.7 Global temperature rise relative to 1981-2010 based on climate model calculations performed for the IPCC 2013 report. Two different IPCC emission scenarios: RCP4.5 (stabilization) and RCP8.5 (high emissions). Coloured bands: model spread; lines: model means; dots: global temperature rise determined for the KNMI'14 climate scenarios for the Netherlands.

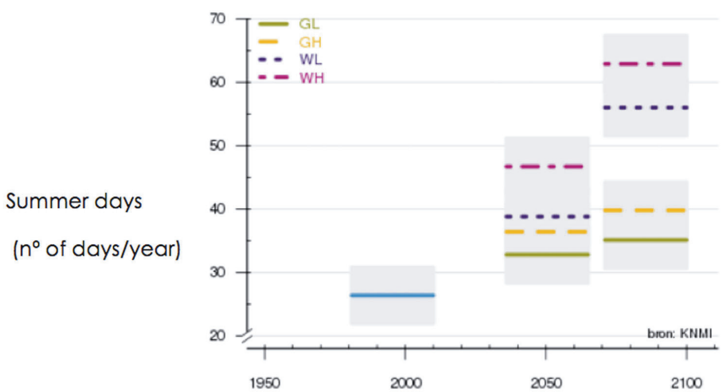

FIGURE 1.8 Average summer days per year (maximum temperature of at least 25 degrees °C) for the Bilt in the past (blue) and for the KNMI'14 scenarios, with natural variability between 30-year periods (gray).

Temperature observations and predictions in De Bilt refer to temperatures in a rural environment, which in the summer happen to be lower than in the urban (and suburban) areas.

Several studies predict an increase of the UHI in Dutch cities (Figure 1.9).

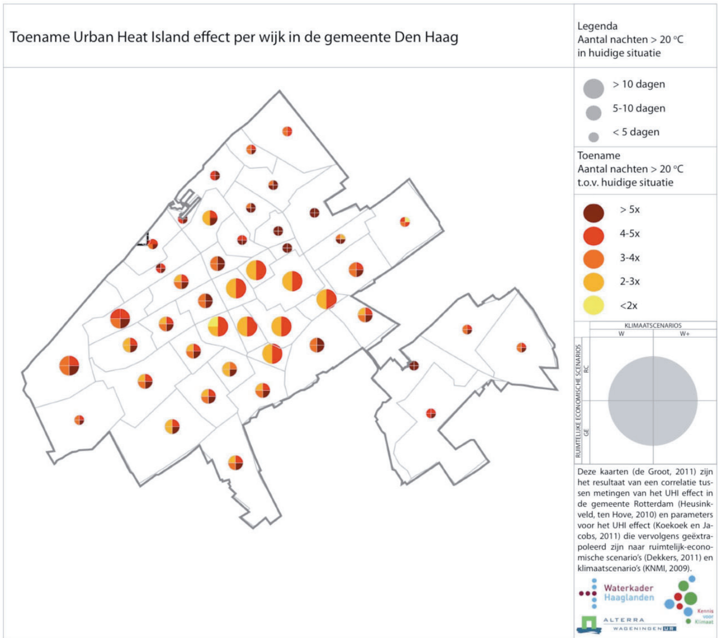

FIGURE 1.9 Increase in Urban Heat Island effect per district in the Hague. Alterra Wageningen UR (De Groot, 2011).

Thermal comfort not only depends on air temperature but also on other parameters such as atmospheric humidity, radiant temperature, wind speed, metabolic activity and clothing. Even though it does not take into consideration wind speed and radiant temperature, the approximated wet bulb globe temperature (AWBGT) is often used as a threshold value –for a specific level of activity and clothing- below which the human being experiences no heat stress.

FORMULA 1.1.

$$AWBGT=0.567Ta + 0.393e + 3.94$$

where Ta is the air temperature and e is the water vapor pressure (hPa).

Even though the Netherlands is located in a mild climate of Cfb (maritime temperate climate dominated by the polar front), a study on 24 Dutch cities (Steeneveld et al., 2011) reveals that 50% of the analysed urban areas are subject to heat stress seven days per year (Figure 1.10). The differences of absolute and relative atmospheric humidity between city and rural environment are minimal: 5% and 9-15% respectively (CPC, 2014), and thus in this case, the dry bulb temperature studies are relevant when studying the UHI.

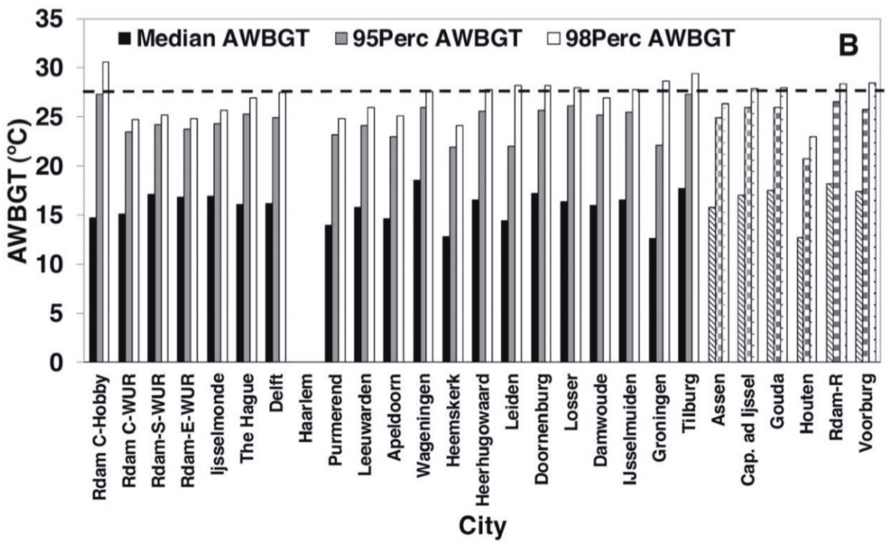

FIGURE 1.10 Observed median and percentile values of AWBGT for thes tudied cities in the Netherlands. The roof level stations are shown in modified fill (Steeneveld et al.,2011)..

In the Netherlands, the relatively recent awareness of the UHI phenomenon explains the lack of historical urban air temperature records to allow a consistent analysis of UHI patterns throughout the country (Hove et al. 2011).

Concerned by the future predictions of the KNMI scenarios, Dutch scientists, climatologists and urban planners have had to fill in the shortage of historical urban air temperature records, by using alternative methods:

- Using hobby meteorologists' data (Hove et al., 2011; Steeneveld et al., 2011; Koopmans, 2010).
- Using cargo bicycles to retrieve temperature variations through different cities during hot summer days (Heusinkveld et al., 2010; Brandsma & Wolters, 2012).
- Using satellite imagery to map land surface temperature variations during hot days (Hoeven & Wandl, 2013; Klok et al., 2010).

The revision of the literature on UHI assessment specific to the Netherlands reveals two important elements. On the one hand, existing studies are based on a wide variety of tools to fill in the lack of historical air temperature data records due to recent awareness of the phenomenon. In the authors studies (Echevarria Icaza et al., 2016a; Echevarria Icaza et al., 2016b; Echevarria Icaza et al., 2016c) the same tools were used (parameters retrieved through satellite imagery: LST day and night, NDVI, albedo, heat fluxes, etc.) to carry out the analysis at the different scales, in order to ensure the transferability and comparability of the results. On the other hand, in these studies (Echevarria Icaza et al., 2016a; Echevarria Icaza et al., 2016b; Echevarria Icaza et al., 2016c) the authors have always tried to relate the interventions proposed to the existing neighbourhood, city and regional visions (see section "societal impact"in chapter 8).

The two regions most affected by the UHI in The Netherlands are the Southern region of the country (North Brabant belongs to that region) and the Western region (South Holland belongs to that region). The Southern region concentrated in relative terms the highest amount of extra deaths during the heat wave of 2006 (reaching only during the month of July of that year more than 270 extra deaths), and the Western region (which is the densest of the country and which registered 470 extra deaths) registered in absolute terms the highest amount of extra deaths during the same period of 2006 (CBS, 2006). This is the reason why most of the case study cities and regions analysed are located in these two regions. The article "The Urban Heat Island Effect in Dutch City Centers: Identifying relevant indicators and first explorations" (Echevarria Icaza et al., 2016c) analyses six cities, five of which are located either in South Holland (The Hague, Delft, Leiden and Gouda), or in North Brabant (Den Bosch), the article "Surface thermal analysis of North Brabant cities and neighbourhoods during heat waves" (Echevarria Icaza et al., 2016b) analyses the effect in medium-size cities of the province of North Brabant, and finally the article "Using satellite imagery analysis to redesign provincial parks for a better cooling effect on cities. The case study of South Holland" (Echevarria Icaza et al., 2016a) focuses on the province of South Holland.

§ 1.5 Problem statement and objective

In a context where the spatial planner´s work requires more than ever the instruments to address the integration of multiscale and multidisciplinary parameters, it seems that the study of tools to develop urban design guidelines to positively influence the heat islands in Dutch cities and regions (where historical records of urban air temperatures are lacking) could be divided in two parts: on the one hand an overall reflection on the heat island phenomenom, the relevance of the larger scales (city to regional) for its reduction, existing technology (remote sensing) and instruments for its assessment (online platforms) and suggestion of catalising mapping strategies (game-board, rhizome, layering and drift); and on the other hand a specific assessment of the phenomenom at regional, city and neighbourhood scale for relevant locations in The Netherlands testing the instruments, tools and mapping strategies suggested in the first part.

§ 1.6 Research questions

Main research question:

Could the use of satellite imagery help analyse the urban heat in the Netherlands and contribute to suggest catalysing mitigation spatial planning guidelines implementable in the existing urban contexts of the cities, regions and provinces assessed?

The first two research subquestions are part of a generic reflection on the relevance of the large scale assessment of the UHI phenomenon.

Subquestion 1: SCALE

How would the implementation of the 1920´s regionalist premises of Geddes and Mumford affect the UHI phenomenom?

Subquestion 2: TOOLS

What satellite imagery and remote sensing processing techniques could be used for the heat island assessment at supra-urban scale?

Subquestion 3: STRATEGIES

What representation and mapping strategies could we use to ensure the proposed measures are accurate enough to actually make a difference and open enough to be compatible with the rest of elements?

Part A method is a theoretical exercise, where the authors have investigated the relevance of the large scale (city to regional) for urban heat adaptation purposes, they have selected the tools suitable for the study (satellite imagery and processing software) and they have defined the relevance of the mapping strategies for the presentation of the results. In part B results, the authors have applied the conclusions of part A method -concerning scale, tools and strategies- in order to carry out a specific assessment of urban heat in three different locations of the Netherlands, and with three different scales (Figure 1.10 and Figure 1.11).

§ 1.7 Block scheme

METHODOLOGY				
ANALYSIS				ADAPTATION
STATE OF THE ART	SCALE	PARAMETERS	TOOLS	DESIGN ADAPTATION GUIDELINES
UHI IN THE WORLD, MITIGATION STRATEGIES and EXISTING ANAL. TOOLS	Region City Neighborhoods	RURAL and URBAN ENVRNMT CHARACTERISTICS GENERATING UHI	REMOTE SENSING, GIS	WHAT TO DO TO REDUCE UHI?
		OUTPUT		
MAPPING STRATEGIES TO GENERATE URBAN PLANNING MAPS INTEGRATING MULTIDISCIPLINARY PARAMETERS (INCLUING UHI)				

FIGURE 1.11 Block Scheme

§ 1.8 Research Scheme

RESEARCH QUESTIONS	METHODS	INSTRUMENTS
Main research question		
Could the use of satellite imagery help analyse the urban heat in the Netherlands and contribute to suggest catalyzing mitigation spatial planning guidelines implementable in the existing urban contexts of the cities, regions and provinces assessed?		
PART A: METHOD. Tools and strategies to allow a mutliscale and mulidisciplinary assessment of the heat islands		
Overview of the phenomenom	Analysis and classification of UHI literature in three groups: 1/characteristics of the phenomenom in different cities, 2/Analysis of mitigation strategies 3/Analysis of online assessment tools	Books, papers, scientific journals and online assessment tools.
How would the implementation of the 1920´s regionalist premises of Geddes and Mumford affect the UHI phenomenom?	Overlap and cross check of 1920´s regionalist principles (original regionalist literature and recent studies and reinterpretations of this urban theory) with UHI litterature, at regional, urban and neighbourhood scales.	Books, papers and scientific journals.
What satellite imagery and remote sensing processing techniques could be used for the heat island assessment at supra-urban scale?	Literarture research to obtain an overview of satellite imagery for UHI assessment, and for mitigation proposal development.	Books, papers, scientific journals, urban planning research articles using satellite imagery for the UHI assessment (more specifically articles 4, 5 and 6 of the preset research).
What representation and mapping strategies could we use to ensure the proposed measures are accurate enough to actually make a difference and open enough to be compatible with the rest of elements?	Literarture research to obtain an overview of the role of mapping as a design tool (analysing first the nature of the urban planner´s work, identifying the new parameters to be integrated in contemporary urban planner´s practice, and the methods to assess the UHI at neighborhood, city and regional scale).	Books, papers, scientific journals, urban planning research articles using satellite imagery for the UHI assessment (more specifically articles 4, 5 and 6 of the preset research).
PART B: RESULTS. Neighborhood, city and regional heat island case studies in The Netherlands: remote sensing assessment and adaptation proposals		
Could the use of satellite imagery help analyse the urban heat in the Netherlands and contribute to suggest catalyzing mitigation spatial planning guidelines implementable in the existing urban contexts of the cities, regions and provinces assessed?	Interdisciplinary literature research (urban planning, climatology, geophysical, science…), part A investigation, as well as research on the urban visions for the different areas analysed in the Netherlands: Dutch city centers (The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch), North Brabant medium size cities and South Holland provincial parks (more specifically Midden-Delfland).	Landsat 5 TM and Modis 11A1 satellite imagery. Software ENVI 4.7 and GIS.

FIGURE 1.12 Research Scheme

THEORETICAL/PRACTICAL	CONTENT	PRODUCTS
THEORETICAL	OVERVIEW. Analysis of diversity of methods used for the UHI assessment. Variety of parameters -spatial contiguity, density, sprawl, storage heat flux, vegetation index, land surface temperature, albedo, sky view factor, coolspots, land use, imperviousness, social vulnerability and building vulnerability, cool wind paths,...-variety of mitigation proposals -increase of urban green, enhancement of peri-urban natural vegetation areas, consistent roof albedo modification in specific areas, maximising cooling properties of water bodies, raise social awareness, of influence the building and urban design-, and variety of online assessment tools.	CHAPTER 2 (ARTICLE 1)
THEORETICAL	SCALE. Description of regionalists principles that would help reduce the UHI.	CHAPTER 3 (ARTICLE 2)
THEORETICAL	TOOLS. Revision of parameters and mapping possibilities of satellite imagery combined with GIS for UHI assessment.	CHAPTER 4 (ARTICLE 3)
THEORETICAL	STRATEGIES. Revision of four catalyzing mapping strategies (Game-board, Rhizome, Layering and Drift) and how these could help integrate UHI considerations into the broader urban planning plans.	CHAPTER 4 (ARTICLE 3)
PRACTICAL CHAPTERS 5, 6 AND 7	CASE STUDIES.Examples of the use of satellite imagery for the analysis and mitigation proposals of the UHI in the Netherlands: in Dutch city centers (The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch), in North Brabant medium size cities and surrounding Midden-Delfland (South Holland provincial park).	CHAPTER 5 (ARTICLE 4), CHAPTER 6 (ARTICLE 5) and CHAPTER 7 (ARTICLE 6)

PART A Method

Scale

Most satellite images are through the combination of coverage and grain size more regional than local. Chapter 3 illustrates to which extend the large scale (city to region) assessment of the UHI phenomenom is critical for the proposal of adaptation measures.

Tools

The development of a multi-scale and multidisciplinary urban planning vision, that incorporates among others, UHI-related parameters, requires the use of specific and appropriate technological tools. In this PhD thesis the use of satellite data was suggested because of several reasons. First, it allows providing a consistent assessment across the earth surface, as satellites retrieve imagery of the whole surface of the globe. The degree of consistency is even higher for areas located within one same satellite image. For example, the size of one single Landsat 5TM image is 170 km x 183 km, with data homogeneity within the areas inside one same image. Second, it allows to retrieve land surface information since the 1980´s, thus to analyse the evolution in time of the changes in the earth surface, and third it allows mapping not only UHI indicators − such as daytime and night-time Land Surface Temperature (LST) or storage heat flux − but also UHI-related parameters − such as normalised difference vegetation index (NDVI), albedo ...−. Furthermore, the analysis of satellite imagery with GIS software allows calculating systematically imperviousness percentages, distances between urban areas, shape index of specific land use patches, or the creation of systematic land use classifications.

In this study the satellite images were retrieved by Landsat 5TM and by Modis sensors; more specifically Modis 11A1, which provides specific layers with daytime and night-time maps. Landsat 5TM is a moderate resolution satellite (with a resolution of 30 m for all its bands, except for band 6 which has a resolution of 120 m resampled to 30 m), and which has a temporal frequency of 16 days. Modis, in turn has a resolution of 1 km, and screens the surface of the earth on a daily basis. The main difference between the imagery retrieved by these two satellites is the resolution (Landsat is much better than Modis), and the fact that Modis provides night-time land surface temperature maps, whereas with Landsat 5TM only daytime land surface temperature imagery can be obtained.

The parameters used as UHI indicators are: storage heat flux (calculated using daytime Landsat imagery), night-time land surface temperature (which have been retrieved through Modis) or daytime land surface temperature (retrieved through Landsat 5TM). In the urban environment, storage heat flux maps were used for small surface analysis, such as in the article "The Urban Heat Island Effect in Dutch City Centers: Identifying relevant indicators and first explorations" (Echevarria Icaza et al., 2016c) where the average hotspot size analysed is 70.6 ha, in turn, Modis night-time imagery was used for the analysis of larger areas such as in the study "Surface thermal analysis of North Brabant cities and neighbourhoods during heat waves" (Echevarria Icaza et al., 2016b) where the average city size analysed is 1,565 ha. In the study "Using satellite imagery analysis to redesign provincial parks for a better cooling effect on cities. The case study of South Holland" (Echevarria Icaza et al., 2016a) Modis images were also used for the analysis of small land use patch surfaces, and as a matter of fact insignificant variations were found between the different land uses, and this is probably due to the coarse resolution compared to the patch size. Daytime land surface temperature (retrieved with Landsat 5TM) was used because the storage heat flux is not an UHI indicator for water patches and for non-urban patches due to the evapotranspiration effect.

The set of UHI parameters analysed varied depending on the purpose of the study. In all studies NDVI and albedo were mapped, and depending on the nature of the investigation other specific parameters were added.

In the article "The Urban Heat Island Effect in Dutch City Centers: Identifying relevant indicators and first explorations" (Echevarria Icaza et al., 2016c), sky view factor was also incorporated into the analysis. Imperviousness was not mapped because the quality of the available GIS files from the municipalities did not provide sufficient accuracy for the scale of the analysis. In the study "Surface thermal analysis of North Brabant cities and neighbourhoods during heat waves" (Echevarria Icaza et al., 2016b) the impact of the size of the city on the average night LST was also analysed, as well as the relevance of the distance to the closest urban area and the imperviousness (using available GIS files). Finally, in the article "Using satellite imagery analysis to redesign provincial parks for a better cooling effect on cities. The case study of South Holland" (Echevarria Icaza et al., 2016a) for each land use the patch imperviousness, the patch size and the patch shape index were also analysed.

FORMULA A.1:

$$LSI = \frac{P_t}{2\sqrt{\pi \times A}}$$

Where LSI is the landscape shape index, Pt is the perimeter of the patch and A is the area of the patch (Cao, 2010).

Strategies

The use of open source satellite imagery such as Landsat or Modis, treated with ENVI (which is specifically designed to process and analyse any kind of satellite imagery) and/or with GIS is an extremely powerful combination for urban planners, however urban planners need to find ways of mapping the information that allow to integrate this wide variety of parameters into the urban design process. The action of mapping which consists in four main processes "scaling, framing, selecting and coding" (Cosgrove, 2002) is per definition in itself already a way of understanding and interpreting the information. Each of these four processes implies a certain degree of subjectivity and thus requires the author to take some decisions and to position himself. Our study "Integrating Urban Heat Assessment in Urban Plans" (Echevarria Icaza et al., 2016d) highlights that the mapping strategies: game-board, rhizome, layering and drift (Corner, 2002) can specifically contribute to the integration of a wide variety of considerations into the urban plans.

The approach described in chapter 4 introduced four lenses through which we can approach the mapping of urban heat islands (game board, rhizome, layering and drift) at different urban planning stages and at different scales. Drift, layering game board and rhizome are four creative mapping strategies that have been studied as urban planning catalytic strategies first by James Corner (Corner, 2002) and further by Arie Graafland (Graafland, 2010). Even though there can be some overlaps and similarities between the before mentioned mapping principles (and the practical examples used to illustrate them) each of these techniques is meant to provide different visions of existing and future urban environments and landscapes. Each of them is meant to be created by different stakeholders (e.g. urban planners and decision makers), addresses different audiences (e.g. citizens and politicians) and are meant to trigger different actions and processes (e.g. revolution, interrelate different parameters, identify main processes taking place in cities). These four categories have been used here to come up with innovative ways of suggesting urban design measures to adapt existing and future urban areas to the UHI, and each of them is associated with a different phase of the urban planning process.

They not only represent a specific reality, but they also unfold hidden connections, suggest potential interventions, overlap concepts, integrate disciplines and propose organising structures, accompanying thus the creative process since its preliminary stages. The article “Integrating Urban Heat Assessment in Urban Plans” (Echevarria Icaza et al., 2016d) suggests a way in which these catalysing mapping categories could be integrated into the urban planning process. Game-board could be used for the preliminary overall assessment and it would identify the different disciplines/priorities intervening. Rhizome would consist in integrating the influences of the “actants” identified during the game-board phase, relating one to the other and suggesting open and combinable actions. Further, the layering phase would help the physical overlap of the different layers of maps identified in the two previous phases and finally the drift phase would represent the final translation of the maps into specific routes for citizens.

2 Impacts, strategies and tools to mitigate UHI

Article 1: Impacts, strategies and tools to mitigate UHI. Submitted but not published.

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Abstract

The impacts of climate changes to cities, which are home to over half of the world´s population, are already being felt. In many cases, the intensive speed with which urban centres have been growing means that little attention has been paid to the role played by climatic factors in maintaining quality of life. Among the negative consequences of rapid city growth is the expansion of the problems posed by urban heat islands, defined as areas in a city that are much warmer than in other sites, especially in comparison with rural areas.

This paper analyses the consistency of the UHI related literature in three stages: first itoutlines its characteristics and impacts in a wide variety of cities around the world, which poses pressures to public health in many different countries. Then it introduces strategies which may be employed in order to reduce its effects, and finally it analyses available tools to systematize the initial high level assessment of the phenomenon for multidisciplinary teams involved in the urban planning process. The analysis of literature on the characteristics, impacts, strategies and digital tools to assess on the UHI, reveals the wide variety of parameters, methods, tools and strategies analysed and suggested in the different studies, which does not always allow to compare or standardize the diagnosis or solutions.

Key words

Climate change – Urban Heat Islands- Cities- Urban – Models

§ 2.1 Introduction

The attractiveness of cities and the diversity of economic and social opportunities available there, are the main drivers of the continuously increasing rate of urbanised areas during the last centuries. According to United Nations reports, around 54% of the world's population has been residing in urban areas (2014 figures), in comparison to 3% in 1950. Current projections show that urbanisation may increase to 66% by 2050 (United Nations Department of Economic and Social Affairs 2014). By occupying only 3% of the Earth's land (United Nations 2016), cities account for 60%-80% of total energy consumption and 75% of carbon emissions (United Nations 2016). Urbanisation means that these figures are also likely to increase.

In addition to the significant direct impact of cities on global climate change due to the substantial CO_2 emissions they release, there are also other indirect impacts due to unsustainable consumption, pollution and waste generation. Therefore, experts point out that a growing urban population is also likely to increase the direct influence of cities on the regional and global climate (Emmanuel & Krüger 2012, United Nations Department of Economic and Social Affairs 2014). There are also some health implications here to be considered: apart from the many links between climate change and health (Leal Filho et al 2016), extreme temperatures in many cities are known to be associated with many detrimental health effects (US Centres of Disease Control and Prevention 2012) and often with higher mortality (Mills et al 2015).

There is also a need to address urban sustainability matters at a regional scale (Echevarría Icaza and Van der Hoeven 2017), in order to ensure a social, economical and environmental balance between the cities and their rural surroundings (Péti 2010). However, when it comes to the assessment of climate change impacts and adaptation options, comparatively little attention is being paid to sub-regional and regional scale processes. Or to vulnerability, which is often overlooked (Cuevas, 2011). This, in turn, leads to a reduced willingness to engage on adaptation processes, which make extreme events, when they occur quite costly (Mechler, Hochrainer, Aachein, Salen, Wreford 2010).

Furthermore, political and social awareness often concentrate either on macro-scale climate modelling, with the main focus on greenhouse gas mitigation, or adaptation to climate change, or on disaster management where little attention is given to the exposure and responses of cities to climate change and extreme weather events (Rosenzweig 2011). As a consequence, regional climatic phenomena such as the identification of flood catchment areas or the urban heat island effect are not being appropriately assessed (Hebbert & Webb 2011).

The urban environment is known to have an influence on its climate as well. One of such effects is an urban heat island (UHI) (Kleerekoper et al. 2012), whose trends in Europe have been analysed by Santamouris (2007).

UHI can be formally defined as a metropolitan area, which is significantly warmer than surrounding rural areas (National Center for Atmospheric Research (UCAR) 2011). Most references indicate that during the summer in temperate cities, generally the UHI reaches its peak during the night (Oke 1987; IPCC 2001; Moreno García MC 1993; Kershaw 2010). The contribution of anthropogenic heat varies depending on location and season: during the summer it has a negligible contribution whereas during the winter it can have a significant one (Lee DO, 1984).

The phenomenon is associated with a variety of factors, among which mentioned can be made to changes in runoff, the concrete jungle effects on heat retention, changes in surface albedo, changes in pollution and aerosols, and so on (Solomon et al. 2007, Echevarría Icaza et al. 2016a, Echevarría Icaza et al. 2016b), combined with atmospheric conditions. These effects are to a large extent caused by changes in the land surface. The replacement of trees and vegetation by surfaces with less permeable materials, minimizes the natural cooling effects of shading and evaporation of water from soil and leaves (National Center for Atmospheric Research (UCAR) 2011). Waste heat from traffic, industries and air conditioners increase temperature and thus further exacerbate the heat island effect. Moreover, densely constructed buildings, from materials with large thermal admittance, and narrow streets, reduce air flow and natural cooling effects by holding and blocking heat from rising into the cold sky (National Center for Atmospheric Research (UCAR) 2011). Cities also have a larger surface area compared to rural areas and therefore more heat can be stored (Kleerekoper et al. 2012). The land use and the design of the peri-urban landscapes surrounding the cities, together with the design of the city boundaries (e.g. high constructions blocking wind paths versus green wind corridors) also influences the intensity of the phenomenom (Echevarría et al. 2016c).

Some recent studies such as Li & Bou-Zeid (2013) and Li et al (2015), have addressed the synergetic reactions of heat waves with UHIs which coupled with increased population density, exacerbates the problem in urban settings.

Heat islands can occur year-round during the day or night (National Geographic 2016). The UHI is the most obvious atmospheric modification attributable to urbanisation. It occurs in settlements of all sizes in all climatic regions (Roth 2013). Heat urban island was first observed in London by Luke Howard in 1833 (Chow et al. 2012). Today, it is the most studied climate effect of cities (Roth 2013).

UHIs have multiplied effects on climate and urban dwellers, mainly on local level. It increases summertime peak energy demand that elevates emissions of air pollutants and greenhouse gases, which in turn contribute to an even hotter UHI (US EPA 2015b; National Geographic 2016). Increased emissions lead to lower air quality compromising human health (US EPA 2015b). UHIs also impair water quality. Warm water ends up flowing into local streams: rivers, ponds, and lakes that stresses the native species that have adapted to life in a cooler aquatic environment (US EPA 2015b; National Geographic 2016). Keramitsoglou et al (2017) outlined the roots of urban thermal risk reduction whereas Lauwaet et al (2015) offered a detailed urban heat island projections for some cities.

However, the key issue is the effect of urban heat island on urban climate and surroundings. Consistent with the need to investigate this important topic, the aim of this paper is to analyse the different parameters, scales, intensities, health impacts, mitigation proposals and diagnosis tools, used to assess the UHI phenomenon across the globe, in order to highlight the huge disparity of methods, which can complicate the transferability of the results.

§ 2.2 Materials and Methods

In order to understand how consistent the different studies are, how comparable the results, and how formalised the procedures of analysis and tools, this study analyses and classifies UHI literature in three stages:

- Characteristics of the phenomenom in different cities across the world, identifying parameters analysed and mitigation proposals suggested based on the analysis.

- Analysis of different UHI mitigation strategies proposed, and description of the principle and effects.
- Analysis of digital UHI online tools, identifying geographical cover, scale of assessment, type of assessment and limitations.

§ 2.3 Results

§ 2.3.1 Trends on urban heat islands in cities round the world

Urbanisation impacts the climate on both regional and local levels. It results in differences between a city and rural area in cloud cover, precipitation, solar irradiation, air temperature and wind speed. The geometry, spacing and orientation of buildings and outdoor spaces strongly influence the microclimate in the city (Kleerekoper et al., 2012). Perturbation of surface energy balance caused mainly by reduction of evaporative cooling, release of anthropogenic heat and increase of solar radiation input due to decreased albedo. All these contribute to UHI (Zhao et al., 2014), which in turn exacerbate the impact of heat waves, periods of abnormally hot, and often humid, weather (US EPA 2015b). However, UHIs might also have positive effects in cities in cold climates, namely, a smaller number of snowfall and frost events, longer growing season as well reduced energy demand for domestic heating (Roth 2013).

The caused and impacts of the urban heat island effect have been well studied in different cities around the globe, and some examples are herewith documented (Figure 2.1).

- Example 1: USA. According to the EPA, many U.S. cities have air temperatures up to 5.6°C warmer than the surrounding natural land cover (National Center for Atmospheric Research (UCAR), 2011). Analysis of the regional temperature trends calculated from seven long-term observation stations for the summer and winter seasons between 1950 and 2014 identified an UHI effect in Reno, Nevada that is maximized during summer (June- August) (Hatchett et al., 2016). Debbage & Shepherd 2015 estimated the urban heat island intensities of the 50 most populous cities in the United States. Their findings indicate that the spatial contiguity of urban development, regardless of its density or degree of sprawl, is a critical factor that influenced the magnitude of the urban heat island effect. An increase of 10% of urban spatial contiguity might enhance the minimum temperature annual average UHI intensity by between 0.3 and 0.4°C (Debbage & Shepherd, 2015).

- Example 2: UK. Kershaw et al. 2010 estimated the heat island effect in the UK cities. The obtained results showed that the UHIs are largest in the summer, but not for every city. For example, in small cities such as Leicester or York, the UHIs are very small and do not vary with season. The annual average UHIs for different UK cities range between 0.1 and 1.9°C, whereas in a summer period between 0.1 and 2.0°C, for example, in London it varies between 1.6°C and 1.9°C for summer (Kershaw et al., 2010).
- Example 3: Belgium. Lauwaet et al. 2016 examined the urban heat island of the country´s capital, Brussels, for 2000–2009 and projected 2060–2069 climate conditions. The obtained results indicate that the presence of the urban heat island has an impact on extreme temperatures, especially during the night. Such temperatures are also expected to occur more frequently in the future. At the same time the authors project only very small change in the magnitude of Brussels' UHI in the near future. Overall, the mean night-time UHI of Brussels accounted to 3.15°C for the 2000–2009 (Lauwaet et al., 2016).
- Example 4: The Netherlands. Echevarria et al. 2016c made a comparative analysis of heat related parameters (storage heat flux, vegetation index, land surface temperature, albedo, sky view factor and coolspots) retrieved through satellite imagery analysis of six Dutch cities: The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch. The analysis revealed that the hotspots of the six cities were located in the seventeenth century city centres. The increase of the albedo of all roof surfaces comprised within the hotspot boundaries was estimated to reduce the UHI effect by 1.5°C. For the cities of The Hague, Delft and Leiden the maximum UHI (based on hobby meteorologists data) was estimated to range from 4.8°C to 5.6°C (Hove et al., 2011). The UHI of the city of Amsterdam was analysed by Van der Hoeven and Wandl 2015 who produced a set heat related maps: landuse, imperviousness, social vulnerability, building vulnerability. The nocturnal air temperature images present air temperature differences of above 7°C.
- Example 5: Greece. Greece´s capital, the city of Athens, is characterised by strong heat island effect, mainly caused by its geographical position and its accelerated industrialisation and urbanisation during the last decades. The UHI in the city is mainly linked to limited green and open space areas, lack of water evaporation, the high heat storage capacities of building and surface materials, air pollution as a result of dense traffic and nearby industries, and intense air conditioning (Kourtidis et al. 2015). According to Santamouris et al. 2007, the ecological footprint of the additional CO_2 emissions caused by the presence of the heat island effect ranges 1.5–2 times the Athens's political area of 2,929 km², whereas the maximum potential ecological footprint, provided that all buildings are air conditioned, is approximately 110,000 hectares (Santamouris et al., 2007).
- Example 6: Germany. An example from Germany is provided by the city of Stuttgart, located in the Neckar basin, surrounded by steep hill slopes, and with an area of 207,4

km². The city is located at around 240 m above sea level, whereas the surrounding hills reach up to 500 m. This particular topography worsens the UHI effect as well as the air quality. The mean annual temperature will be increased by 2°C in the climate projections for 2071-2100 and the Great Stuttgart region will experience more than 30 days heat stress by 2100 (Adapt, 2015). In such context, preserving and enhancing existing green infrastructure surrounding the city becomes critical. The Climate Atlas of the Region of Stuttgart is one of the best-known examples of integrating climate knowledge into spatial planning. The city of Stuttgart has around 600,000 inhabitants, and its metropolitan region has around 2,600,000 inhabitants. This is primarily an industrial region and has had a long tradition of air quality concern, which is probably the triggering factor for its climatic awareness. Its 2008 Climate Atlas City of Stuttgart (Office for Environmental Protection, Section of Urban Climatology, 2008) highlights cold production areas, air catchment areas, as well as different breeze systems. The most important cold production green infrastructure area is located near to the western part of the city, and has a surface area of around 1,000 ha. One important characteristic of this climate buffer is that it is actually connected to a larger territorial landscape between the cities of Leonberg, Sindelfingen, Vaihingen and Boblingen.

- Example 7: Malaysia. Morris et al. 2015 investigated the existence and distribution of UHI in the administrative capital of Malaysia, Putrajaya. The city that is built on the garden-city concept. The obtained results have shown that UHI intensity of Putrajaya varies temporally and spatially. It increases during the night to a peak value and then diminishes in the morning with a negligible value during mid-day. During the night the UHI ranges from 1.9°C to 3.1°C. The overall effect of urbanized local climate zones heating of Putrajaya is Normalised by the total amount of area reserved for vegetation (Morris et al., 2015).
- Example 8: India. Borbora & Das 2014 assessed the urban heat Island intensity (UHII) during the summertime in Guwahati, a small but rapidly growing city of India, where humidity conditions are high. The findings show the existence of UHII above 2°C. The highest magnitude of daytime urban UHII accounts to 2.12°C while highest night-time UHII to 2.29°C. They also found that that the formation of daytime UHII of =1.5°C is fairly common. Therefore, the authors conclude that with incremental decrease in green cover associated with urbanisation, will enhance the UHI phenomenon that will result in substantially higher level of discomfort for dwellers (Borbora & Das, 2014).
- Example 9: Japan. According to Fujibe 2011, in some cities in Japan, the increase in annual extreme minimum temperature exceeds 10°C/century. The studies also revealed widespread urban warming (the extended heat island) around Tokyo and other megacities such as Osaka and Nagoya in the afternoon in summer. The obtained results are explained by the enhanced surface heating over a large urban area, and a reduction of sea breeze penetration caused by increased surface convergence. An analysis of meteorological data indicated the existence of anomalous temperature

changes. Locations with population density of 100 to 300 inhabitants per km² has the anomalous trend of 0.04°C /decade (Fujibe, 2011).
Some trends are also seen in Africa (Taylor, 2016) where efforts to handle the problem are seen. Indeed, numerous mitigation strategies are being employed as a response from city authorities across the world to the adverse effects caused by the urban heat island phenomenon. Some of them are introduced in the next section of this paper.

Country	Reference	City
USA	National Center for Atmospheric Research, 2011	
	Hatchett et al.2016	Reno, Nevada
	Debbage & Shepherd, 2015	50 most populous cities in the US
UK	Kershaw et al. 2010	
Belgium	Lauwaet et al. 2016	Brussels
The Netherlands	Echevarría et al. 2016 b	The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch
	Hove et al. 2011	The Hague, Delftand Leiden
	Van der Hoven and Wandl 2015	Amsterdam
Germany	Office for Environmental Protection, section of urban climatology, 2008	Stuttgart
Malaysia	Morris et al. 2015	Putrajaya
India	Borbora & Das 2014	Guwahati
Japan	Fujibe 2011	Tokyo, Osaka and Nagoya

FIGURE 2.1 Overview of a set of literature on UHI distributed by country.

Air Temperature Difference	Summer	Winter	Period of analysis	Parameters analysed	Mitigation measures suggested
5,6					
	X	X	1950-2014		
				Spatial contiguity, density and sprawl.	Spatial contiguity critical factor UHI. An increase of 10% in spatial contiguity might increase annual UHI by 0,3 and 0,4.
0,1 to 1,9	X	X			
3,15			2000-2009 and 2060-2069		
	X			Storage heat flux, vegetation index, land surface temperature, albedo, sky view factor and coolspots	Hotspots of 5 of the 6 cities were located in the seventeenth century City Center. Albedo interventions on those could reduce the effect by 1,5
4,8 and 5,6	X				
7	X			Land use, imperviousness, social vulnerability and building vulnerability.	
				Cold production areas, air catchment areas and breeze systems.	Preservation and enhancement of existing green infrastructure surrounding the city.
1,9 to 3,1				Vegetation surface	The overall effect of urbanised local climate zones is normalised by the total amount of area reserved for vegetation.
> 2				Green cover	The reduction of green cover associated with urbanisation, increases the UHI.
	X			Surface heating over large surfaces, sea breeze penetration, temperature change evolution per decade, density.	

§ 2.3.2 Strategies to reduce heat islands

By diminishing the accumulation of heat and applying cooling techniques, cities can reduce the temperature difference between urban and rural areas (Rotem-Mindali et al., 2015). There have been several attempts to produce catalogues describing not only the causes and impacts of UHI, but also suggesting mitigation strategies:

- In Quebec the Urban Heat Island Mitigation Strategies catalogue (Giguère M. et al., 2009) organizes the mitigation strategies around four sections:
  - Vegetation.
  - Sustainable urban infrastructure.
  - Sustainable stormwater management.
  - Reduction of anthropogenic heat.

  It then also classifies by scale (building and urban planning) the mitigation measures. The building mitigation measures are classified in three sections: protection from solar radiation, minimization of heat infiltration, reduction of anthropogenic heat and maintaining comfortable thermal environment, whereas the urban planning and development measures are grouped in three areas: greening, urban infrastructure and reduction of anthropogenic heat.

  This catalogue comprises short term mitigation measures such as ensuring the access to the so called "cooling centres" which are any airconditioned public buildings that can accommodate public (shopping centres, schools, cultural centres…), the creation of air-conditioned shelters for outdoor workers (CSST, 2004) or even the access to aquatic facilities (including pools and misters) in natural environment or public installations (Raymond et al., 2006).

- The catalogue developed within the framework of the UHI project which was implemented through the Central Europe Programme co-financed by the ERDF (Vienna University of Technology, 2014) structures the actions in four packages:
  - Buildings.
  - Pavements.
  - Vegetation.
  - Street morphology.

  Its classification does not organize the mitigation actions by the immediacy of its effect (short, medium or long term effect), and in turn in its introduction a clear distinction is made between adaptation measures and mitigation measures. Adaptation measures are considered measures where the direct intervention of users is necessary -clothing, air conditioning (Solecki et al., 2005)….- and that do not have any positive effect on the outdoor thermal comfort, or even that have a negative one -heat released by air conditioning (Hsieh et al. 2007, Wen and Lian 2009). In turn, the mitigation strategies are considered well prepared and consistently applied actions. This is the reason why the mitigation measures presented include less actions than other catalogues.

- The Yamamoto compilation study (Yamamoto, 2006) organizes the mitigation strategies in three blocks:
  - Reduction of anthropogenic heat release.
  - Improvement of artificial surface covers.
  - Improvement of urban structure.

  And introduces important characteristics for each mitigation strategy:

  - Scale (individuals, buildings, ward, city).
  - Period (short, medium or long term).
  - Degree of effect (on sweltering nights or on daytime temperature rise).
  - And administrators of the actions (individuals, business institutions, local governments...).

- There are other catalogues that attempt to keep updated the review of the UHI mitigation literature, such as the catalogue of strategies for tropical Singapore, which focuses in improving the outdoor thermal comfort in the tropical climate (Cooling Singapore, 2017).

The conclusion of the review of the above-mentioned catalogues is that even though the structure of the catalogues varies, there is a consensus in the nature of the UHI mitigation strategies. Below a summary of these.

§ 2.3.2.1 At building scale

- Choice of Roofing Materials: The choice of roofing colour can contribute to temperature reduction by approximately 12%. Roofing materials with high albedo reduce absorbed solar heat and make a house less warmer that results in lower energy consumption (Nuruzzaman, 2015). Studies in Singapore demonstrated that the city-scale deployment of cool roofs can greatly reduce the near-surface air temperature and surface skin temperature during the daytime (Li & Norford, 2016).

- Use of Green Roofs: The wide conversion of the black roofs into green roofs can have positive effects on micro- and urban scale as well provide better storm-water management- improving water retention by 7% to 10%, also leading to improvements of air quality and increases in urban biodiversity (Susca et al., 2011).
- Reduction of anthropogenic heat production: Anthropogenic heat generated by exhaust heat from outdoor AC units also contributes to the formation of UHI. Appropriate nocturnal cross ventilation, window shading, appropriate building insulation (Déoux, 2004) or the implementation of green roofs help decrease the use of energy for cooling and heating by between 20% and 25% depending on the construction materials used and whether or not green roofing is being used. The use of geothermal energy and radiant cooling systems, are alternative solutions to conventional air conditioning systems, which contribute to the reduction of anthropogenic heat.

§ 2.3.2.2 At city scale

- More Urban Green Vegetation: Vegetation provides shade, thermal insulation to keep the interior cool, manage noise and air pollution (Roth, 2013). According to Takebayashi & Moriyama, 2007, the sensible heat flux is small on the green surface (Takebayashi & Moriyama, 2007). Vegetation reduces the near-surface air temperature on average by of 1 – 4.7°C, particularly during night-time when the UHI intensity is high (Kleerekoper et al., 2012; Li & Norford, 2016). Assessments of the thermal load in terms of surface temperature in Tel Aviv demonstrated that the relatively low vegetation cover to free space ratio decreases the cooling effect of residential areas. Therefore, the authors recommend to 'green' areas within the private urban space instead of building new small-medium parks in metropolitan areas that are usually lack of free space (Rotem-Mindali et al. 2015). It is also important to note that increased urban green areas might potentially be offset by increased municipal water usage, especially, in the regions with scarce water resources, e.g. in Phoenix, Arizona, where per capita residential water use is significantly higher compared to other U.S. cities (Chow et al., 2012).
- Choice of Pavement Materials: The finishing materials of urban ground surfaces also have a major impact on the UHI effect (Gago et al., 2013). Replacing materials with new surface cover reduces the radiative heat gain in the material by about 18%-20% and improves evaporative properties of the urban surface (Roth, 2013). Cool pavements have substantially lower surface temperature and reduce sensible heat flux to the atmosphere. The current research trends in the field are focused on the development of highly reflective pavements and permeable pavements that use the cooling evaporation capacity of water (Santamouris, 2013).
- Urban structure: Changes in building development and design options might have a positive impact on reduction of building energy use and the UHI (Roth, 2013). The

distribution of the buildings and urban structures in a city affect the formation of the urban heat island, since this distribution usually determines the absorption of solar radiation and the formation of air flows (Gago et al., 2013). Designing building with considering wind properties can also lead to effective cooling of buildings in urban areas (Kleerekoper et al., 2012), reducing heat by about 25% depending on the area and properties of the building.

– Access to cooling centres: These are air conditioned public buildings: shopping centres, schools, cultural centres...As discussed at the beginning of section 2.3.2. these are controversial, as they provide shelter to vulnerable population, but in turn they contribute to the formation of the UHI due to the production of anthropogenic heat. Thus, they can be considered short term adaptation measures.
– Stormwater management infrastructure: Retention ponds (receive runoff water and infiltrate it into the ground, can be used as green recreational areas), infiltration trenches (receive runoff water and can be easily integrated in the urban environment), dry wells (receive runoff water and are covered with gravel and sand), reservoir pavement structures (collect water at the source, through pervious finishing materials).
– Reduction of anthropogenic heat: At city scale anthropogenic heat is produced either by buildings (section 2.3.2.1.) or by cars. Several measures can help reduce traffic anthropogenic: greener cars, improving public transit, reducing sprawl, increasing mixed-used development and by encouraging the use of electro-mobility.

§ 2.3.2.3 At regional scale

– More Peri-urban vegetation: The European Environment Agency urban adaptation document (EEA, 2012) suggests interventions to reinforce green infrastructure outside the city boundaries in order to manage the three main climate change phenomena threatening cities: heat waves, floods and droughts, which are projected to increase in frequency, intensity and duration (Barriopedro et al., 2011). Further, as far as governance is concerned, it also specifically highlights the importance of developing multi-level territorial spatial planning approaches to coordinate the responses to climate change challenges, from the city level through to national and EU levels. The regional level is the intermediate scale that links and connects cities with national territorial policies.
– Catering for Wind corridors: Wind corridors are designed to maximize the cool air transportation from natural cooling sources (typically green infrastructure) towards urban hotspots through advection (Echevarria et al., 2016c). Relevant examples of the study of the air circulation patterns applied to spatial planning are Climate Analysis Map for the Stuttgart region 2008 (Office for Environmental Protection, Section of Urban Climatology, 2008), the Urban climate analysis map for the city of Arnhem

(Burghardt et al., 2010) the Netherlands and the ones envisioned by the Land Use Plan 2020 of the city of Freiburg (City of Freiburg, 2013).

- Using the ecological functions of water bodies: Water might reduce temperature by evaporation, absorbing heat and transporting heat out of the area by moving, as in rivers. It has an average cooling effect of 1–3 °C to an extent of about 30–35 m. Such functions of water are already applied in Dutch cities (Kleerekoper et al., 2012). Hendel et al. 2016 assessed the thermal effects of pavement-watering in Paris during the summers of 2013 and 2014. The obtained results showed that pavement-watering has UHI-mitigation effects and is an effective measure to reduce maximum daily heat stress. The maximum reduction of 0.79 °C, 1.76°C and 1.03°C for air, mean radiant, UTCI-equivalent temperatures and UHI-mitigation of -0.22°C have been recorded during the day (Hendel et al., 2016).
- Land use considerations: The average night-time land surface temperature of different land use patches varies depending on the size, shape and nature of the land use (forests, cropland, grassland, water surfaces, built areas and greenhouse areas) (Echevarría et al., 2016a). These should be taken into consideration when designing landscapes nearby to UHI hotspots.

§ 2.3.2.4 Raising awareness among residents

Apart from technical mitigation strategies, governments implement measures aiming directly at reduction of the climate discomfort of urban residents and their vulnerability to heat stress. The US EPA provides guidelines to the local governments to assist in the developing plans to adapt to heat. Among the main components are forecasting and monitoring, education and awareness, and heat wave response. Reliable weather forecasts allow city officials to warn citizens of heat waves in a timely manner and to prepare responses. Education and awareness efforts help to disseminate information about symptoms of excessive heat exposure and heat-related illness, recommended response and treatment, and potential risk factors (US EPA, 2015a). Bearing in mind that the economic and environmental effects of unilateral climate actions are limited,(Kiuila et al., 2016), these measures should ideally be implemented by groups of cities, so as to maximise their impacts.

These measures have the advantage of addressing the roots of the problem of UHI on the one hand, and inter alia reducing the changes of their detrimental impacts to human health on the other.

§ 2.3.3 Systematising estimation and adaptation measures to UHI

Several studies (Echevarria Icaza et al., 2016d) indicate that the need for deep climatological studies on the UHI is as critical as the need for quick, multidisciplinary, high level understanding of the impact of the phenomenon to ensure it is taken into consideration since the initial stages of the spatial design. Since the options to mitigate and or adapt to the UHI phenomenon are numerous, there have been several attempts to create tools for urban planners to obtain an overview of its actual effect and potential mitigation strategies available.

§ 2.3.3.1 The "Decision Support System" (DSS)

The "Decision Support System" (DSS) was developed in the framework of the UHI Project, co-financed by the European Regional Development Fund. It covers 8 metropolitan areas and mega urban regions in the Central Europe Region (Bologna/ Modena, Venice/Padua, Wien, Stuttgart, Lodz/Warsaw, Ljubljana; Budapest and Prague). For each of these areas, the tool provides an overview of the extent of the phenomenon, and suggests mitigation actions at two different scales: the building and the urban ones, and analyses the feasibility of the implementation of measures affecting facades, roofs, surface lots, urban structure and urban green in existing structures and new constructions (Urban Heat Island project, 2014).

This webpage can be considered an interactive tool for urban planners, as these first select the location in which they are interested, the scale at which they wish to intervene, an economic assessment which is actually an online calculator and a checklist of the skills on which one chooses to be assessed (Figure 2.2). Based on these, a customised report is issued which consists of three main elements: a climate change assessment of the selected area, a set of normative applicable to the selected area and skills, a set of potential mitigation strategies. The final part of the report is common to all reports and consists of a description of the pilot actions undertaken within the UHI project and a list with the contact details of the partners involved in the project.

The climate change assessment of the area consists of a set of maps: one showing the change in the average annual mean temperature every decade (Figure 2.3), one showing the projected changes in the annual near-surface temperature for the periods of 2021-2050 (Figure 2.4), and 2071-2100 and finally one identifying the heat wave frequency for the period of 1961-1990 and 2071-2100 (Figure 2.5).

FIGURE 2.2 Screenshot of the interactive assessment configuration of the DSS tool.

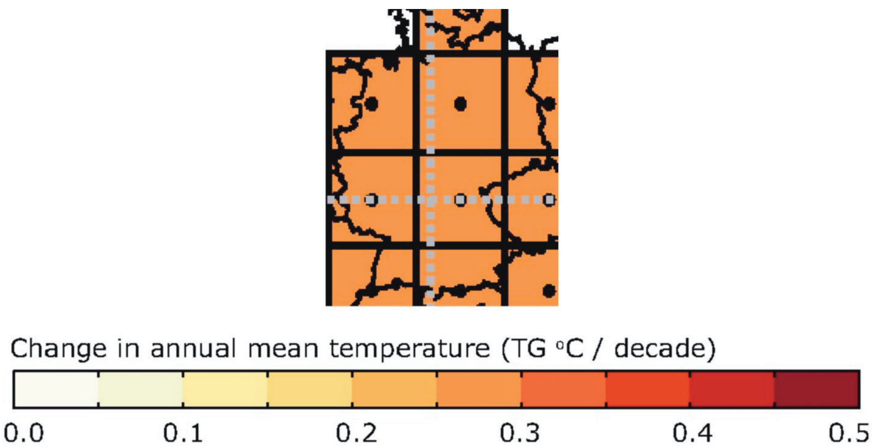

FIGURE 2.3 Screenshot of the customised map output showing the change in annual mean temperature per decade for the city of Stuttgart.

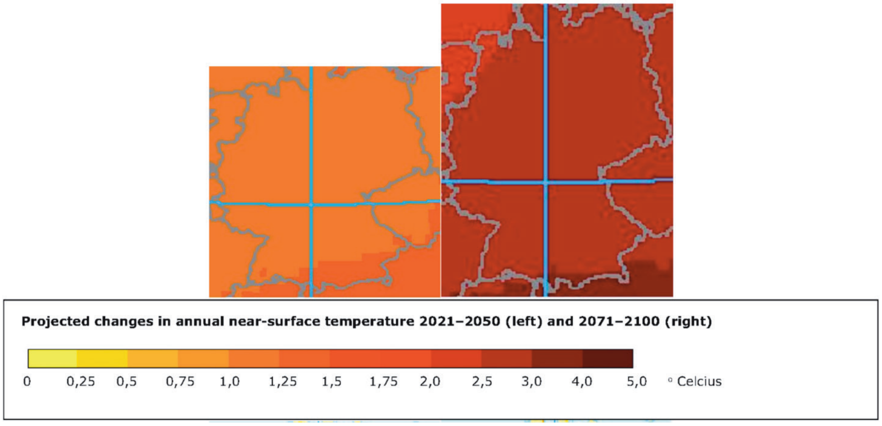

FIGURE 2.4 Screenshot of the customised map output showing the projected changes in the annual near-surface temperature for the periods 2021-2050 and 2071-2100 for the city of Stuttgart.

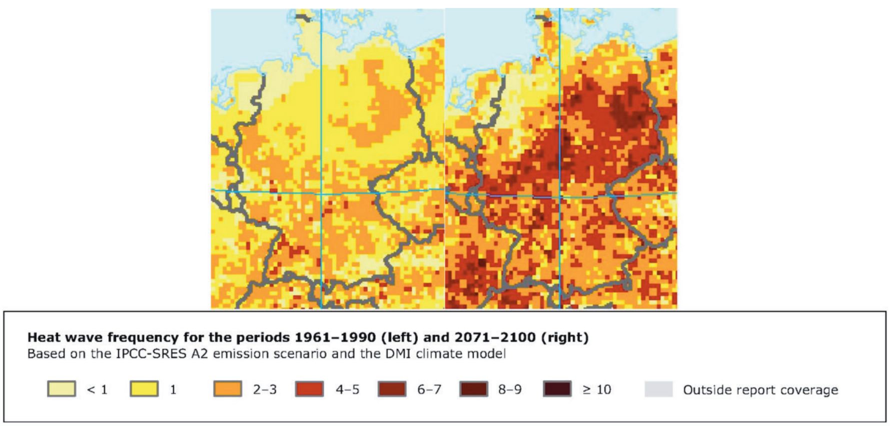

FIGURE 2.5 Screenshot of the customised map output showing the heat wave frequency for the periods 1961-1990 and 2071-2100 for the city of Stuttgart.

§ 2.3.3.2 The CE Urban Heat Island Atlas

The CE Urban Heat Island Atlas was also developed in the framework of the UHI Project, and is actually an interactive digital map which allows overlapping layers of parameters which play a role in the formation of the UHI phenomenon in the Central Europe region. The different layers available are: location of the project partners, air temperature, digital elevation model, land surface temperature (day and night), Normalised differential vegetation index, land cover (corine), and urban atlas land use (Figure 2.6).

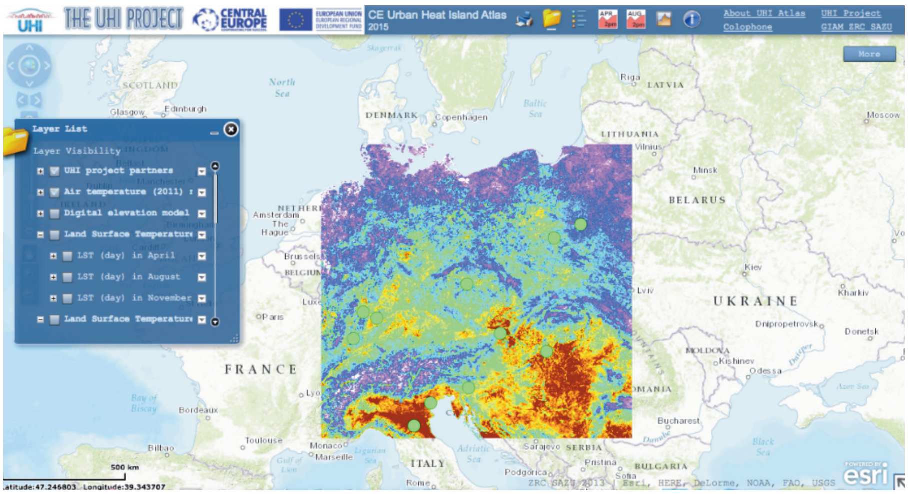

FIGURE 2.6 Screenshot of the CE Urban Heat Island Atlas.

§ 2.3.3.3 The STAR tools

The STAR tools was developed within the framework of Green and Blue Space Adaptation for Urban Areas and Eco Towns (GRaBS) project (The Interreg IVC EU program) which aims to improve the planning and development policy making in the context of climate change. It has been developed of the North West region of England and it includes a surface temperature tool and a surface runoff tool, which allows to estimate the impact on surface temperature and surface runoff for several land use scenarios under different temperature and precipitations scenarios (STAR tools, 2016).

This webpage can be considered an interactive tool for urban planners, as these can select the location in which they are interested, the land cover scenario they wish to analyse (where buildings, major roads, other impervious surfaces, green and blue surfaces and bare soil or gravel areas can be differentiated) as well as the temperature scenario for the 2050´s they wish to consider (10, 50 or 90% probability level) (Figure 2.7). Even though the tool can be used at different scales, it is best used at neighbourhood scale. The output of the surface temperature tool, is an exportable spread sheet (Figure 2.8) indicating the maximum surface temperature estimated based on the selected land cover and temperature scenario considered.

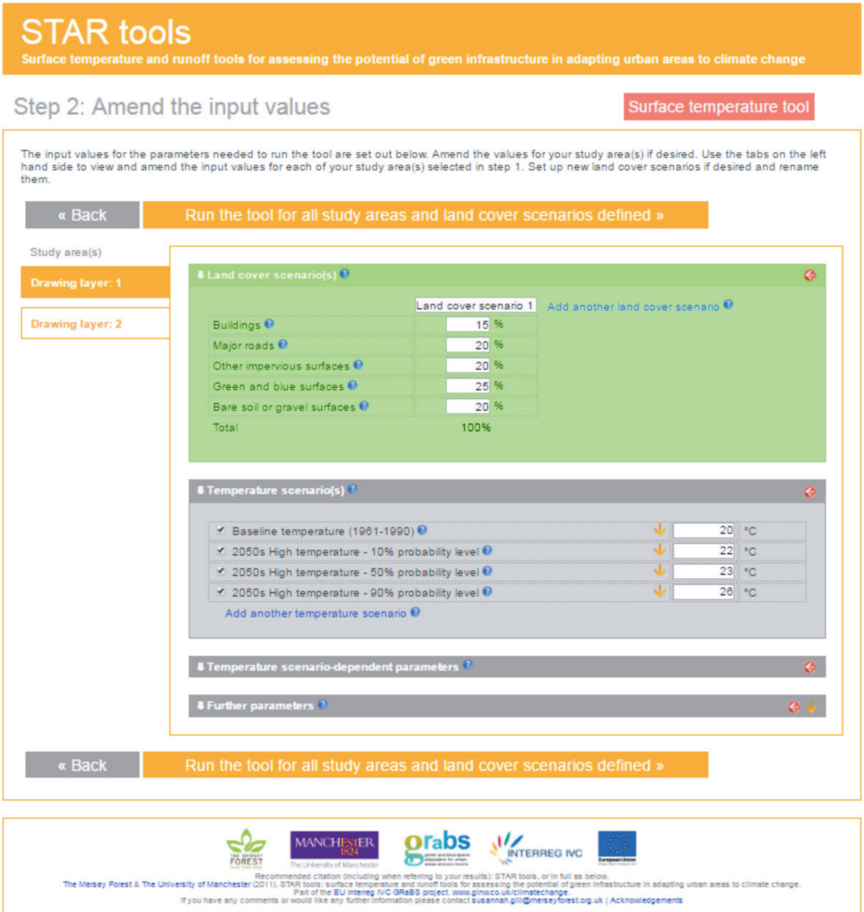

FIGURE 2.7 Screenshot of the input values that should be incorporated by the user, which refer to the land cover scenario for the selected area, the considered temperature scenario

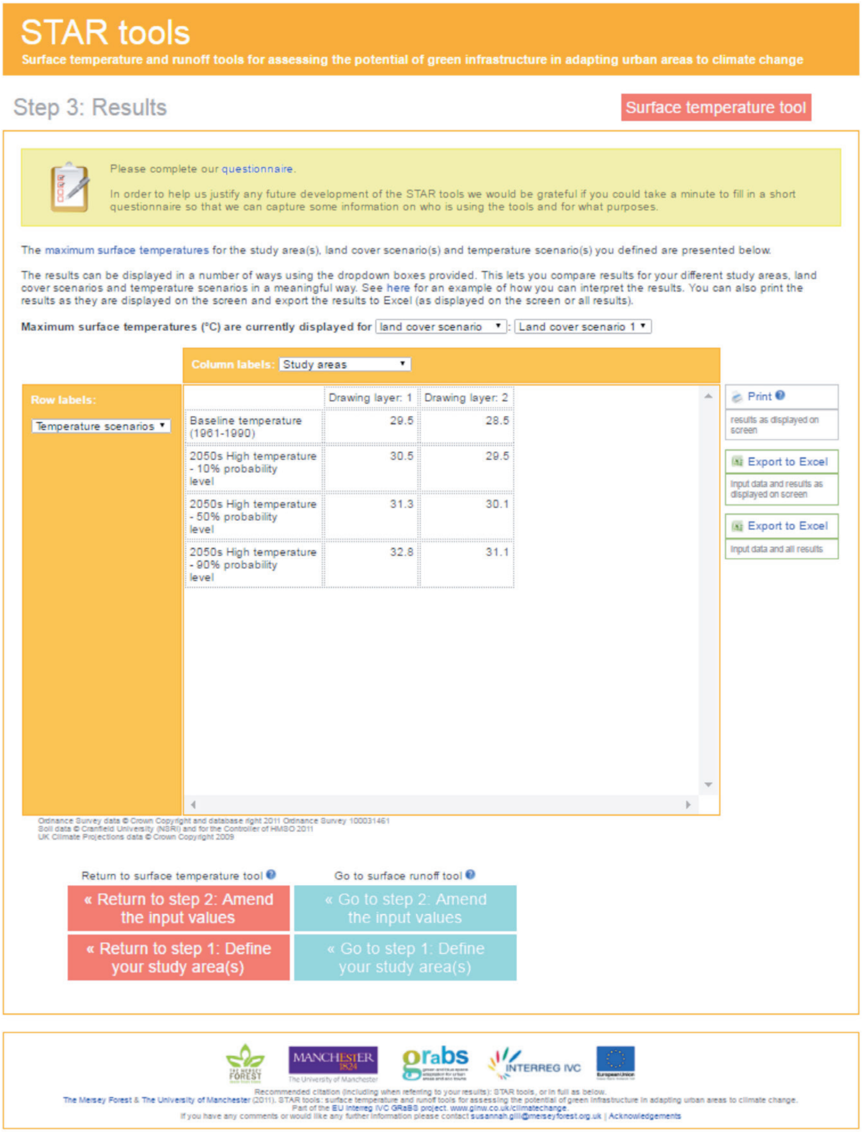

FIGURE 2.8 Screenshot of the input values that should be incorporated by the user, which refer to the land cover scenario for the selected area, the considered temperature scenario

§ 2.3.3.4 The "London unified model" (Londum)

The "London unified model" (Londum) developed within the Lucid program (Lucid, 2016) is a city wide climate atmospheric model at 1km grid, which features city wide air temperature maps at 1.5 m height. It has been developed for the city of London which estimates the impact of the volume on long and short wave radiation (reflection, shadow, conduction of heat into the building and calculation of the flux into the atmosphere) (Figure 2.9) (Hamilton et al. 2012; University College London, 2012).

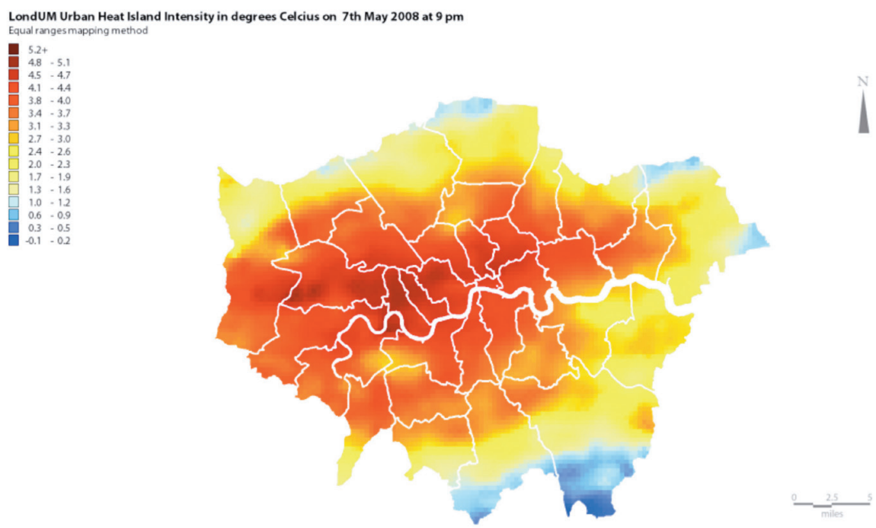

FIGURE 2.9 Screenshot of the output map of Londum model estimating the Urban Heat Island Intensity on May 2008 at 9.00 PM.

§ 2.3.3.5 The ADMS model

The ADMS model is an atmospheric dispersion model which was also developed within the Lucid program for the city of London and which features the perturbation on temperature and humidity atneighbourhood scale model basedon the building volume and surface covers (it considers albedo, evapotranspiration and the thermal admittance of surfaces) (Figure 2.10).(Hamilton et al., 2012; University College London, 2012).

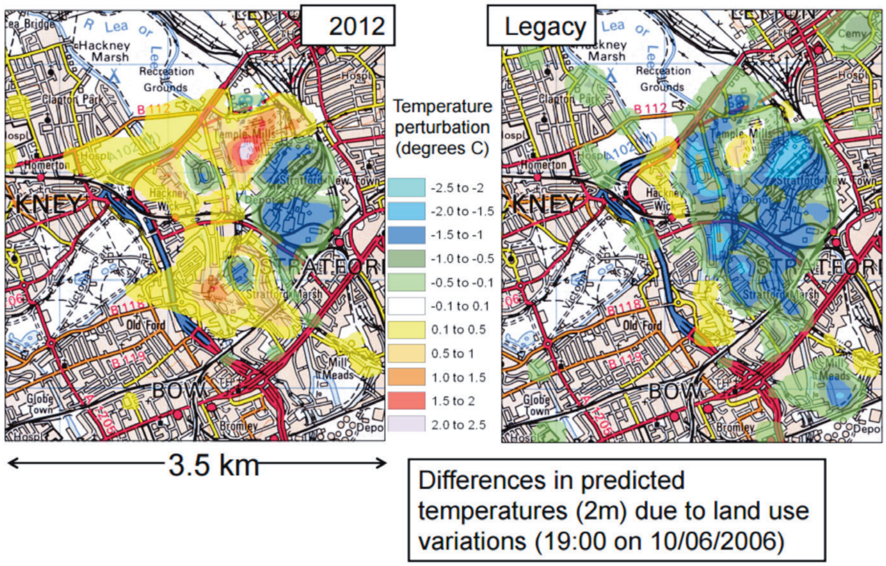

FIGURE 2.10 Screenshot of the output map of ADMS model estimating the temperature changes due to land use variations on the Olympic Parkland site development.

§ 2.3.3.6 The LSSAT

The London site-specific air temperature prediction model (LSSAT) predicts on an hourly basis the air temperature at discreet locations within the city of London (based on input data from one meteorological station for the time the prediction is required and historic measured air temperatures within the city). It allows testing building performance compared to neighbourhood, city or regional weather (Figure 2.11) (Hamilton et al., 2012).

FIGURE 2.11 LSSAT model, fixed temperature stations along the 8 transects of the Greater London Area. Measurement locations are marked in squares.

§ 2.3.3.7 EPA Mitigation Impact Screening Tool (MIST)

EPA Mitigation Impact Screening Tool (MIST) (EPA, 2016) is a software tool developed by the US Environmental Agency to provide an assessment of the impacts of several UHI mitigation strategies (mainly albedo and vegetation increase) on the reduction of the urban air temperatures, ozone and energy consumption for over 200 US cities (Sailor DJ and Dietsch N, 2007). The tool is currently unavailable, it was disabled by EPA due to the need to update the methodology and data inputs. Nevertheless, the authors have analysed how it functioned, as it attempted to provide a practical and customised assessment for the UHI reduction.

As for most interactive tools, the first step is the selection of the city. The latitude, the cooling degree day (CDD), the heating degree day (HDD), the population, the mean annual temperature and the typical peak (1 hour) ozone can be adjusted manually (Figure 2.12).

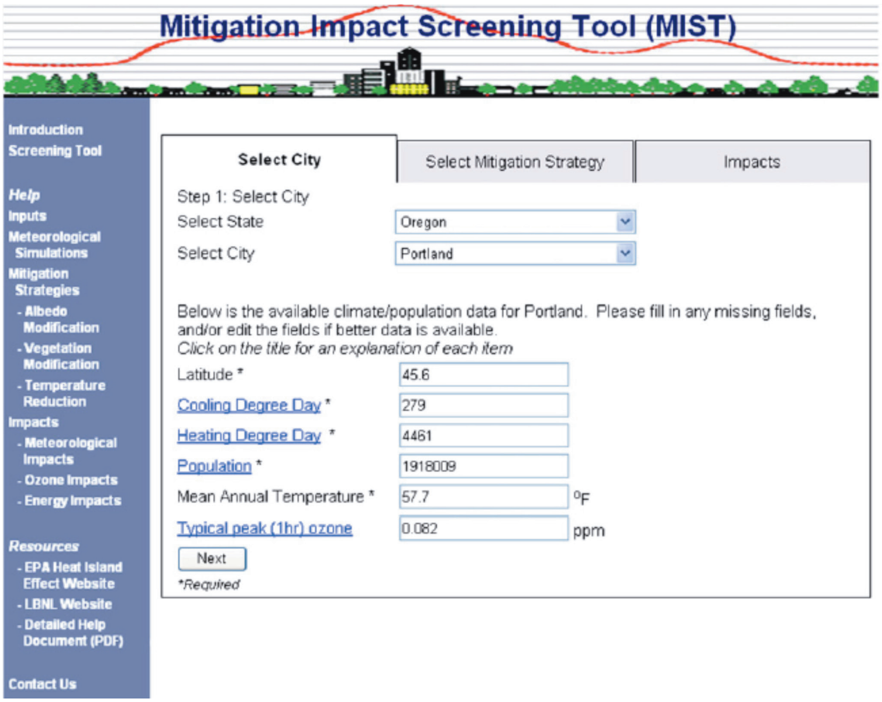

FIGURE 2.12 Screenshot of the input values that should be incorporated by the user, which refer to the selection of the city, and the corresponding city parameters (which can be adjusted manually).

The second step consists in the selection of the mitigation strategy and its quantification. The two options available consist in the modification of albedo and or the modification of the vegetation. The level of mitigation change is considered to be uniform across the selected city, it does not allow discriminating surfaces (roof tops from pavements), nor does it discriminate neighbourhood strategies within cities (Figure 2.13).

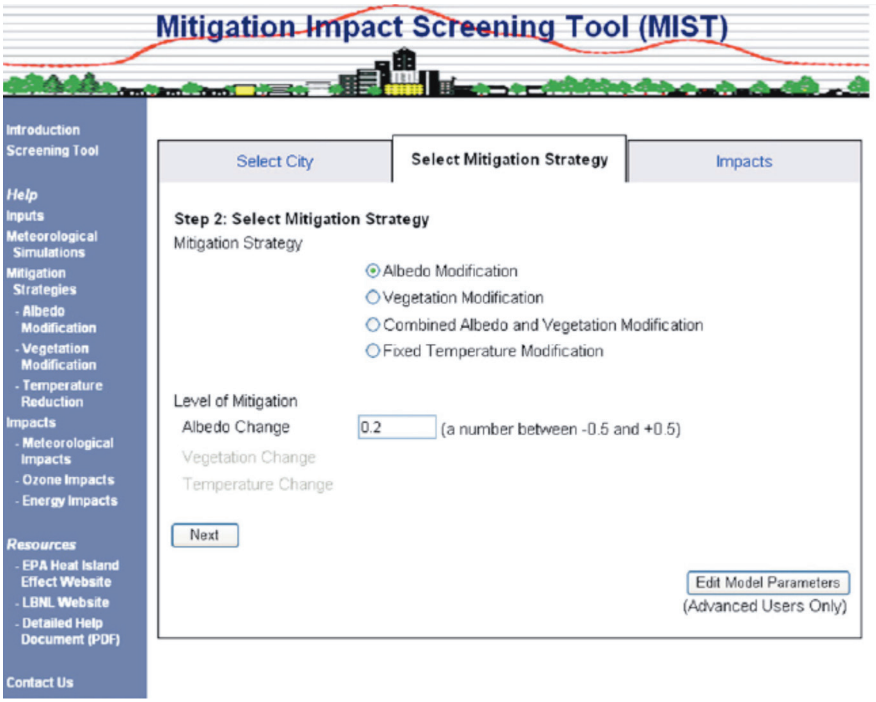

FIGURE 2.13 Screenshot of the mitigation strategy selected and its quantification. The mitigation strategy options are mainly albedo and vegetation modification or a combination of both.

The final step is the impacts estimation of the selected strategy in the selected city. The tool calculates the effect of the mitigation strategy on the reduction of the mean city temperature, the cooling degree days, the heating degree day, the typical 1hr and 8hr max ozone and on the energy consumption (Figure 2.14).

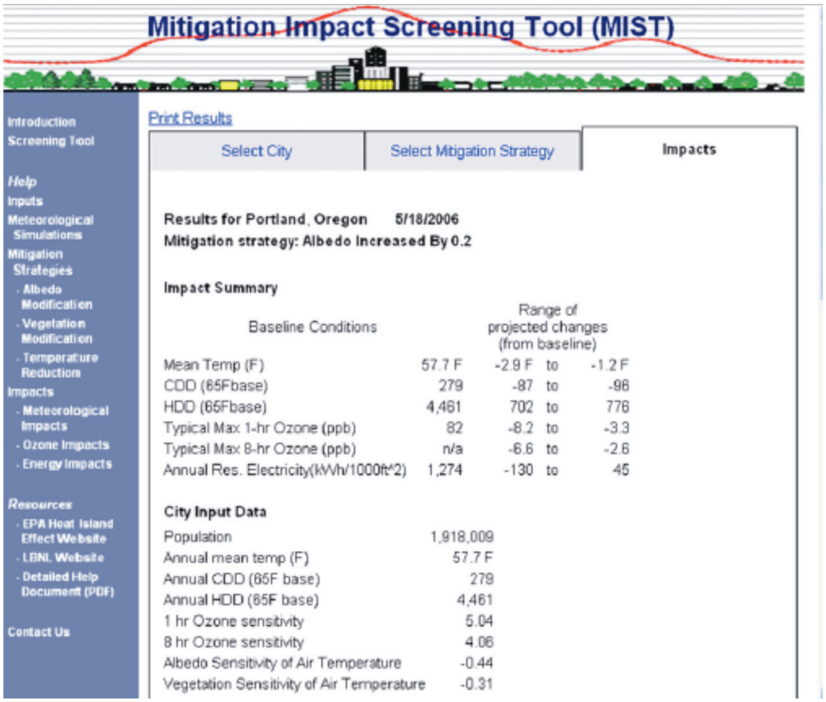

FIGURE 2.14 Screenshot of the impact estimation for the selected city and mitigation strategy.

§ 2.3.3.8 The Urban Microclimate tool

The Urban Microclimate tool is being developed at MIT, in order to control UHI to allow not only an increase of the thermal comfort but also a reduction of the energy use. It will be integrated in Rhinoceros, thus allowing ensuring urban planners workflow continuity.

UHI assessment TOOL	Geographical cover	Scale of the assessment
Decision Support System (DSS) UHI project	Bologna/Modena, Venice/Padua, Wien, Stuttgart, Lodz/Warsaw, Ljubljana, Budapest and Prague.	Supra-metropolitan
CE Urban Heat Island Atlas UHI project	Central Europe region	Regional
STAR tools GRaBS project	North West region of England	Neighbourhood
London unified model (Londum)	City of London	City
ADMS model	City of London	Neighbourhood
London site-specific air temperature prediction model (LSSAT)	City of London	Neighbourhood
EPA Mitigation Impact Screening Tool (MIST)	U.S.A.230 cities	City

FIGURE 2.15 Overview of different digital UHI tools available

	Type of assessment	User input parameters	Tool output
	Phase 1: Mapping Urban Heat. Phase 2: Understanding regulations and policies related to UHI (greenery: street or roof, material reflectance…)	1/Location, 2/Scale (building or urban) 3/Typology of the intervention (building, facade, roofs, surface lots, urban structure and urban green) 4/Economic assessment 5/Skills	1/climate change assessment (Change in annual mean temperature per decade, changes in annual near-surface temperature for 30 year periods and heat wave frequency), 2/a set of normative applicable to the selected area and skills, 3/a set of potential mitigation strategies
	Phase 1: Mapping Urban heat related parameters.	1/Location	1/Air temperature 2/ Digital elevation models 3/Land surface temperature 4/ Land cover regional scale (corine) 5/Urban land use.
	Phase 4: Testing conceptual design	1/Location 2/Land cover proposal (% of buildings, major roads, other impervious surfaces, green and blue surfaces and bare soil or gravel surfaces) 3/Temperature scenario for 2050 (Baseline temperature, 2050´s 10% probability level, 50% probability level or 90% probability level)	1/Maximum surface temperature
	Phase 1: Simluation map of the Urban Heat Island of the existing city. Phase 4: Simulation map of the Urban Heat Island of the projected city.	1/ Volume (Reflection, Shadowing, conduction of heat into the buildings, flux of heat into the atmosphere). Provided by the tool for the city of London.	1/Urban heat island intensity (air temperature at 1,5m height)
	Phase 1: Simluation map of the Urban Heat Island of the existing city. Phase 4: Simulation map of the Urban Heat Island of the projected city.	1/Location 2/Surface cover (Albedo, evapotranspiration, thermal admittance).	2/Air temperature variations -due to land cover- at 2m height.
	Phase 1: Air temperature mapping at a particular time. Phase 4: Air temperature prediction based on intervention proposed.	1/Location	1/Hourly prediction of air temperature based on site specific transects (Global solar radiation, cloud cover, wind velocity and relative humidity)
	Phase 4: Testing the mitigation effect of the selected mitiation strategy.	1/Location 2/The latitude 3/the cooling degree day (CDD) 4/the heating degree day (HDD) 5/the population 6/the mean annual temperature 7/the typical peak (one hour) ozone 8/Mitigation strategy (albedo or vegetation modification)	Calculation of the effect of the mitigation strategy 1/Reduction of the mean city temperature 2/Cooling degree days 3/the heating degree day 4/the typical 1hr and 8hr max ozone 5/The energy consumption

The type of assessment of the analysed tools has been classified in 4 phases (Figure 2.15): phase 1 corresponds to the phase where the existing situation is analysed (current UHI mapped or mapping UHI related parameters), phase 2 corresponds to the analysis of the existing regulations or policies in force affecting UHI, phase 3 is the development of the concept design and phase 4 is the UHI assessment of the proposed conceptual design. Tools that provide mainly an assessment on phase 1 are actually databases, that provide an assessment on UHI related parameters for a specific location. Tools that provide an assessment on phase 4 are simulation tools, which allow to test the efficiency of specific design proposals. Each of the tools requires different input parameters from the user (on the intervention to be tested) and provides different outputs and in different formats (urban heat island intensity, maximum surface temperature, applicable regulations.

These tools are valuable attempts to improve the understanding of the UHI for urban planners and decision makers, however the limitation of these tools is always geographical, as the accuracy of the assessment is directly connected to the quality of the input data, the resolution of the used maps and the complexity of the simulation models used.

Finally, each of the tools uses different input data and technologies (satellite imagery, meteorological stations measurements, meteorological model simulation algorithm…), and assess the user's proposal based on: surface cover, volume and land use parameters.

Surprisingly none of the tools provide an estimation on the benefits of the implementation of the UHI mitigation measures on populations health, which would help decision makers the direct benefits of such actions on populations health.

§ 2.4 Conclusions

A wide variety of cities -with different sizes, geographical characteristics, urban structures and in different climatological zones- are affected by the UHI phenomenon. The revision of related literature shows how broad the range of analysed parameters is -spatial contiguity, density, sprawl, storage heat flux, vegetation index, land surface temperature, albedo, sky view factor, coolspots, land use, imperviousness, social vulnerability and building vulnerability, cool wind paths,…- and how varied the suggested mitigation proposals are -increase of urban green, enhancement of peri-urban natural vegetation areas, consistent roof albedo modification in specific areas, maximising cooling properties of water bodies, raise social awareness, of influence the building and urban design-.

In terms of health impacts of UHI, most of the health problems and fatal incidents take place during times of thermal extreme. In particular, persons with preexisting diseases, especially cardiovascular and respiratory diseases, are more often affected. In both sides of the scale, i.e. the very old, and the very young, are the most susceptible to such health problems. The effects of UHI on health are however difficult to quantify, because specific data about it is limited, and cases are poorly reported. Therefore, more attention should be paid to documentation in the occurrence as part of public health policies and measures.

Most of the UHI studies are site specific investigations, and the extrapolation of the results to other climate zones, geographies and urban areas might be challenging. In order to be able to provide a high level, first diagnosis on the phenomenon, several investigation groups have attempted to build UHI tool kits which provide a general UHI overview of the impact and potential solutions for specific regions, which can be taken into consideration by all parties involved in the process of construction and development of the urban environment (urban planners, politicians, economists, architects, teachers, citizens, ..). However, these remain isolated cases, for specific locations and they do not quantify the effect of the measures on populations health.

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Conflicts of Interest: The authors declare no conflict of interest.

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3 Regionalist principles to reduce the urban heat island effect

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Abstract

Scientists, climatologists, and urban planners have started to recognize the importance of nature at two very different scales: the global (metabolic) and the local (liveability) scales. The regional scale is the one at which these macro and micro approaches overlap. Future predictions foresee an increase of more than 2450 million urban inhabitants by 2050, thus new balanced urban visions need to be developed in order to guarantee the sustainability of urban areas. The Urban Heat Island (UHI) effect is a climate phenomenon resulting from unbalanced urban design arrangements. This paper analyses several design principles proposed by the 1920's regionalists from the UHI perspective. The preservation of the regional geographical landmarks, the implementation of urban containment policies (limiting city sizes), the increase of greenery and the development of green multifunctional blocks would help reduce the UHI in future urban developments.

Keywords: regionalism; urban heat island; urbanisation; green infrastructure

§ 3.1 Introduction

Scientists, climatologists, and urban planners have started to recognize the importance of the role of nature at two very different scales. On the one hand there is a metabolic approach to sustainability, which highlights the fact that nature is no longer the endless city supplier of resources (food, water, fuel, etc.) and its insatiable waste and emission disposal sink (Meadows et al., 1972; Hajer and Dassen, 2014; Ibañez and Katsikis, 2014; Acebillo et al., 2012). Already at the beginning of the 1970's, the Club of Rome aimed to examine "the complex of problems troubling men of all nations" and identified the degradation of the environment and the uncontrolled urban spread as two of the eight major problems affecting our societies worldwide, and carried out a study on nature's limits in order to define the so called "state of global equilibrium" (Meadows et al., 1972). Also in the 1970's, several professionals formed multidisciplinary teams for the development of integrated and sustainable landscape designs (McHarg, 1969). Up to now, urban planners continue to highlight the indisputable role of nature in urban planning processes, emphasising the metabolic approach (Hajer and Dassen, 2014; Ibañez and Katsikis, 2014; Acebillo et al., 2012). In our globalized and interconnected world, this metabolic approach analyses the role of nature at a planetary scale aiming at promoting more rational transportation and supply/consumption patterns. On the other hand, the role of nature at the city scale is also being examined: pollution, the effects of the urban heat island, and endless transportation journeys inside cities threaten to jeopardize the liveability of many modern cities. The answer to most of these issues, which considerably deplete the comfort of cities, is most often to create greener cities. More specifically, at the local level, green infrastructure plays a provisioning (such as food and water), supporting (habitat, nutrient, water cycling, etc.), regulating (climate, air quality, soil quality, etc.), and cultural (recreational, educational, etc.) role (Sitas et al., 2014).

Agrarian societies relied on the large energy and material flows of the rural regions around the cities, creating a "concentric hinterland" around an urban nucleus (Baccini, 2014), the natural environment background remaining "unaltered". In turn, the evolution towards modern cities has altered that original regional balance. Even though the surface covered by cities does not actually occupy more than 3% of the earth (Rockstrom, 2009a; Rockstrom, 2009b), agricultural land use and settlements have already transformed more than three-quarters of the planet (Ellis and Ramankutty, 2008; Ellis et al., 2010; Ellis, 2014). As pointed out by Ellis EC, these changes are due not only to the fact that the global population has quadrupled in the 20th century but also to the fact that per capita human consumption of food, energy, and resources has grown even faster (Fisher-Kowalski et al., 2014). Currently only 1/3 of the global population has reached the state of well-being (Raudsepp-Hearne et al., 2010).

As highlighted by Hajer and Dassen (Hajer and Dassen, 2014), the increase of population—which will increase by 2.7 billion people in the next 50 years (UN, 2012)—and the increase of urbanisation—settlements and infrastructures are expected to expand by 260–420 million hectares by 2050 without policy interventions (Kemp-Benedict et al., 2002) and around half of these developments will occur on agricultural land (Angel, 2012)—will inevitably generate land related issues (Romano and Zullo, 2013). Thus, existing consumption patterns, population growth tendencies, urbanisation dynamics, and production/consumption flows are undoubtedly unsustainable in the light of a changing climate. Politicians, urban planners, scientists, economists, corporations, and citizens need to urgently find ways of reverting this disastrous inertia. The United Nation's 2030 Agenda for Sustainable Development addresses these issues with Goal 11: "Make cities and human settlements inclusive, safe, resilient and sustainable", and Goal 13: "Take urgent action to combat climate change and its impacts" (UN, 2015). In parallel, the European Union aims to make the Union's cities more sustainable, and help the Union address international environmental and climate challenges more effectively through its 7th Environment Action Programme. There are two main environmental consequences of the above mentioned global interdependency propensity: the first being the generation of anthropogenic heat emissions and the second being the generation of air pollution from carbon dioxide (automobile, industrial, and domestic combustions), particulates, and water vapour (Shahmohamadi et al., 2011), which affect the radiation budget thus increasing the air temperatures (Oke, 1987). This overall increase of global temperatures in turn intensifies the Urban Heat Island (UHI). The UHI is the temperature difference existing between the city (centre) and its immediate rural or natural surroundings Global and local climate change drivers do have an impact on the magnitude of UHI (McCarthy, 2010).

Cities are by definition areas for the concentration of human activity or in Lewis Mumford's words, "a point of concentration for the power and culture of a community" (Mumford, 1961). This definition has not varied throughout the centuries. Despite the huge technological changes that have revolved around the nature of human relations in the last few decades, cities continue to be at the heart of economic, cultural, and social activity, and because of this they keep on growing and expanding (Glaeser, 2011). Nowadays we can count several giant agglomerations such as Tokyo (more than 38 million inhabitants), Delhi (25 million), Shanghai (23 million), Mexico City (21 million), Mumbai (21 million), and Sao Paulo (21 million). By 2030 there will be more than 41 cities with more than 10 million inhabitants (Rockstrom, 2009a, Rockstrom, 2009b). The urban population is supposed to increase dramatically in India where the increase of the urban population will exceed 400 million dwellers, in China where the increase will be of 292 million inhabitants, and in Nigeria with a predicted increase of 212 million people (UN, 2014).

The UHI phenomenon is a clear particularity of the city climate. The UHI increased the impact of the European heat wave of 2003 that caused over 30,000 excess deaths across Europe, and it also increased the impact of the European heat wave of 2010 that caused 55,000 deaths in Russia alone (Barriopedro et al., 2011). Design and planning measures that can help reduce these impacts include: limiting the expansion of the city's footprint, the introduction of greenery at the regional and local scale (street and roof level)—which also helps reduce the imperviousness, the introduction of high albedo materials (at the street and roof level), and the creation of cool wind corridors. Thus the introduction of greenery in city design is key.

It seems that the scale at which these two macro and micro sustainability approaches overlap is the regional one. Redefining the concept of regions is the first step to reaching a balance at the global and local level. At the global scale, promoting the creation of self-sufficient regions should reduce the interdependency among worldwide areas, thus reducing anthropogenic heat emissions, pollution, and therefore contributing to the reduction of global warming (which would in turn reduce the exacerbation of the UHI). At the local scale, reaching a regional balance would mean achieving a balance between compactness and sprawl, thus ensuring that cities are green enough to prevent them from overheating but still dense enough to ensure efficient transportation and infrastructural systems. Mumford L already developed in the first half of the 20th century the concept of regionalism to ensure a rational, balanced, and sustainable urban development (Luccarelli, 1995). This paper analyses how the regionalist principles suggested by Mumford L. can contribute to the reduction and mitigation of the urban heat island (UHI). It is the replication of sustainable and balanced regional patterns, which will guarantee global sustainability. More specifically, the reduction of the UHI effect will not only increase the comfort in cities and reduce the excess mortality, but will also reduce the energy consumption and even contribute to the reduction of global warming. Researchers reveal that the contribution of UHI to global warming might range from 2 to 4% (Jacobson and Ten Hoeve, 2012).

Mumford highlighted the importance of the geographical factors (terrain, climate, and soil) which actually define regions (Mumford, 1927). Regionalism precisely revolves around three concepts: idea of restoring nature through the adaptation of new technologies (neotechnics), the principle of restoring the nature´s influence on culture through literature, architecture, and the built environment (organicism) and the concept of recovering the human-scaled, civic-minded social order through the community. Thus Mumford's regionalism was not only rooted in environmental/ scientific principles, but also had literary, political, and social implications (Lucarelli, 1995; Mumford, 1919). The neotechnics and organicism premises strongly connect the natural and the built environment. The recovery of the harmony between these two worlds is actually the key for the reduction of the UHI effect and this is how the idea of analysing the implications of regionalism on UHI mitigation was born. The UHI phenomenon varies in time and is affected by the physical geography and by the built environment at the metropolitan region scale (Grimmond and Oke, 1999). UHI varies depending on the physical properties of the surfaces, urban configuration, regional meteorology, and localized microclimate (Oke, 1987; Sailor, 1995). The first two parameters are related to the city itself, and the last two are specific to the region.

The aim of this investigation is to answer to the following research questions:

- Do the regionalist principles developed by Geddes and Mumford still apply to the 21st century urbanisation context?
- If so, how would the implementation of these regionalist premises affect the UHI phenomenon?

§ 3.2 Materials and Methods

This paper evaluates Mumford's regionalist principles to test the validity of design and planning guidelines that help to define regional balance and equilibrium between compactness and sprawl in order to reduce UHI formation. With this purpose, first a qualitative analysis was completed, with overlapping and cross checking at three different scales (regional, urban, and neighbourhood) of the regionalist design principles with the UHI related literature, in order to be able to conclude whether the implementation of those regionalist design principles would play a positive or a negative role in the formation of UHI. The analysis of the regionalist principles was conducted through the revision of the original regional literature (Lucarrelli, 1995; Mumford, 1927; Mumford, 1919; Geddes, 1915; MacKaye, 1928; Mumfod 1925; Mumford, 1963), as well as through the study of recent studies and reinterpretations of this urban theory (Ibañez and Katsikis, 2014; Baccini, 2014; Moore, 2014).

Furthermore, a quantitative analysis of the garden city models—which were presented by regionalists as the optimal urban planning forms to reach regional balance—was completed. The purpose of this quantitative analysis is to determine if the ratios and benchmarks put forward by the regionalists would still be implementable—with a positive effect on UHI formation—. A comparison was carried out between the city size, population density, and greenery standards of the regionalist city model (the garden city), existing urban ratios, and UHI principles. The comparative analysis of these ratios allows us to determine whether these are alignable or not, and thus whether the garden city model is still applicable or not (Figure 3.1), and to what extent.

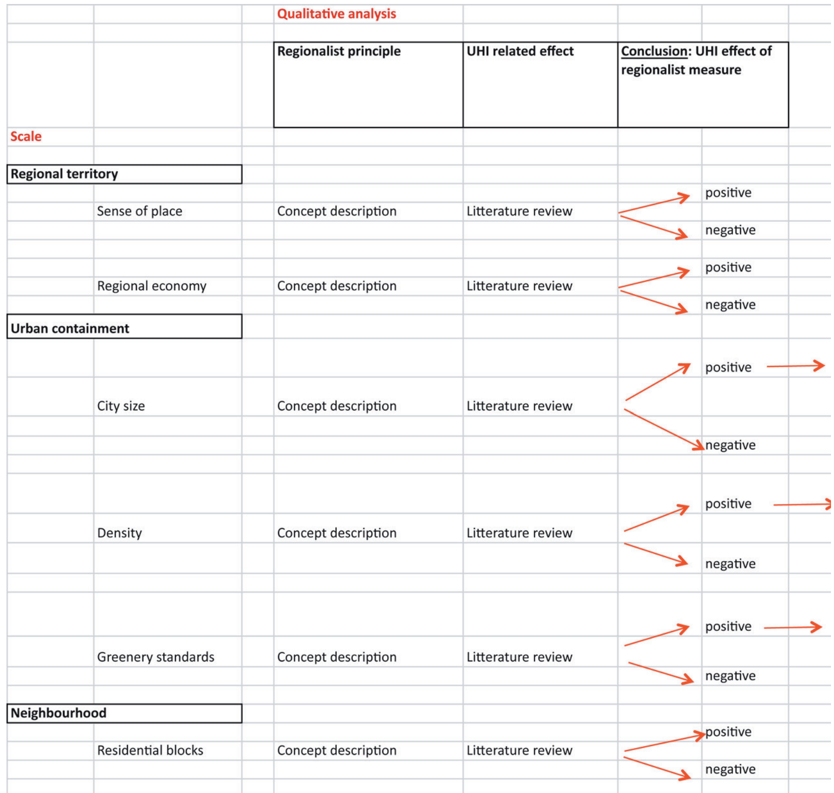

FIGURE 3.1 Methodology scheme

Quantitative analysis

Garden city regionalist analysis	Existing urban environment analysis	UHI benchmarks	Value comparison	Conclusion: garden city ratio usable or not as benchmark
			Alignable	Garden city ratio usable as benchmark.Not site specific
Ratio calculation	Ratio calculation	Ratio calculation		
			Non alignable	Garden city ratio not usable as benchmark.Site specific
			Alignable	Garden city ratio usable as benchmark.Not site specific
Ratio calculation	Ratio calculation	Ratio calculation		
			Non alignable	Garden city ratio not usable as benchmark.Site specific
			Alignable	Garden city ratio usable as benchmark.Not site specific
Ratio calculation	Ratio calculation	Ratio calculation		
			Non alignable	Garden city ratio not usable as benchmark.Site specific

§ 3.3 Results

§ 3.3.1 Regional territory

§ 3.3.1.1 Sense of Place/The Concept of Nature

As highlighted by Luccarelli, Mumford saw the basis of regionalism in the literary and artistic imagination rather than in a political idea. Mumford proposed the recovery, identification, and promotion of natural geographic features at the regional level—through scientific and imaginative exploration—in order to cultivate the so-called "sense of place" (Luccarelli, 1995). These regional geographic elements often represent natural regional cooling sources: mountains, forests, pastures, rivers, sea side, etc. The recommendation to enhance and preserve specific large-scale regional geographical elements is also often prescribed to mitigate the UHI effect. Climatologic plans typically foresee the creation of wind paths connecting these natural cooling sources to the urban hotspot areas.

It is the case of the Climate Analysis Map for the Stuttgart region in 2008 (City of Stuttgart, 2008) which looks at maximising the cooling capacity of the hilly forests surrounding the city, or the case of the climate maps of Arnhem in The Netherlands (Burghardt et al., 2010) which identify specific parks and forests outside the city as fresh air production zones to be preserved and or enhanced. In Tokyo the natural cooling source to be enhanced and preserved is the Tokyo Bay, and the renovation plans of the Tokyo Station vicinity aim at maximising the cool wind paths connecting the cool bay breeze with the urban hotspots (Japan for Sustainability, 2016). Finally, rivers often also act as the best wind paths to channel sea breeze into cities (Yamamoto, 2006). Vapour pressure and relative humidity on adjacent constructions vary depending on their orientation (Ichinose, 2003).

§ 3.3.1.2 Regional economy

Geddes and Mumford (Ibañez and Katsikis, 2014; Baccini, 2014; Luccarelli, 1995; Moore, 2014) highlighted that capitalism and globalization promoted the interdependency and specialisation of regions, ultimately increasing the destabilisation of the natural metabolism balance of regions. One of the pillars of their regionalism concept was the promotion of self-sufficient forms of metabolic structures. As expressed by Luccarelli, Mumford's regionalist concept aimed at reaching a balance between human activities (including agriculture and industry) and regional realities, thus a balance between population and resources, vegetation, and animal life. The Congress for the New Urbanism also views metropolitan regions as fundamental economic units, and highlights the importance of the relationship and interconnection between the metropolis and its agrarian and natural landscapes (Congress of the New Urbanism, 2016). In that sense The International Tripartite Conference on Urban Challenges and Poverty Reduction in African, Caribbean, and Pacific countries also expressed the potential of urban and peri-urban agriculture and forestry to improve the urban adaptation to climate change (Zeeuw, 2011; UN-HABITAT, 2009). The idea supporting regionally self-sufficient agricultural production, thus promoting local and varied crops and avoiding agricultural over specialisation, can be considered as a contemporary translation of Mumford's regionalist concept.

Several UHI mitigation studies analyse the cooling capacity of agrarian fields. Irrigated agricultural fields can present air temperature differences of up to 3°C with bare soil (Bernstein, 2004), and the overall surface temperature of crops is—in the case of the South Holland provincial parks—up to 5°C less than the average surface temperature of built areas, however they are 2°C higher than that of forests and up to 7°C higher than that of large water surfaces during heat waves (Echevarria Icaza et al., 2016a). Hence, despite the fact that green and irrigated agricultural fields might have a cooling effect on the adjacent urban areas, they are not the coolest form of regional greenery. Thus the removal of forests for the increase of monocrop overspecialised agricultural land reduces the natural cooling capacity of the regions.

Further, crop cycles imply that at certain periods of the year, cropland is either not green, or not irrigated, reducing its potential cooling capacity, depending on the crop species. Thus, the reduction of regional agricultural specialisation (suggested by Mumford in his regionalism proposal), would on the one hand allow us to maintain other native land use cover present at a regional scale (such as forests or water surfaces), and on the other hand would promote the presence of different crop typologies, with potentially different crop cycles, which would in principle reduce the surface affected during greenless periods.

§ 3.3.2 Urban containment

Geddes warned against the sprawl of British and North American cities, and referred to those as “conurbations” (Geddes, 1915) anticipating what we could call the dilemma of modern urbanism. On the one hand, human concentration is not only desirable—to ensure activity (or positive collision) and exchange—but is also even critical to ensure the efficiency and sustainability of those exchanges. At an infrastructural scale, MacKaye—one of the fathers of regionalism—was extremely concerned by the planning of highway networks and their corresponding uncontrolled commercial strip developments, which precede residential and industrial sprawl, and in turn proposed the limitation of accesses to highways in order to create “townless highways” (MacKaye, 1930).

Since Geddes, MacKay and Mumford, urban planners, climatologists, and ecologists have preached against urban sprawl. Countries like France, Switzerland, England, and the Netherlands introduced borderlines in planning documents in order to preserve ecological conservation zones and to protect agricultural land, while stimulating new urban developments in areas served by public transport corridors and hubs. On the other hand, this “aimed” compactness or high density seemed to have its limits, since the largest cities would benefit from the creation of new green infrastructure, meaning that a certain reduction of density is thus also desirable (Figure 3.2).

§ 3.3.2.1 City sizes and population densities for regionally balanced environments

The regionalists already suggested the idea of urbanisation containment. MacKaye compared suburbanisation to the backflow of a water system and highlighted the importance of limiting growth (in his own words, the population flow) and referred to the need to definite boundaries (MacKaye, 1928). Limiting growth is also a part of the UHI mitigation strategy. Several studies relate the maximum UHI to the logarithm of the population of the analysed city, not only for European cities, but also for North American (Oke, 1973; Hawkins et al., 2004; Runnalls and Oke, 1998), Japanese (Kukuoka, 1983; Park, 1987; Sakakibara, 2005; Park, 1986), and South Korean (Stein, 1925) cities. Containing city growth was a concern not only for the last century’s regionalists but also for UHI researchers.

In order to avoid city growth, the regionalists suggested the creation of autonomous garden cities in the countryside (Stewart and Oke, 2012) MacKaye and Mumford used the garden cities as examples. The model used was the one developed by Howard E but they also referred to built cases such as Letchworth and Welwyn in England and Radburn in New Jersery, United States, and identified the uncontrolled metropolitan growth of New York or Blanktown as examples to avoid (MacKaye, 1928). Mumford proposed the garden city models, such as Sunnyside—from Henry Wright—as examples for the use of new technologies of that time (hydro-generated electric power and automobiles) to revert the harm done by the industrial cities to the environment (Mumford, 1925; Mumford, 1963).

The garden city models used as examples of regionally balanced urban environments can be assimilated to the “sparsely built” and to the “open low rise” local climate zones developed for the city of Vancouver (Stewart and Oke, 2012). In this study, 17 different local climate zones are defined, each with specific arrangements of built structures, surface cover, and human activity, which makes them present different UHI behaviours. In Vancouver, during calm clear evenings in the month of March 2010, the “sparsely built” and “open low rise” typologies presented lower temperatures than the “compact high rise”, “open high rise”, and “large low rise” typologies. Thus a reduction of the percentage of impervious surfaces, an increase of the surface greenery, and a reduction of the built mass which actually characterize the garden city urban design proposals, would contribute to the reduction of the formation of UHI. The surface cover analysis of sixteen cities in the region of North Brabant in The Netherlands also reveals that the small urban centres present better thermal behaviour than the larger urban city centres (with more impervious areas and lower Normalised Difference Vegetation Index–NDVI–), the majority of the analysed cities had surfaces below 20 km^2 and populations also below 50,000 inhabitants (Echevarría Icaza et al., 2016b).

In such contexts, urban planners and climatologists can be tempted to seek an optimal city size and density. However, it seems quite difficult to integrate metabolic, economic, and climatologic parameters, with cultural, social, and historical parameters to arrive at such an optimum value. A quick overview of figures shows how important the differences between cities can be, and thus how sterile the use of global benchmarking can be.

Howard’s ideal garden city would cover 6,000 acres (that is 24.3 km^2) and would house around 32,000 inhabitants (Howard, 1902), which means that the average density for these cities would be 1316 inhab/km^2. Letchworth which was founded in 1905, and which is actually the first garden city built in the world, covers 5500 acres (22.3 km^2) and has a population of 33,249 inhabitants (Office National Statistics UK, 2011), thus presenting an average density of 1,491 inhabitants per sqm, similar to the ideal model defined by Howard. Welwyn, in which construction began 15 years later (in 1920), occupied 2,377 acres (9.6 km^2) and until 1956 housed less than 19,000 inhabitants, far below the maximum population planned which was 50,000 inhabitants. Thus the actual density of Welwyn was 1,979 inhabitants/km² for decades, below the level established as a reference of 5,200 inhabitants/km².

The analysis of "sustainable" city sizes shown as examples by regionalists, reveals there is a great divergence of sizes and characteristics. Baccini proposes "metabolic" urban designs to develop robust urban systems, and refers to the urban nucleus with populations ranging from 10 to100 million inhabitants, with population densities ranging from 300 to 600 inhabitants/km² (Baccini, 2014). In turn, another regional pattern established as a reference of regional balance of another era (Early Bronze Age) is the tells landscape in the Khabur Basin (Syrian Jazira nowadays), with each tell covering more than 1 km², and housing between 10,000 to 20,000 people, and each one managed other smaller tell distributes every 10 km (Salgueiro Barrioet al., 2014). Thus the different regionalist researchers state that cities with different city sizes and densities can be regionally balanced. "Sustainable" city size and density has to be established on a case by case basis, however the main message here is that regional balance can only be reached if the urban form is contained and planned. Urbanisation cannot take place as the result of particular needs; it has to be the result of a regionally orchestrated plan.

Qualitative analysis

Scale		Regionalist principle	UHI related effect	Conclusion: UHI effect of regionalist measure
Regional territory				
	Sense of place: Recovery of natural geographic features	Luccarelli, 1995	Office for Environmental Protection, Section of Urban Climatology, 2008	→ Positive
			Burghardt et al., 2010	
			JFS, 2016	
			Yamamoto, 2006	
			Ichinose T, 2003	
	Regional economy	Luccarelli M, 1995	Bloomington, 2016	→ Positive: in case of crop diversification (mix of species ans life cycles), maintenance of native land cover (forests and water surfaces)
		Ibañez D and Katsikis N, 2014	Echevarria et al., 2016a	
		Moore JW, 2014		
		Baccini P, 2014		
		CNU, 2016		
		Zeeuw H, 2011		
		UN-HABITAT, 2009		
Urban containment				
	Spawl avoidance	Geddes, 1915		
		MacKaye, 1928		
	Townless highways creation	MacKaye B, 1930		
	Limiting **city size**/garden city concept	Stein, 1925	Oke, 1973	→ Positive
	Letchworth and Welwyn garden cities	Howard E , 1902	Hove LWA, 2011	
		MacKaye, 1928	Oke, 1973	
		Mumford L, 1925	Hawkins et al., 2004	
		Mumford L, 1934	Runnalls and Oke, 1998	
	Baccini " reg. metabolic urban design"	Baccini P, 2014	Fukuoka, 1983	
	Tells land. in Khabur Basin	Slagueiro Barrio R et al., 2014	Park, 1987	
			Sakakibara and Matsui, 2005	
			Park, 1986	
	Density ranks corresponding to garden city = sparsely built, large low rise		Stewart ID and Oke TR, 2012	→ Positive
			Echevarria et al., 2016b	
	Greenery standards		Huang YJ et al., 1987	→ Positive
			Jauregui E , 1990	
			Taha H et al., 1991	
			McPherson EG, 1994	
			Spronken-Smith RA and Oke TR, 1998	
			Upmanis H et al., 1998	
			Wong NH and Yu C, 2005	
			Chen Y and Wong NH , 2006	
			Chang CR et al., 2007	
			Lee SH et al., 2009	
			Wong N et al., 2010	
			Bowler DE et al., 2010	
			Shashua-Bar L et al., 2011	
			Tian Y et al., 2012	
			Cheng X et al., 2014	
			Echevarria L et al., 2016c	
			Jauregui E, 1975	
			Oke TR, 1989	
			Saito I et al., 1990	
			Ahmad SA, 1992	
			Spronken-Smith RA, 1994	
			Chang CR et al., 2007	
			Li X et al. 2012	
Neighbourhood				
	Residential blocks			
	Radburn and Sunnyside	Wright H, 1935	Echevarria Icaza L et al., 2016b	→ Positive
	Cité Radieuse	Le Corbusier, 1945	Yamamoto Y, 2006	
	Contemporary renovation proposals	Echevarria Icaza L., 2004		

FIGURE 3.2 List of the references reviewed to complete the regionalist principles analysis and the Urban Heat Island related literature at the regional, urban, and neighbourhood scales.

Even though the main focus of the regionalists was not actually in the tools used to communicate, convince, or implement their planning principles, the rejection of Adam's Regional Plan of New York and Its Environs (RPNY) (GLP, 1932) did somehow open the debate regarding the manipulation of scientific arguments to defend a specific urban vision. Mumford actually denounced the use of empirical studies to narrow the depth of the urban planning discussion (Luccarelli, 1995). The post-war era was actually characterized by the technification of the urban planning discipline, which ended up pulling it out of the public debate (Hall, 1992). The debate on the use of scientific findings to defend a particular urban vision is still in force; Echevarría Icaza L et al. investigated mapping strategies to suggest UHI mitigation measures accurate (and scientifically proven) enough to actually reduce the urban heat, and open enough to ensure their compatibility with other city priorities (Echevarria Icaza et al., 2016d).

§ 3.3.2.2 Greenery Standards

Regionalists' ideal garden city (Howard, 1902) establishes a total of 5,265.5 acres (21.3 km²) of greenery for a city of 6,000 acres (24.3 km²), so that around 87.8% of the city surface would be covered by different greenery typologies. Five thousand acres would be occupied by agricultural land, and the rest of the greenery would be located within the city area, as concentric garden rings: 5.5 acres of watered garden at the confluence of the boulevards, 145 acres of the Central Park encircled by the Crystal Palace, and finally the Grand Avenue which can actually be considered as an additional park of 115 acres (Figure 3.3). Considering a population of 32,000 inhabitants, in the city there would be a ratio of 33.6 m² per inhabitant. If we compare this ratio with the greenery thresholds established nowadays for different cities (Kabisch et al., 2015) such as Berlin (Germany), where the target is to have at least 6 m² per person (Senatsverwaltung fur Stadtentwicklung und Umwelt, 2013) or Leipzig (Germany) with a target of 10 m² per inhabitant (City of Leipzig, 2003), the ratio of the garden city is more than three times the target of those cities.

Greener cities are cooler cities, and several researchers have attempted to quantify the cooling effect of greenery (Echevarria Icaza et al., 2016c; Huang et al., 1987; Jauregui, 1990; Taha et al.1991; McPherson, 1994; Spronken-Smith and Oke, 1998; Upmanis et al., 1998; Wong and Yu, 2005; Chen and Wong, 2006; Chang et al., 2007; Lee et al. 2009; Wong et al., 2010; Bowler et al., 2010; Shashua-Bar et al. , 2011; Tian et al., 2012; Cheng et al., 2014). The temperature difference between the parks and their urban surroundings seems to depend on the size of the parks (Jauregui, 1990; Upmanis et al., 1998; Jauregui, 1975; Oke, 1989; Saito et al., 1990; Ahmad, 1992; Spronken-Smith, 1994) and on the design of the park (Chang et al, 2007; Li et al.2012). In turn, the cooling distance of the parks, which can range from 15 m (Saito et al., 1990) to 2,000 m (Jauregui, 1990; Jauregui, 1975), seems to depend on the temperature difference. Thus the garden city proposal would also have prevented the formation of the UHI (Figure 3.4).

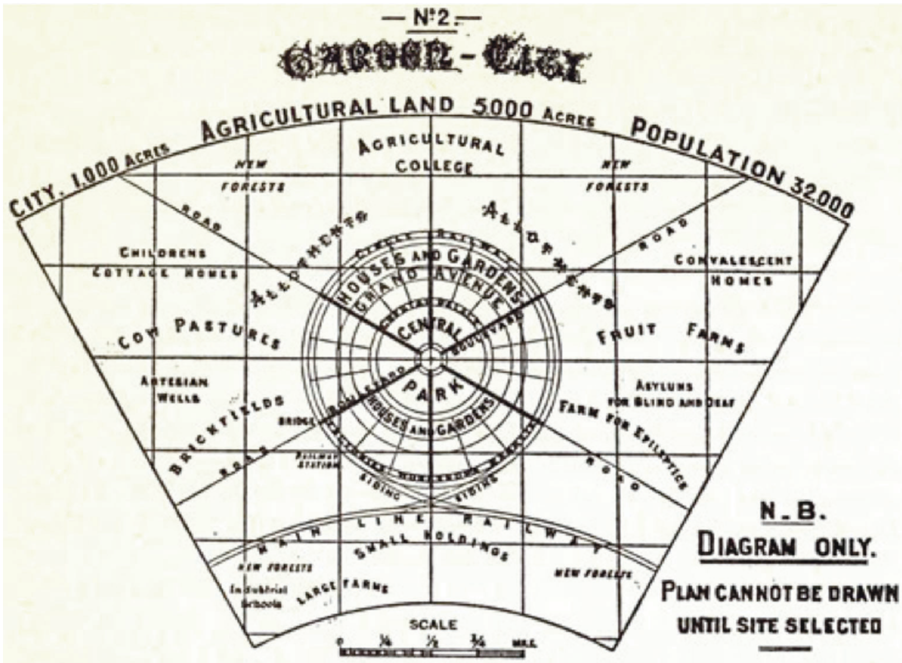

FIGURE 3.3 Howard's Garden city proposal. Diagram of the municipality ground-plan (Office National Statistics UK, 2011).

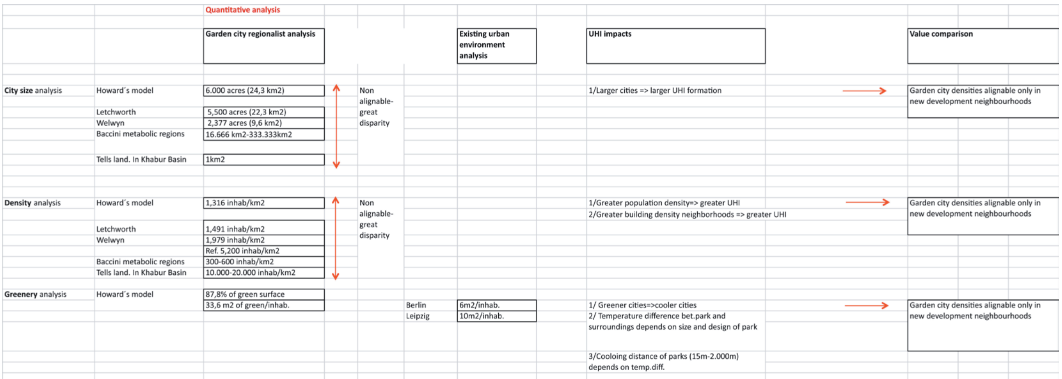

FIGURE 3.4 Analysis of garden city and other regionalist model benchmarks for city size, density, and greenery standard.

§ 3.3.2.3 The Neighborhood Scale

In order to reach a regional balance, regionalists suggested not only guidelines at the regional scale, they also envisioned the materialisation of the smaller (neighbourhood) and larger (supra-regional/infrastructural) scales.

At the neighbourhood or community scale, the City Housing Corporation (CHC)—affiliated to the Regional Planning Association of America—attempted to build garden communities in Radburn and Sunnyside. In Sunnyside, streets and grids were already developed, and in order to create the communities a mix of housing typologies was proposed, ranging from row houses to apartment blocks with important interior gardens (Wright, 1935). In Radburn the “super blocks” were developed, with large interior greenery and underpasses. They have certain common aspects with the modernist post-war residential block prototype Unité D’Habitation or Cité Radieuse (in English “Radiant City”) proposed by Le Corbusier in the 1920's, and built for the first time in Marseille (from 1945 to1952), which actually became after the 1929 crash a theoretical reflection on the materialisation of urban concentration, as well as a proposal for the achievement of a certain degree of self-sufficiency (with the incorporation of offices, supermarkets, bakeries, cafeterias, hotel restaurants, book shops, nurseres, gyms, small swimming pools, open air auditoriums, etc.). The model proposed the concentration of density in the block, to be able to vacate the surrounding space, allowing a total integration of the block within the surrounding nature. The materialisation of residential blocks interspersed with greenery was executed in the Netherlands and in many other European cities after World War II to overcome the housing shortage. Many of these residential blocks have failed to reach the "self-sufficiency" principle which was associated with the original block design, thus questioning the whole urban concentration model.

Several researchers have proposed design renovation strategies to actually prove that these block typologies actually represent a viable model as long as they are appropriately renovated. The program proposals include the introduction of mixed uses within the blocks (child day care and cafeterias on the ground floor, offices on the lower floors, and a common terrace on the upper floor), a mix of housing typologies (to accommodate students, families, the elderly, etc.) and the introduction of greenery in new private and common terraces (Echevarria Icaza, 2004) (Figure 3.5).

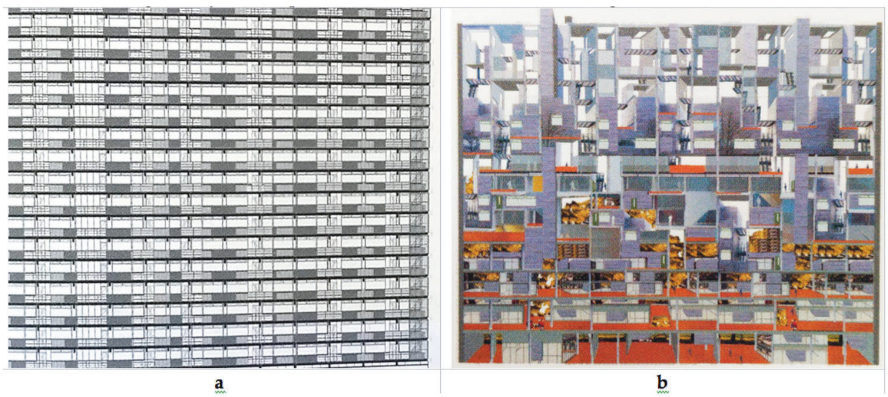

FIGURE 3.5 Renovation proposal for the creation of a "community" within the post war residential blocks in The Netherlands. (a) original block elevation. (b) proposal (Echevarria Icaza, 2004).

As far as the impact of these residential typologies on UHI is concerned, in The Netherlands, post war residential neighbourhoods seem to have a better thermal behaviour than conventional city centres (Echevarria Icaza et al., 2016b; Echevarria Icaza et al., 2016c), however, they could still benefit from the integration of greenery in the facades and rooftops, the use of highly reflective materials, and the creation of indoor cross ventilation (Yamamoto, 2006) —which are also part of the design proposal for the community creation—as these would have a beneficial impact on the reduction of heat accumulation at the building block size.

§ 3.4 Discussion

Even though revisiting the regionalist principles is inspiring for the creation of design guidelines for reducing the Urban Heat Island in new urban developments, it is important to highlight that these are precisely only applicable in certain contemporary scenarios. Thus Mumford's concept of "reversal" is often no longer valid in the current context, since in the last 100 years, automobile technology has in most cases only accentuated the ravages caused by the 19th century city that Mumford described in the 1920's, and thus in that sense the recovery of the garden city principles in an existing metropolis is no longer seems feasible. He referred to that "reversion phase" as "neotechnics". Even though in the last century technology (automobile, railways, airplanes, etc.) has not really changed—at the local scale—its efficiency (reduction of transportation times) and cost (these transportation means are now available to a much larger portion of the global population) have improved considerably involving social exchanges at the global scales. The local infrastructure that allows cars, trains, and airplanes to operate have pretty much remained unchanged, thus its direct impact at the local scale remains limited. In turn, the increase in its efficiency and costs have allowed the true globalization of the planet, enabling flights around the world in less than 24 h and more than 100,000 flights worldwide. To a certain extent we can establish that the evolution of these transportation means has been critical for the consolidation of capitalism and globalization, which are identified as the indirect but true causes of urban unsustainability by many urban researchers. To some extent, the increase of the automobile and air traffic, allows for perpetuating unsustainable production/consumption patterns, involving aberrant food, material and human transportation distances, hazardous agricultural specialisation regional patterns, and inadmissible daily CO_2 emissions.

The UHI is aggravated by anthropogenic heat emissions, resulting from energy loss, and heating from commercial, residential, and transport sectors; heating from the industrial and agricultural sectors; and heating from human metabolism. Whereas in developing cities human metabolism is still a factor to be reckoned with, the contribution of the commercial, residential, and transport sectors increases rapidly alongside the increase in city level gross domestic product (McPherson, 1994) (Figure

3.6 and Figure 3.7). The anthropogenic heat emission patterns that have emerged have reached a truly global scale.

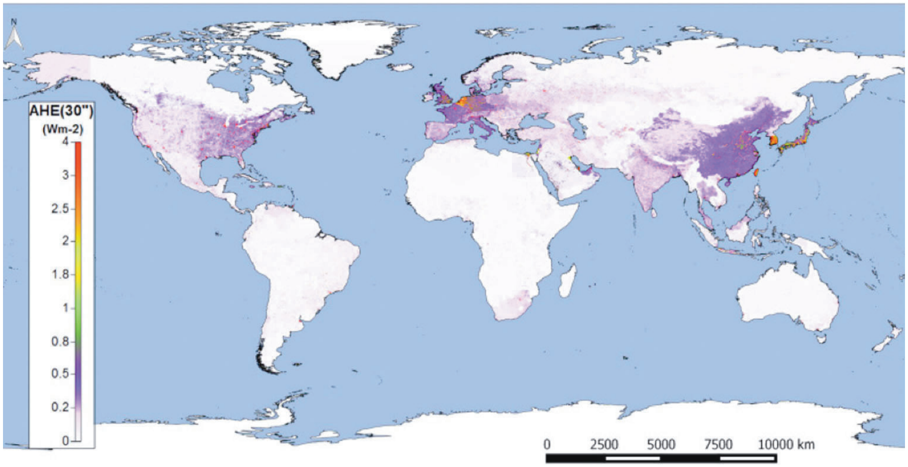

FIGURE 3.6 Anthropogenic heat emissions: Annual averages with global coverage for 2013 (Dong et al., 2017).

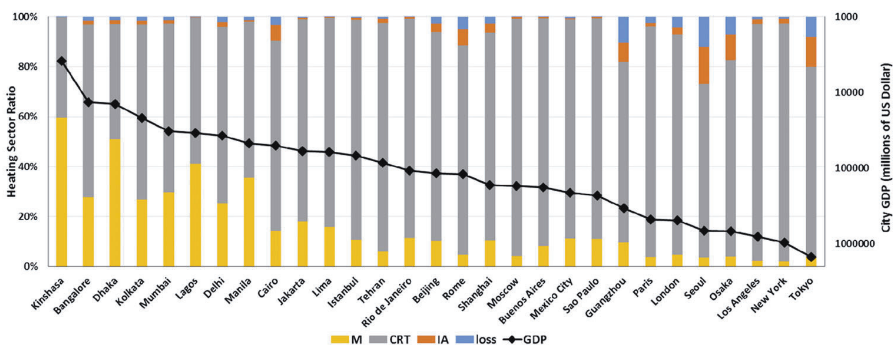

FIGURE 3.7 Anthropogenic heat emissions: The percentage contribution of energy loss (loss), heating from commercial, residential, and transport sectors (CRT); heating from the industrial and agricultural sectors (IA); and heating from human metabolism (M). Bars represent the largest urban agglomerations. The dotted black line indicates the city-level gross domestic product in 2010 (Dong et al., 2017).

As far as UHI mitigation is concerned, some measures can be introduced to palliate the UHI effect in existing cities, however others affect the structure of the city itself, which can only be implemented in urban areas built from scratch (not in existing ones). The UHI-related parameters affecting the structure of the cities are: the orientation of the streets (Japan for Sustainability, 2016) and the urban geometry (size and distance between buildings), which can actually be quantified by measuring the ratio of the height of the buildings by the width of the street (Oke, 1981) or the sky view factor (share of the sky observed from a point compared to the total sky hemisphere) (Hove et al., 2011; Park, 1987; Oke 1981).

§ 3.5 Conclusions

The aim of this article is to answer two questions considering the regional territory principles and urban containment principles: Do the regionalist principles developed by Geddes and Mumford still apply to the 21st century urbanisation context? If so, how would the implementation of these regionalist premises affect the UHI phenomenon?

The regional territory concept includes elements such as sense of place/the concept of nature and the regional economy. Enhancing and preserving large-scale regional geographical natural and/or green elements is still a very appropriate and much used approach to maintain quality of life at a regional scale. Reaching a regional balance between the population and resources, vegetation, and animal life has been a bigger challenge so far but also here the concept fits well in contemporary planning approaches.

From a UHI perspective, the measures that are part of "sense of place/the concept of nature" are often prescribed to mitigate the UHI effect. Climatologic plans typically foresee the creation of wind paths connecting these natural cooling sources to the urban hotspot areas. However, the need to have a self-sustaining regional economy may require an agricultural specialisation that may put pressure on other native land use cover present at a regional scale (such as forests or water surfaces). This will not automatically help the reduction of the impact of the UHI.

The urban containment concept includes elements such as garden cities, size of the cities, greenery standards, and the neighbourhood scale. Attempts to limit the growth of the cities' actual footprint is still relevant in present times. With the current growth of the urban population it will not be possible to achieve such an objective by using the densities proposed in the original garden city concepts. The opposition to the scientific underpinning of urban plans by the regionalists is in the current data-driven society a lost cause. The need for citizen involvement and public debate on spatial plans on the other hand is growing. The greenery standards applied in such garden cities are far from what is realistic in current cities. However, the materialisation of residential blocks interspersed with greenery did find a broad acceptance.

From a UHI perspective, garden cities would perform best, the use of scientific findings is essential, greenery standards can be useful to reduce the impact of the UHI, and the application of greening principles on a neighbourhood scale is recognised as an indispensable instrument in climate proofing cities.

Overall most key elements of the regionalist concept are still very much relevant today and would indeed help to reduce the impact of the Urban Heat Island. The garden city idea requires a revision.

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4 Integrating urban heat assessment in urban plans

Article 3: Integrating urban heat assessment in urban plans. Published in Sustainability 8 (4), 320, 2016; doi:10.3390/su8040320 (http://www.mdpi.com/2071-1050/8/4/320)

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Abstract

The world is increasingly concerned with sustainability issues. Climate change is not the least of these concerns. The complexity of these issues is such that data and information management form an important means of making the right decisions. Nowadays, however, the sheer quantity of data is overwhelming; large quantities of data demand means of representation that are comprehensible and effective. The above dilemma poses questions as to how one incorporates unknown climatologic parameters, such as urban heat, in future urban planning processes, and how one ensures the proposals are specific enough to actually adapt cities to climate change and flexible enough to ensure the proposed measures are combinable and compatible with other urban planning priorities.

Conventional urban planning processes and mapping strategies are not adapted to this new environmental, technological and social context. In order come up with more appropriate urban planning strategies, in its first section this paper analyses the role of the urban planner, reviews the wide variety of parameters that are starting to be integrated into the urban planners practice, and considers the parameters (mainly land surface temperature, albedo, vegetation and imperviousness) and tools needed

for the assessment of the UHI (satellite imagery and GIS). The second part of the study analyses the potential of four catalysing mapping categories to integrate urban heat into spatial planning processes: drift, layering, game-board, and rhizome.

Key words:

mapping; urban planning; urban design; climate adaptation, urban heat; urban heat island

§ 4.1 Introduction

There seems to be a clear mismatch between existing urban planning tools and the actual urbanisation processes (Corner, 2002). Corner refers to urbanists such as Banham, Soja, Harvey, Koolhaas or Tschumi to highlight the need to study a broader range of parameters (territorial, political, psychological, social etc.) and interactions beyond the purely formal ones, to ensure alignment between the urban planning discipline and the on-going urbanisation processes. Traditional urban planning focused on the production of rigid proposals, organizing objects and functions, and seeking to reinstate in a certain way a lost stability, instead of evolving and adapting to the instability of today´s spaces and structures (Cosgrove, 2002).

One of the parameters that growingly affect cities' comfort is urban heat accumulation. The temperature difference between the urban environment and its immediate rural surroundings is (Bohnenstengel et al., 2011) defined as the Urban Heat Island (UHI). Several studies analyse the UHI in cities such as London, Paris (Pal et al., 2012; Lac et al. 2013) or Pune (Pal & Devara, 2012). There is an increasing awareness of the impact of urban heat on health and comfort of the population (Rydin et al., 2012). In the framework of the Dutch research program Climate Proof Cities, the authors were assigned with the task to develop urban design guidelines to improve the adaptation of cities and regions to urban heat accumulation.

The research questions for this particular study were:

- How can we incorporate climatologic parameters, such as urban heat, in future urban planning processes?

- How can we ensure that the mitigation proposals are accurate enough to prevent heat accumulation and open enough to ensure they are compatible with other urban planning priorities?

In order to come up with renewed urban planning mapping strategies and tools, the first part of this study reflects on the mapping processes connected to the original nature of urban planners activity – which somehow falls in between the artistic creation and the scientific assessment – then illustrates the diversity of the parameters affecting contemporary practice – which are mainly environmental and digital – and finally identifies relevant indicators and mapping instruments to represent urban heat accumulation during heat waves. The second part of the study suggests catalysing mapping strategies -drift, layering, game-board, and rhizome (Corner, 2002) - for the integration of the urban heat into future urban planning processes.

§ 4.2 Methodology: overview of the role mapping as a design tool

§ 4.2.1 The nature of the urban planners' work

Many instruments have been developed throughout history, in order to help increase the accuracy with which the physical world that surrounds us is represented. These instruments can probably be classified into two groups: the instruments that help represent the world we perceive, and the instruments that allow visualizing the world that the bare human eye cannot grasp. Regarding the representation of the world we perceive, Nuti (Nuti, 2002) reminds that Vermeer and Saenredam consulted geodesists or surveyors to construct their paintings, while a couple of centuries later other artists used transparent glasses. In the 19th century the use of Panorama also became pretty extended. Artists were mostly concerned with the accuracy of the representation of the perceived world. In turn, it seemed that scientists were rather more concerned with the representation of the world that the human eye cannot see. Cosgrove associates this concern to modern scientific curiosity, and mentions the telescope and microscope as the most extreme examples (Cosgrove, 2002). Both artists and scientists used instruments to increase the accuracy of their representations, however the representations by artists contained comparatively a higher degree of subjectivity than those by scientists. The observation of cities by urban planners seems to fall somewhere between these two worlds. On the one hand cities and landscapes are physically perceived by the human eye, and on the other, cities are more than ever influenced by “invisible” parameters that need to be taken into consideration. The urban planner is therefore supposed to reconcile both the tangible world that shapes the cities, and the intangible parameters that influence it. Urban planners can be seen as both artists and scientists, or as Weller states (Weller, 2006) planners need to address both planning (which typically refers to mechanical systems and land-use designation) and design. Many urban planners urge for the development of new urban planning tools to update our discipline to the current times. Girot (Girot, 2006) precisely refers to the need to achieve a balance between scientific and empirical data through the development of new instruments when intervening in our cities.

The potential of mapping is somehow undervalued because many urban planners and designers still believe in the undisputed neutrality of maps, which makes them perceive mapping as a systematic action, consisting merely of the automatic translation of data into drawings, thus missing the opportunity to explore its unique potential. Accepting this inherent “opacity” and subjectivity should not detract the value of maps; on the contrary, it just unfolds the endless possibilities of the tool. As Cosgrove states “mapping a priori features are scale, framing, selection and coding” (Cosgrove, 2002). Regardless of the degree of intentionality with which these actions are undertaken, the four of them are inherent to the mapping activity. They all imply decisions that alter our way of representing and interpreting a given reality, unfolding connections between dissociated elements and revealing the emergence of hidden structures (Corner, 2002).

§ 4.2.2 New parameters to be integrated in contemporary practice

Traditionally, urbanism studied shapes and land uses, which change little over time. In the 1970´s exogenous parameters started to be integrated into design, and already by then Science magazine praised the landscape architecture department of the University of Pennsylvania, founded by McHarg (McHarg, 1981) because of its multidisciplinary team, which integrated physicists, biologists, sociologists, architects, landscape designers, urban planners and territory planners. McHarg´s Design with Nature (McHarg, 1969) was actually the seed of the integration of new parameters in the design of landscapes. (We shall note that back then the polarity between the urban and the rural delimitated very clearly the field of action of urban planners and the one of landscape architects), overlapping wildlife habitats, with geological landmarks, water-table constraints or scenic value into the design guidelines. In the 1990s Corner took over McHarg´s legacy with a less guided approach towards the integration of disciplines, generating a set of inspiring and revealing maps during his aerial trip with MacLean, which actually culminated in the production of the book "Taking measures Across the American Landscape" (Corner, 1996). In parallel, Deleuze & Guattari (Deleuze and Guattari, 1987) reflected on the dynamism of the processes influencing the lives in cities.

In the present days new instruments need to be explored in order to be able to assess the two main changing realities that characterize the post-industrial world, which according to Shane are the technological and the ecological ones (Shane, 2006). Grimm N.B. et al. stress the need to incorporate geological, ecological, climatic, social and political data, to describe and understand urban functioning (Grimm et al., 2000). Girot refers to the invisible "natural substrate of the sites" and more specifically mentions the natural water flows (covered or diverted), the erased topographies or the fragmentation of forests (Girot, 2006). Cities have started to be considered as dynamic, living organisms. Ridd & Hipple refer to cities as ecosystems, and as such they identify the energy and moisture fluxes as the main drivers of their activity (Ridd and Hipple, 2006). They use remote sensing to investigate parameters such as anthropogenic energy or the percentage of imperviousness of surfaces, parameters that affect these two balances. Aligned with this dynamic concept of cities, Acebillo refers to the urban metabolism and studies parameters such as energy consumption, waste emissions or mobility matrixes (Acebillo et al., 2012). Chao et al. (Chao et al, 2010) have produced a review of the evolution of the urban climatic maps which propose urban planning guidelines based on parameters that range from thermal imagery to topographic maps, land use maps, urban air paths, emission maps… By means of energy potential mapping, or heat mapping, Broersma tracks city's heat characteristics; these can be represented by layered maps or three-dimensional images (Broersma et al., 2013). Their heat map of Rotterdam maps the heat demand and yield potential. Van der Hoeven F. and Wandl A. mapped air and land surface temperatures, the components of the surface energy balance, as well as social and physical factors that contribute to the vulnerability of the urban population for urban heat (Van der Hoeven and Wandl, 2015). Other urban planners have started to study a wide range of statistics concentrating in the behaviour of citizens, crime rates, surveillance, traffic, light-switch activity (Amoroso, 2010) (Figure 4.1), or even cell phone activity (MIT, 2016) (Figure 4.2).

The incorporation of new disciplines in urban planning processes, imply not only the need to study, analyse and interpret new parameters but also the need to understand the way these evolve in space and time. The most didactic metaphor to describe this phenomenon is Weller´s "fluid field" of data, ideas and form when referring to cities and landscapes (Weller, 2006).

§ 4.2.3 Urban heat assessment

– Urban heat indicators

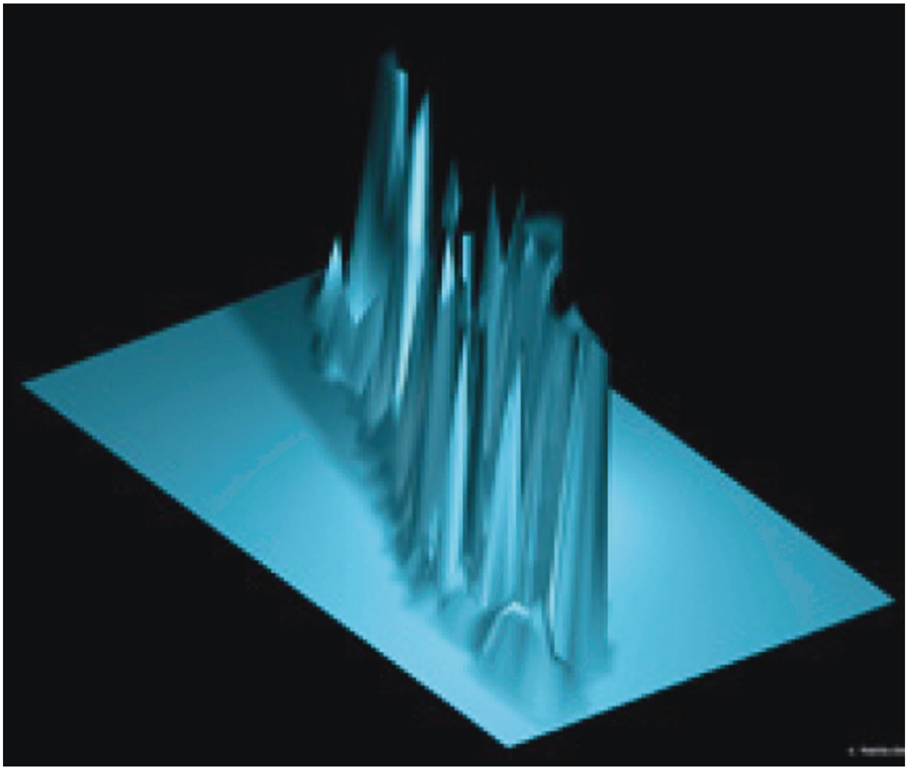

FIGURE 4.1 Densityscape, New York City, a three dimensional map depicting the super-dense residential population landscape of Manhattan Island. The exposed city: Mapping the urban invisibles. London: Routledge (Amoroso, 2010)

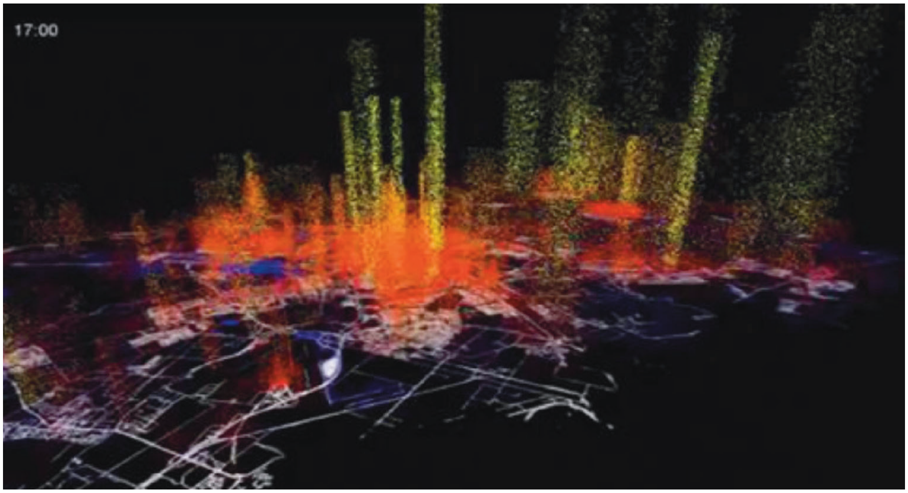

FIGURE 4.2 SMS activity at midnight, New Year´s Eve in Amsterdam (MIT, 2016).

There are two main categories of urban heat islands: the air temperature urban heat island (UHI) which concentrates in the air temperature difference and the surface urban heat islands (SUHI) which measures the surface temperature difference. They have different behaviours and patterns. The SUHI hits its peak during daytime, when the sun is still shining, reaches up to 15°C difference (EPA, 2015), whereas UHI reaches its peak after sunset, when warm urban surfaces start radiating the heat absorbed during the day towards the atmosphere, registering air temperature differences of up to 12°C. There are several studies that correlate the urban heat to the size of the cities. A linear correlation was established in 1973 by Oke between maximum urban heat island intensity and the logarithm of the population of cities in Europe and North America (Oke, 1973). In Japan and South Korea similar studies have been carried out (Park, 1986; Fukuoka, 1983). It was only after the heat wave of 2003, which caused over 80.000 deaths across Europe (Robine et al., 2007), that urban heat started to be perceived as a concern (Van Hove et al., 2011).

Air temperature seems a more relevant indicator of human comfort than surface urban heat island. However, retrieving consistent air temperature data in the urban environment is a challenge. In the particular case of the Netherlands, the KNMI meteorological stations are all located in the rural environment, precisely to erase the influence of urban heat in the temperature retrieval. With the emergence of the Internet of Things and the involvement of citizens in the gathering of scientific data new possibilities emerge. Netatmo, producer of personal weather stations gathers live data of all of its connected weather stations, to visualize it online on a scalable weather map, while allowing the data to be harvested by means of a public application (Netatmo Weathermap, 2016).

Consistent surface temperature data can also be mapped using satellite imagery. Even though the spatial pattern of UHI and SUHI differs (Dousset and Gourmelon, 2003), many climatologists use land surface temperature to assess the urban heat accumulation behaviour (Price, 1979; Roth et al., 1989; Parlow, 2003; Van Hove et al., 2011; Yuan & Bauer, 2007; Cao et al.2010; Li et al., 2011; Zhou et al., 2011; Choi et al., 2012). Moreover, remote sensing also allows mapping parameters that influence the urban thermal behaviour, such as albedo, vegetation index, imperviousness, storage heat flux, latent heat flux and sensible heat flux.

The vegetation index can be considered as a relevant indicator for urban heat studies. Several studies show that minimum air temperatures and vegetation indexes (more specifically the normalised difference vegetation index – NDVI-) are correlated: there is a linear relationship between the difference of urban and rural NDVI and the difference of the urban and rural minimum air temperatures (Gallo et al., 1993). In rural environments, heat fluxes can be expressed as a function of the vegetation index (Choudhury et al., 1994; Carlson et al., 1995).

Albedo is an index that represents surface reflectance. It is strongly related to urban heat. Increasing the albedo of roofs and pavement reduces their surface temperatures. When a surface has an albedo of 0, it means that it doesn´t reflect any radiation whereas an albedo of 1 means that all the incoming radiation is reflected by the surface to the atmosphere. In European cities the average albedo is around 0.20 (Taha, 1997). Increasing the surface albedo from 0.25 to 0.40 could lower the air temperature as much as 4°C (Taha et al., 1988).

Imperviousness makes a strong contribution to urban heat. Imperviousness seals the surface, it prevents water from evaporating, and hinders the growth of vegetation, in this way it prevents solar radiation from being converted into latent energy. Impervious surfaces have in addition, the capacity to store heat during the daytime. The heat that is stored in this process is then released at night.

The influence of other factors such as sky view factor (SVF) does not seem to be clear. Some studies find a clear correlation between SVF and nocturnal UHI (Svensson, 2004; Unger, 2004), while in other cases the correlation is not so clear (Blankenstein & Kuttler, 2004). In any case the 3-dimensional analysis of the areas is often critical to ensure that the effect of the building radiation is also taken into consideration.

– Instrument and technology used to produce urban heat maps: remote sensing

For urban planners the principal limitation of remote sensing lies in the fact that even though aerial view provides a very comprehensive overview of cityscapes and landscapes, these must be complemented by the analysis of other tangible (street level views, pedestrian flows…) and intangible parameters (economic activity, social cohesion, …). Weller (Weller, 2006) also warns about the risks of granting excessive attention to aerial photography. However, the most important challenge for urban planners is to be able to turn these accurate and precise images into maps. Satellite imagery per se cannot be taken as true record of reality. First, the selection of scale and frame are critical and then the way in which the information is filtered and represented also plays an important role. Mastering the use of software to treat satellite imagery becomes critical for urban planners to be able to integrate these into design.

ENVI is a geospatial software designed by Exelisvis (Exelis Visual Information Solutions, 2016) to process and analyze any kind of satellite imagery. The combination of ENVI and GIS allows for the greatest integration between the available raster and vector information. There is a third type of software consistently needed to work with satellite information. These are the programs that atmospherically and geometrically correct the raw satellite imagery. The geometrical correction is needed in order to be able to transpose the information retrieved from the curved surface of the earth into a two-dimensional image. The atmospheric correction is needed because the satellites retrieve the radiation emitted by the surface of the earth through the atmosphere. The radiance retrieved is somehow distorted due to the composition of the atmosphere (humidity, chemical content). Atmospheric correction software "erase" the effect of the atmosphere from the retrieved radiance through the use of certain atmosphere composition models which vary, depending on the latitude and longitude, on the season and on whether the image captures a rural or an urban environment.

The satellite images themselves, can be downloaded through the US Geological Survey Global EarthExplorer (USGS, 2016), such as Landsat or Modis. Landsat 8 has a resolution of 100 m and Modis of 1 km. Land surface temperature, heat fluxes and albedo can be mapped using Landsat imagery (100 m resolution) and processing it in ATCOR (Atmospheric & Topographic Correction: the ATCOR Models, 2016), which allows not only completing the geometric and atmospheric correction of the images but also calculates the before mentioned parameters. Satellite imagery product Modis 11A1 (1 km resolution) contains a layer where land surface temperature (day and night averages) and albedo are already processed and calculated. In this study we have only focused in the use of open source satellite imagery which have enough resolution to assess the SUHI at a city and regional scale. There is high-resolution satellite imagery which provide a more accurate analysis, however these are not open-source.

Normalised difference vegetation index is typically used to calculate vegetation index. It can be mapped after calculating NDVI.

FORMULA 4.1.

NDVI = (NIR-VIS)/(NIR+VIS).

Where NDVI is the Normalised Difference Vegetation Index, VIS is the surface reflectance in the red region (650 nm) and NIR is the surface reflectance in the near infrared region (850 nm).

With Landsat, both NIR and VIS are bands of the satellite imagery. With Modis, NDVI is included as one of the satellite products.

The production of land surface temperature maps, vegetation index maps and albedo maps is therefore not straightforward. Urban planners have started to integrate new tools and parameters into their plans and maps, to ensure their designs address the concerns of a world in constant change. The great disparity of newly assessed features and map typologies reveals the struggle of urban planners to find means to represent and integrate new disciplines into their plans. New planning processes require updated mapping typologies that efficiently address climatic and social contemporary issues, while providing an overall spatial vision and direction.

§ 4.3 Results: Catalysing mapping strategies to suggest urban heat adaptation guidelines

Drift, layering game board and rhizome are four creative mapping strategies that have been studied as urban planning catalytic strategies first by James Corner (Corner, 2002) and further by Arie Graafland (Graafland, 2010). Even though there are some overlaps and similarities between the before mentioned mapping principles (and the practical examples used to illustrate them) each of these techniques is meant to provide different visions of existing and future urban environments and landscapes. Each of them is meant to be created by different author categories (urban planners, decision makers...), addresses different audiences (citizens, politicians...) and are meant to trigger different actions and processes (revolution, interrelate different parameters, identify main processes taking place in cities...). These four categories are used to come up with innovative ways of suggesting urban design measures to adapt existing and future urban areas to the UHI, and each of them is associated with a different phase of the urban planning process.

§ 4.3.1 Game-board: preliminary strategic analysis

Game-board is a mapping process which aims at identifying hidden driving forces which "strongly affect physical states and behaviour" and which are actually manifestations of global influences on local environments (Bunschoten, 1996). Unplanned urbanism or slums probably represent the most extreme example of the variety of factors (beyond the urban plans, regulations and policies) intervening and affecting the urbanisation process. In Bunschoten´s book "Urban Flotsam" (Bunschoten, 2001), he describes different phases to identify the "field of forces" –first chapter "proto-urban conditions"-, analyse their way of functioning -second chapter "taschenwelt", in English pocket world- and investigates ways of intervening in those on going processes –chapters three and four "taxonomy and unfolding"-. The whole process´s aim is to develop scenarios to promote and inspire negotiations between the different driving forces. Game-board is not just one more mapping procedure; it should actually be the first phase of any urban planning process. Many extraordinary spatial plans and visions never actually see the light of day because they fail to involve all "actants" (partners, agents and actor). Game-board is a strategical analysis, which is even more crucial, in the case of the implementation of design guidelines to adapt cities to urban heat. Urban heat is one of the most worrying consequences of climate change in cities, however the measures to reduce it should always be combinable and compatible with the rest of social, economic and environmental priorities defined in the spatial visions of the different municipalities. In thermal study of Midden-Delfland park´s (Echevarria Icaza et al., 2016a) the preservation and promotion of the cooling capacity of this provincial park located between Rotterdam and The Hague, could be considered as one proto-urban condition to be incorporated into the Spatial Vision of the region of South Holland (Structuurvisie Zuid-Holland, 2016) which on the one hand aims at developing the necessary infrastructure to connect the two cities, and on the other hand intends to protect and preserve the park. Echevarria et al. carried out a detailed land use assessment to come up with different design scenarios (Figure 4.3) to increase the Midden-Delfland park´s natural cooling capacity suggesting landscape interventions which are flexible and combinable with the rest of spatial planning priorities. Several urban hotspots were identified in the park´s surroundings and different design measures are proposed to increase the cooling capacity of the park areas adjacent to the hotspots. The study analyses how the average night and daytime surface temperature varies depending on the nature of the park land use (forests, cropland, grassland, water surfaces, built areas and greenhouse areas) size and shape of the patches, and the design solutions proposed to increase the cooling capacity of specific park areas are based on these conclusions.

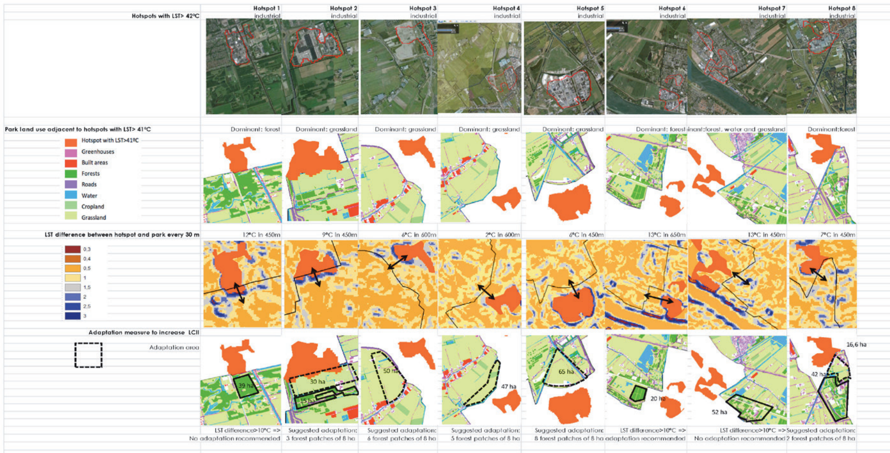

FIGURE 4.3 Diagnosis and adaptation design for hotspots with an LST>42°C (Echevarria Icaza et al., 2016a).

§ 4.3.2 Rhizome: integration schemes

The "plane of consistency" (Deleuze and Guattari, 1987) is highlighted by Corner as the core of the rhizomatic mapping, and summarized as an inclusive (of existing elements) and structuring (of new connections) plane (Corner, 2002).This representation practice can be used as a second phase of the planning process, which would take place after the game board phase. If game-board is the strategic thinking, rhizome would consist in mapping the "actants" influences, relating one with the other and suggesting open and combinable actions. In this context rhizome mapping would contain and represent not only the physical environment, but also abstract considerations, political or administrative neighbourhood boundaries, accessibility, social tendencies... identified during the game-board phase. The implementation of urban heat adaptation measures in existing cities will often require the intervention in existing urban contexts, as the sole thermal argument is most of the times by itself insufficient to justify integral neighbourhood interventions. In their study called "Surface thermal analysis of North

Brabant cities and neighbourhoods during heat waves" (Echevarria Icaza et al., 2016b) Echevarría et al. relate conventional neighbourhood classifications (high-density city centre, city centre, pre-war neighbourhood, post-war compact neighbourhood…) –developed (among others) for housing policy implementation and created based on density, accessibility, function mix and building quality criteria- with surface thermal clusters (Figure 4.4 and Figure 4.5). Each thermal cluster comprises surfaces with specific combinations of albedo, NDVI and imperviousness, and thus specific interventions are associated to each of them for their surface temperature reduction. (Cluster 1 signature corresponds to areas with large asphalt patches. Intervention proposals to reduce surface temperature of asphalt patches would include introducing a high reflective coating, reducing the imperviousness of the surface in specific areas or introducing shades to prevent exposure to radiation). Relating the surface thermal analysis, to an existing neighbourhood classification is a way of integrating the climatologic study into the existing political, operational and administrative framework.

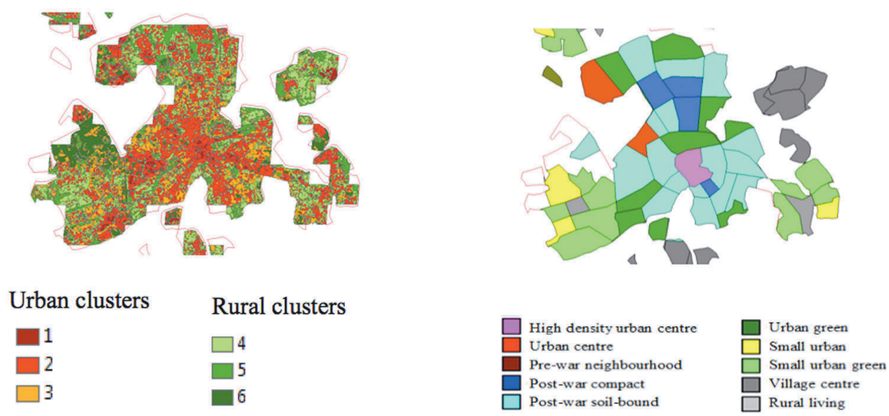

FIGURE 4.4 Compilation of LST-related maps for Eindhoven metropolitan area:Surface cover clustering and "urban living environment" categories (Echevarria Icaza et al., 2016b).

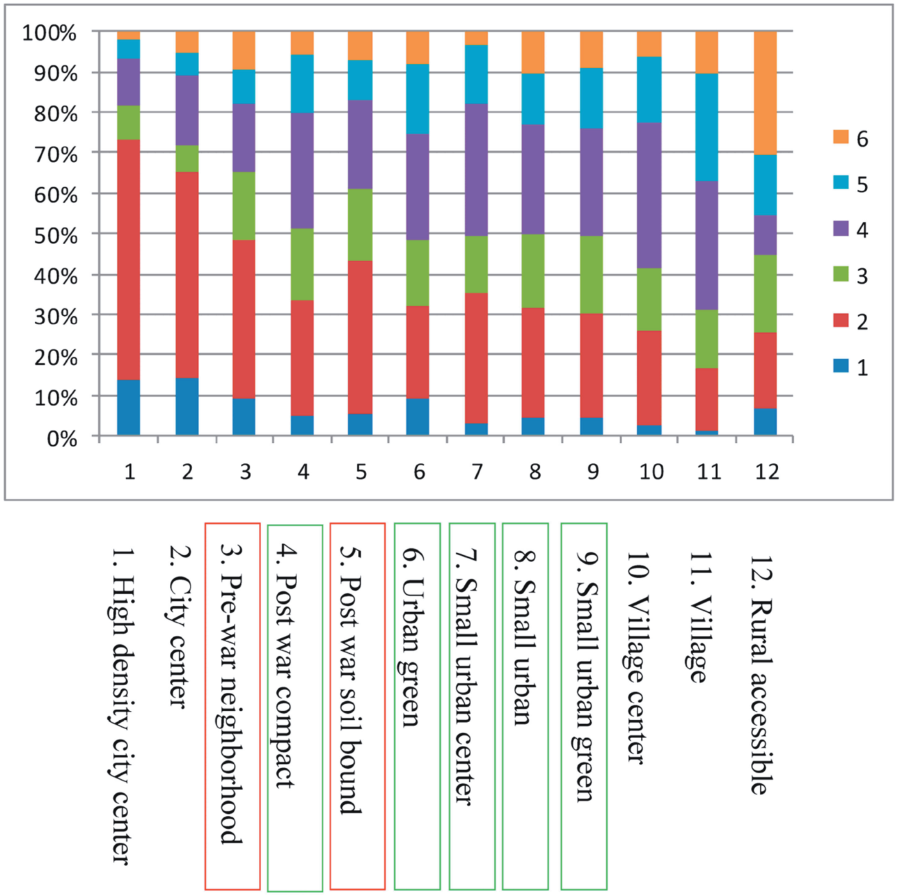

FIGURE 4.5 Surface cover cluster proportions for each of the "urban living environment" categories in the analysed medium-size cities of the North Brabant region. Neighbourhoods 3 and 5 present similar cluster proportions, and thus could be grouped. Neighbourhoods 4, 6, 7, 8 and 9 present similar cluster proportions, and thus could be grouped (Echevarria Icaza et al., 2016b).

§ 4.3.3 Layering: physical overlap

Following the rhizome mapping which represents the integrative representation of existing and proposed urban planning conditioning and determining factors, we would suggest introducing the layering phase. Layering consists of the physical overlap of different structures over a common territory. In the context of this study, layering corresponds to a more concrete activity than rhizome. The main difference between these two mapping principles is that layering integrates mainly physical parameters. Layering is an appropriate mechanism to represent different heat reduction options for one particular urban area since there are several mechanisms to reduce urban heat and the selection of these depends on many other factors. Echevarria et al. (Echevarria Icaza et al., 2016 c) (Figures 4.6, 4.7, 4.8, 4.9, 4.10 and 4.11) map different temperature related parameters for several Dutch cities. Figure 6 presents the results obtained for the city of The Hague. The storage heat flux mapping (Figure 4.6.1) is used to identify hotspot areas, these are areas that tend to accumulate heat throughout the day, and that are likely to release it at night. Thus these are areas where to concentrate design adaptation efforts. Figure 4.6.4 represents day land surface temperature, higher LST mainly correspond to industrial areas, which warehouses could benefit from flat roof cooling measures, consisting primarily of the introduction of high reflection coatings. Figure 4.6.3 shows vegetation maps, and identifies in white, the areas with a total lack of green. Greenery can always be implemented at street and roof level, however it requires a deeper assessment, as both implementation and maintenance are critical for the survival of the introduced species. Figure 4.6.5 maps albedo and allows identifying areas with low surface reflection, figure 4.6.7 and figure 4.6.8 represent the quantification of specific material surfaces which allow estimating the heat mitigation effect of the replacement of low albedo materials by higher albedo materials. The coolspot maps (Figure 4.6.10, which maps the storage heat flux in rural environments), together with the heights map (Figure 4.6.9) and the sky view factor map (Figure 4.6.12), allow identifying potential cool wind corridors (Figure 4.6.11) that would promote the natural fresh air circulation from coolspots to hotspots. Finally the “life quality map” (Figure 4.6.6) (Leefbaarometer, 2014) introduces a layer of combined physical and social parameters which is used by the Dutch Ministry of the Interior and Kingdom Relations to assess the municipalities´ quality of life.

This set of heat related layers can be overlapped, combined and filtered by urban planners with other discipline´s layers in order to produce integrating urban plans.

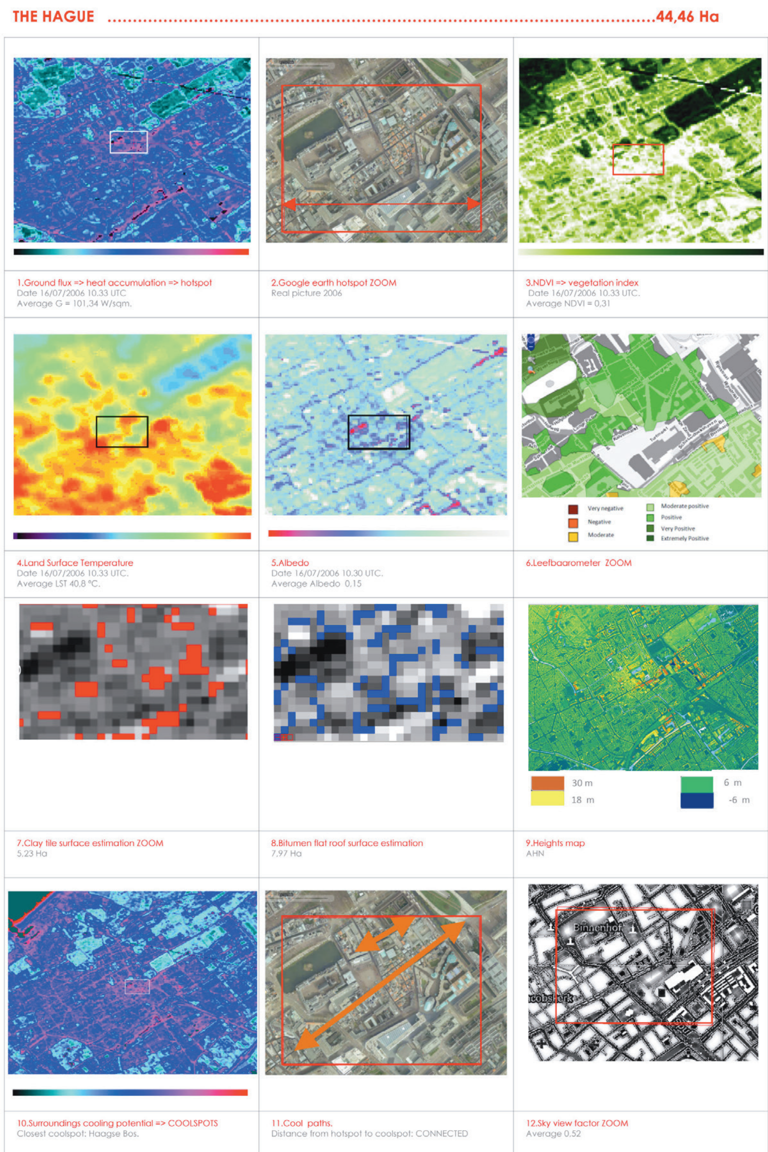

FIGURE 4.6 Modified from layers for the urban heat assessment of the city of The Hague (Echevarría Icaza et al., 2016 c)

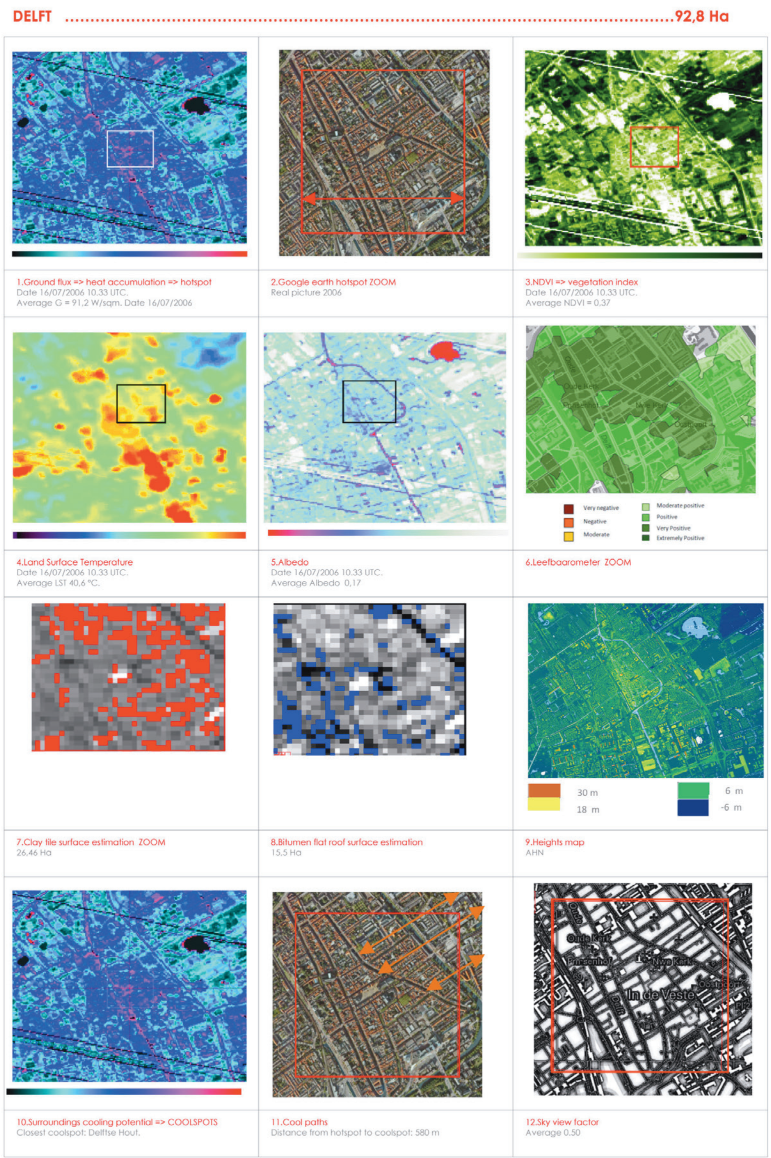

FIGURE 4.7 Modified from layers for the urban heat assessment of the city of Delft (Echevarría Icaza et al., 2016 c)

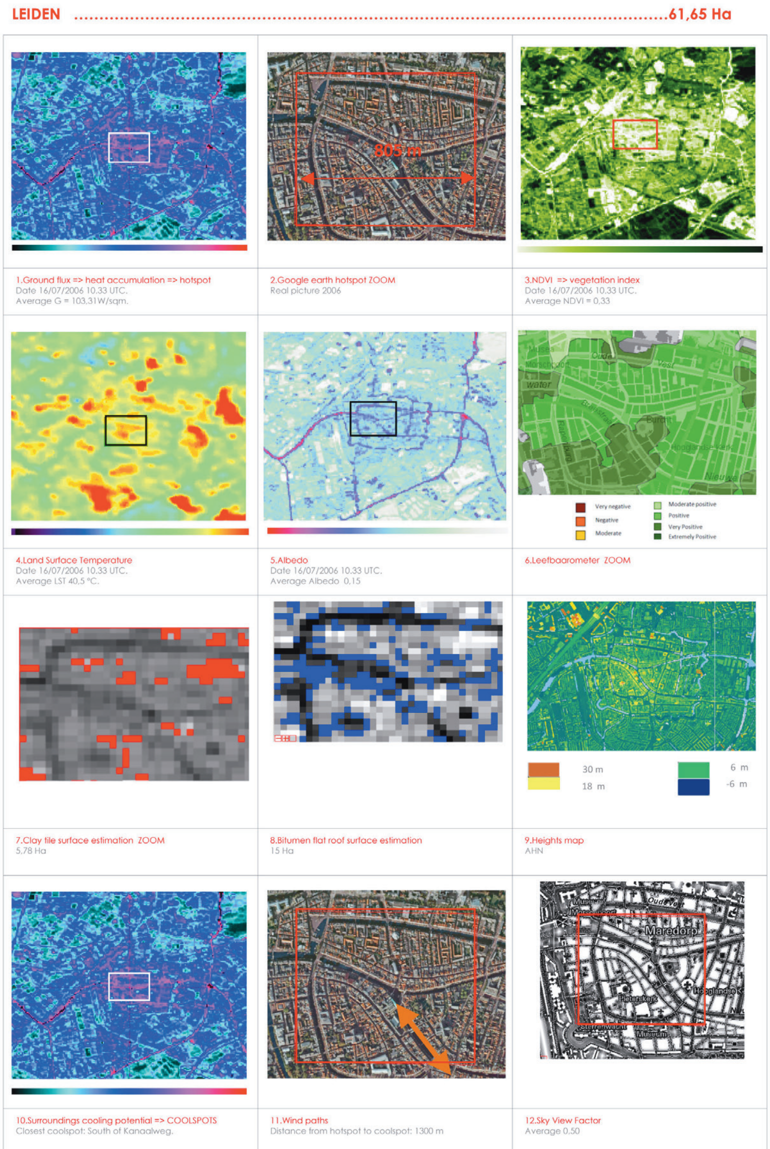

FIGURE 4.8 Modified from layers for the urban heat assessment of the city of Leiden (Echevarría Icaza et al., 2016 c)

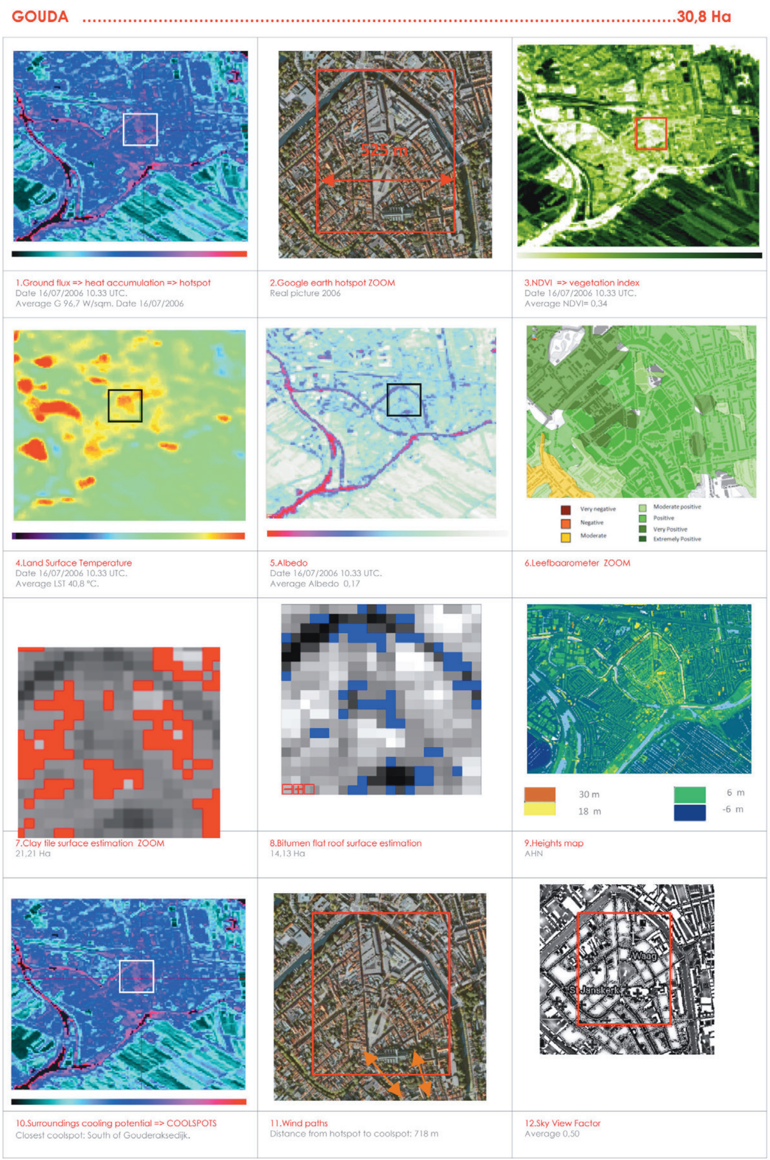

FIGURE 4.9 Modified from layers for the urban heat assessment of the city of Gouda (Echevarría Icaza et al., 2016 c)

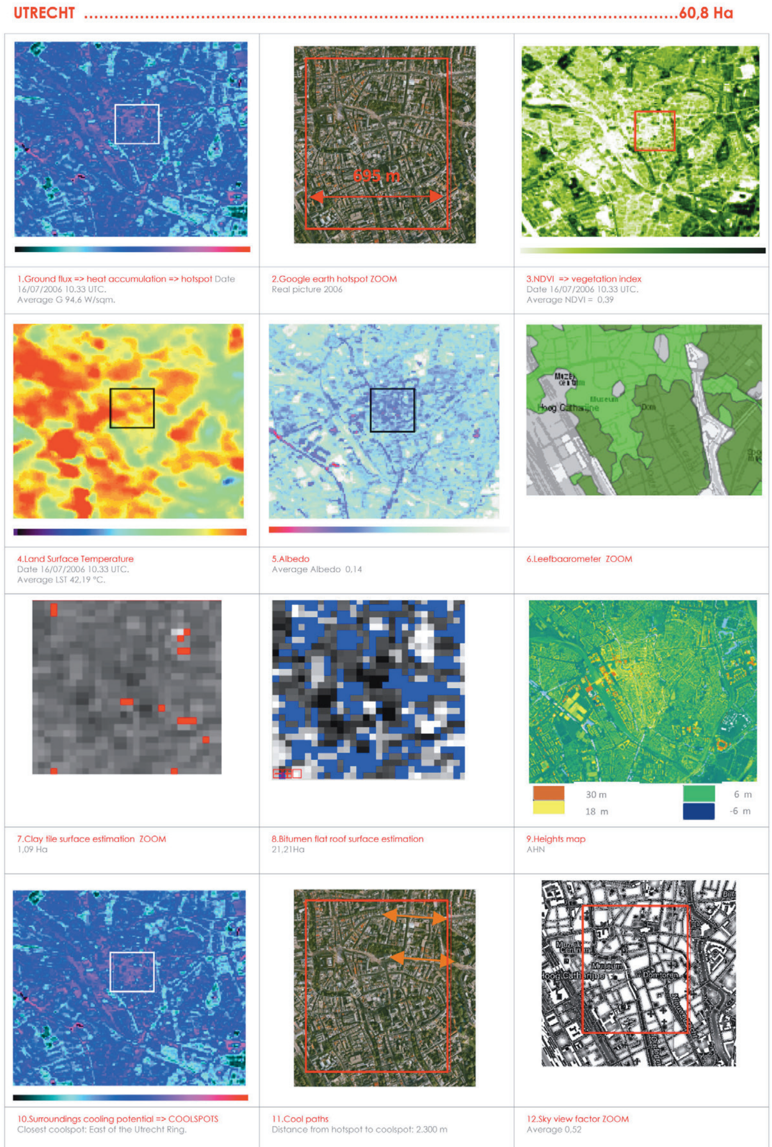

FIGURE 4.10 Modified from layers for the urban heat assessment of the city of Utrecht (Echevarría Icaza et al., 2016 c)

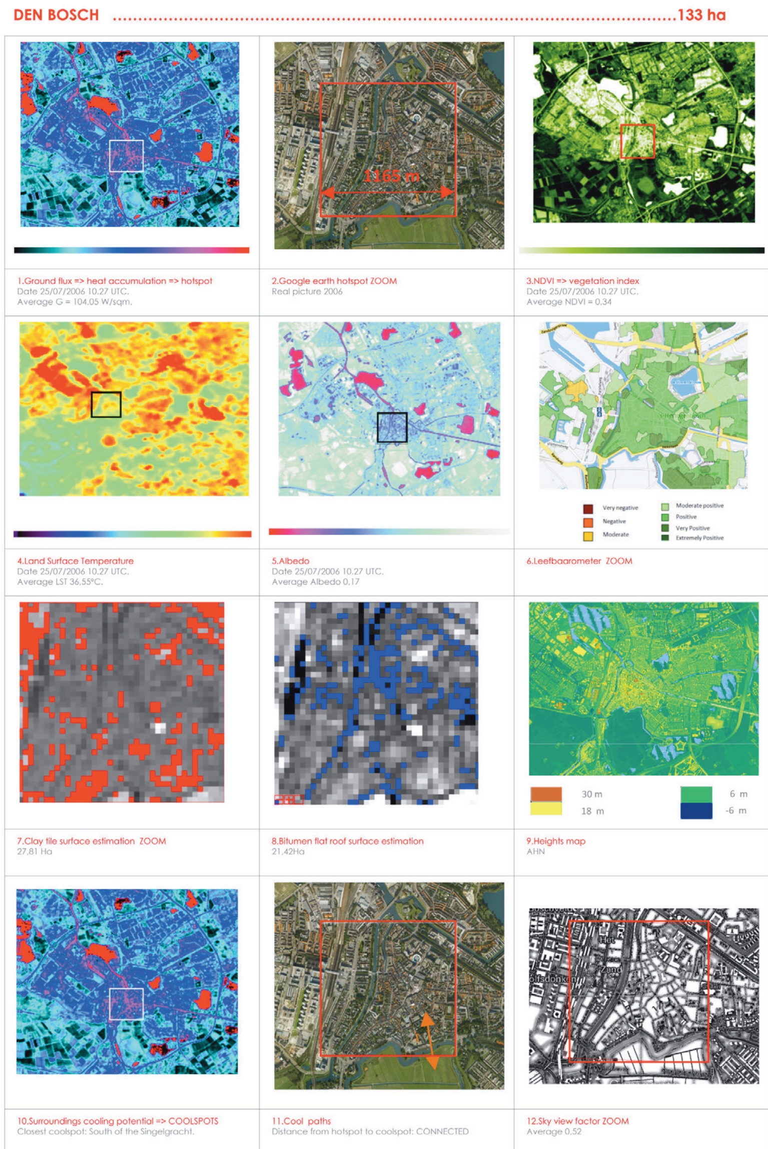

FIGURE 4.11 Modified from layers for the urban heat assessment of the city of Den Bosch (Echevarría Icaza et al., 2016 c)

§ 4.3.4 Drift

The concept of drift was originally introduced by the situationists and the main driver of this mapping category was a political one, which aimed at actually empowering the working class to promote a revolution. Corner uses the work of the situationists and of Richard Long (Knabb, 1981; Hollevoet et al., 1992; Long, 1994; Fuchas, 1986), to illustrate the drift concept, which emphasises the importance of how the user experiences the city. Data collection was done through the city walks, and the actual data collected consisted of the urban scenes perceived and experienced during those pedestrians' itineraries. However, the authors of these journey guides were not random citizens, but instead some sort of super head (Graafland, 2010)-not necessarily urban planners- aiming at restoring a lost social justice bringing back the public space to citizens. The scale of this assessment was done at street and neighbourhood level. Even though the nature of these maps was actually political, the essence of this mapping category is to guide citizens through the city public spaces. A certain parallelism can be found between this mapping category and the existing mobile phone applications containing GPS and guiding unequivocally 21st century pedestrians through cities in their search for public transportation directions and schedules, identification of specific commercial information…. However, a deeper analysis reveals that these mobile applications can precisely be very limiting depending on how they are used. The most extreme case would be to use them as a subway map, allowing an efficient circulation through its corridors without any reference or connection to the surrounding environment, which precisely represents the opposite of the drift´s aim. Thus mobile applications can be useful tools if they are used to guide us through cities, but also if they encourage us to discover and experience unexpected situations throughout the city, thus if they promote the interaction between citizens and with surrounding environment. Drift mapping could for example provide street level temperatures to guide pedestrians to fresher public areas during hot summer days. The parameter actually mapped would be storage heat flux using satellite imagery retrieved during previous heat waves, and it would be overlapped in GIS with squares, parks and streets to create routes to guide pedestrians to cooler open space areas. Echevarría et al. 2016 (Echevarria Icaza et al., 2016c) carried out the hotspots, coolspots and wind corridor analysis for the Dutch cities of The Hague, Delft, Leiden, Utrecht, Den Bosch and Gouda. Where several high level arrows suggest the direction to follow in order to reach cooler areas during heat waves (Figure 4.12).

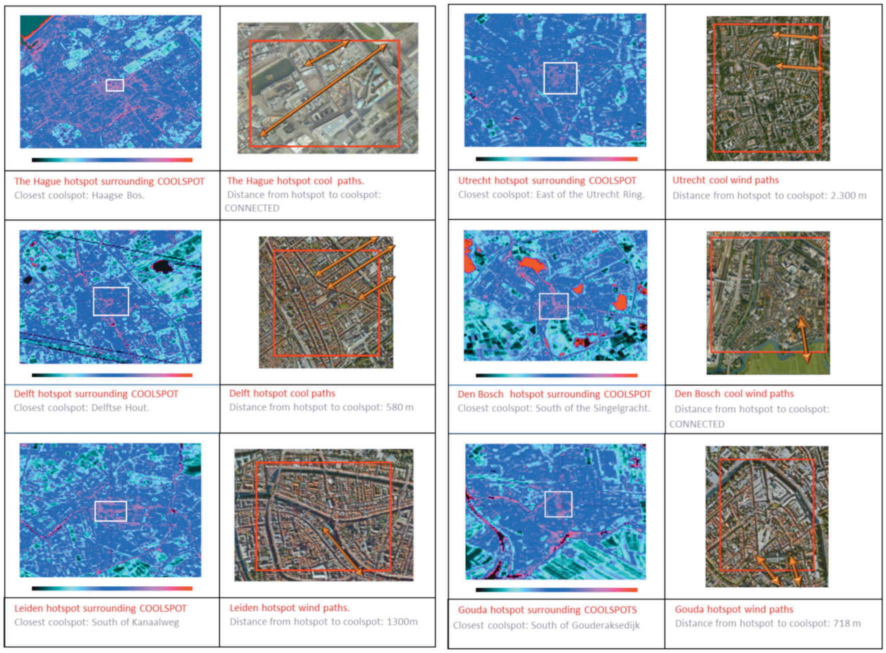

FIGURE 4.12 Comparative hotspot, coolspot, and wind corridor analysis for the Dutch cities of The Hague, Delft, Leiden, Utrecht, Den Bosch, and Gouda (Echevarria Icaza et al., 2016c)

§ 4.4 Conclusion

Even though urban planners should aim at producing integrating plans, the urban planner cannot be an expert in all disciplines of mobility, sociology, economy, climatology... The urban planner needs to be able to retrieve input from different experts, and build up integrating proposals from there. In principle, the urban planner should not necessarily have a specific command of the tools used by climatologists, sociologists, transportation engineers, ... However, some of the instruments used for the assessment of those specific disciplines, have proven to have wider applications, which can be used for a more general assessment by urban planners. It is the case of remote sensing, which is often used by climatologists, to study in depth the Urban Heat Island (for example) phenomenon, but which can also be used by urban planners for a more superficial assessment of the phenomenon, more oriented towards the development of design adaptation guidelines, rather than focusing in the accuracy of the retrieved measurements. Remote sensing, combined with GIS not only provides information on the distribution of heat, it can also calculate gradients, provide urban classification maps based on thermal behaviour and vegetation density assessment, calculate the influence of the size of an urban core in its overall surface temperature, identify locations with albedo (reflectance) below a certain threshold, identify coolspots and their land uses… The applications are manifold. The maps of urban planners need to give answers to specific questions that can often be answered using satellite imagery. The depth and accuracy of the climatological assessment produced by urban planners is inevitably not comparable to the ones issued by climatological experts. In that sense it is important to remind the different purposes of these two disciplines. Climatologists aim at having the most accurate insight of the phenomena themselves, while the focus of urban planners is in developing design guidelines to reduce the effect of the phenomena and that are flexible and compatible with other urban planning priorities. The use that those two disciplines make of certain tools is therefore not the same.

§ 4.5 Discussion

In order to be able to incorporate critical climatologic parameters, (such as urban heat) in future urban planning processes it is important first to identify relevant indicators affecting the studied phenomena, then to understand the instruments needed to map the indicators and finally to choose the scale, frame and representation code to visualize best the information and to ensure that the output can be integrated into catalysing mapping categories drift, layering, game-board and rhizome.

For the integration of the urban heat assessment in the urban planning processes, the heat fluxes, the land surface temperature, the albedo, the NDVI and imperviousness have been proved to be relevant. The instruments used to map these parameters are satellite images, treated with specific geospatial software (such as ENVI), vector analysis software (Geographic Information Systems – GIS) and atmospheric and geographic correction software (such as Modtran or Atcor). Urban planners need to reinterpret the use of these powerful tools in order to ensure they do not lead to static prescriptions, but instead they need to reveal inspiring connections and information, which triggers interactions between actants, parameters and systems.

The incorporation of these parameters and tools into open and integrative urban plans can be done through the use of the before mentioned catalysing mapping categories, which can be used in a particular order during the urban planning process. Since urban heat is often not the only priority to be addressed during the planning process, the need to find integrative and catalysing mapping strategies becomes even more crucial. Game-board is the strategical analysis to be carried out in order to understand which are the "driving forces" affecting the process, rhizome is used to define the representation of all aspects (including abstract considerations) that condition the process, layering describes the mapping phase which displays the overlap the different strategies that could be used to reduce urban heat, and finally drift is used as a tool to guide citizens to fresher areas during heat waves.

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PART B **Results**

Interventions in existing urban environment: Thermal behaviour of Dutch neighbourhoods

– Land use surface thermal analysis in medium size cities

The surface thermal analysis (unsupervised cluster classification of the three most relevant surface thermal parametres -albedo, NDVI and imperviousness-) carried out for the North Brabant medium size cities reveals that cities there are six main categories: cluster 1 (poorest thermal behaviour) mainly present in industrial areas and in some specific areas of the city centers, cluster 2 represents surface areas mainly located in city centers, cluster 3, urban residential areas (row houses) with interspersed green areas, cluster 4 can be identified with low density residential areas (detached houses), cluster 5 urban trees and water surfaces and cluster 6 bare soil areas.

– Thermal analysis of the “urban living environment” categories:

The surface cover analysis of the 12“urban living environment” categories used in the region of North Brabant, reveals on the one hand pre-war neighbourhood, and post-war ground based present similar surface covers and on the other hand post-war compact, urban green, small urban centre, small urban and small urban green also present similar surface cover mixes. Thus when it comes to thermal behaviour, the 12 urban living environment categories can be reduced to seven: high density city centre, city centre, pre-war neighbourhood & postwar soil bound, post-war compact & urban green & small urban centre & small urban & small urban green, village centre, village and rural accessible.

In either cases, the city centers clearly present a worst thermal behaviour than the rest of residential categories.

– Dutch city centers study:

The hotspots (areas with highest storage heat flux concentration ranging from 90 W/m^2 to 105 W/m^2 and with areas ranging from 30.8 ha to 133 ha) of Delft, Leiden, Gouda, Utrecht and Den Bosch, correspond to the old city centres, these are dense traditional 17th century Dutch neighbourhoods with red ceramic roof tiles, brick street paving, and canals. These are typical dwelling neighbourhoods with commercial premises in the ground floor, characterised by a high quality of life. These inner-city areas belong to representative neighbourhoods with very intense street activity (commercial, leisure, and touristic). In contrast, the hotspot of the city of The Hague corresponds with an area with bituminous flat roofs and asphalt paving. Since the old city centers are listed, the interventions allowed are limited, and thus the proposals to mitigate the UHI effect are reduced to: vegetation increase at roof and pavement level (in areas with vegetation index values below 0.2), enhancement of natural cooling wind paths (the coolspot analysis reveals that in the cities of The Hague, Delft, Gouda and Den Bosch the distance between hotspots and coolspots is below 1,000 m, which suggests that the creation of wind corridors could efficitiently contribute to the mitigation of the urban heat), and consistent roof albedo improvement (The quantification of the bituminous flat roofs and clay sloped roofs, reveals that increasing the albedo of both type of surfaces could help reduce the UHI from 1.4 to 3°C in the cities analysed).

Interventions in future urban growth areas: city scale results:

The analysis of 21 medium-size cities in the region of North Brabant reveals that the future urban developments will not per se aggravate the UHI phenomenon of the cities, in turn, the design of the new neighbourhoods will impact the formation of the urban heat in the province.

The multiple regression analysis of the average values obtained for Albedo, NDVI, imperviousness, distance to the nearest urban area and town size of 21 medium-size cities in the region of North Brabant reveals that there is a multiple correlation coefficient of R=0.7 and R2=0.5 that relates these parameters with the average night-time surface temperature. The following parameter coefficients were obtained.

FORMULA B.1

$$LST\ (average\ night) = 27.7 - 34.8*A + 2.3E\text{-}08*S - 0.1*NDVI$$

Where A = Albedo, S = surface and NDVI = Normalised Difference Vegetation Index.

It seems that the most relevant indicators in this case are albedo and NDVI. Imperviousness, the distance to nearest town and the area of the analysed cities do not seem to play a significant role in the LST night values for the medium-size cities analysed in the region of North Brabant, which do not exceed 7,700 ha in any case. The maximum calculated average city night-time LST difference is 2.9°C. The average city albedo values are pretty similar for all cities and range from 0.20 to 0.23. NDVI variations vary from 0.31 to 0.50 and imperviousness coefficient ranges from 23% to 37.4%.

Landscape interventions: regional scale results

At regional scale, the preservation of the regional geographical landmarks, the implementation of urban containment policies (limiting city sizes), the increase of greenery, the preservation and enhancement of existing natural coolspots, and the landscape design (implementation of land uses which increase the natural cooling capacity of the landscape -the size and the shape index also influence the cooling capacity-)) are measures than could help reduce the UHI in future urban developments. The first three design principles were already proposed by the 1920´s regionalists.

– Cooling capacity varies depending on size, shape and landuse

The average day LST within South Holland provincial parks varies from 25.9°C for water surfaces, to 31.4°C for forests, 33°C for cropland, 33.1°C for greenhouse areas, 34.9°C for grassland patches and 37.9°C for built areas. Within each land use category, NDVI, imperviousness and patch shape index influence the thermal behaviour of the patches differently. NDVI is inversely correlated to day LST for all categories, imperviousness is correlated to day LST for all areas which do not comprise a significant presence of greenhouses (grassland and built patches) and inversely correlated to LST for areas with a high presence of greenhouses (cropland and warehouses). This is due to the fact that greenhouses have very high reflective roofs which contribute to the reduction of heat formation. Finally, the shape index varies depending on the nature of the surrounding patches, especially for small patches (built areas, forests and greenhouse areas).

The influence of the patch shape in the average LST is very much influenced by the nature of the areas surrounding the studied patches. In that sense the studied land uses can be organised in three groups. The first one comprises large patches surrounded of warmer areas: it is the case of cropland, grassland and water surfaces. The second group is made of small patches clustered around each other: this is the case of forest patches and built area patches. The third group is formed by small scattered patches surrounded by warmer areas: this is the case of the warehouse patches. The first land use group (cropland, grassland and water surfaces) sees its average LST increase with the increase of the slenderness of its patches. Slender patches are more influenced by their warmer surroundings. The second group (forest and built areas), is influenced by the average LST of their own patches. Slender forest patches are cooler due to the presence of the surrounding forests. Slender built area are more influenced by the high LST of the surrounding built areas. The third group of greenhouses, is surrounded by warm areas; the slenderer the patches, the higher the day LST.

Most of the hotspots surrounding the Midden-Delfland park are adjacent to grassland patches. The measure to increase the cooling capacity of those patches would consist in a change of land use and or an increase of the NDVI of the existing grassland patches. These suggestions to increase the cooling potential of the parks remain deliberately open in order to allow combining these measures with other spatial planning priorities.

5 The urban heat island effect in Dutch city centres – Identifying relevant indicators and first explorations

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Abstract

In the Netherlands awareness regarding the Urban Heat Island (UHI) was raised relatively recently. Because of this recent understanding, there is a lack of consistent urban micro-meteorological measurements to allow a conventional UHI assessment of Dutch cities during heat waves. This paper argues that it is possible to retrieve relevant UHI information – including adaptation guidelines – from satellite imagery.

The paper comprises three parts. The first part consists of a study of suited indicators to identify urban heat islands from which a method is presented based on ground heat flux mapping. The second part proposes heat mitigation strategies and identifies the areas where these strategies could be applied within the hotspots identified in the cities of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch. The third part estimates the reduction of urban heat generated by the increase of roof albedo in the hotspots of the six cities. The six cities hotspots are located within the boundaries of the 17th century city centres. In order to avoid interference with cultural values of these

historical environments most likely UHI mitigation measures regard improving the thermal behaviour of the city roofs. For instance, applying white coatings on bitumen flat roofs (or replacing them by white single-ply membranes) and replacing sloped roof clay tiles by coloured tiles with cool pigments can reduce the urban heat hotspots by approximately 1.5°C.

Remote sensing provides high level information that provide urban planners and policy makers with overall design guidelines for the reduction of urban heat.

Keywords: Climate Change, Urban Heat Island, Storage Heat Flux, Remote Sensing, Climate Adaptation, NDVI, Albedo

§ 5.1 Introduction

§ 5.1.1 UHI studies despite the lack of micro-measurements

According to the Royal Netherlands Meteorological Institute (KNMI) 33 heat waves have struck the Netherlands since the beginning of the 19th century (KNMI, 2014). Nevertheless, Dutch urban meteorologists only started to study the Urban Heat Island (UHI) phenomenon after the heat wave of 2003, when the amount of heat-related deaths reached more than 1,400 (Garssen et al., 2005) in the Netherlands and more than 22,000 across Europe (Schar & Jendritzky, 2004). In the Netherlands, this relatively recent awareness of the phenomenon explains the lack of historical air temperature records to allow a consistent analysis of the UHI patterns throughout the country (Hove at al., 2011). Future climate scenarios predict that the frequency, the intensity and the duration of heat waves will increase (Meehl et al., 2004), more specifically in the Netherlands the four climate scenarios predicted for 2050 by the KNMI forecast that the average summer temperatures in the rural environment will continue to rise, and so will the amount of 'summerly days' (maximum temperature above or equal to 25°C) per year in the rural environment across the country. Concerned by these future predictions, Dutch scientists, climatologists and urban planners have had to develop alternative ways to fill in the shortage of historical urban air temperature records, in order to study more in depth the phenomenon in different Dutch cities. Some have used hobby meteorologist's data (Hove et al., 2011; Steeneveld et al., 2011; Koopmans S. 2010), others have used cargo bicycles (Heusinkveld et al., 2010; Brandsma et al., 2012) to retrieve temperature variations through different cities during hot summer days and finally others have chosen to use satellite imagery to map land surface temperature variations during hot days (Hoeven et al., 2013; Klok et al. 2009).

§ 5.1.2 Bridging the gap between scientific and applied knowledge

Even though in the Netherlands the scientific community has started investigating the phenomenon already more than five years ago, it seems there is still a gap between the scientific knowledge developed and the urban policies of large and medium size cities, which haven't started implementing measures to mitigate urban heat yet. Precisely one of the goals of the research programme Knowledge for Climate (Knowledge For Climate, 2015) is to develop not only scientific but also applied knowledge for climate proofing the Netherlands, investigating a wide variety of topics ranging from the climate adaptation for rural areas (Climate Adaptation for Rural Areas, 2015) to the climate adaptation of cities (Climate Proof Cities, 2014), to which this study belongs. Many Dutch cities have taken part in the Climate Proof Cities Program either as stakeholders or as case cities and would be willing to implement measures to mitigate the urban heat problem however they often lack a basic overview of the most affected neighbourhoods (to identify the areas where to concentrate the urban heat mitigation efforts), the different mitigation options (to be able to select design mitigation proposals that match best the rest of urban planning priorities) and a high level estimation of the potential heat reduction achieved (to be able to quantify the mitigation effect).

§ 5.1.3 Remote sensing as a tool to identify, mitigate and quantify urban heat.

For this study the authors have chosen to use satellite imagery because on the one hand it allows mapping and analysing many heat related parameters, such as surface heat fluxes (Parlow, 2003), land surface temperatures (Dousset, 2011), albedo (Taha, 1997; Sailor 1997) vegetation indexes (Yuan et al., 2007; Gallo et al., 1993) and on the other hand the analysis of satellite imagery provides consistent information of several cities at the same time. Being able to analyse several heat related parameters allows not only to identify vulnerable areas within cities, but also to assess on the different potential mitigation strategies for each city analysed and to provide a high level quantification of surface materials. The possibility of producing a simultaneous analysis of several comparable cities allows the analysed cities to join efforts, share scientific knowledge and implementation strategies. In this study the cities of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch (Figure 5.1 and Figure 5.2) were analysed. These cities have in common that they have a dense historical inner-city, dating back to medieval times but mostly consisting of buildings from the seventeenth century, the 'Golden Age' of the Netherlands, when most cities expanded rapidly with stone building that often still remain. Thanks to this comparable past and development, the chosen cities are comparable, although their urban layout and recent alterations differ.

FIGURE 5.1 Analysed cities. Google earth image. Data SIO, NOAA, U.S. Navy, NGA, GEBCO ©2015Google. Image Landsat ©2009 GeoBasis-DE/BKG

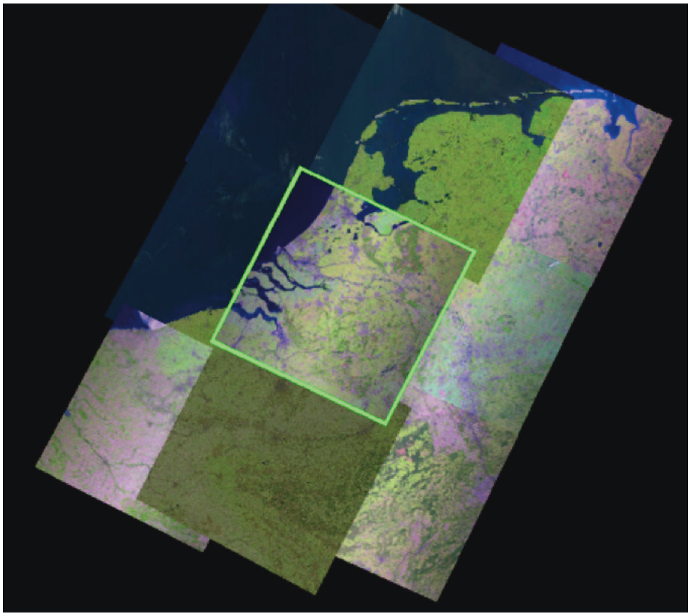


FIGURE 5.2 Size of the Landsat 5 TM image analysed.(image extracted from the USGS Global Visualization Viewer). Courtesy of the U.S. Geological Survey. USGS/ NASA Landsat.

§ 5.2 Methodology

§ 5.2.1 Research framework

– Problem statement and objective

Since in the Netherlands UHI awareness is relatively recent, there is a lack of consistent urban micro-meteorological measurements to allow a conventional and consistent UHI assessment of Dutch cities during heat waves (Hove at al., 2011). This lack of appropriate data hampers UHI scientific studies and hinders the development of guidelines for climate adaptation in cities. Therefore, as part of this study the authors aim to retrieve relevant UHI information from satellite imagery, in order to help develop UHI adaptation guidelines for Dutch cities.

The objective of this study is twofold: to develop a method to assess the UHI phenomenon for cities with a lack of micro-meteorological datasets, and to develop a customised set of urban planning adaptation measures for the studied cities.

- Research questions: The underlying research questions for this paper are:
  - Can remote sensing help identify urban heat hotspots when there is lack of micro-measurements? If so, what are suited indicators?
  - Which are the most common heat mitigation strategies to reduce urban heat? How can we use remote sensing to identify where to implement these within the hotspots identified for the cities of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch?
  - Could we quantify the mitigation effect of the increase of roof albedo in the identified hotspots?

§ 5.2.2 Research methodology

- Research structure

Based on the research questions this paper primarily comprised three parts.

The first part consists of a study of suited indicators to identify urban heat hotspots in areas with a lack of micro-measurements, from which a method is presented based on storage heat flux mapping. This was validated by application in 2 Dutch cities, The Hague and Utrecht.

The second part proposes heat mitigation strategies and identifies the areas where these heat mitigations could be applied within the hotspots identified in the cities of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch. The third part estimates the reduction of urban heat generated by the increase of albedo in the hotspots of the six cities.

- Data collection instruments

Landsat 5 TM satellite imagery was used for the assessment of the tree parts of the research. Landsat is often used for UHI assessment (Bechtel, 2011; Liu and Zhang, 2011; Rajasekar and Weng, 2009; Cao et al., 2008), for the development of mitigation strategies (Rosenzweig et al., 2006; Baudouin Y. and Lefebvre S. 2014) or for the estimation of the heat mitigation effect (Odindi et al. 2015; Onishi et al. 2010). Landsat imagery has a high resolution and is open source. The raw satellite images can be downloaded from the US Geological Survey (USGS) webpage, Earth Resources Observation and Science Center (EROS). The approximate size of each retrieved scene is 170 km North-South by 183 km East-West. One Landsat image covers most of the country surface, which allows completing the simultaneous analysis of several cities at the same time (fig. 1b.). The sensor carried onboard Landsat 5 is Landsat Thematic Mapper (TM) which has a 16 day repeat circle. For this study the autho chose to analyse satellite images retrieved during the second heat wave that struck The Netherlands in 2006 (on the 16th of July at 10:33 UTC for all cities, except for Den Bosch, for which the Landsat image used was from the 25th of July, at 10:26 UTC).

Two software have been used to process the raw satellite imagery: ATCOR 2/3 and ENVI 4.7. ATCOR 2/3 was used for the atmospheric and geometric correction of the satellite imagery, as well as for the production of the albedo and surface heat flux maps (Richter & Schlapfer, 2013) and ENVI 4.7 (Exelisvis, 2015) was used for the analysis and enhancement of the images processed in ATCOR 2/3.

– Identifying hotspots

For the selected cities urban heat island hotspots were mapped by means of the storage heat flux. The storage heat flux was mapped using ATCOR 2/3 (Figure 5.3).

Analytical phases	Scale	Parameter analysed	Methods and tools	Design guidelines
PHASE 1				
Hotspot identification	City	Storage heat flux	Landsat 5 TM for July 2006. Geometrical correction, atmospherical correction and **Storage heat flux** calculation for urban environment in ATCOR 2.3.	Definition of intervention area.

FIGURE 5.3 Hotspot identification process

The calculation of the heat fluxes is done through different models for urban and rural surfaces. In order to identify the hotspots (areas with the highest storage heat flux values) within the studies cities,the authors have chosen to use the model used for urban surfaces, where latent heat is usually smaller. The dominant fluxes are the storage and the sensible heat fluxes, for which Parlow´s equations are applied (Parlow, 1998).

FORMULA 5.1

$$G = 0{,}4\ Rn$$

where Rn is the net radiant energy absorbed by the surface; G is the storage heat flux, i.e. the energy dissipated by conduction into the ground or into the building materials

FORMULA 5.2

$$LE = 0{,}15\ (Rn - G)$$

where Rn is the net radiant energy absorbed by the surface; G is the storage heat flux, i.e. the energy dissipated by conduction into the ground or into the building materials; and LE is the latent heat flux, that is the energy available of evapotranspiration.

FORMULA 5.3

$$H = Rn - G - LE$$

where Rn is the net radiant energy absorbed by the surface; G is the storage heat flux, i.e. the energy dissipated by conduction into the ground or into the building materials; H is the sensible heat flux, that is the energy dissipated by convection into the atmosphere (its behaviour varies depending on whether the surface is warmer or colder than the surrounding air); and LE is the latent heat flux, that is the energy available of evapotranspiration.

– Heat mitigation strategies

The analysis of remote sensing imagery can provide an overview of several urban heat related parameters: normalised difference vegetation index (NDVI), land surface temperature (LST), coolspot presence, and albedo (Figure 5.4). In this section an overview of the relevance of each of these parameters is provided. However, since in five of the six analysed cities the "storage heat flux hotspots" are within the limits of the 17th century city centres – and in these areas the implementation of design strategies is fairly restricted due to the historical protection of the neighbourhoods – in the following sections the authors have only estimated the effect on the urban heat reduction of the mitigation strategies consisting of increasing the city roofs' albedo.

Analytical phases	Scale	Parameter analysed	Methods and tools	Design guidelines
PHASE 2				
Adaptation measures	City	Cool Corridors	Coolspot identification: Landsat 5 TM for July 2006. Geometrical correction, atmospherical correction and **Storage heat flux** for rural environment calculation in ATCOR 2.3. Wind corridor identification: through AHN.	1/Creation of cool wind corridors connecting hotspots to natural coolspots. 2/Enhancement and preservation of the existing coolspot.
	Hotspot	Albedo	Landsat 5 TM for July 2006. Geometrical and atmospherical correction and **Albedo** calculation in ATCOR 2.3.	Proposal of surface material changes to improve albedo, depending on existing surface materials.
	Hotspot	NDVI	Landsat 5 TM for July 2006. Geometrical and atmospherical correction in ATCOR 2.3. **NDVI** calculation in ENVI 4.7.	Vegetation introduction in highlighted hotspots.
	Hotspot	Land Surface Temperature	Landsat 5 TM for July 2006 .**LST** calculation in ENVI 4.7.	In industrial areas: deeper analyisis is required to confirm the energy efficiency of the buildings with high LST on roofs.

FIGURE 5.4 UHI adaptation measures recapitulation chart

– UHI reduction potentials

In order to estimate the UHI reduction for the six cities the implementation of the roof mitigation strategies was studied. These concern the measures that will be most likely adopted. The following methodology was adopted: the albedo maps of each hotspot were used to estimate the area of bituminous flat roofs and of clay tile sloped roofs. This area estimation was calculated using ENVI 4.7. For the estimation of the bituminous flat roofs, the authors considered all surfaces with albedos of 0.13 to 0.15, and for the clay tile surface estimation they considered all surfaces with albedos of 0.18 to 0.22. This way of estimating material surfaces has its limitations.

– Detailed assumptions

The following reference-based assumptions were used:

It was assumed that an increase of 0.1 of the hotspot overall albedo reduces the UHI by 1°C (Sailor, 1995; Taha, 1988).

As a reference, the maximum UHI values for the 95 percentile were provided, calculated with hobby meteorologists' data (Hove et al., 2011) for the cities of The

Hague, Delft and Leiden. For the cities of Gouda, Utrecht and Den Bosch, it was estimated that the max UHI will be around 5°C as well.

For each city the authors have estimated the UHI reduction for several roof intervention scenarios:

- Mitigation action 1:

Bituminous flat roof albedo (0.13 to 0.15) is improved by applying a white coating (albedo 0.7) or by replacing it by a white single-ply membrane (albedo 0.7). This action is likely to take place in the next 10 years. Minor repairs can be treated with white coating solutions, and major repairs will require full replacement by single ply membranes.

- Mitigation action 2:

Clay tiles sloped roof (albedo 0.18 to 0.22) are replaced by coloured tiles with cool pigments (albedo 0.5). This action is likely to take place in the coming 50 years as the lifespan of clay tiles is 50 years.

- Mitigation action 1+2:

Consists in improving the albedo of bituminous flat roofs by applying a white coating or a single-ply membrane, and in improving the clay sloped roof albedo by cool pigment coloured tiles.

- Limitations

Landsat 5TM is an appropriate tool to assess urban heat accumulation at city scale (sections 5.3 and 5.4) due to the resolution of its spectral bands: 30m for bands 1 to 7, and 120m for band 6 which is resampled to 30m. However, in this study the authors have also used Landsat 5 TM to quantify the surface of bituminous flat roof and of clay sloped roofs (section 5.6). The resolution of Landsat 5TM for material discrimination is a little rough. Nonetheless, the purpose of the surface estimations is to provide a high-level quantification of the mitigation effect of the proposed measures, therefore a certain degree of inaccuracy in the surface quantification is acceptable. Further, the objective of the study is not only to quantify the mitigation effect of the measures, but also to suggest a methodology that could also be replicated with finer resolution satellite imagery, allowing more accurate surface classification results.

§ 5.3 Identification of UHI hotspots in areas with a lack of micro-measurements

§ 5.3.1 Possible UHI indicators

– UHI and SUHI

The most common variable assessed through remote sensing imagery is land surface temperature (LST). However, LST assesses the surface heat Island (SUHI) phenomenon, which has different characteristics than the canopy layer air temperature urban heat island (UHI).

The first important difference between SUHI and UHI is that, even though both present higher intensities on cloudless and windless days (Oke 1973; Oke 1982; Uno et al., 1988; Morris et al., 2001) SUHI has its peak during the day when the surfaces receive the maximum radiation (Carlson et al., 1981), whereas the canopy UHI has its peak at night when the surfaces start radiating the stored energy into the atmosphere (Oke et al., 1997).

The second difference is that diurnal SUHI pattern does not match the nocturnal UHI pattern (Dousset et al., 2011; Parlow, 2003; Voogt et al., 2002; Roth et al., 1989; Price, 1979). Urban planners and climatologists are typically more interested in understanding nocturnal air temperature UHI patterns because they are more strongly connected to the accumulation of heat and to human comfort; there is a high correlation between high nocturnal temperatures and excess of mortality during heat waves (Dousset et al., 2011).

– Night-time UHI

Some studies suggest that the nocturnal surface temperatures are better correlated to nocturnal air temperatures than diurnal ones, due to the stabilization of the atmosphere and to the cessation of the direct solar radiation (Nichol & Wong, 2004). The reality is that most remote sensing studies on the UHI phenomenon focus on the day-time surface temperature variations due to the lack of fine resolution night-time thermal images. High-frequency thermal sensors that allow retrieving both day-time and night-time surface temperature typically have low resolutions (AVHRR: 1.1 km, Modis: 1 km) whereas finer resolution satellites such as Landsat TM (120 m) and

Landsat ETM (60 m) have lower frequencies and are therefore limited to day-time observations (Nichol & Wong, 2004). Thus finer resolution satellites mainly allow the retrieval of day-time LST which cannot be considered as the most relevant UHI indicator.

- Heat fluxes

Studies carried out in Basel by Parlow reveal that heat fluxes might be more relevant indicators of the UHI phenomenon than day-time surface temperature patterns (Parlow, 2003). Therefore in this study remote sensing imagery is therefore used as a basis for mapping heat fluxes, more precisely storage heat fluxes.

The energy balance equation for radiant energy absorbed by heat fluxes can be written as (Asrar, 1989):

FORMULA 5.4

$$Rn = G + H + LE$$

where Rn is the net radiant energy absorbed by the surface; G is the storage heat flux, i.e. the energy dissipated by conduction into the ground or into the building materials; H is the sensible heat flux, that is the energy dissipated by convection into the atmosphere (its behaviour varies depending on whether the surface is warmer or colder than the surrounding air); and LE is the latent heat flux, that is the energy available of evapotranspiration.

- Storage heat flux as indicator of UHI

Studies on heat storage of paved surfaces in urban areas reveal that these may be the principal contributor to the nightly UHI effect (Doll et al., 1985). Net radiation, storage heat flux, latent heat and sensible heat distribution vary in the urban and rural environments. Studies on the 'Urban Energy Balance' derived from satellite data for the city of Basel (Parlow, 2003) reveal that during day-time, urban pavements, industrial pavements and roofs present low latent heat fluxes, sensible heat fluxes similar to the ones obtained in their rural surroundings (among other reasons, due to the high surface temperatures of the urban surfaces) and extremely high storage heat fluxes. The heat accumulated during the day is released to the atmosphere during the night thus causing the UHI peak. Materials with higher conductivity – such as black top concrete and asphalt – present lower surface temperatures during the day, however at night – due to the different heat storage capacity of the two materials – black top concrete presented higher surface temperatures than the asphalt pavement (Asaeda et al., 1993). Therefore, storage heat flux proves to be a relevant indicator for the UHI assessment. Urban areas present higher temperatures at night due to thermal conductivity, heat capacity and thermal admittance of the built materials (Parlow, 2003). Furthermore, other studies confirm that the data modelled with remote sensing imagery is in agreement with the micrometeorological in-situ measurements. (Rigo & Parlow, 2007).

– Practical storage heat flux values

As a reference, the urban areas of Mulhouse and Basel, as well as their industrial sites, present storage heat fluxes of more than 200 W/m², whereas the forest areas present values of 26 to 50 W/m² (Parlow, 2003). Other storage heat flux values per surface types are compiled in the ATCOR-2/3 User Guide (Version 8.0.2), which to dark asphalt areas assigns storage heat flux values of 240 W/m², to bright concrete values ranging from 164 to 240 W/m², to partially vegetated areas values of 185 W/m² and to fully vegetated areas values of 77 W/m² (Richter & Schlapfer, 2013).

§ 5.4 Validation examples: comparing storage heat flux mapping with multi-day mobile observations for the cities of The Hague and Utrecht

§ 5.4.1 The Hague

Although there is a lack of ground measurements during heat waves, some research groups have attempted to map the UHI hotpots through other methods. This is the case for the maps issued by De Groot (2011), which for the city of The Hague forecasts the number of nights with temperatures above 20°C for the 2050 KNMI climate scenarios W and W+ (KNMI, 2009). These maps were produced as a result from the correlation between the bike measurements of the UHI for the city of Rotterdam (Heusinkveld et al., 2010), which was further extrapolated to the spatial and economic scenarios and to the climate scenarios (KNMI, 2009). The number of nights with temperatures above 20°C are higher in the area comprised between the Haagse Bos Park, Zuiderpark, Laakkwartier and Zorgvliet (Figure 5.5).

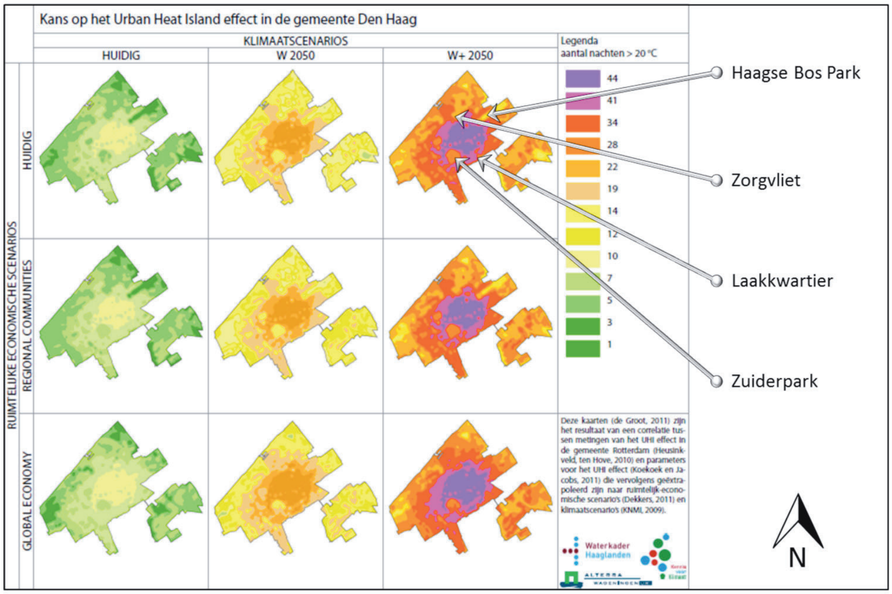


FIGURE 5.5 Night-time temperature in The Hague, the Netherlands. These maps (De Groot-Reichwein et al., 2014) are the result of a correlation between measurements of the UHI effect in the municipality of Rotterdam and parameters for the UHI, which are then extrapolated to spatial economic scenarios and climate scenarios.

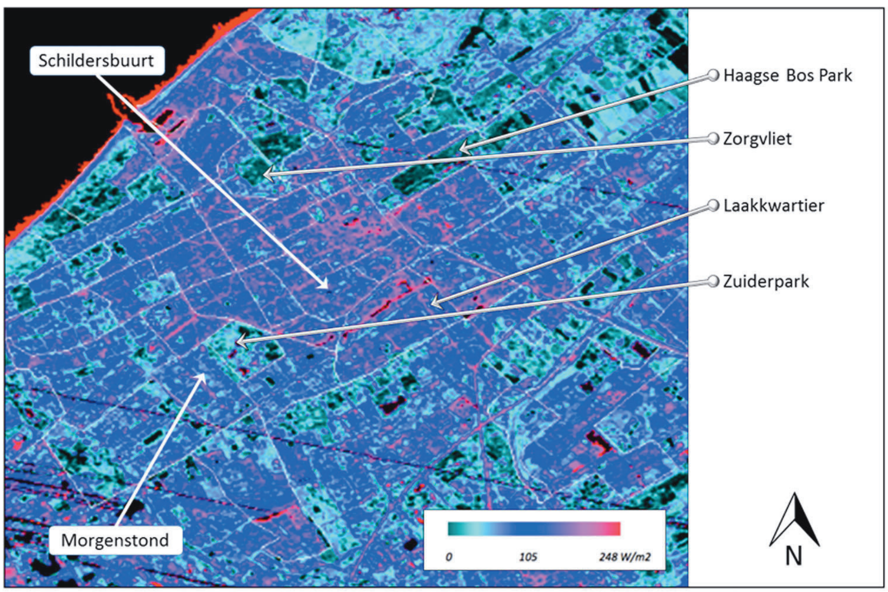


FIGURE 5.6 Storage heat flux map for The Hague, 16 July 2006. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3

Figure 5.6 presents the The Hague area comprising different neighbourhoods. For the city centre an average storage heat flux of 92.82 W/m² was determined for the 16th of July 2006. For the Schildersbuurt area the average storage heat flux turned out to be 85.08 W/m². In contrast, in all scenarios the neighbourhood of Morgenstond has a lower average storage heat flux value than the area comprised between the Haagse Bos park, Zuiderpark, Laakkwartier and Zorgvliet also presents: 68 W/m². Morgenstond also presents less nights with temperatures above 20°C.

These examples, together with the visual comparison of the two images show that the maps depicting the prediction of nights with temperatures above 20°C are aligned with the results obtained when mapping the storage heat flux results during heat waves.

§ 5.4.2 Utrecht

Brandsma & Wolters (2012) have attempted to map the night-time UHI intensity for the city of Utrecht and its surroundings using high-resolution multi-day mobile observations for a single transect through the city for the period of March 2006-January 2009 (Figure 5.7).

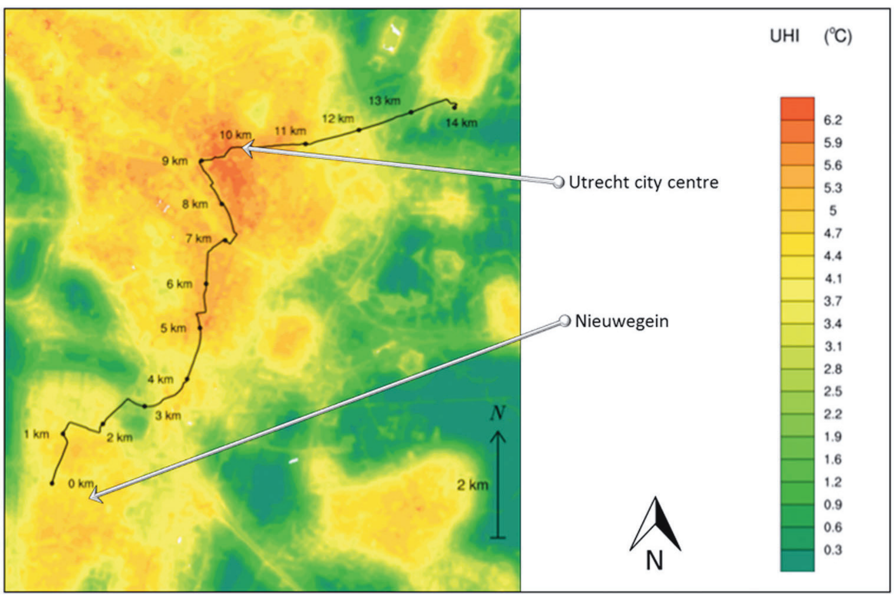


FIGURE 5.7 Spatial distribution of the maximum night-time UHI intensity for the city of Utrecht and its surroundings, from Brandsma & Wolters, 2012.

The areas with the highest night-time UHI – a temperature difference of around 6 °C – are those in the North-Eastern part of the city centre, which also present the highest storage heat flux values on the 16th of July 2006 (Figure 5.8). As a reference, the average storage heat flux value in the city centre of Utrecht is 88.67 W/m². In contrast, the area of Nieuwegein Noord, which is mapped with an UHI of around 4.3 °C also has a considerably lower storage heat flux value: 65.8 W/m².

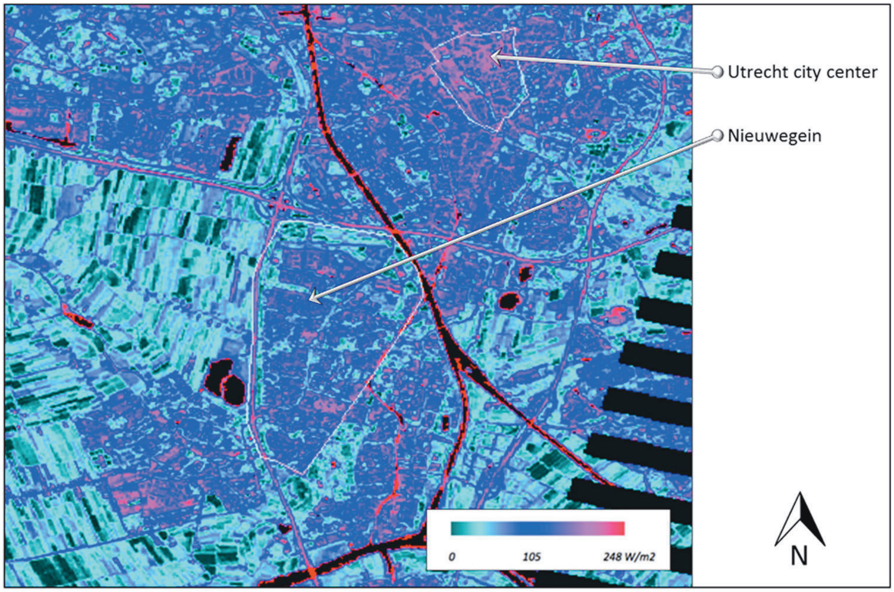


FIGURE 5.8 Storage heat flux map for Utrecht, 16 July 2006. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3

These examples, together with the visual comparison of the two images show that UHI mapping based on multi-day mobile observations seems aligned with the results obtained when mapping the storage heat flux results during a heat wave.

§ 5.5 Heat mitigation strategies in Dutch cities: relevant parameters

§ 5.5.1 Normalised Difference Vegetation Index (NDVI)

The NDVI is the Normalised Difference Vegetation Index which is used to quantify the vegetation density. Studies on land surface temperatures reveal that the imperviousness coefficient has a stronger linear relationship with land surface temperature values than with NDVI (Yuan et al., 2007), particularly in bare soil locations (Carlson et al., 1994). However, looking at the correlation between minimum air temperatures and NDVI we observe that the difference in urban and rural NDVI is linearly related with the difference in urban and rural minimum air temperatures (Gallo et al., 1993). The NDVI variation is more strongly related with the temperature variations than with the population data used in previous studies (Gallo et al., 1993). Moreover, several studies indicate that the heat fluxes can be expressed as a function of the vegetation indexes in rural environments (Choudury et al., 1994; Carlson et al., 1995). Therefore, NDVI can be considered as a relevant indicator for UHI studies.

– NDVI determination

The atmospheric correction of the satellite image was done in ATCOR 2/3 and the NDVI calculation was done in ENVI 4.7. using the index definition below:

FORMULA 5.5

NDVI = (NIR-VIS)/(NIR+VIS) Where VIS is the surface reflectance in the red region (650 nm) and NIR is the surface reflectance in the near infrared region (850 nm).

– Results of NDVI analysis

The ATCOR-2/3 User Guide, version 8.2.1, serves as a reference for the different NDVI values corresponding to different surface types. For fully vegetated surfaces it establishes an NDVI of 0.78, for partially vegetated surfaces 0.33, for dark asphalt areas 0.09, and for bright concrete areas of 0.07 (Richter & Muller, 2005). In Switzerland, the studies carried out by Parlow revealed that the lowest NDVI values with less than 0.2 could be detected in the city centre of Basel and Mulhouse as well as in some agricultural fields without vegetation during the particular time of the year when the satellite imagery was retrieved. The highest NDVI values reached values of up to 0.7 or more and these corresponded to forests and grassland areas (Parlow, 2003). In the hotspots of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch, the average NDVI ranges from 0.31 to 0.39. Even though the average NDVI values is pretty similar for all the hotspots, the NDVI visualisation (Figure 5.9) suggests that there might be some consistent NDVI differences within the hotspots. These maps provide an indication of the areas with the lowest values, thus the areas where to increase the vegetation. Overall, the storage heat flux hotspots of these six cities are located in the historical city centres and it seems delicate to suggest increasing NDVI at street level without analysing in detail the design implications of such a mitigation proposal. The implementation of green roofs would therefore be the most plausible option. Several studies (Kurn et al., 1994; Sailor, 1995) estimate that the near-surface air temperatures over vegetated areas were 1°C lower than background air temperatures.

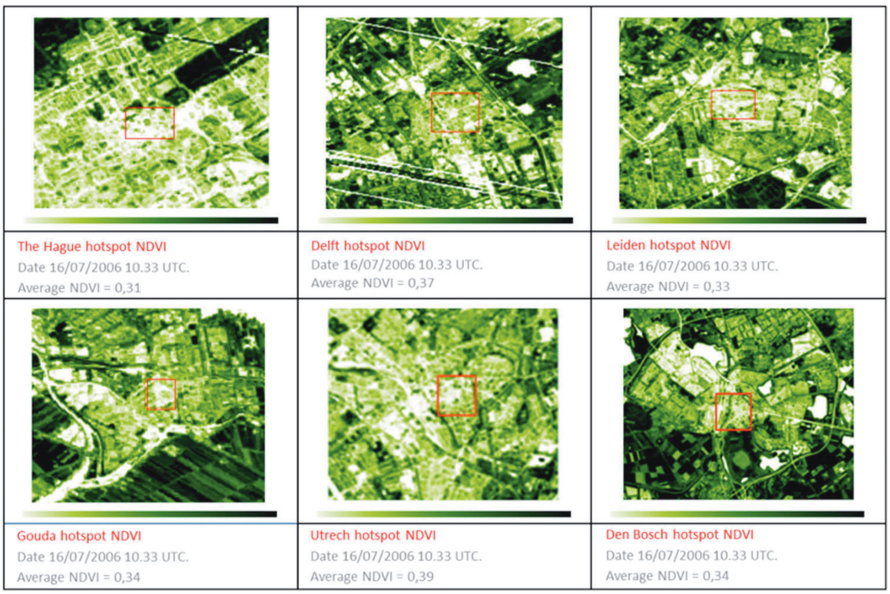


FIGURE 5.9 Normalised Difference Vegetation Index (NDVI) of the different Dutch cities. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3

§ 5.5.2 Land Surface Temperature (LST)

Areas with high diurnal LST represent areas whose heat can either be released to the atmosphere and/or to the interior of buildings within the day, or during the night, `depending on the roof properties of the buildings assessed.

- LST determination

The LST image has been obtained treating Landsat 5 TM imagery in ENVI 4.7, following the Yale Center for Earth Observation 2010 instructions to convert Landsat TM thermal bands into temperature. First the images are geometrically corrected and calibrated in ENVI 4.7, then the atmospherically corrected radiance is obtained applying Coll´s equation (Coll et al., 2010):

FORMULA 5.6

$$CV\ R2 = [(CV\ R1 - L\uparrow)/\varepsilon\tau] - [(1-\varepsilon)*(L\downarrow)/\varepsilon]$$

Where:

CV R2 is the atmospherically corrected cell value as radiance.

CV R1 is the cell value as radiance

$L\uparrow$ is upwelling radiance

$L\downarrow$ is downwelling radiance

T is transmittance

E is emissivity (typically 0.95)

The transmittance as well as the upwelling and downwelling radiance can be retrieved from NASA´s web page (NASA, 2014). Finally, the radiance can be converted into temperature (in Kelvin) as follows:

FORMULA 5.7

$$T = K2 / [\ln((K1/CVR2) + 1)]$$

Where:

T is degrees Kelvin

CVR2 is the atmospherically corrected cell value as radiance.

K1 and K2 are prelaunch calibration constants

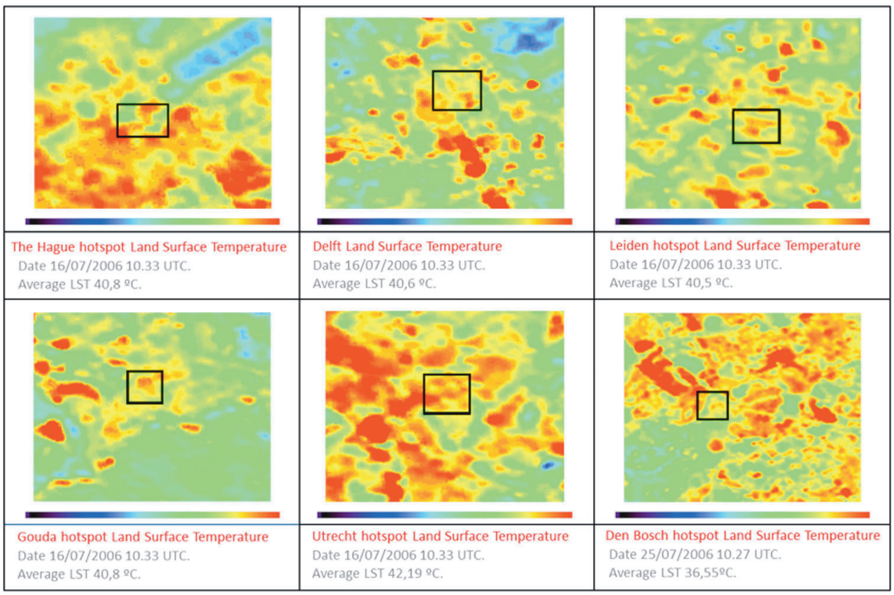


FIGURE 5.10 Land Surface Temperature (LST) of the different Dutch cities. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3

– Results of LST analysis

The land surface temperature images reveal that the storage heat flux hotpots do not necessarily present the highest diurnal LST values. As a matter of fact average land surface temperatures at 10:33 UTC in these city centers hotspots range from 36.55°C to 40.8°C (Figure 5.10), whereas other areas of the same cities present surface temperatures of up to 50°C. This is the case of The Brinckhorst, the Southern

Transvaal, Kerketuinen en Zichtenburg in The Hague, the case of Schieweg in Delft, of the industrial area close to the Zijlkwartier in Leiden, to the Kromme Gouwe in Gouda or the industrial area between the Rietveldenweg and the Koenendelsweg in Den Bosch. These areas typically represent industrial areas that heat up very fast, but that also cool off very fast. This means that either the heat quickly penetrates into the buildings, or that it is quickly reflected back into the atmosphere. In the case of industrial buildings, which typically have bituminous sheet roofs, the heat retrieved by the roof is normally transferred to the interior of the buildings. If the industrial building does not need to preserve specific thermal conditions (storage use for example), it might not be worth it to implement any adaptation measure. If instead the building needs to preserve certain thermal conditions inside, the roof thermal behaviour could easily be improved by applying a reflective coating or surface coatings.

§ 5.5.3 Sky View Factor (SVF)

The sky view factor (SVF) was defined by Oke as the ratio of the amount of the sky seen from a given point to that potentially available (Oke, 1987). Its values range from 0 for full obstruction, to 1 for completely open areas. The average SVF in central parts of European cities ranges from 0.40 to 0.75, and the relationship with the nocturnal UHI was established by Oke (1981) and Park (1987), as follows:

FORMULA 5.8

$$UHImax = 13.20 - 10*SVF$$

Where UHI max is the maximum UHI and SVF is the sky view factor.

These results are aligned with the studies carried out in Gothenburg (Sweden) and in Szeged (Hungary), which find a strong relationship between the SVF and the nocturnal UHI in calm, clear nights (Svensson, 2004; Unger, 2009). However, other investigations carried out in Germany reveal that the nocturnal UHI is not only affected by the horizon obstructions (SVF) but also by the thermal properties of the materials, and they only find a correlation between the long-wave radiation and the UHI, but not between the UHI and the SVF (Blankenstein & Kuttler, 2004). Many of these studies highlight the importance of the way the SVF is calculated, and at which height it is calculated.

– Sky View Factor determination

In the present study the calculation is done through the use of a SVF visualization tool developed by the Scientific Research Centre of the Slovenian Academy of Sciences and Arts (Zakšek et al., 2011) applied to the geographic Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) of the concerned Dutch cities.

The Sky View Factor analysis allows to draw the city limits, to identify different urban structures within a city and to identify specific streets or urban areas with higher or lower sky view factors.

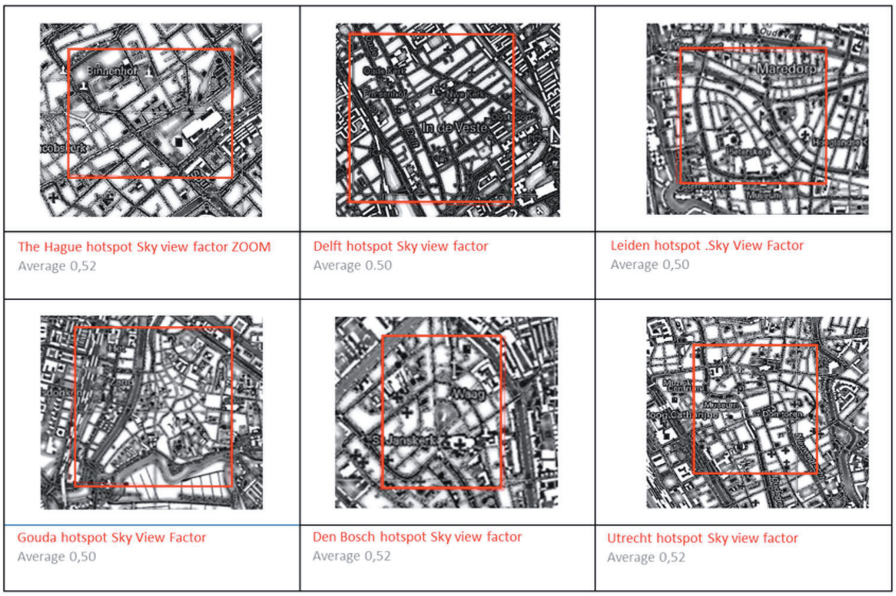


FIGURE 5.11 Sky View Factor (SVF) of the different Dutch cities

– Results of SVF analysis

The average Sky View Factor is almost the same for all hotspots (Figure 5.11). In the hotspots of the six analyzed cities, The Sky View Factor maps do not allow to identify specific hotspots within the urban areas. The Sky View Factor analysis allows to draw the city limits, to identify different urban structures within a city and to identify specific streets or urban areas with higher or lower sky view factors.

§ 5.5.4 Anthropogenic heat losses

Anthropogenic heat is not assessed in this paper. Average anthropogenic heat values in Europe range from 1.9 to 4.6 W/m^2 (Lindberg et al., 2013). These values increase in the urban environment reaching the 20 W/m^2 in cities as Berlin (Taha, 1997). Anthropogenic heat plays a role in the formation of UHI but they are not decisive in European cities.

§ 5.5.5 Coolspots and cool wind corridors

Just as hotspots, coolspots can be identified through the storage heat flux mapping. Coolspots are areas with the lowest storage heat flux values; if they are situated close to a hotspot, climate adaptation measures could be focused on transporting cool air from the coolspots to the hotspot, or on getting the heat from the hotspot dissolved in the coolspots. The calculation of the heat fluxes is done through different models for urban and for rural surfaces. In order to identify the coolspots surrounding the cities, the rural areas algorithm was applied.

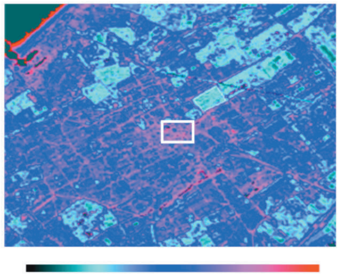
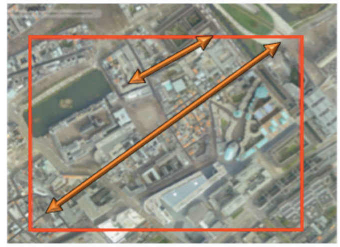
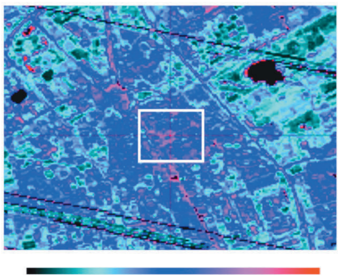
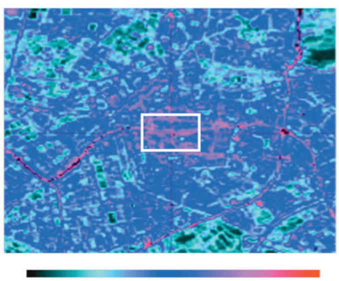
– Coolspot determination

Storage heat flux is mapped in this study using Landsat 5 TM imagery and ATCOR 2/3 for the storage heat flux calculation. Since the coolspots often correspond to green areas, the ATCOR "rural" algorithm was applied for the estimation of the storage heat flux which employs a parametrization with the soil adjusted vegetation index (SAVI) (Choudury 1994, Carlson et al. 1995).

FORMULA 5.9

$$G = 0.4\ Rn\ (SAVIm - SAVI)/SAVIm$$

Where G is the storage heat flux, Rn represents the net radiation, SAVI represents the Soil Sdjusted Vegetation Index and and SAVIm = 0.814 represents full vegetation cover.

	
The Hague hotspot surrounding COOLSPOT Closest coolspot: Haagse Bos.	The Hague hotspot cool paths. Distance from hotspot to coolspot: CONNECTED
	
Delft hotspot surrounding COOLSPOT Closest coolspot: Delftse Hout.	Delft hotspot cool paths Distance from hotspot to coolspot: 580 m
	
Leiden hotspot surrounding COOLSPOT Closest coolspot: South of Kanaalweg	Leiden hotspot wind paths. Distance from hotspot to coolspot: 1300m

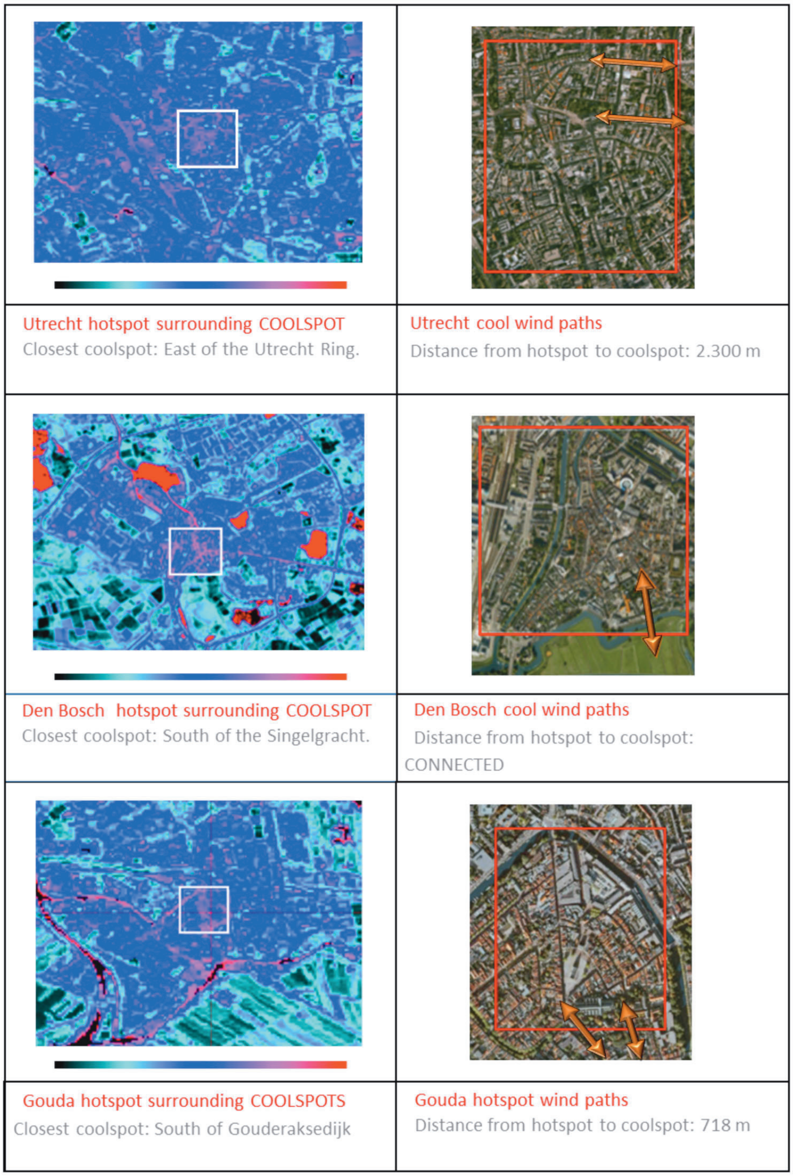


FIGURE 5.12 Coolspot analysis (Storage heat flux map for The Hague, Delft, Leiden, Utrecht, Den Bosch and Gouda 16 July 2006. Landsat image courtesy of the U.S. Geological Survey. USGS/NASA Landsat. further processed with ENVI 4.7 and Atcor 2.3) and wind corridor analysis of the different Dutch cities. Right column google earth imagery.

- Results of coolspot analysis

For the hotspot of the Hague, the coolspot identified is The Haagse Bos, in Delft the Delftse Hout, in Leiden the potential coolspot is located at around 1,300 m from the hotspot and corresponds to the greenfields to the South of the Kanaalweg and to the West of Zaalbergweg; in Gouda the greenfields to the South of the Gouderaksedijk (West of the Goudeseweg) although they are located 700 m away from the hotspot; in Utrecht the hinterland located to the East of the Utrecht Ring, in the areas of Fort Voordorp could also have a cooling effect on the hotspot although it is located at a distance of 2,300 m from it, in Den Bosch the greenfields located to the South of the Singelgracht and to the West of the Zuiderplas could represent a natural cooling source for the hotspot (Figure 5.12).

The identification of coolspots in the surrounding areas of the hotspots allows promoting the creation of cool wind corridors connecting the coolspots to the hotspots. In the case of The Hague, Delft, Gouda and Den Bosch the cooling sources are relatively close to the hotspots, and the efficiency of the cool corridor is almost guaranteed, as they would also benefit from the urban heat island plume. The adaptation measure in this case would consist of ensuring that the selected "cool corridors" (existing streets or canals, connecting the cool and hotspots) remain cleared from obstacles to ensure the maximum wind circulation during heat waves. The cases of Leiden and Utrecht probably require deeper wind analysis studies, as in both cases the cooling source is at a distance greater than 1,000 m from the hotspot.

§ 5.5.6 Albedo

In the urban environment it can be assumed that the storage heat flux represents 40% of the net radiation (Parlow, 1998). Increasing the surface reflectance (albedo) of the urban surfaces is considered as a means to reduce the UHI since it reduces the net short-wave (solar) radiation, thus reducing the total surface net radiation. Albedo the index representing the surface reflectance. It indicates the fraction of short-wave radiation that is reflected from land surfaces into the atmosphere. When a surface albedo is 0 it doesn´t reflect any radiation, and when it is 1 all the incoming radiation is reflected to the atmosphere.

Most US and European cities have albedos of 0.15 to 0.20 (Taha, 1997). A white surface with an albedo of 0.61 is only 5°C warmer than ambient air whereas conventional gravel with an albedo of 0.09 is 30°C warmer than air (Taha et al., 1992). Other studies carried out by Taha et al. reveal that increasing the surface albedo from 0.25 to 0.40 could lower the air temperature as much as 4°C (Taha et al., 1988), or even that an increase of 0.1 of the hotspot overall albedo reduces the UHI by 1°C. (Sailor 1995).

It is important to analyse albedo surface images, since vegetated areas or water bodies might present low albedo values, yet not necessarily have a negative impact on the UHI.

– Albedo determination

The albedo of the six Dutch cities is mapped again using Landsat 5 TM imagery and importing it into ATCOR 2/3 for the albedo calculation (Figure 5.13).

In ATCOR 2/3 (Richter & Schlapfer, 2013) the wavelength-integrated surface reflectance (in a strict sense the hemispherical-directional reflectance), is used as a substitute for the surface albedo (bi-hemispherical reflectance) and it is calculated as:

FORMULA 5.10

$$a = \left[\int_{0,3\mu m}^{2,5\mu m} \rho(\lambda) d\lambda \right] / \int_{0,3\mu m}^{2,5\mu m} d\lambda$$

Where a is the wavelength-integrated surface reflectance (used as a substitute for the surface albedo

For Landsat 5 TM the following assumptions are made by ATCOR 2/3 for extrapolation:

Extrapolation for the 0.30-0.40 µm region: $\rho_{0.3-0.4\mu m} = 0.8\ \rho_{0.45-0.50\mu m}$.

Extrapolation for the 0.40-0.45 µm region: $\rho_{0.4-0.45\mu m} = 0.9\ \rho_{0.45-0.50\mu m}$.

The reflectance reduction factors in the blue part of the spectrum account for the decrease of surface reflection for most land covers (soils, vegetation). The extrapolation to longer wavelengths is computed as:

$\rho_{2.0-2.5\mu m} = 0.5\ \rho_{1.6\mu m}$, if $\rho_{850}/\rho_{650} > 3$ (vegetation)

$\rho_{2.0-2.5\mu m} = \rho_{1.6\mu m}$, else

Wavelength gap regions are supplemented with interpolation. The contribution of the 2.5 - 3.0 µm spectral region can be neglected, since the atmosphere is almost completely opaque and absorbs all solar radiation.

Albedo: range 0-1000, scale factor 10, e.g., scaled albedo=500 corresponds to albedo=50%.

FIGURE 5.13 Albedo of the different Dutch cities. Landsat image (Courtesy of the U.S. Geological Survey. USGS/ NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3

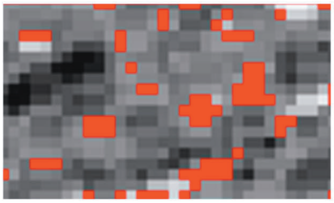
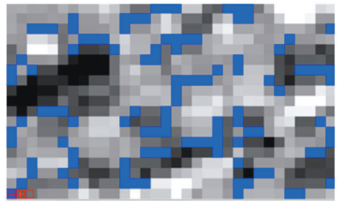
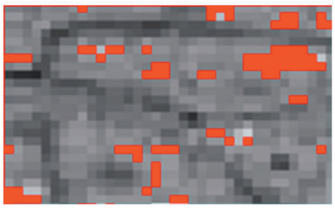
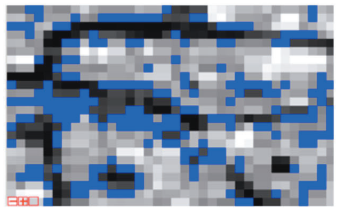
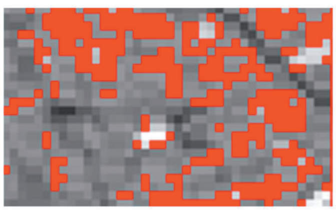
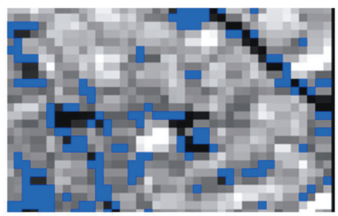
§ 5.6 Quantification of heat reduction through roof mitigation strategies.

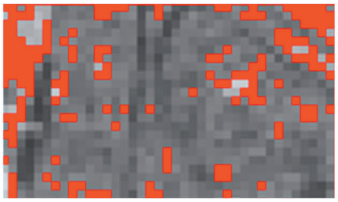
§ 5.6.1 Increasing the albedo

Delft, Leiden, Gouda, Utrecht and Den Bosch have a dense traditional 17th century inner-city with red ceramic roof tiles, brick street paving and canals. In order to improve the albedo in these hotspots, intervening on the brick street paving is provocative, as it is considered as part of the cultural heritage of these neighbourhoods. Instead, on the long run the existing roof tiles could be replaced by cool colour tiles, once the existing ones arrive to the end of their life cycle. Traditional tiles have albedo values that ranges from 18 to 22%, whereas the reflectance of orange cool tiles have a reflectance of around 50% (U.S. Environmental Protection Agency's Office of Atmospheric Programs). It is important to note that the market for these cool tiles is not consolidated yet, and that one possible municipal or regional adaptation measure would be to encourage the production or the import of these innovative products.

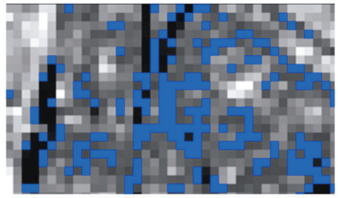
As far as the bitumen flat roofs are concerned the primary cool roof option for moderate repair would be to install highly reflective coatings or surface treatments that can be applied to bituminous cap sheets, gravel, metal and various single ply materials. For more extensive repairs of flat roofs the primary option is the application of thermal insulation and highly reflective single ply membranes (or pre-fabricated sheets) generally glued to the entire roof surface.

The results of the estimation of the UHI reduction through the implementation of albedo (sloped and flat) (Figure 5.14) roof mitigation actions have an UHI reduction effect that ranges between 1.4°C and 3°C. (Figures 5.15, 5.16, 5.17, 5.18, 5.19 and 5.20) Considering that the max UHI values for the 95 percentile, calculated with the hobby meteorologists data (Hove et al., 2011) for the cities of The Hague, Delft and Leiden ranges from 4.8°C to 5.6°C implementing roof mitigation strategies seems an efficient way of reducing the UHI in these Dutch cities.

	
The Hague hotspot: Clay tile surface estimation 5,23 Ha	The Hague hotspot: Bitumen flat roof surface estimation 7,97 Ha
	
Leiden hotspot: Clay tile surface estimation 5,78 Ha	Leiden hotspot: Bitumen flat roof surface estimation 15 Ha
	
Delft hotspot: Clay tile surface estimation 26,46 Ha	Delft hotspot: Bitumen flat roof surface estimation 15,5 Ha

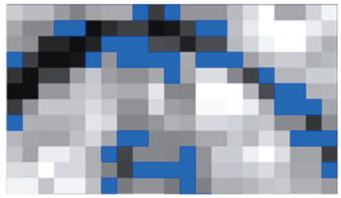


Den Bosch hotspot: Clay tile surface estimation
27,81 Ha



Den Bosch hotspot: Bitumen flat roof surface estimation
21,42Ha

Gouda hotspot: Clay tile surface estimation
21,21 Ha



Gouda hotspot: Bitumen flat roof surface estimation
14,13 Ha

Utrecht hotspot: Clay tile surface estimation ZOOM
1,09 Ha

Utrecht hotspot: Bitumen flat roof surface estimation
21,21Ha

FIGURE 5.14 Albedo increase analysis of the different Dutch cities.

– The Hague: The UHI reduction estimation for several roof intervention scenarios can be seen in figure 5.15.

THE HAGUE					
Current situation					
	Hotspot surface (Ha)	Hotspot average albedo	Estimated UHI max for 95 percentile		
	44,46	0,15	5,3		
Mitigation scenario:					
Mitigation action 1: Next 10 years	Apply over flat bitumen roofs (albedo 0.13 to 0.15) white coating (0.7) OR replace by white single -ply membrane (0.7)				
	surface	albedo of white coating or of single-ply membrane	Hotspot new average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.130 to 0.150 or highlevel estimation of **flat bitumen roof** surface	7,97	0,7	0,25	0,10	4,31
				UHI reduction:	**0,99**
Mitigation action 2: Next 50 years	Replace all hotspot sloped roof clay tiles (albedo 0.18 to 0.22) by coloured tiles with cool pigments (albedo 0.5)				
	surface	albedo of coloured tiles with cool pigments	Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.185 to .0220 or highlevel estimation of **sloped roof clay tile** surface	5,23	0,5	0,19	0,04	4,89
				UHI reduction:	**0,41**
Mitigation action 1 + 2: Next 50 years					
			Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
			0,29	0,14	3,90
				UHI reduction:	**1,40**

FIGURE 5.15 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of The Hague

– Delft: The UHI reduction estimation for several roof intervention scenarios can be seen in figure 5.16.

DELFT					
Current situation					
	Hotspot surface (Ha)	Hotspot average albedo	Estimated UHI max for 95 percentile		
	92,8	0,17	4,8		
Mitigation scenario:					
Mitigation action 1: Next 10 years	Apply over flat bitumen roofs (albedo 0.13 to .15) white coating (0.7) OR replace by white single -ply membrane (0.7)				
	surface	albedo of white coating or of single-ply membrane	Hotspot new average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.130 to 0.150 or highlevel estimation of **flat bitumen roof** surface	15,5	0,7	0,26	0,09	3,91
				UHI reduction:	**0,89**
Mitigation action 2: Next 50 years	Replace all hotspot sloped roof clay tiles (albedo 0.18 to 0.22) by coloured tiles with cool pigments (albedo 0.5)				
	surface	albedo of coloured tiles with cool pigments	Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.185 to .0220 or highlevel estimation of **sloped roof clay tile** surface	26,46	0,5	0,26	0,09	3,86
				UHI reduction:	**0,94**
Mitigation action 1 + 2: Next 50 years					
			Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
			0,35	0,18	2,97
				UHI reduction:	**1,83**

FIGURE 5.16 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of Delft

– Leiden: The UHI reduction estimation for several roof intervention scenarios can be seen in figure 5.17.

LEIDEN					
Current situation					
	Hotspot surface (Ha)	Hotspot average albedo	Estimated UHI max for 95 percentile		
	61,65	0,15	5,6		
Mitigation scenario:					
Mitigation action 1: Next 10 years	Apply over flat bitumen roofs (albedo 0.13 to .15) white coating (0.7) OR replace by white single -ply membrane (0.7)				
	surface	albedo of white coating or of single-ply membrane	Hotspot new average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.130 to 0.150 or highlevel estimation of **flat bitumen roof** surface	15	0,7	0,28	0,13	4,26
				UHI reduction:	**1,34**
Mitigation action 2: Next 50 years	Replace all hotspot sloped roof clay tiles (albedo 0.18 to 0.22) by coloured tiles with cool pigments (albedo 0.5)				
	surface	albedo of coloured tiles with cool pigments	Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.185 to .0220 or highlevel estimation of **sloped roof clay tile** surface	5,78	0,5	0,18	0,03	5,27
				UHI reduction:	**0,33**
Mitigation action 1 + 2: Next 50 years					
			Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
			0,32	0,17	3,93
				UHI reduction:	**1,67**

FIGURE 5.17 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of Leiden

– Gouda: The UHI reduction estimation for several roof intervention scenarios can be seen in figure 5.18 .

GOUDA					
Current situation					
	Hotspot surface (Ha)	Hotspot average albedo	Estimated UHI max for 95 percentile		
	30,8	0,17	5		
Mitigation scenario:					
Mitigation action 1: Next 10 years	Apply over flat bitumen roofs (albedo 0.13 to .15) white coating (0.7) OR replace by white single -ply membrane (0.7)				
	surface	albedo of white coating or of single-ply membrane	Hotspot new average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.130 to 0.150 or highlevel estimation of **flat bitumen roof** surface	4,13	0,7	0,24	0,07	4,29
				UHI reduction:	**0,71**
Mitigation action 2: Next 50 years	Replace all hotspot sloped roof clay tiles (albedo 0.18 to 0.22) by coloured tiles with cool pigments (albedo 0.5)				
	surface	albedo of coloured tiles with cool pigments	Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.185 to .0220 or highlevel estimation of **sloped roof clay tile** surface	21,21	0,5	0,40	0,23	2,73
				UHI reduction:	**2,27**
Mitigation action 1 + 2: Next 50 years					
			Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
			0,47	0,30	2,02
				UHI reduction:	**2,98**

FIGURE 5.18 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of Gouda

– Utrecht: The UHI reduction estimation for several roof intervention scenarios can be seen in figure 5.19.

UTRECHT					
Current situation					
	Hotspot surface (Ha)	Hotspot average albedo	Estimated UHI max for 95 percentile		
	60,8	0,14	5		
Mitigation scenario:					
Mitigation action 1: Next 10 years	Apply over flat bitumen roofs (albedo 0.13 to .15) white coating (0.7) OR replace by white single -ply membrane (0.7)				
	surface	albedo of white coating or of single-ply membrane	Hotspot new average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.130 to 0.150 or highlevel estimation of **flat bitumen roof** surface	21,21	0,7	0,34	0,20	3,05
				UHI reduction:	**1,95**
Mitigation action 2: Next 50 years	Replace all hotspot sloped roof clay tiles (albedo 0.18 to 0.22) by coloured tiles with cool pigments (albedo 0.5)				
	surface	albedo of coloured tiles with cool pigments	Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.185 to .0220 or highlevel estimation of **sloped roof clay tile** surface	1,09	0,5	0,15	0,01	4,94
				UHI reduction:	**0,06**
Mitigation action 1 + 2: Next 50 years					
			Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
			0,34	0,20	2,98
				UHI reduction:	**2,02**

FIGURE 5.19 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of Utrecht

– Den Bosch: The UHI reduction estimation for several roof intervention scenarios can be seen in figure 5.20.

DEN BOSCH					
Current situation					
	Hotspot surface (Ha)	Hotspot average albedo	Estimated UHI max for 95 percentile		
	133	0,17	5,5		
Mitigation scenario:					
Mitigation action 1: Next 10 years	Apply over flat bitumen roofs (albedo 0.13 to .15) white coating (0.7) OR replace by white single -ply membrane (0.7)				
	surface	albedo of white coating or of single-ply membrane	Hotspot new average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.130 to 0.150 or highlevel estimation of **flat bitumen roof** surface	21,42	0,7	0,26	0,09	4,65
				UHI reduction:	**0,85**
Mitigation action 2: Next 50 years	Replace all hotspot sloped roof clay tiles (albedo 0.18 to 0.22) by coloured tiles with cool pigments (albedo 0.5)				
	surface	albedo of coloured tiles with cool pigments	Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
Area within hotspot with albedo ranging from 0.185 to .0220 or highlevel estimation of **sloped roof clay tile** surface	27,81	0,5	0,24	0,07	4,81
				UHI reduction:	**0,69**
Mitigation action 1 + 2: Next 50 years					
			Hotspot average albedo	Average albedo increase	Estimated UHI max for 95 percentile
			0,32	0,15	3,96
				UHI reduction:	**1,54**

FIGURE 5.20 Estimation of UHI reduction derived from the implementation of the roof mitigation strategies in the storage heat flux hotspot of Den Bosch

§ 5.7 Conclusions of UHI analysis of Dutch cities

§ 5.7.1 General findings

This study has two main objectives: the first one is to develop a method for the urban heat assessment based on the analysis of satellite imagery, and the second one is to develop some customised UHI adaptation guidelines for the cities of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch.

– Satellite imagery analysis for UHI assessment:

Remote sensing can effectively be used to identify urban heat hotspots in areas where there is a lack of micro-measurements. Storage heat flux seems a relevant indicator for the identification of urban areas with a high tendency to accumulate heat. Storage heat flux can be mapped using Landsat 5 TM imagery and processing it in ATCOR 2/3 and ENVI 4.7.

The use of Landsat 5TM processed in ATCOR 2/3 and ENVI 4.7. also allows defining mitigation strategies to reduce urban heat in the identified hotspots. Mapping vegetation indexes, land surface temperature, coolspots and albedo, allows identifying areas where to implement more vegetation, areas where wind corridors (connecting hotspots to coolspots) could be created and areas where to increase the reflectance of the materials (to improve the albedo).

The same satellite imagery can be used to quantify the surface of bituminous flat roofs and of clay sloped roofs, in order to calculate a high level estimation of the mitigation effect of the increase of albedo of those surfaces.

– Customised UHI assessment for the cities of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch:

The storage heat flux analysis for the 6 cities reveals that the hotspots have average storage heat flux values that range from 90 W/m² to 105 W/m². See figure 5.21. Hotspot areas (areas with highest storage heat flux concentration) range from 30.8 ha in Gouda to 133 ha in Den Bosch.

Dutch cities	Surface of the hotspot **Ha**	Storage Heat Flux **W/m2**	NDVI	LST **ºC**	Albedo	Average SVF	Sensible heat	Coolspot stge flux (distance to hotspot m)
The Hague	44,5	101	0,31	40,8	0,15	0,5	156	26 (connected)
Delft	92,8	91,2	0,37	40,6	0,17	0,5	76,3	47 (580)
Leiden	61,7	103	0,33	40,5	0,15	0,5	173,6	40 (1300)
Gouda	30,8	96,7	0,34	40,8	0,17	0,5	168,4	41 (718)
Utrecht	60,8	94,6	0,39	42,2	0,14	0,5	184,4	47,7 (2300)
Den Bosch	133	104,1	0,34	36,6	0,17	0,5	138,8	58,7 (connected)

FIGURE 5.21 Analysis of storage heat flux hotspots in the cities of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch. It is important to highlight that the storage heat flux images and values might be distorted in areas covered by water, since the algorithm used by ATCOR for the storage heat flux calculation is based on Parlow´s equation G=0.4 Rn, which is a valid assumption for urban areas but not for water surfaces

The hotspots in all cities correspond with the old city centres of each city, except for the case of The Hague, where it is not related to a homogeneous urban structure. The hotspots of Delft, Leiden, Gouda, Utrecht and Den Bosch, correspond to the dense traditional 17th century Dutch neighbourhoods with red ceramic roof tiles, brick street paving, and canals. These are typical dwelling neighbourhoods with commercial premises in the ground floor, characterised by a high quality of life. These inner-city areas belong to representative neighbourhoods with very intense street activity (commercial, leisure, and touristic). In contrast, the hotspot of the city of The Hague corresponds with an area with bituminous flat roofs and asphalt paving.

The analysis of the vegetation index maps allows to identify areas where the average value is below 0.2, and that could eventually benefit from an increase of vegetation, whether that vegetation is implemented at street level or at roof level. The coolspot analysis reveals that the in the cities of The Hague, Delft, Gouda and Den Bosch the distance between hotspots and coolspots is below 1,000m, which suggests that the creation of wind corridors could efficitiently contribute to the mitigation of the urban heat, and the analysis of the albedo maps allows to identify the areas that could benefit from an increase of the surface reflectance.

The quantification of the bituminous flat roofs and clay sloped roofs, reveals that increasing the albedo of both type of surfaces could help reduce the UHI from 1.4 to 3 °C in the analysed cities.

§ 5.7.2 Implications of the work

Using remote sensing for UHI assessment allows cities to identify the areas where to concentrate their mitigation efforts. Further, it provides them with an overview of different adaptation alternatives (vegetation, albedo, wind corridors,…) to help combine the climate mitigation efforts with other urban planning priorities, and finally it facilitates the quantification of the measures mitigation effect. Cities often only need this kind of high level overview to start taking urban heat into consideration in their urban plans. Deeper climatological studies can always be carried out to provide a more detailed assessment where needed.

The simultaneous analysis of several cities can help increase their awareness, and develop parallel mitigation plans, which can benefit from one another, sharing not only scientific and applied knowledge, but also implementation and management strategies. Remote sensing is specifically suited to carry out the analysis of several cities at the same time due to the large size of its scenes.

§ 5.7.3 Replicability of the study

The study can be replicated with a basic remote sensing and climatological knowledge and requires a certain command of the two main software utilised (ENVI 4.7 and ATCOR 2.3). One critical item is the selection of the satellite imagery, which should preferably be retrieved during a heat wave, and on a cloudless and windless day.

The satellite imagery used for this study is Landsat 5 TM however the same exercise can be performed with finer resolution satellite imagery, thus obtaining more accurate results.

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6 Surface thermal analysis of North Brabant cities and neighbourhoods during heat waves

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Abstract

The urban heat island effect is often associated with large metropolises. However, in the Netherlands even small cities will be affected by the phenomenon in the future (Hove et al., 2011), due to the dispersed or mosaic urbanisation patterns in particularly the southern part of the country: the province of North Brabant. This study analyses the average night-time land surface temperature (LST) of 21 North-Brabant urban areas through 22 satellite images retrieved by Modis 11A1 during the 2006 heat wave and uses Landsat 5 Thematic Mapper to map albedo and Normalised difference temperature index (NDVI) values. Albedo, NDVI and imperviousness are found to play the most relevant role in the increase of night-time LST. The surface cover cluster analysis of these three parameters reveals that the 12 "urban living environment" categories used in the region of North Brabant can actually be reduced to 7 categories, which simplifies the design guidelines to improve the surface thermal behaviour of the different neighbourhoods thus reducing the Urban Heat Island (UHI) effect in existing medium size cities and future developments adjacent to those cities.

Keywords: urban heat island; climate change; sustainable urban planning; remote sensing

§ 6.1 Introduction

§ 6.1.1 Heat islands and medium size cities

The urban heat island (UHI) refers to the temperature difference between urban areas and their rural and/or natural surroundings. This temperature difference may affect the air temperature, the land surface temperature (LST) or both. Although the two are related, the difference is that while land surface temperature´s peak takes place during the day, the air temperatures differences are largest after sunset. The air temperature difference peak that is typically reached after sunset can reach up to 12°C for a city of 1 million inhabitants (United Stated Environmental Agency). These relative high temperatures are especially problematic during heat waves and can easily result in heat stress among vulnerable segments of the urban population, leading to widespread mortality. Several climate studies show that even though The Netherlands may seem relatively safe from heat events due to its moderate maritime climate and its polycentric urban structure, it is actually also affected by heat events like those that took place in France in 2003 or in Russia in 2010 (Hove et al., 2011; Van der Hoeven. and Wandl, 2014; Albers et al., 2015).

Many studies highlight the importance of developing and implementing urban planning measures to adapt our cities to climate change (Galderisi and Ferrara, 2012; Papa et al., 2015; Deppisch and Dittmer ,2015; Balaban, and Balaban, 2015). The impact that heat islands can have on society has been studied in the last decade by several research groups (Stone., 2012). A link was found between the night-time urban heat island as observed by satellites and the excess mortality in Paris during the heat wave of 2003 (Dousset et al., 2011). Other investigations showed that the urban heat island did have a measurable effect on aggravating the impact of the same heat wave event in Paris (Vandentorren et al., 2006). Similar conclusions were drawn in the case of London (Mavrogianni et al., 2011). In all of these cases the object of research is the large metropolis. Similar investigations into dispersed regional urbanisation patterns are lacking.

North Brabant is a province located in the South and Center of the Netherlands. It is one of the biggest and most populated Dutch provinces. Due to its polycentric urban structure the Netherlands still has a relative high population density. The population that inhabits the Dutch towns and cities is ageing and becomes more vulnerable to heat. The four climate scenarios that are drawn up by the Royal Netherlands Meteorological Institute (KNMI) predict an increase of the global temperatures of at least 1°C (Van den Hurk et al., 2006) and predictions foresee an increased probability of summer heat waves (Sterl et al, 2008). The definition of a heat wave differs from country to country. In the Netherlands each period of at least five consecutive days with a maximum temperature above 25°C, of which at least three days peak above 30°C is registered as an official heat wave.

§ 6.1.2 North Brabant: particular mosaic urban structure

In the context of urban heat, the province of North Brabant is particularly interesting. The urban structure of NorthBrabant (2.5 million inhabitants, 500,000 ha) consists of a network of almost 300 small-size cities (urban cores in rural areas with surfaces below 900 ha) and some 60 midsize cities (urban concentration areas with surfaces below 8,000 ha) interleaved with rural and natural park areas. The overall percentage of urbanized land represents 15.4%. The future spatial vision of North Brabant region (Provincie Noord-Brabant, 2010) organizes the midsize cities in three clusters: the first one comprises the two most important agglomerations Tilburg (12,000 ha and 550,000 inhabitants) and Eindhoven (750,000 inhabitants), the second one which comprises a group of cities to the west: Bergen op Zoom, Roosendaal, Etten-Leur, Breda, Oosterhout, Waalwijk, ´s-Hertogenbosch and Oss (with sizes ranging from 12,900 ha in Breda to 5,590 ha in Etten-Leur) and the third category which consists of Uden (6,700 ha) and Veghel (7,900 ha), two former villages that have strongly grown in the last decade and that have a marked suburban and industrial character. The urban structure is considered as a network up to the point that the five most important cities of the region - Tilburg, Breda, ´s-Hertogenbosch, Eindhoven and Helmond - receive the name of Brabantstad, which means in Dutch as much as: Brabant City.

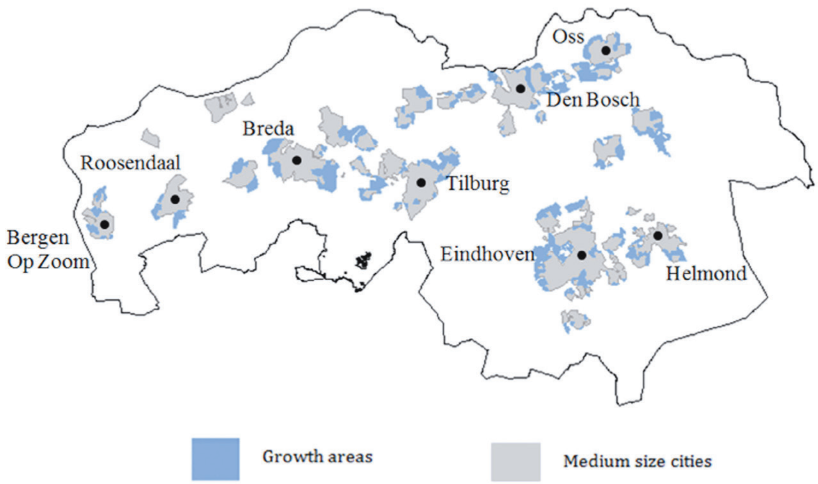

FIGURE 6.1 Growth areas adjacent to medium-size cities (Province North Brabant. Spatial vision, 2010)

– Future expansion plans of the region

The future spatial vision of North-Brabant (Provincie Noord-Brabant, 2010) foresees to enhance the spatial structure of the urban network through two different development prospects for small cities and for medium-size cities. The intention is to have midsize cities host regional urban infrastructures, as opposed to the small cities, which will inevitably play a role at a more local scale. In order to materialise the reinforcement of the urban network, the region of North Brabant has identified growth areas (in Dutch "zoekgebieden voor verstedelijking") connected both to small and midsize cities (Provincie Noord-Brabant, 2014). These are rural areas, which will be converted into urban plots, connected to existing cities (Figure 6.1). The Province plans to urbanise over 25,000 hectares of which roughly 17,000 ha are adjacent to midsize cities. Overall the future percentage of urbanised land will increase from 15.4% to 20.4%. The province of North Brabant is aware of the implications of increasing the urbanised areas, and has used the "ladder for sustainable urbanisation" developed by the Dutch Ministry of Infrastructure and Environment to compare the urban development needs with the options to restructure nearby derelict areas prior to delimiting the "growth areas". However, the potential urban heat island aggravation produced by the growth of urban areas has not been taken into consideration.

§ 6.1.3 Research questions

How can we ensure that future development plans do not aggravate the urban heat island effect in the province of North Brabant?

In order to answer this question, four sub questions have been formulated:

- What is the extend of the current heat island problem in North Brabant?
- How does albedo, Normalised difference vegetation index (NDVI), imperviousness, city size and proximity to other urban areas influence the phenomenon?
- Which of these play the most relevant UHI role?
- Can we establish a surface thermal urban classification to provide design guidelines to ensure that future developments do not aggravate the UHI phenomenon?

§ 6.2 Methodology

§ 6.2.1 Determining the role of different parameters in the formation of the UHI in the region of North Brabant

In the first section of the study the authors have mapped and calculated the average night-time land surface (LST) temperature (which has been calculated for 21 medium-size cities in the region of North Brabant with MODIS 11A1 images retrieved during the heat wave of 2006 in The Netherlands), albedo (calculated with Landsat 5TM imagery retrieved during the 2006 heat wave), NDVI (calculated with Landsat 5TM imagery retrieved during the 2006 heat wave), imperviousness coefficient (calculated using official Netherlands ArcGis files) and surface, and a multiple regression analysis has been completed to understand how each of these parameters affected the average night-time LST, and which of them played the most important role in the region of North Brabant. Excel´s dynamic charts have been used to establish thresholds and reference figures for each of the analysed parameters.

§ 6.2.2 Night-time land surface temperature from July 2006 as a key UHI indicator

The spatial pattern of the daytime (LST) urban heat island differs often significantly from the spatial pattern of the night-time (air temperature) urban heat island. However, the night-time air temperature and LST heat islands have strong correlations (Nichol,. 2005). The main exceptions are water surfaces. Because the cities in the province North-Brabant have relatively little open water, night-time satellite imagery can be used as a source of data for determining for the overall UHI effect.

In this context the authors analysed the average night-time surface temperature of 21 midsize cities (with surfaces ranging from 117 ha to 7,700 ha) using 22 satellite images retrieved by Modis 11A1 during July 2006 (Figure 6.2). July 2006 was the warmest month on record since systematic measurements started some 300 years ago in the Netherlands. The mean daily temperature in July 2006 was 22.3°C, almost 5°C higher than the average over the period of 1971-2000: 17.4°C according to the Royal Netherlands Meteorological Institute (KNMI, 2006). Temperatures reached on July 19th 2006 a maximum of 35.7 °C (KNMI, 2013).

Statistics Netherlands published an article in its web magazine that states that 1,000 inhabitants died in July 2006 above the average mortality in a July month. Predominantly in the western part of the country, by the way.

Topography plays a significant role in many regions in the world when it comes to climate. Not so in the case of North-Brabant. North-Brabant is like much of the rest of the Netherlands: flat. The lowest parts in the western part of the province measure 1-2 metres above sea level. The highest parts in the east at a distance of 100 kilometres are 45 metres above sea level.

There is a lack of prevailing winds during heat waves. Heat waves emerge in the Netherlands predominantly under the condition of low or even lacking wind speeds. Problems with urban heat occur especially when there is no or little wind. For example, during the temperature peak on July 19th the KNMI measured wind speeds between 2.0-3.0 m/s2, while in urban areas these wind speeds would be significantly lower due to the many buildings, trees and other obstacles. Temperature is the dominant factor here.

MOD11A1 as used. It is a satellite imagery product issued by the Moderate Resolution Imaging Spectro-radiometer (MODIS), which has a resolution of 1,000 m and a daily temporal frequency. The images have been downloaded from the United States

Geological Survey webpage. First, the average night-time surface temperature for each of the medium size cities was calculated for each of the satellite images and afterwards the average value of all the heat wave satellite images retrieved during the heat wave. These two operations were performed using ArcGis.

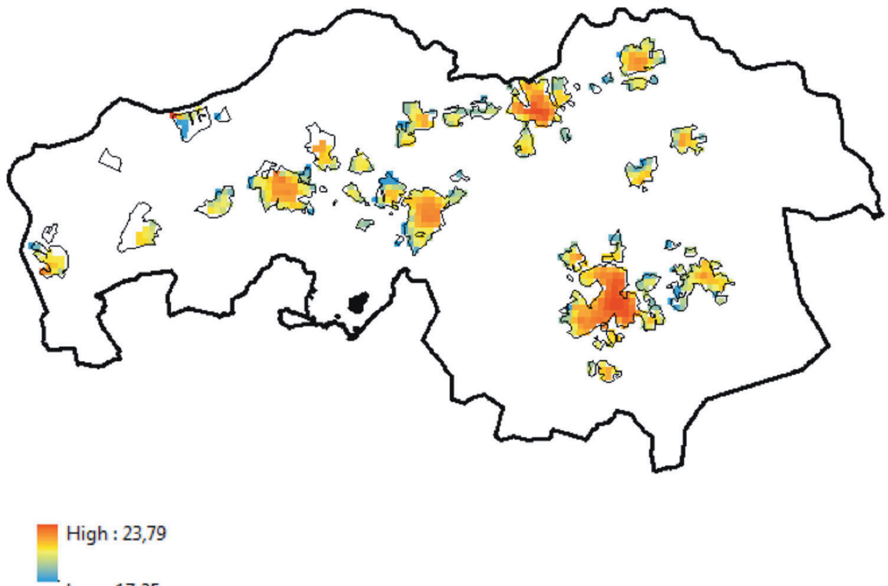

FIGURE 6.2 Average night-time LST urban areas of the province of North Brabant. LST values retrieved from Modis 11A1 imagery of the 23rd of July 2006. (Courtesy of the U.S. Geological Survey. USGS/NASA Modis)

§ 6.2.3 UHI-related parameters analysed

§ 6.2.3.1 Parameters related the urban design

Albedo, imperviousness and vegetation seem to be relevant parameters influencing the UHI. Several works have investigated the role of surface albedo in the UHI formation (Gao et al., 2014; Prado & Ferreira, 2005; Akbari et al., 2001; Taha, 1997; Sailor, 1995; Taha et al. 1992; Taha et al., 1988). Other studies have found a strong linear relationship between the land surface temperature (LST) and the imperviousness percentage and an inverse linear relationship between LST and the NDVI during the summer seasons (Nie & Xy, 2014, Yu & Lu, 2014; Heldens et al., 2013; Xu et al., 2012; Zhang et al., 2009; Weng & Lu, 2008; Xiao et al., 2007; Yuan & Bauer, 2007).

In this study the authors have used Landsat 5 TM satellite imagery from the 25th of July 2006 to calculate albedo and NDVI. The raw satellite images were downloaded from the US Geological Survey (USGS) webpage, Earth Resources Observation and Science Center (EROS). For the albedo calculation, the authors have used software for satellite imagery atmospheric topographic correction called ATCOR 2/3 which allows not only to correct atmospherically the images but also to generate the corresponding albedo distribution image (Richter & Schlapfer, 2013) (Figure 6.3). For the NDVI calculation the authors have first corrected Landsat 5 TM spectral bands 3 (visible) and 4 (near-infrared) – both with a 30 m resolution - in ATCOR 2/3 and further us a geospatial imagery treatment software called ENVI 4.7 was used to map the actual index, which is defined as (NIR-VIS)/(NIR+VIS), where VIS (visible radiation) is the surface reflectance in the red region (650 nm) and NIR (near-infrared radiation) is the surface reflectance in the near-infrared region (850 nm) (Figure 6.4). The final average calculation of the average albedo and NDVI values for each of the 21 analysed cities has been done in ArcGis.

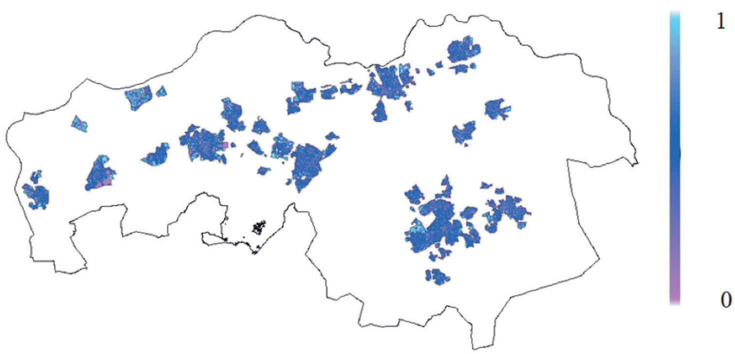

FIGURE 6.3 Average albedo in urban areas of the province of North Brabant. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3.

FIGURE 6.4 Average NDVI in urban areas of the province of North Brabant. Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3.

The mapping and calculation of the average imperviousness was done calculating for each of the 21 midsize cities, the surface occupied by buildings and roads.The authors have processed in ArcGis the TOP10NL file to obtain the percentage of imperviousness for each city.

§ 6.2.3.2 Parameters related to city size

The accumulation of urban heat is correlated with the size of cities. Several studies have made an effort to quantify the relationship between city size and the UHI effect. Oke (1973) found a linear relationship between the maximum urban heat island intensity (max UHI) and the logarithm of the population of cities in North America and in Europe: formulas 6.1 and 6.2 that were obtained using data from the 1970´s and 1980´s.

FORMULA 6.1

[max UHI = 2.96 log (P) - 6.41]. North America

Where max UHI is the maximum urban heat island intensity and P is the population.

FORMULA 6.2.

[max UHI=2.01 log (P) - 4.06]. Europe

Where max UHI is the maximum urban heat island intensity and P is the population.

Park and Kufuoka have attempted to find the relationships for South Korea and Japan (Park, 1986; Fujuoka, 1983; Hove et al., 2011) highlights that the studies carried out with results from 1987 to 2008 reveal that there is a steeper relationship between the maximal UHI intensity and the population, and that the maximal UHI for Dutch cities with a population between 100,000 and 800,000 inhabitants would range from 4 to 8°C. In North-Brabant the vast majority of the midsize cities have less than 100,000 inhabitants (except for Tilburg, Breda,'s-Hertogenbosch and Eindhoven). This study aims at analysing how the size of smaller Dutch cities affects the UHI effect. For the analysis of the size of the cities the authors have chosen to analyse the city surface instead of the city population, since they have found a very high correlation (r2= 0.99) between the number of inhabitants (2006, PBL Netherlands Environmental Assessment Agency) and the surface of the cities (Figure 6.5).

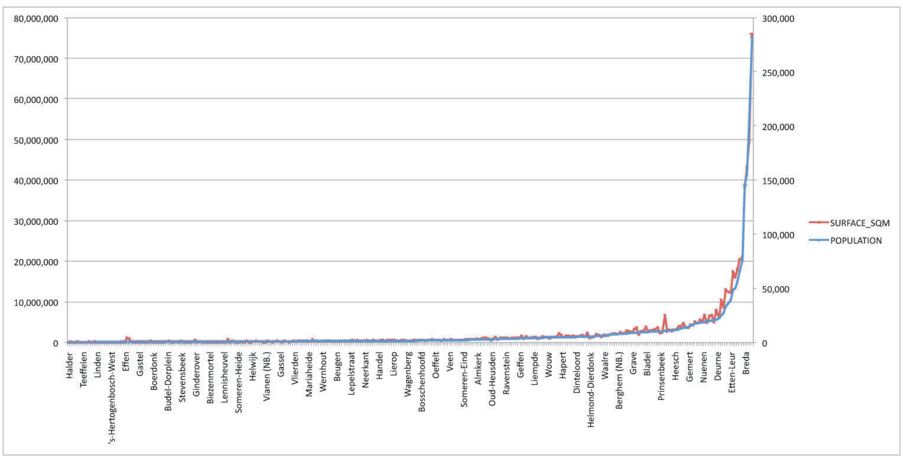

FIGURE 6.5 Analysis of surface and population of North Brabant medium-size cities.

– Thermal urban classification of medium-size cities in the region of North Brabant

In the second part of our study the authors have created a surface thermal classification map of the different neighbourhood typologies present in the analysed medium-size cities of the region of North Brabant. Urban climate classification maps provide practical information on the behaviour of different urban structures and climate, thus connecting climatological studies to urban planner´s reality. There is a first group of investigations that have been completed based on site measurements and available urban morphology documentation. It is the case of several studies carried out before. Chandler (1965) used climate, physiography and built form to classify Greater London in four zones. Auer (1978) analysed vegetation and building characteristics to create 12 "meteorologically significant" land uses in the city of St. Louis. Ellefsen (1990) analysed geometry, street configuration and construction material for the creation of "urban terrain zones". Wilmers (1991) worked on urban and rural structures, use and vegetation to identify the main "climatotopes" in Metropolitan Hannover. Scherer (1999) analysed land use and topography for the generation of a refined "climatope" classification of the region of Basel. Oke (2004) studied urban structure, cover, fabric, metabolism and potential to generate "urban climate zones".

Stewart & Oke (2012), finally, researched "local climate zones" for urban heat island observation. There is a second group of papers that have produced urban climate classifications based on remote sensing analysis, which systematizes and makes it more cost effective. It is the case of the semi-automatic classification carried out for the city of Toulouse (Houet & Pigeon, 2011) to classify sample areas in "urban climate zones", the surface material assessment of urban zones for the generation of "urban structure types" in the city of Munich (Heiden et al., 2012), the socio-economic and environmental impacts of the different urban structures in the same city (Pauleit & Duhme, 2000), the object-based image classification used to map urban structure typologies also in Munich (Wurm et al. 2010) and the land-use classification produced for metropolitan Atlanta (Tang, 2007).

In the Netherlands there are two main "urban living environment" classification systems. One is the one developed by ABF (ABF research, 2005) and the other one is RIGO-typology for neighbourhoods built before and after the war (RIGO 1995; RIGO, 1997). Both analyse physical characteristics of housing and urban equipment but Rigo classification also takes into consideration socio-economic factors (Planbureau voor de leefomgeving, 2006). Even though these "urban living environment" typologies are consistent throughout the country, since 2004 the role of these classification systems has considerably been reduced since the approval of the Spatial Strategy of 2004 - Nota Ruimte 2004 (VROM, 2004) - which conferred most of the spatial policy competences to provinces and municipalities. Most provinces and municipalities have used these as a basis to develop their own classification systems to analyse the existing built environment and to create design guidelines for future developments from different angles. In the case of the province of North Brabant, an "urban living environment" classification was carried out based on physical characteristics of the neighbourhoods (location, density, housing typology and mix of uses) (Figure 6.6) in the context of a housing survey carried out in 1998 (WBO, 1998) and further been used in other housing surveys of the region (Poulus & Heida, 2002). This classification establishes 12 main categories: high-density city centre, city centre, pre-war neighbourhood, post-war compact neighbourhood, post-war soil bound neighbourhood, urban green, small urban centre, small urban, small urban green, village centre, village, rural accessible.

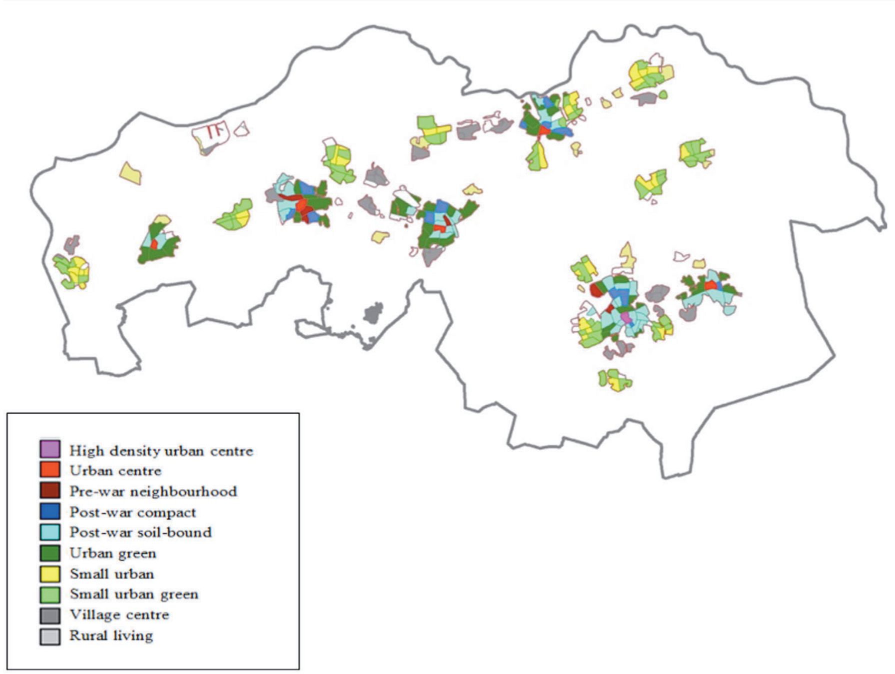

FIGURE 6.6 Analysis of surface and population of North Brabant medium-size cities (ABF research, 2005)

In this study a 6-cluster surface cover thermal classification of the urban cores of the region of North Brabant was created using the three most relevant parameters (identified in the first part of the study) influencing night-time urban LST to complete an unsupervised cluster classification in GIS. Further the surface cluster classification was overlapped with the "urban living environment" classification of the region of North Brabant, in order to review this official "urban living environment" classification with surface cover thermal criteria.

§ 6.3 Results

§ 6.3.1 The role of different parameters in the formation of the UHI in the region of North Brabant

The multiple regression analysis of the average values obtained for Albedo, NDVI, imperviousness, distance to the nearest urban area and town size, shows that there is a multiple correlation coefficient of R=0.7 and R2=0.5 that relates these parameters with the average night-time surface temperature (Figure 6.7). The following parameter coefficients were obtained:

FORMULA 6.3

$$LST\ (average\ night) = 27.7 - 34.8*A + 2.3E\text{-}08*S - 0.1*NDVI$$

Where A = Albedo, S = surface and NDVI = Normalised Difference Vegetation Index

Average Modis night time LST. July 2006.	Albedo	NDVI	% impervious surface	Distance to nearest town (in m)	Surface (in sqm)
19,1	0,23	0,40	23,0	1051	1.731.927
19,3	0,22	0,36	31,0	1175	1.185.046
19,5	0,22	0,35	32,0	445	5.344.222
19,6	0,22	0,33	31,7	1472	7.077.232
19,6	0,22	0,32	34,2	306	4.523.848
19,8	0,21	0,50	28,8	1101	1.699.638
20,1	0,21	0,41	28,0	154	1.815.197
20,4	0,21	0,40	30,5	419	5.880.326
20,5	0,21	0,46	28,4	220	6.569.954
20,6	0,21	0,30	35,4	135	42.534.733
20,6	0,22	0,35	31,0	264	4.112.599
20,7	0,22	0,39	37,2	509	8.318.652
20,9	0,21	0,36	30,5	0	1.328.614
20,9	0,22	0,31	31,9	532	12.355.689
21,0	0,20	0,50	24,9	225	229.409
21,0	0,21	0,33	31,1	0	40.850.073
21,0	0,22	0,33	36,9	365	43.619.598
21,0	0,22	0,34	33,0	733	21.948.146
21,2	0,21	0,33	32,9	0	26.512.601
21,3	0,22	0,34	30,2	2500	13.259.052
21,8	0,22	0,31	37,4	0	77.728.224

FIGURE 6.7 Data list of the analysed medium size cities of the region of North Brabant. Parameters analysed: night-time LST, albedo, NDVI, imperviousness, distance to nearest town and surface.

It seems that the most relevant indicators in this case are albedo and NDVI (Figure 6.8). Imperviousness, the distance to nearest town and the surface of the analysed cities do not seem to play a significant role in the LST night values for the medium-size cities analysed in the region of North Brabant, which do not exceed 7,700 ha in any case. The maximum calculated average city night-time LST difference is 2.9°C. The average city albedo values are pretty similar for all cities and range from 0.20 to 0.23. NDVI variations vary from 0.31 to 0.50 and imperviousness coefficient ranges from 23% to 37.4%. The future growth of most medium-size cities of the regions will not per se aggravate the UHI phenomenon, in turn it will be the design of the new neighbourhoods, which will impact or not the formation of urban heat in the province.

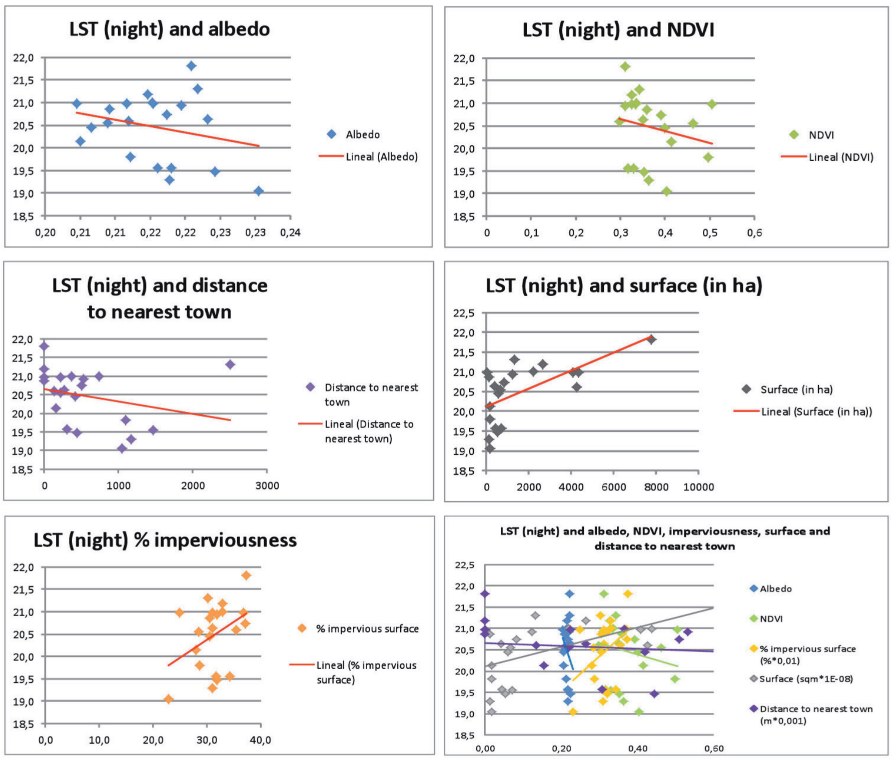

FIGURE 6.8 Analysis of the relationship between the different parameters and night-time average LST, for each of the analysed medium size cities in the region of North Brabant.

§ 6.3.2 Redefining the “urban living environment” classification based on thermal surface cover criteria

– Unsupervised surface thermal clustering

Even though the average LST presents maximum variations of 3°C (section 6.3), an unsupervised cluster classification of the three most relevant surface cover parameters (albedo, NDVI and imperviousness) was completed, in order to understand the different surface behaviours within each town. 6 different clusters were obtained. Even though the average night-time LST of these clusters are pretty similar, each of these clusters has a singular albedo, NDVI and imperviousness combination (Figure 6.9). The thermal surface cover assessment is more accurate when performed through the unsupervised classification of albedo, NDVI and imperviousness than through the calculation of the night-time LST, due to the tools used in this study for these calculations. Albedo and NDVI are calculated based on Landsat satellite imagery which has a resolution of 30 m and imperviousness is calculated based on a GIS model whereas night LST is calculated based on Modis 11A1 satellite imagery which has a 1km resolution. Modis 11A1 has a resolution appropriate for average city LST calculations, but not for surface cover discrimination.

The combined analysis of these three parameters allows classifying different surface typologies. The scatterplots analysis (Figure 6.10, figure 6.11 and figure 6.12) highlights the importance of the combined analysis. There are many areas from different clusters sharing identical values for each parameter separately; however they present different albedo, NDVI and imperviousness combinations. Even though the average city values for albedo, NDVI and imperviousness did not differ considerably from one city to the next (Figure 6.8), the surface cover cluster analysis presents average albedo ranging from 0.11 to 0.30, NDVI varying from 0.18 to 0.55 and imperviousness coefficients going from 0.21% to 0.41%.

The spatial distribution of each of these clusters reveals that three of these clusters (clusters 1 to 3) correspond to clusters of built area surface cover, and three of these clusters (clusters 4 to 6) correspond to non-built areas surface cover clusters (Figure 6.13). Cluster 1 corresponds to specific urban areas with the poorest surface thermal behaviour, mainly present in small specific areas of the city centres or of industrial areas. They have very low albedo (0.11), high imperviousness (39%), and low NDVI (0.17)). Cluster 2 presents a similar average NDVI value (0.19), slightly higher imperviousness (0.42) and considerably higher albedo (0.2) than cluster 1. The main difference between cluster 1 and cluster 2 is the albedo. The majority of the city centre surfaces belong to cluster 2. Cluster 3 seems to correspond to urban residential areas (row houses) with interspersed green areas, presenting a slightly higher albedo (0.24), higher NDVI (0.28) and lower imperviousness (0.31). Cluster 4 can be identified with low density residential areas (detached houses) areas of urban parks with trees with higher NDVI, lower albedo (due to the presence of greenery) and slightly higher imperviousness. Cluster 5 corresponds to urban trees and water areas with the highest NDVI (0.55), the lowest imperviousness 22% and a relatively low albedo (0.21 due to the presence of vegetation) and cluster 6 corresponds to bare soil areas with the highest albedo (0.31), considerably low NDVI (0.20) and small imperviousness 26% (Figure 6.9).

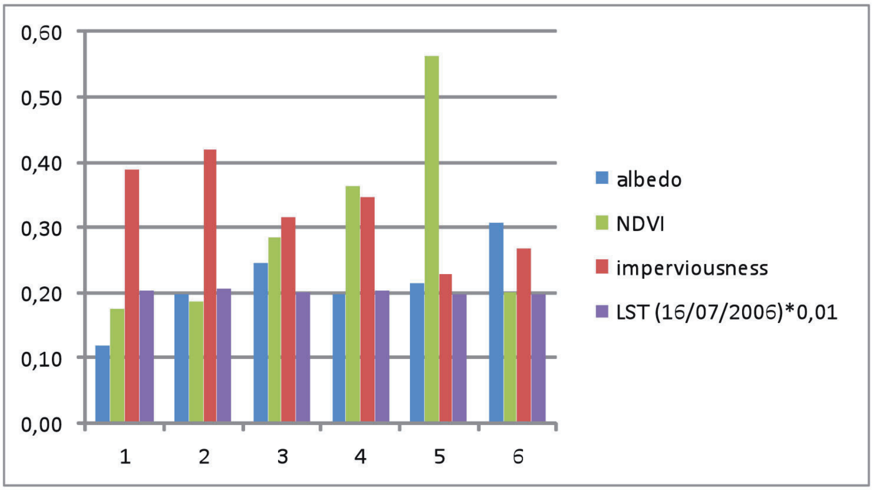

FIGURE 6.9 Average albedo, NDVI, imperviousness and night LST values for each of the 6 clusters resulting from the unsupervised classification of the albedo, NDVI and imperviousness maps of the analysed medium-size cities of North Brabant.

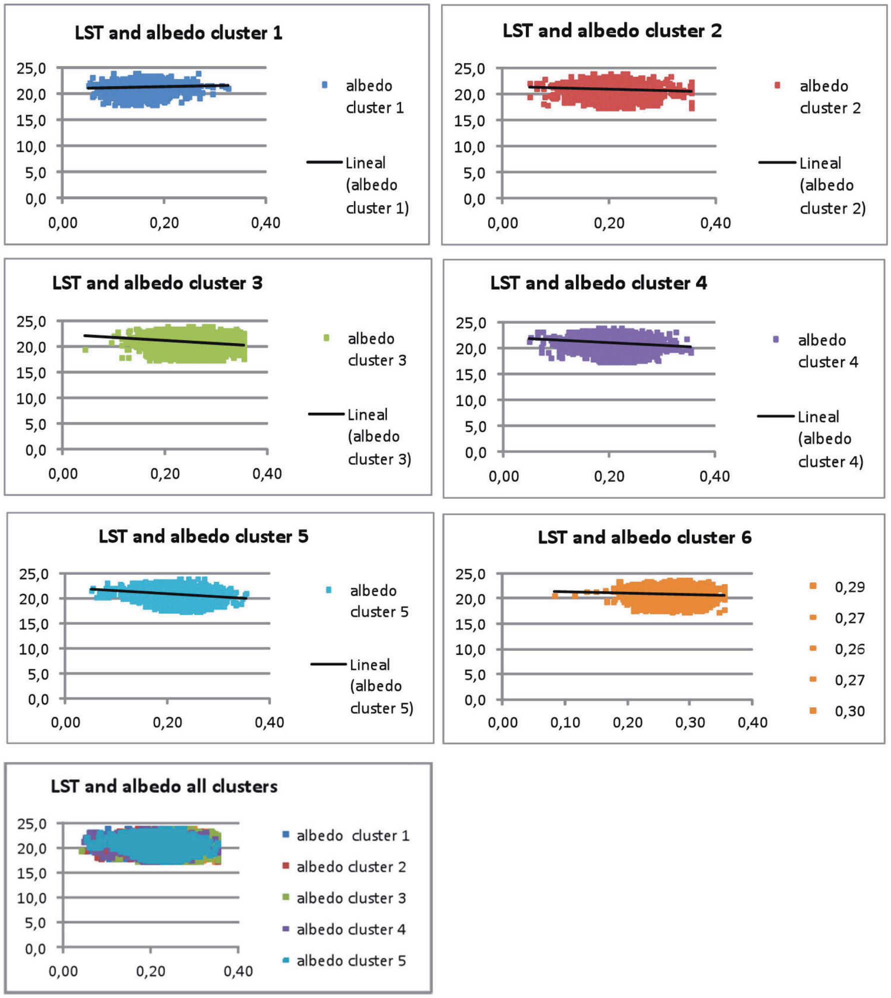

FIGURE 6.10 Scatterplots of night LST and albedo, for each of the different surface cover clusters.

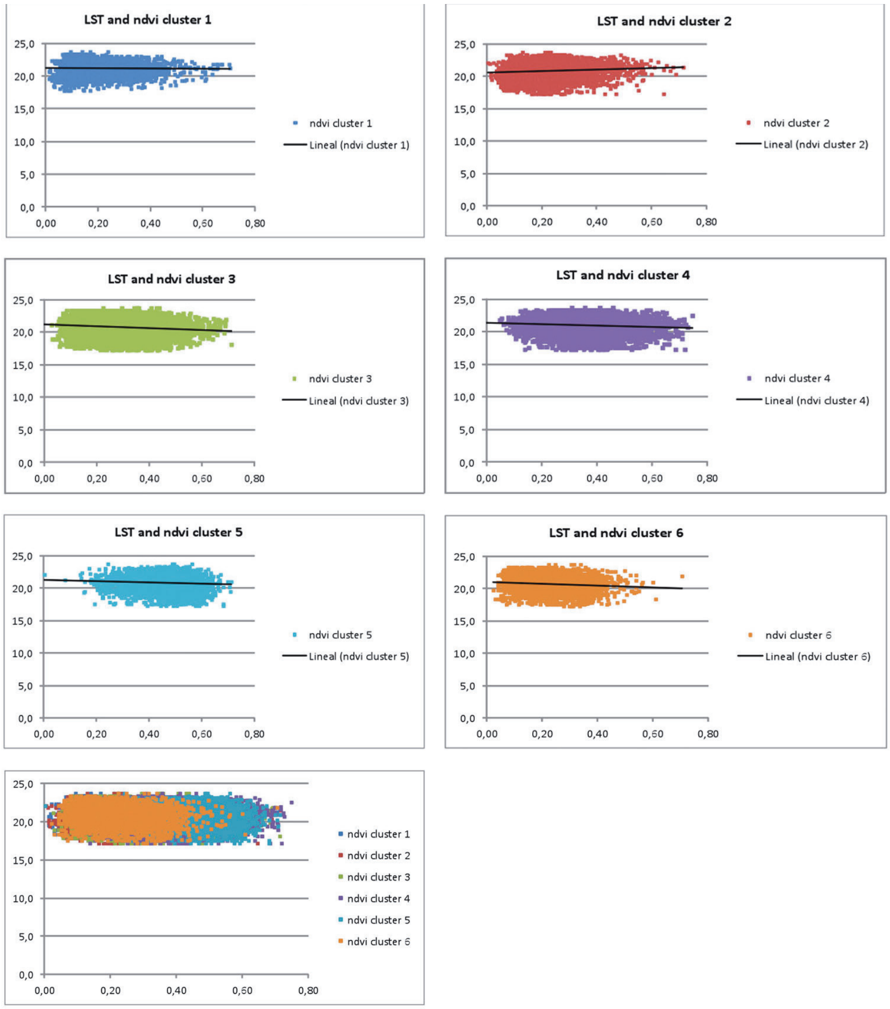

FIGURE 6.11 Scatterplots of night LST and NDVI, for each of the different surface cover clusters.

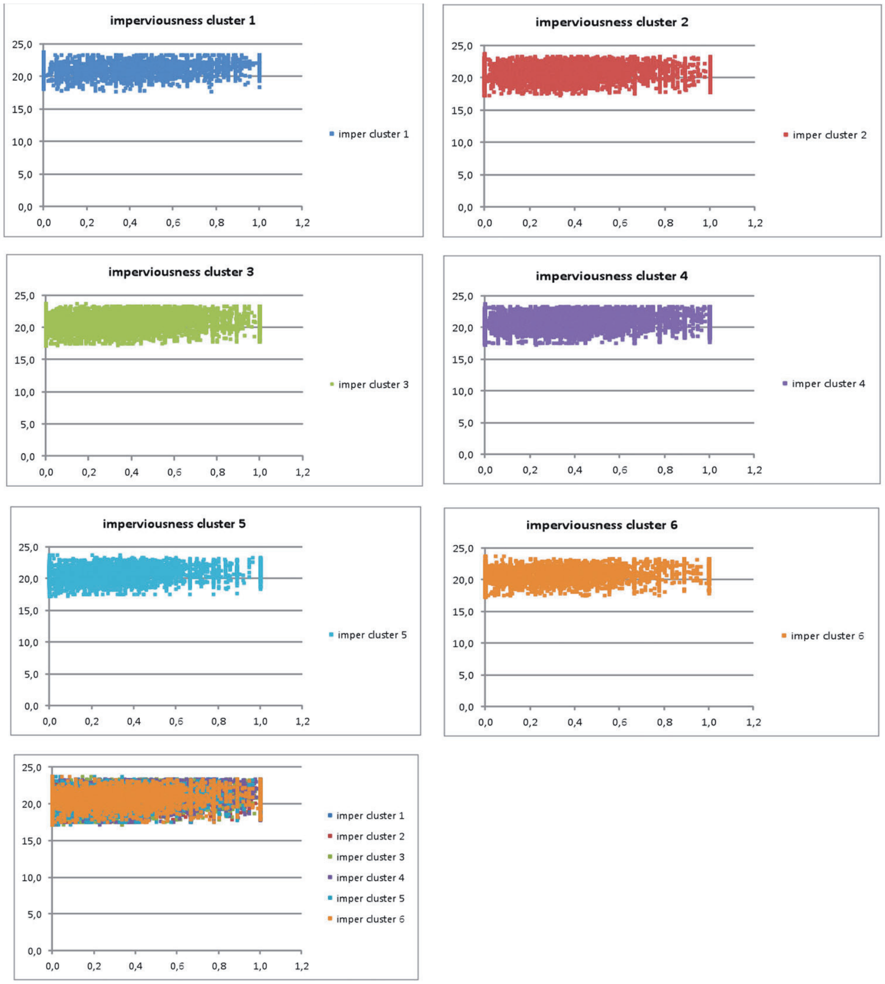

FIGURE 6.12 Scatterplots of night LST and imperviousness, for each of the different surface cover clusters.

The analysis of Eindhoven metropolitan area reveals that the city centre is mostly covered with cluster 2 surfaces, and that in turn, cluster 4 has more presence in areas outside the city centre. Cluster 1 is only present in very specific, heat absorbing surface areas, whereas cluster 6 is hardly present in the city area (this is why it was not included in the analysed figure) (Figure 6.13 and Figure 6.14).

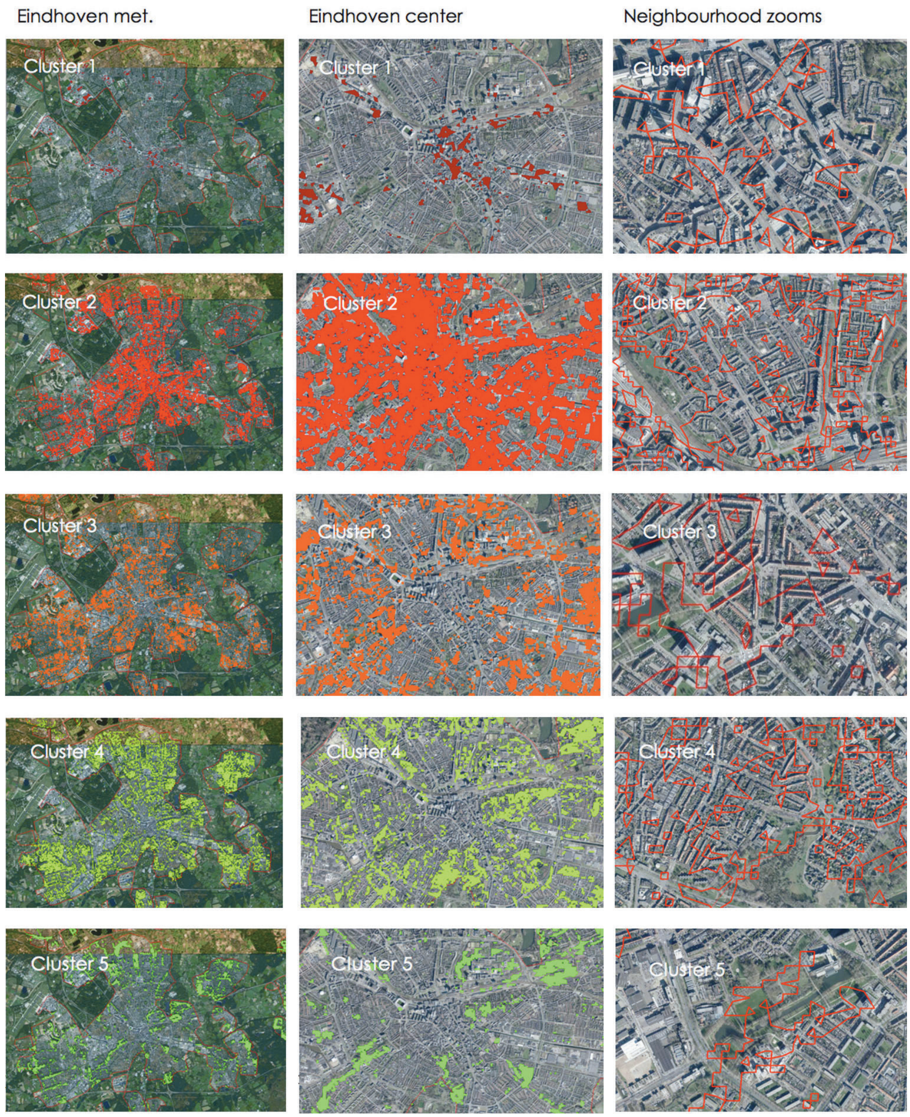

FIGURE 6.13 Spatial distribution of surface cover clusters in Eindhoven metropolitan area.

– Analysis of the presence of surface thermal clusters in "urban living environment" categories

The maps of Eindhoven metropolitan area illustrate the different spatial distribution of the clusters and the "urban living environment" maps. Each "urban living environment" map comprises a specific surface cluster mix (Figure 6.14). In order to analyse how the surface thermal clusters match with the "urban living environment" categories of the region of North Brabant, the proportion of clusters found in each of the " urban living environment" categories (Figure 6.15) was calculated. This analysis reveals that "urban living environment" classes 3, and 5 (pre-war neighbourhood and post-war ground based) present similar surface covers where clusters 2 cover more than 35% of the surface and where the proportion of urban clusters (1, 2 and 3) is in all cases above 60%. The cluster mix analysis, also reveals that "urban living environments" 4, 6, 7, 8 and 9 (post-war compact, green, small urban centre, small urban and small urban green) present similar surface cover mixes, with similar cluster 2 and 4 presence, and where the proportion of urban surface cover clusters (1,2 and 3) is around 50%. The 12 category "urban living environment" classification applied in North Brabant, could actually be reduced to a 7 surface cover classification.

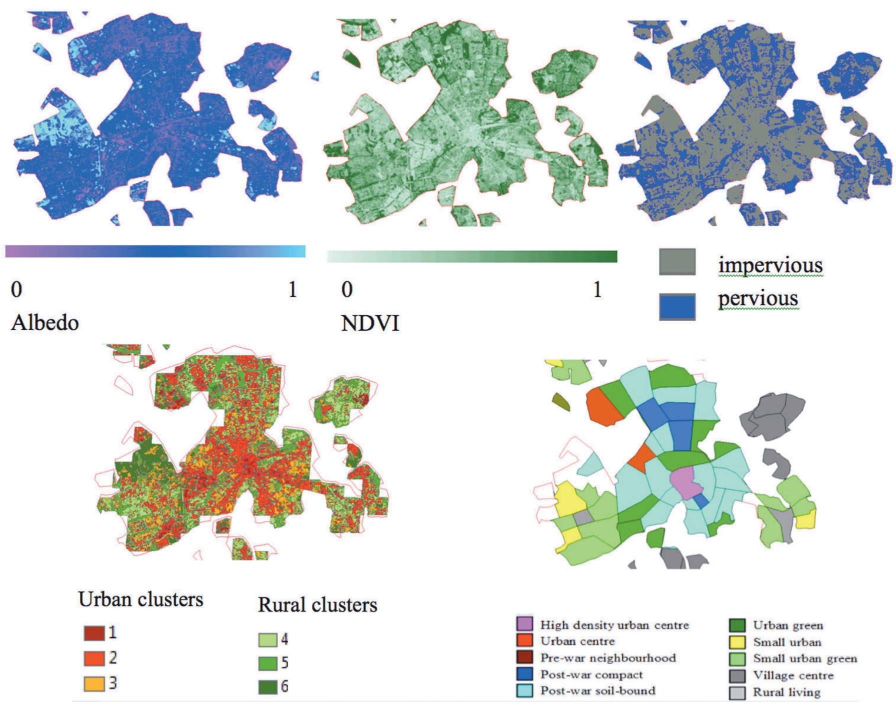

FIGURE 6.14 Compilation of LST-related maps for Eindhoven metropolitan area: Albedo, NDVI, imperviousness, surface cover clustering and "urban living environment" categories.

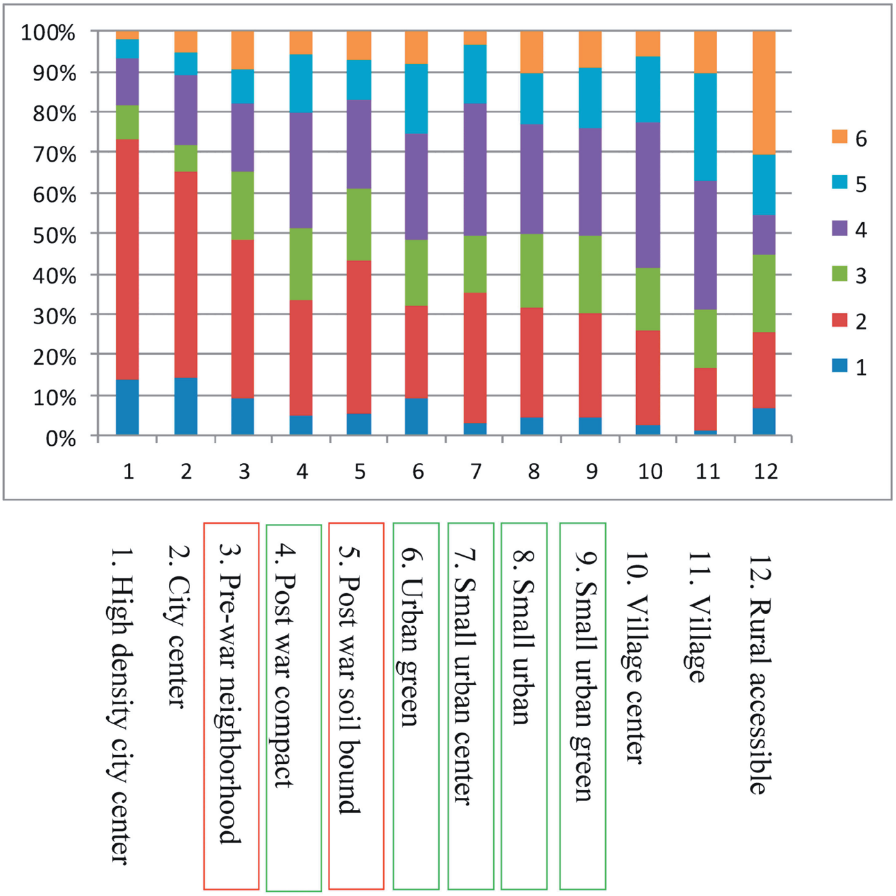

FIGURE 6.15 Surface cover cluster proportions for each of the "urban living environment" categories in the analysed medium-size cities of the North Brabant region. Neighbourhoods 3 and 5 present similar cluster proportions, and thus could be grouped. Neighbourhoods 4, 6, 7, 8 and 9 present similar cluster proportions, and thus could be grouped.

– Analysis of average night LST of the different "urban living environment" categories.

The analysis of the average night-time LST retrieved by Modis 11A1 in 16 satellite images during the heat wave experienced in the month of July 2006 (Figure 6.16) reveals that 12 "urban living environment" categories could actually be grouped in 7, since categories 3, 4 and 5 (pre-war neighbourhood, post-war compact and post-war ground based) could be grouped into one single category since they present similar average LST (around 21°C) and categories 6,7, 8 and 9 could be grouped into another category because they present similar average LST (around 20.3°C).

FIGURE 6.16 Average night LST for each of the "urban living categories". Neighbourhoods 3, 4 and 5 present similar night LST, and thus could be grouped. Neighbourhoods 6, 7, 8 and 9 present similar night LST , and thus could be grouped.

– Proposed “urban living thermal categories” for the region of North Brabant

The surface cluster analysis of the different “urban living environment categories” suggests that these can be grouped into 7 categories. 1/ High density city centre 2/ City centre 3/ pre-war neighbourhood & post-war soil bound 4/ post-war compact & urban green & small urban centre & small urban & small urban green 5/Village centre 6/Village 7/Rural accessible. The average night-time land surface temperature analysis of the “urban living environment categories” suggests the same groups except for the post-war compact neighbourhood’s category which has a night LST similar to pre-war and post war soil bound. The main reason is that post-war compact neighbourhoods is a category that consists of scattered high rise dwelling blocks, interleaved with green areas and large infrastructural roads. The proportion of green areas that can be found in these neighbourhoods is similar that the ones of small urban areas, however the overall night LST is higher in these post-war areas.

§ 6.4 Conclusions

This paper addressed the main question how to ensure that the future development plans do not aggravate the urban heat island (UHI) effect in the North-Brabant urban areas, by focusing on three sub-questions: How bad is the urban heat island problem currently? How does albedo, Normalised difference vegetation index (NDVI), imperviousness, city size and proximity to other urban areas influence the phenomenon? Which of these play the most relevant UHI role? Can we establish a surface thermal urban classification to provide design guidelines to ensure that future developments do not aggravate the UHI phenomenon?

The answer to the main question is found in adjusting the design of the growth areas that are designated by the province North-Brabant. The growth areas are based on the “ladder for sustainable urbanisation” developed by the Dutch Ministry of Infrastructure and Environment. The aspect of urban heat islands is not included in this methodology. The authors propose to include considerations about albedo, greenness (NDVI) and imperviousness, in the design of these future developments.

Our study has revealed that albedo and NDVI are the most relevant parameters influencing the average night-time LST for the analysed North Brabant medium-size cities. Correlation coefficients extracted from the multiple regression analysis are:

FORMULA 6.3

LST (average night) = 27.7 – 34.8*A + 2.3E-08*S - 0.1*NDVI

Where A = Albedo, S = surface and NDVI = Normalised Difference Vegetation Index

The surface cover cluster analysis of these three parameters reveals that the 12 "urban living environment" categories used in the region of North Brabant (high-density city centre, city centre, pre-war neighbourhood, post-war compact neighbourhood, post-war soil-bound neighbourhood, urban green, small urban centre, small urban, small urban green, village centre, village, rural accessible) can actually be reduced to 7 categories, since classes 3, 4 and 5 (pre-war neighbourhood, post-war compact and post-war ground based) present similar surface covers (and could thus be grouped) and the "urban living environments" 6, 7, 8 and 9 (green, small urban centre, small urban and small urban green) also present similar surface cover mixes (and could thus be grouped).

This surface cover classification provides guidelines to improve the surface behaviour of the most common urban typologies that can be found in the province of North Brabant and to guide the urban design of the planned future urban developments. All of these conclusions could be integrated in a climate-robust growth areas policy.

§ 6.5 Discussion

The purpose of using the surface cover cluster analysis for the thermal assessment of the different "urban living environment" assessment (instead of calculating directly the average night-time LST of each of these neighbourhood typologies) is to actually map and quantify parameters that can be addressed and improved. Measures to improve albedo, NDVI and imperviousness can be simulated and quantified. Mapping surface cover categories allows designing specific mitigation solutions, instead of only assessing on the intensity of the problem (night LST temperature).

The intention of the study is to analyse the thermal surface cover behaviour of the different "urban living environment" categories in order to design UHI adaptation measures in the existing neighbourhoods and to produce some surface adaptation guidelines for the future developments that will grow adjacent to the existing medium-size cities. The same urban structures can considerably improve their thermal behaviour though the implementation of measures that only affect their surface covers. Parameters related to the neighbourhood structure (sky view factor, wind, shadow, …) as well as factors such as anthropogenic heat emissions should be the object of another study to determine to what extent they influence the formation of the UHI in the province of North Brabant, and to explore and design the development of design guidelines concerning the urban structure for the design of future urban developments.

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7 Using satellite imagery analysis to redesign provincial parks for a better cooling effect on cities – The case of South Holland

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Abstract

The purpose of this research is to analyse the thermal behaviour of South Holland provincial parks during heat waves, in order to provide design adaptation guidelines to increase their cooling capacity over the hotspots present in their urban surroundings.

This research analyses the thermal behaviour of different land use patches (forests, cropland, grassland, water surfaces, built areas and greenhouse areas) present in the six South Holland provincial parks during heat waves. It studies their average night land surface temperature (LST) (with Modis 11A1), day LST (with Landsat 5TM), NDVI, imperviousness, patch size and patch shape index, and analyses through a multiple regression analysis the impact of each of these last four parameters in the night and day LST for each land use. Based on these conclusions, a set of design guidelines are provided to improve the cooling capacity of Midden-Delfland park areas which are adjacent to hotspots with day LST above 41°C and with day LST between 36°C and 41°C.

The average day LST within South Holland provincial parks varies from 25.9°C for water surfaces, to 31.4°C for forests, 33°C for cropland, 33.1°C for greenhouse areas, 34.9°C for grassland patches and 37.9°C for built areas. Within each land use category, NDVI, imperviousness and patch shape index influence differently the thermal behaviour of the patches. NDVI is inversely correlated to day LST for all categories, imperviousness is correlated to day LST for all areas which do not comprise a significant presence of greenhouses (grassland and built patches) and inversely correlated to LST for areas with a high presence of greenhouses (cropland and warehouses). Finally, the shape index varies depending on the nature of the surrounding patches, especially for small patches (built areas, forests and greenhouse areas).

Most of the hotspots surrounding the Midden-Delfland park are adjacent to grassland patches. The measure to increase the cooling capacity of those patches would consist in a change of land use and or an increase of the NDVI of the existing grassland patches. These suggestions to increase the cooling potential of the parks remain deliberately open in order to allow combining these measures with other spatial planning priorities.

§ 7.1 Introduction

§ 7.1.1 The Urban Heat Island effect

In the Netherlands, a heat wave is defined as a sequence of at least five consecutive summer days (days on which the weather station of De Bilt registers a maximum temperature of 25.0°C or higher), among which there are at least three tropical days (days on which the weather station of De Bilt registers a maximum temperature of 30°C or more). The European heat wave of the summer of 2003 led to more than 70,000 excess deaths over four months in Central and Western Europe (Brücker, 2005; Robine et al., 2008; Sardon, 2007). More specifically, in the Netherlands, the number of deaths attributed to this event ranged from 1,400 to 2,200 (Garssen et al., 2005). The following European heat wave took place in 2006 and in The Netherlands caused in the month of July alone 1,000 excess deaths (Hoyois, 2007) of which 470 in the Westen region to which the province of South Holland belongs(Centraal Bureau voor de Statistiek, 2006). The Dutch province of South Holland was in absolute terms the most affected by the 2006 heatwave (CBS, 2006).

During heat waves the Urban Heat Island effect (UHI) – which refers to the temperature difference between the built-up areas and their natural surroundings – reaches its peak. The UHI increases daily average temperatures and reduces the capacity to cool off during the night. Urban Heat Islands are caused by changes in the radiative and thermal properties of the environment introduced by human constructions. Recent studies reveal that Dutch cities experience a mean daily UHI effect of 2.3 K and a 95 percentile of 5.3 K during summer (Steeneveld et al., 2011). Moreover, the UHI phenomenon is likely to become a concern in the Netherlands affecting not only larger settlements but also smaller ones (Van Hove, 2011). Even though on site air temperature measurements provide a better overview of the intensity of the phenomenon (since it measures directly the temperatures experienced by the population at a particular area) LST is often used as an indicator because for large surfaces it provides a more global overview of the temperature distribution. Because of that reason, most of the previous climatological studies on the cooling potential of parks analyse the LST instead of air temperature (Cao et al. 2010, Choi. et al. 2012, Cheng. et al. 2014).

§ 7.1.2 Greenery as a cooling source

During heat waves cities can benefit from the cooling effect of different greenery typologies existing in and around them. Previous studies on the cooling role of greenery can be divided in two groups: studies dealing with large green infrastructure, and studies concentrating on urban parks.

– Green infrastructure

In the first group of large green infrastructure, landscape is considered as an existing natural cooling source and focuses in the design of the urban environment to promote the cool wind flow within the cities. This is the case for air circulation patterns applied to spatial planning in the Climate Analysis Map for the Stuttgart region, 2008 (City of Stuttgart, 2008; Hebbertand Jankovic, 2010; Hebbert, 2011; Kazmierczakand Carter, 2010). For the Urban Climate Analysis Map for the Dutch city of Arnhem (Burghardt et al., 2010), developed within the future cities programme, or for the cool wind corridors of the German city of Freiburg, where the adoption of a Sustainable Urban Development Policy and the Land Use Plan 2020 envision the transformation of 30 hectares of building space into open areas, not only to extend and connect the city's green infrastructure, but also 'to emphasize the cool air flow areas and urban ventilation lines within and outside the city' (City of Freiburg, 2013).

- Urban Parks

The second group concentrates on urban parks with sizes of up to 500 ha and analyses their cooling effect in the surrounding urban environment during calm weather conditions. These studies use several indicators to quantify the cooling capacity of the parks in their surrounding urban areas. Chang (2007) defines the local cool island intensity as the temperature difference between the interior of the park and the urban nearby surroundings; Cheng (2004) defines the maximum local cool island intensity as the maximum mean land surface temperature of the parks' surroundings and the mean land surface temperature of the parks. Cheng also analyses the maximum cooling range of the parks, which is defined as the maximum distance of maximum local cool island intensity. In principle, the longer the cooling distances the smaller the local cool island intensity. Finally, Cheng also defines the maximum cooling area of the parks, as the largest area influenced by the cooling effect of the park. The local cool island intensity, the maximum cool island intensity, the maximum cooling distance and the maximum cooling area of parks are different indicators of the parks cooling effect; however, they are all interrelated.

The main factors influencing the local cool island intensity under calm weather conditions are the size of the parks (Von Stülpnagel et al., 1990; Upmanis, 1998; Cheng, 2014), the height and structure of the surrounding constructions (Upmanis et al., 1998; Jauregui, 1975, 1990-1991; Spronken-Smith, 1994), and the design of the parks. Regarding the design of the parks, previous studies concluded that the role of vegetation in parks differs, depending on whether it is day or night. During the day, local cool island intensity is related to the area of trees and shrubs inside the park (Cao et al., 2010; Potcher et al., 2006; Yu et al., 2006; Zhou, 2011), while at night the coolest parks are those without trees (Chang, 2007; Taha, 1991). Thus, grassland presents higher diurnal surface temperatures than tree areas while at night the surface temperature of grassland drops further compared to the wooded areas, especially when grassland is irrigated (Spronken-Smith, 2000). A strong correlation was also found between paved surfaces and LST (Zhou et al., 2011; Li et al., 2011); more specifically, diurnal LST is correlated with the largest patch index of the urban land use type (Cheng et al., 2014). The same impervious surface produces a smaller UHI effect when it is spatially distributed (Li et al., 2011). Finally, the role of water surfaces is unclear, but appears to depend on the size and depth of the body of water. Some studies revealed water had a positive effect on local cool island intensity (Saaroni and Ziv, 2003), while others have suggested its contribution is negligible (Cao et al., 2010).

§ 7.1.3 South Holland provincial parks

This research falls somewhere between these two groups. On the one hand the South Holland provincial parks analysed (Midden-Delfland, Duin Horst en Weide, Wijk en Wouden, Bentwoud/Rottemeren, Hollands Plassengebied and IJsselmonde) are large enough to be considered as part of the landscape (Figure 7.1) and on the other hand these are man-made parks that were completely designed. All trees were planted and most water elements were dug out. The provincial main strategic guidelines aim at creating a province that is resilient to climate change and that is characterised by its spatial and sustainable quality however it´s spatial vision ("Structuurvisie Zuid-Holland") doesn´t specifically address the UHI phenomenon. Furthermore, with 1,227 inhabitants per km^2 the province of South Holland is the densest province in The Netherlands and the one most affected by the UHI effect (Centraal Bureau voor de Statistiek, 2006).

§ 7.1.4 Research questions

In order to allow urban areas to benefit from the cooling capacity that provincial parks may offer, we need a better understanding of the thermal behaviour of regional parks spatial components. The main research question underlying this paper is:

- How can the development of the regional park system in the province of South-Holland be optimised in order to provide surrounding urban areas with a long-term source of natural cooling capacity?

In order to answer this question several sub-questions have been formlated:

- What is the thermal behaviour of the different land use categories (forests, cropland, grassland, water surfaces, built areas and greenhouse areas) that can be found in South Holland provincial parks? How do the NDVI index, imperviousness coefficient, patch size and patch shape index affect their average night-time LST and their average daytime LST during heat waves?
- How can we design adaptation guidelines to increase the cooling capacity of provincial parks? Can we use remote sensing to diagnose heat accumulation in urban areas surrounding parks and to prescribe measures to increase the cooling capacity of the adjacent park areas?

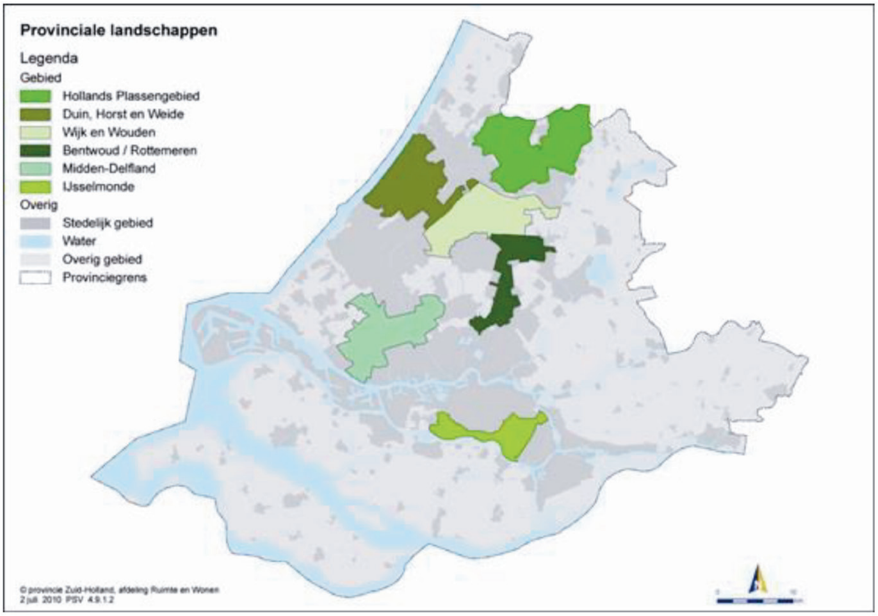

FIGURE 7.1 South Holland provincial parks (Province of South Holland, Spatial Planning and Housing Department, 2011)

§ 7.2 Methodology

§ 7.2.1 Definition of thermal behaviour of land use categories in South Holland provincial parks

The six main land use categories defined in the Spatial Vision of the region of South Holland, and that can be identified in its six provincial parks are: forests, cropland, grassland, water surfaces, built areas and greenhouse areas. For each of these categories the authors have used as indicators of thermal behaviour the average night-time land surface temperature (LST) and the average daytime LST, and as influencing parameters: Normalised difference vegetation index (NDVI), imperviousness coefficient, size of the land use patch and shape index of the surface patch. For each patch in each land use category the average values of the above mentioned parameters have been calculated, and a multiple regression analysis was carried out in order to understand what parameters influence most the thermal behaviour of the patches of each land use category. Satellite imagery has been used to map and calculate night LST, day LST and NDVI. All satellite images have been obtained through the US Geological Survey (USGS) webpage, Earth Resources Observation and Science Center (EROS).

- Mapping thermal behaviour indicators: Night and day LST.

The authors used nine Modis 11A1 satellite images (from the 15th and till the 20th of July) retrieved during the second heat wave of 2006 to map and calculate average night-time LST. Modis 11A1 is a Modis product which bands provide LST and emissivity values on a daily basis with a 1 km resolution. For the calculation of the day LST the authors have used Landsat 5 TM satellite imagery (retrieved on the 16th of July). Landsat 5 has a 16-day repeat cycle referenced to the Worldwide Reference System 2. Its data files, which consist of seven spectral bands, were downloaded from the US Geological Survey (USGS), Earth Resources Observation and Science (EROS) Center webpage. Diurnal LST was calculated and mapped using ENVI 4.7 software and following the Yale Center for Earth Observation 2010 instructions to convert thermal infrared band 6 into temperatures. Landsat TM collects band 6 at a resolution of 120 m and further resamples it to 30 m. First, the geometrical correction and the calibration of band 6 was carried out. The atmospherically corrected radiance was then obtained by applying Coll's equation (Coll et al., 2010):

FORMULA 7.1

$$CVR2 = [(CVR1 - L\uparrow)/\varepsilon\tau] - [(1-\varepsilon)*(L\downarrow)/\varepsilon]$$

Where:

CVR2 is the atmospherically corrected cell value as radiance

CVR1 is the cell value as radiance

$L\uparrow$ is upwelling radiance

$L\downarrow$ is downwelling radiance

Τ is transmittance

Ε is emissivity (typically 0.95)

The transmittance and the upwelling, as well as the downwelling radiance, were retrieved from NASA's webpage. Finally, the radiance was transformed into temperatures (Kelvin and Celsius) (Figure 7.2).

FORMULA 7.2

T = K2 / [ln ((K1/CVR2) + 1)]

Where:

T is degrees Kelvin

CVR2 is the atmospherically corrected cell value as radiance

K1 and K2 are prelaunch calibration constants

The final result of the processed Landsat 5 TM imagery is shown in figure 7.2.

- Mapping influencing parameters: NDVI, imperviousness and patch size and shape.

Landsat 5TM imagery retrieved during the heat wave of 2006 was used to map and (on the 16th of July) to calculate the average NDVI. ATCOR 2.3 was used to correct geometrically and atmospherically the raw satellite imagery.

FORMULA 7.3

NDVI = (NIR-VIS)/(NIR+VIS). Where NDVI is the Normalised Difference Vegetation Index, VIS is the surface reflectance in the red region (650 nm) and NIR is the surface reflectance in the near infrared region (850 nm).

The TOP 10 NL GIS file was used to calculate the impervious surface area within the parks, considering as 100% impervious surfaces the areas covered by buildings and roads and 0% impervious surfaces the rest of the surfaces.

In order to estimate the influence of the patch shape on the thermal behaviour of the patches per land use category, the authors have used the landscape shape index (LSI) defined by Patton (1975) and that calculates the compactness degree (Cao, 2010):

FORMULA 7.4.

$$\mathrm{LSI} = \frac{P_t}{2\sqrt{\pi \times A}}$$

Where LSI is the Landscape Shape Index Pt is the perimeter of the patch and A is the area of the patch.

Overall, the authors analysed the thermal indicators (night and day LST) and the influencing parameters (NDVI, imperviousness and size and shape index) of 32 forest patches, 68 cropland patches, 115 grassland patches, 28 water surfaces, and 2,284 urban areas and 339 greenhouse areas .

– Surface thermal classification of South Holland provincial parks

Even though NDVI and imperviousness of the patches have different influences on night and day LST depending on the analysed land use, the average values of these parameters are often similar. In order to obtain a better understanding of the thermal behaviour of the different land use patches, the authors have carried out in GIS an unsupervised classification of the overlap of the day LST, NDVI and imperviousness maps, and they have obtained 5 thermal clusters in the provincial parks of South Holland. Further the proportion of each of these thermal clusters for each of the studied land uses was calculated.

§ 7.2.2 Definition of design adaptation guidelines to increase the cooling capacity of Midden-Delfland provincial park

In this section the authors have studied how they could use remote sensing to diagnose heat accumulation in urban areas surrounding parks and how they could prescribe measures to increase the cooling capacity of the adjacent park areas.

– Heat diagnosis: heat accumulation in urban areas surrounding parks

As revealed by the climatologic studies previously discussed, the design of parks influences their cooling capacity. One of the indicators used to evaluate a park’s cooling capacity is the local cool island intensity, which measures the temperature difference of the parks immediate surroundings and the temperature inside the park. For large parks such as the South Holland provincial parks, which sizes range from 3,745 to 10,658 ha it is complicated to define the local cool island intensity, since the temperatures within the parks vary greatly and the same occurs with the areas surrounding the parks. The local cool island intensity varies considerably, depending on what area of the park is selected, and what area surrounding the park is picked. Therefore for this study the authors have chosen to analyse the temperature differences between the urban hotspots surrounding one of the parks, and the park areas adjacent to those hotspots and closer than 500 m. Midden-Delfland park was analysed, which is the South Holland provincial park located between the region of The Hague and Rotterdam.

Two types of hotspots were defined within a distance of 500 m from the parks boundary. The first category comprises areas with an LST above 42°C and areas greater than 10 ha. The second hotspot group comprises areas with an LST above 36°C and with lengths connecting the park larger than 1,500 m.

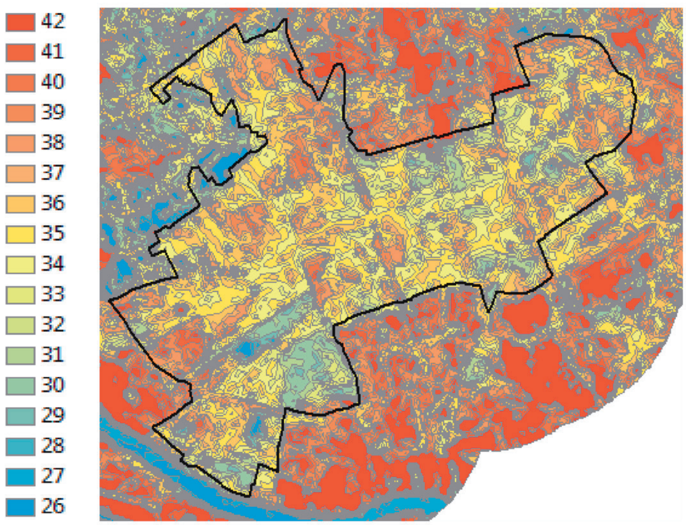

FIGURE 7.2 Land surface temperature image retrieved from Landsat 5TM

Tool:

Day LST maps (obtained through Landsat 5TM processing) were used to map the hotspots in the urban areas surrounding the park. The authors have chosen to map only day LST hotspots, due to the higher resolution of Landsat 5TM imagery (120 m) compared to Modis 11A1 (1 km). Landsat 5TM seems more appropriate for urban analysis (Figure 7.2).

– Identifying park areas adjacent to hotspots with an improvable cooling capacity

Further the park areas adjacent to the hotspots were analysed in order to identify the areas that had LST differences of less than 10°C compared with the hotspots. Those areas have been called "park adaptation areas" (PAA). These are the areas for which the authors suggest to modify the park design in order to increase the temperature difference with the hotspots, and thus to increase the local cool island intensity corresponding to those hotspots.

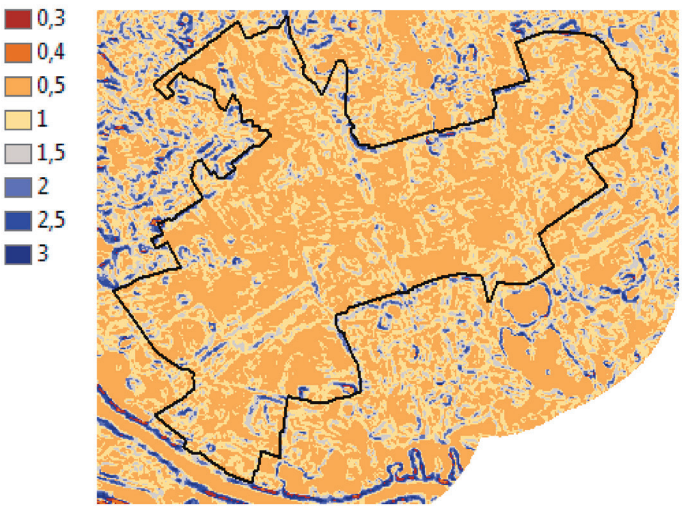

FIGURE 7.3 Land surface temperature differences in Midden-Delfland

Tool:

LST images were imported and combined in Arcmap 10 in order to calculate the temperature difference between the different pixels throughout the LST map (Figure 7.3).

– Prescribing measures to increase the cooling capacity of the park areas adjacent to hotspots.

The results obtained in the first part of the study were used to define adaptation measures to increase the cooling capacity of the PAAs. The measures consist, either in a change of land use, or on the increase of NDVI, decrease of imperviousness or on changing the size and/or shape index of the patches currently occupying the PAAs.

§ 7.3 Results

§ 7.3.1 Results of the analysis of night LST, day LST, NDVI, imperviousness, patch surface and patch shape index for six main land use categories in South Holland provincial parks.

The analysis of the average night LST reveals that the values presented for each land use only vary in 1.4°C. Maximum night LST is 19.2°C registered in built areas and water surfaces and minimum night LST is 17,8°C registered in grassland surfaces. In turn, the average day LST presents differences of up to 12°C with an average day LST of 25.8°C for water surfaces and 37.9°C for built areas. Forest patches present the second lowest day LST with 31.4°C. Greenhouse patches and cropland present an average LST 1.8°C lower than grassland.

greenhouses are characterized byhighly reflective glass roofs, which help reduce the surface temperatures. The difference between cropland and grassland is mainly due to the irrigation of cropland (Figure 7.4).

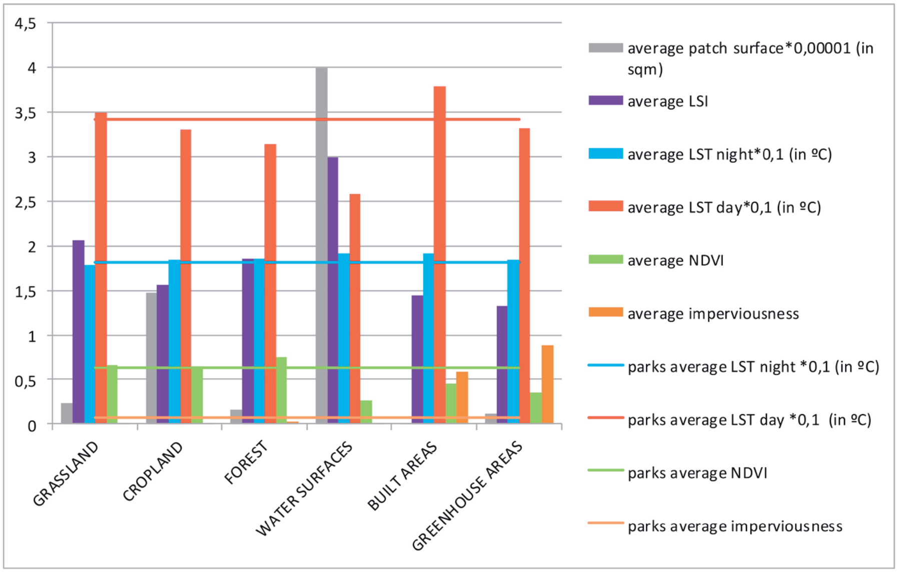

FIGURE 7.4 Average night LST, day LST, NDVI, imperviousness, patch surface and patch shape index for the six main land use typologies of South Holland provincial parks.

– Forests

As concluded by previous scholars, surfaces of trees contribute to increasing the diurnal cooling capacity of parks (Cao et al., 2010; Potcher et al., 2006; Yu et al., 2006; Zhou, 2011). Indeed, the average day LST of forested areas is 2.7°C below the park's average, whereas the forested areas night LST is slightly above the parks average (Figure 7.4). The multiple regression analysis of the average day LST, NDVI, imperviousness, size and shape index of 16 forest patches with surfaces of more than 1 ha of South Holland provincial parks (Figure 7.6) reveals that a multiple correlation coefficient of R=0.8 and R2=0.6 relating day LST to the rest of parameters for forest patches, with the following coefficients:

FORMULA 7.5

$$LST\ d = 76.4 - 59.5*NDVI + 0.1*I + 1.5E\text{-}05*S - 0.2*LSI.$$

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

NDVI and LSI play the most important role for the determination of day LST. The inverse correlation between daytime LST and NDVI (which range from 0.7 to 0.8, figure 7.6) is aligned with previous research, in turn, the inverse correlation between day LST and the slenderness of the patches is surprising. A more detailed analysis of the size and shape of the forest patches reveals that these are relatively small and the larger patches contain numerous narrowings. South Holland provincial parks include a total of 7,774 forest patches, of which only 585 patches (7.5%) have surfaces of more than 10 ha. GIS is only able to calculate the average day LST of 2.7% of these 585 patches, due to the amount of bottlenecks which prevent the program from calculating with Landsat the average patch LST(Landsat 5TM band 6, which is the one used for the day LST calculation, has a resolution of 120 m, which has been further resampled into 30m, this resolution does not allow to calculate LST values of the finer narrowings). The analysed patches (Figure 7.6), present an average patch surface of 1.6 ha, and an average patch LSI of 1.9 ha. They are the ones presenting shapes regular enough to allow GIS to extract the average LST, however, some of the analysed patches present widths below 100 m. Therefore, the inverse correlation found between the day LST and the slenderness of the shape might be the result of the influence of the surroundings of the analysed patches (Figure 7.5), which might increase or decrease the average temperature of the forest patch depending on its land use.

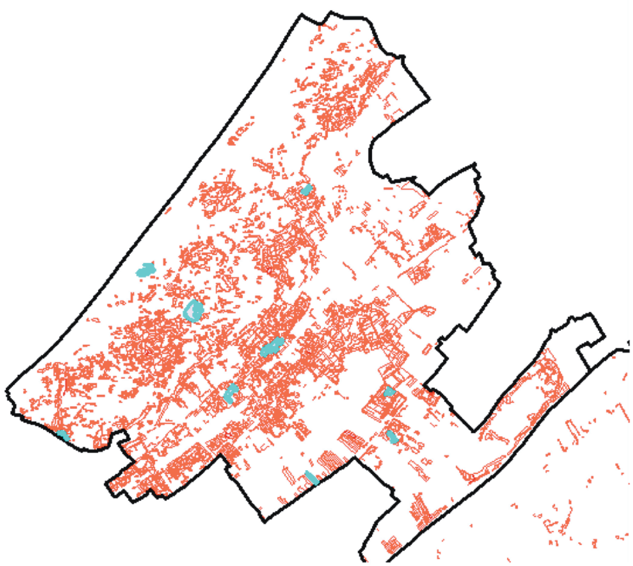

FIGURE 7.5 In red, forest patches of Duin, Horst en Weide provincial park, with small surfaces and numerous narrowings. In blue, analysed forest patches

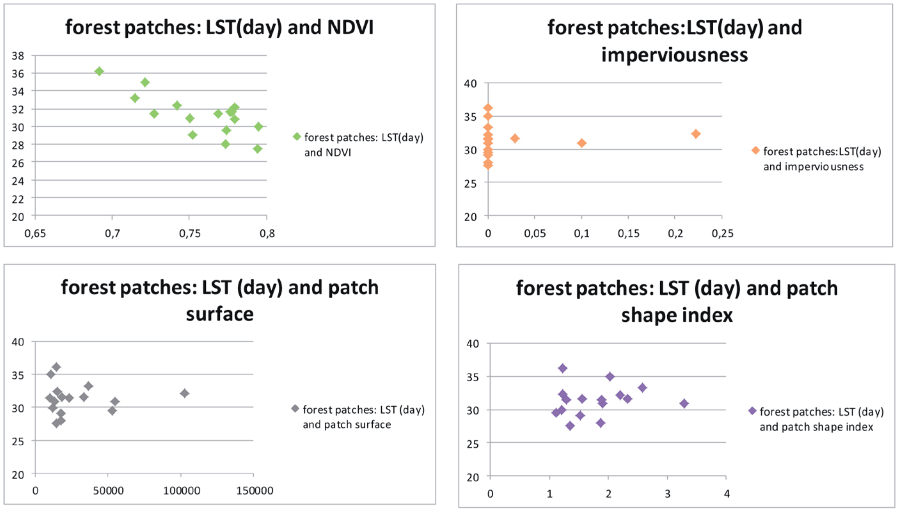

FIGURE 7.6 Analysis of the relationship between the different parameters and daytime LST for forest patches with surfaces above 1 ha in South Holland provincial parks.

– Cropland

Cropland average day LST is approximately 1°C below the average park day LST (Figure 7.4). The multiple regression analysis of the average day LST, NDVI, imperviousness, size and shape index of 68 analysed cropland patches of South Holland provincial parks reveals that a multiple correlation coefficient of R=0.7 and R2=0.5 relating day LST to the rest of parameters for cropland patches, with the following coefficients:

FORMULA 7.6

LST d =42.8 – 15.2*NDVI -18.8*I - 1.4E-06*S + 0.5*LSI.

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

Imperviousness and NDVI play the most important role for the determination of day LST. As discussed earlier the inverse correlation between day LST and NDVI seems predictable, in turn, imperviousness is typically correlated with day LST, whereas in this case an inverse correlation was found. The analysis of the imperviousness of the cropland patches reveals that most of the impervious surface is covered by greenhouses, and that, as described at the beginning of section 7.3., due to the reflectance of the glass, the average day LST of greenhouses is 1°C lower than the park average surface temperature and presents a similar average LST as the cropland patches, thus contributing to the cooling potential of the patches.

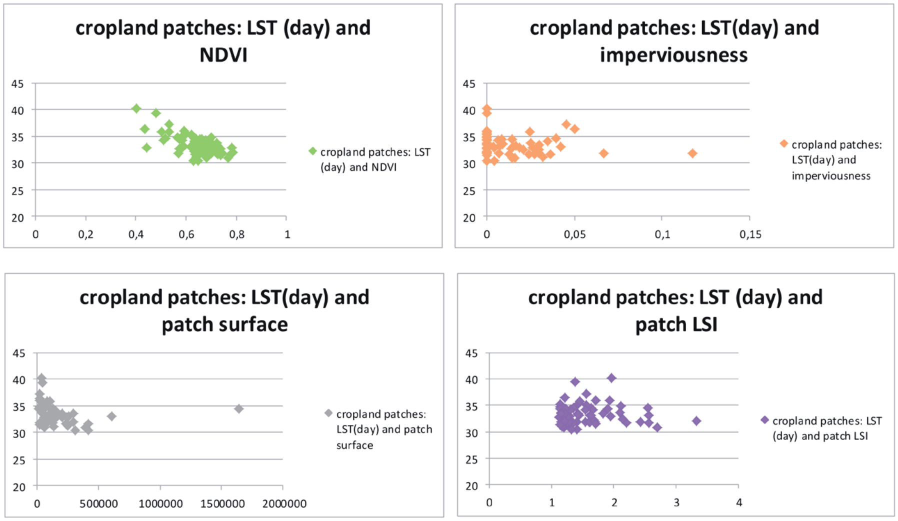

FIGURE 7.7 Analysis of the relationship between the different parameters and daytime LST for cropland patches in South Holland provincial parks.

The regression analysis also reveals that day LST is correlated to the slenderness of the patches. The average size of the analysed patches is of 14.7 ha, and the average LSI of the analysed patches is 1.5. The more compact the cropland patch, the cooler its surface (Figure 7.7).

– Grassland

Grassland is the land use with worst thermal behaviour present in South Holland parks, and it actually presents an average day LST 0.7°C higher than the parks average (Figure 7.4). The multiple regression analysis (Figure 7.8) of the average day LST, NDVI, imperviousness, size and shape index of 189 grassland patches with surfaces above 1 ha of South Holland provincial parks reveals that a multiple correlation coefficient of R=0.5 and R2=0.3 relating day LST to the rest of parameters for grassland patches, with the following coefficients:

FORMULA 7.7

LST d =42.7 – 10.9*NDVI + 0.5*I - 2.3E-05*S + 0.02*LSI.

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

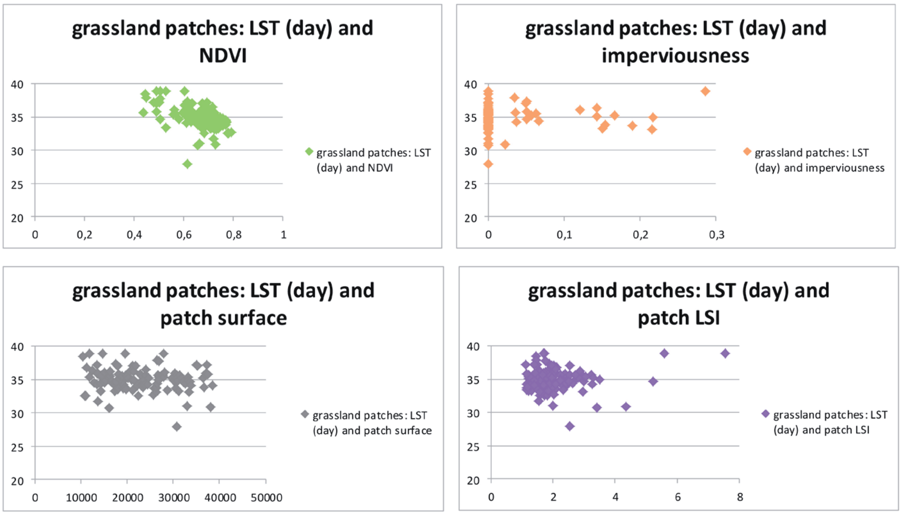

FIGURE 7.8 Analysis of the relationship between the different parameters and daytime LST for grassland patches in South Holland provincial parks.

Even though the multiple correlation analysis presents a pretty weak correlation ($R2=0.3$), NDVI and imperviousness play the most important role for the determination of day LST. Compared to the cropland patch analysis, the imperviousness is correlated to the day LST in the case of the grassland patches. This is due to the fact that most of the impervious surfaces comprise conventional roof and pavement surface materials (instead of glass roofs, which are found in the cropland patches).

Since the main difference between cropland and grassland is their irrigation pattern, it seems that in this case evapotranspiration is generating the surface temperature difference between these two land uses. Spronken-Smith (2000) already highlighted the importance of irrigation to increase the cooling effect of parks.

- Water surfaces

The cooling effect of water surfaces is unclear and seems to vary from case to case (Saaroni and Ziv, 2003; Cao et al., 2010). In the summer of 2006, in the South Holland provincial parks, water surfaces seem to present the lowest average LST with 25.8°C (Figure 7.4). The sizes of the patches present great variations, and have surfaces that range from 600 sqm til 433 ha. Overall the average patch surface is the highest, with 40 ha, and the average LSI is also the highest with a value of 3. Small surfaces with high shape indexes correspond to canals, whereas large compact water surfaces correspond to water ponds.

The multiple regression analysis of the average day LST, NDVI, imperviousness and size and shape index of 28 analysed water surface patches of South Holland provincial parks (Figure 7.9) that a multiple correlation coefficient of $R=0.8$ and $R2=0.6$ relating day LST to the rest of parameters for water surface patches, with the following coefficients:

FORMULA 7.8

$$LST\ d = 26 + 10.7*NDVI - 1.4E\text{-}06*S + 0.02*LSI$$

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

NDVI plays the most important role for the determination of day LST, and it increases the water surface temperature. During the summer, in the Netherlands, the water surfaces get covered with lily pads and other water surface vegetation, which have a negative contribution on the water surface cooling capacity. It seems there is a slight positive correlation between the slenderness of the patch and the day LST.

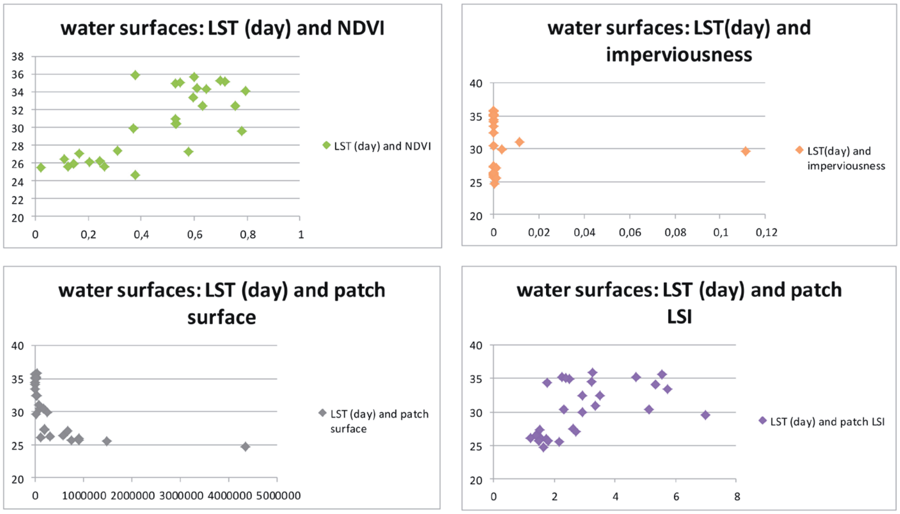

FIGURE 7.9 Analysis of the relationship between the different parameters and daytime LST for water surfaces in South Holland provincial parks.

– Building patches

Built areas are the land use presenting the highest day LST of South Holland provincial parks with an average day LST of 37.9°C, 3.7°C higher than the average park day LST. Previous studies concluded that the size of urban patches and the amount of paved surfaces is normally correlated with the increase of LST (Cheng et al., 2014; Zhou et al., 2011; Li et al., 2011). However, the structure of the built patches of South Holland parks, is one of small and scattered patches. The average built up patch size is 970 sqm and the average LSI is 1.4, which hinders the analysis with the use of Landsat imagery. As a matter of fact, the multiple regression analysis of the average day LST, NDVI, imperviousness, size and shape index of 323 built patches with surfaces below 250 m^2 of South Holland provincial parks (Figure 7.10) reveals that only a weak multiple correlation coefficient of R=0.5 and R2=0.2 relates day LST to the rest of parameters, with the following coefficients:

FORMULA 7.9

$$LST\ d = 39.7 - 9.1*NDVI - 0.02*I + 4.2E{-}03*S + 0.6*LSI$$

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

In this case, NDVI and LSI play the most important role for the determination of day LST. Most of these patches are surrounded by other urban patches, thus the more slender the patch, the more influenced by the surrounding urban environment. The use of Landsat imagery for the assessment of small land use patches can thus be misleading due to the lack of resolution of the satellite imagery.

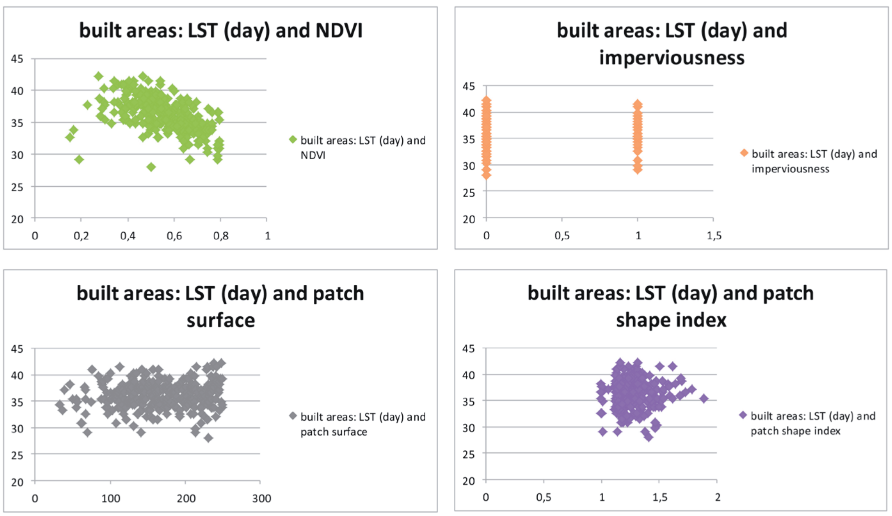

FIGURE 7.10 Analysis of the relationship between the different parameters and daytime LST for built patches with surfaces below 250 m² in South Holland provincial parks.

– Greenhouse patches

Warehouse patches present an average day LST of 33.1°C, which is 1°C lower than the average South Holland park LSTs (Figure 7.4). Thus they have a cooling effect. Most of the warehouses present in South Holland provincial parks are actually greenhouses with highly reflective glass roofs, which is what contributes to the reduction of the surface temperature of these patches.

The multiple regression analysis of the average day LST, NDVI, imperviousness, size and shape index of 28 industrial patches with surfaces below 1,000 m^2 of South Holland provincial parks (Figure 7.11) reveals that a multiple correlation coefficient of R=0.5 and R2=0.3 relating day LST to the rest of parameters, with the following coefficients:

FORMULA 7.10

$$LST\ d = 39.8 - 4.1*NDVI - 0.6*I - 3.7E\text{-}03*S + 0.6*LSI$$

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

NDVI, imperviousness and LSI play the most important role for the determination of day LST. An inverse correlation between day LST and imperviousness was found due to the fact that even though greenhouse areas represent surfaces with high imperviousness, they contribute to the reduction of the surface temperature due to the high reflectance of their glass roofs. Day LST is slightly correlated to the slenderness of the patches, due to the influence of warmer surroundings.

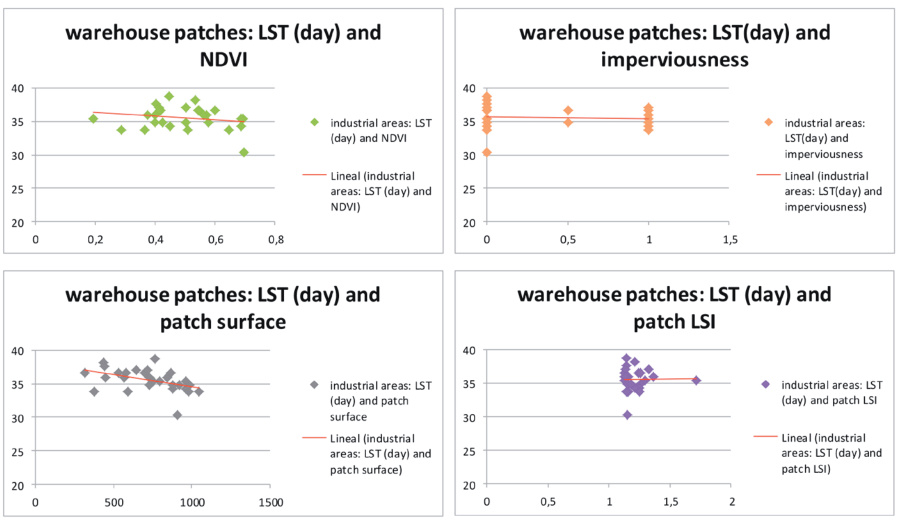

FIGURE 7.11 Analysis of the relationship between the different parameters and daytime LST for warehouse patches with surfaces below 1,000 sqm in South Holland provincial parks.

Conclusion of the patch analysis

The analysis of all the land use patches shows that the LST of the different park components varies depending on their land use. The multiple correlation analysis of the patch night LST and day LST for each land use, reveals that NDVI is inversely correlated to LST (in both cases) for all studied land uses (, forest, cropland, grassland, water surface, built areas and warehouse areas). In turn, imperviousness and the shape of patches vary differently depending on the land use, and the size of the patches.

As far as imperviousness is concerned, generally imperviousness is correlated to the day LST, except for cropland and greenhouseareas, where the impervious surfaces represent greenhouse surfaces which have highly reflective roofs which contribute to the reduction of day LST.

The conclusions regarding the influence of the patch shape in the average LST are highly influenced by the nature of the areas surrounding the studied patches. In that sense the studied land uses can be organised in three groups. The first group is made of large patches surrounded of warmer areas: it is the case of cropland, grassland and water surfaces. The second group is made of small patches clustered around each other: this is the case of forest patches and built area patches. The third group is formed by small scattered patches surrounded by warmer areas: this is the case of the warehouse patches. The first land use group (cropland, grassland and water surfaces) sees its average LST increase with the increase of the slenderness of its patches. The more slender, the more influenced by their warmer surroundings. The second group (forest and built areas), is influenced by the average LST of their own patches. The more slender the forest patch, the cooler the temperature due to the presence of the surrounding forests. The more slender the built area, the more influenced it will be by the high LST of the surrounding built areas. The third group ofgreenhouses, is surrounded by warm areas, the more slender the patches, the higher the day LST.

§ 7.3.2 Surface thermal classification

The unsupervised thermal classification of the day LST, NDVI and imperviousness layers reveals that there are five surface clusters in South Holland provincial parks, each of these clusters have a different average day LST, NDVI and imperviousness combinations. The average night LST doesn´t vary much between the different clusters, in turn, day LST varies considerably, and presents the lowest average values for cluster 1 and the highest values for cluster 5 (Figure 7.14). The analysis of the cluster composition of the different land use categories (Figure 7.15) reveals that cluster 1 can be assimilated to water surfaces, cluster 2 to trees and bush areas, cluster 3 could be assimilated with greener grassland patches, whereas cluster 4 cover warmer grassland patches, and finally cluster 5 can be identified with urban areas and bare soil zones (Figure 7.13).

Since the greenhouse patches only represent a very small part of the parks surface (Figures 7.20, 7.21, 7.22, 7.23, 7.24 and 7.25) the unsupervised classification hasn´t produced a specific cluster assimilable to glass surfaces. In turn, greenhouse surface fall sometimes into the cluster 1 category (assimilated with water), and other times into cluster 2 category (assimilated with trees and bush areas) (Figure 7.12).

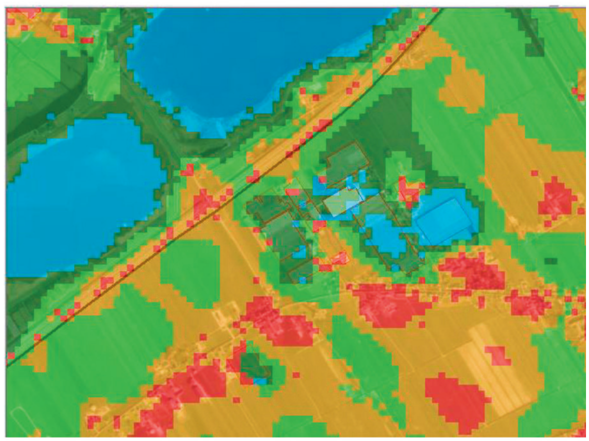

FIGURE 7.12 Unsupervised classification clusters from day LST, NDVI and imperviousness layers. The greenhouse areas are classified either in the same cluster as water or on the same cluster of forested areas. Due to their small presence in the parks, they are grouped with categories with similar thermal behaviour.

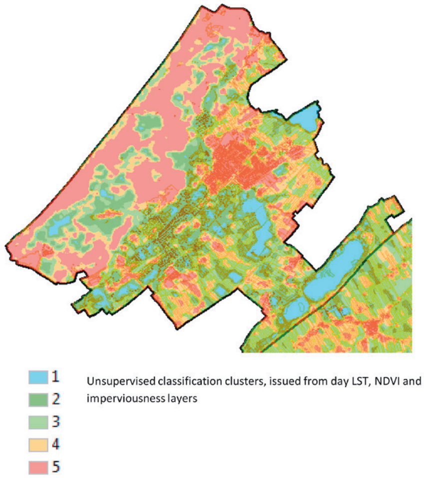

FIGURE 7.13 Unsupervised classification clusters from day LST, NDVI and imperviousness layers. The bare soil areas of the coast are classified in the same cluster as the built up areas, since they have a similar thermal behaviour.

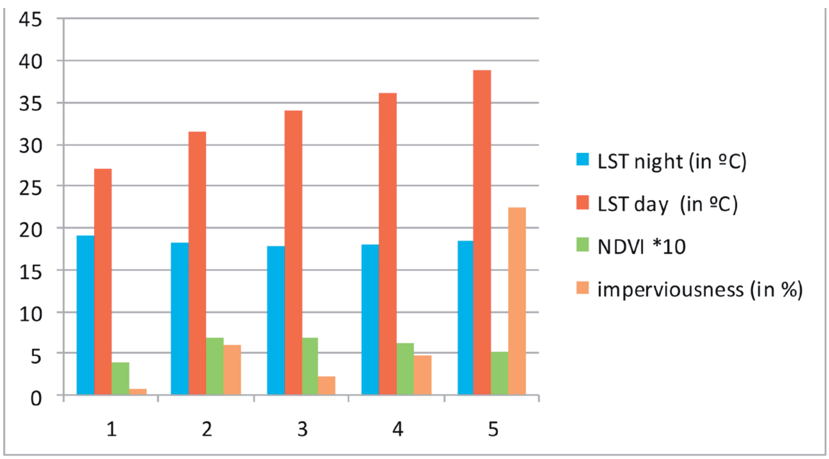

FIGURE 7.14 Average day LST, night LST, NDVI and imperviousness for the five different clusters produced by the unsupervised classification of the day LST, NDVI and imperviousness maps.

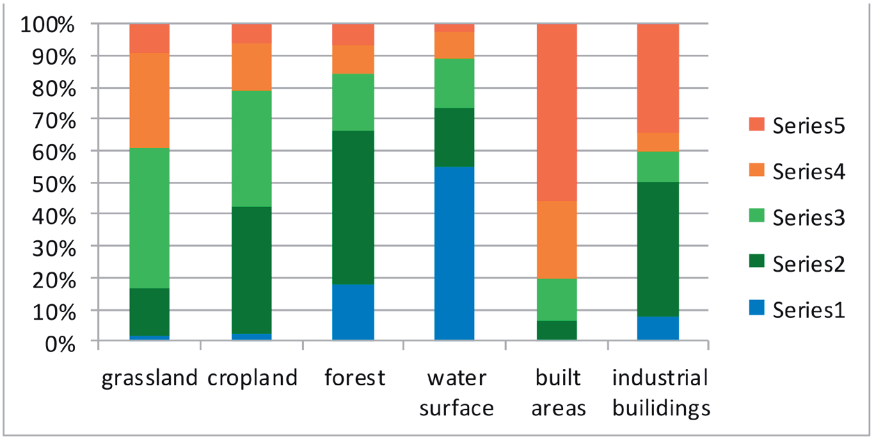

FIGURE 7.15 Cluster composition of the different land use present in South Holland provincial parks.

§ 7.3.3 Defining the adaptation measures to improve provincial parks cooling capacity

Once the thermal behaviour of the different land use typologies encountered in South Holland provincial parks was analysed, the authors have identified park adaptation areas (PAA) (which are park areas adjacent to urban hotspots surrounding the parks, and which could potentially help cool theses hotspots).

- Identifying hotspots in the urban areas surrounding the parks
  - Hotspots with LST above 41°C

The analysis of the hotspots surrounding the Midden-Delfland park reveals that there are 8 major hotspots with an LST above 41°C and with an average size of 86 ha within a distance of 500 m from the park's boundary. All of them correspond with industrial areas (Figure 7.16). They are scattered around the park's perimeter and the length of the hotspots (hotspot's sides connecting to the park) ranges from 450 m (corresponding to hotspot 1) to 1,000 m (corresponding to hotspot 4) (Figure 7.16).

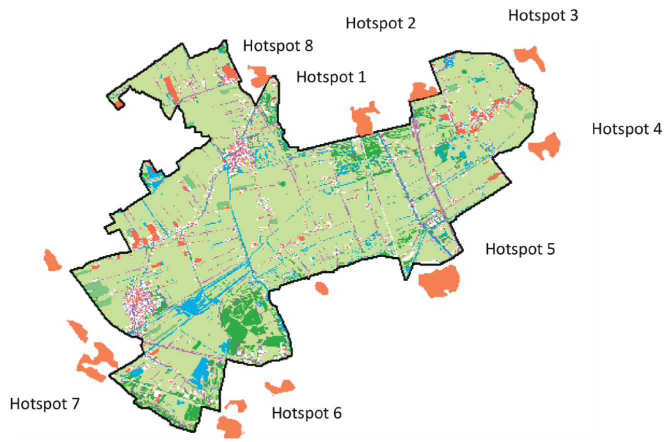

FIGURE 7.16 Midden-Delfland hotspots with and LST>41°C surrounding the park.

– Hotspots with an LST between 36°C and 41°C

The analysis of the hotspots surrounding the Midden-Delfland park reveals that there are 3 major hotspots with an LST ranging from 36°C to 41°C and with a connecting length with the park longer than 1,500 m (Figure 7.17). These hotspots have areas that range from 300 to 600 ha, and their dominant land use is residential. The PAA has areas that range from 100 to 600 ha for each hotspot. In this case, since the dominant hotspot land use is residential.

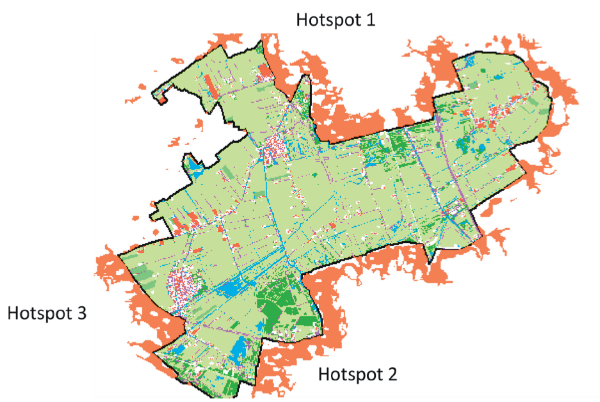

FIGURE 7.17 Midden-Delfland hotspots with 41°C>LST>36°C surrounding the park.

– Prescribing measures to improve the cooling capacity of the park areas adjacent to the urban hotspots.

Once the hotspots have been identified, the authors have prepared a chart to analyse the park adaptation areas (PAA) and the measures that could help increase the cooling capacity of the PAA, thus reducing the intensity of the hotspots (Figures 7.18 and 7.19). For each identified hotspot, the day LST difference between the hotspot and the PAA. was calculated The measures to redesign the PAA´s which have a LST difference below 10°C with the hotspots (for hotspots above 41°C: hotspot 2, 3, 4, 5 and 8; and for hotspots with LST´s between 36°C and 41°C: hotspots 1, 2 and 3) primarily consist in a change of land use. The dominant land use of the before mentioned PAA´s is grassland, which is the land use with the second worst thermal behaviour encountered in South Holland provincial parks (Figure 7.4), after the built up patches. The conversion of those patches into cropland (reduction of up to 1.8°C), forest (reduction of up to 4°C), water surfaces (reduction of up to 8°C) of greenhouse areas (reduction of up to 1.7°C) would increase their cooling capacity. Further, in case the grassland land use is to be maintained, an increase of the existing patches NDVI (through the increase of irrigation or introduction of particular vegetation species) would also contribute to the increase of the cooling capacity of those PAAs. A reduction of those grassland patches imperviousness would also theoretically contribute to a decrease of their average LST, however, the analysis reveals that the analysed PAAs seem to present pretty low imperviousness values already. Overall, there are several options to increase the cooling capacity of the PAAs, which allows combining the thermal considerations with other spatial planning priorities.

Hotspots number 1, 6 and 7 with LST above 41°C, present LST differences with their corresponding PAA´s greater than 12°C. Those patches are primarily occupied by forested areas. The adaptation measures to be introduced would consist in increasing the advection between hotspot and park (through the creation of cool wind corridors, reduction of the height of buildings surrounding the parks…) rather than modifying the land use of the park adjacent area, since forests already present the second lowest surface temperature after water surfaces.

FIGURE 7.18 Diagnosis and adaptation design for hotspots with an LST>41°C.

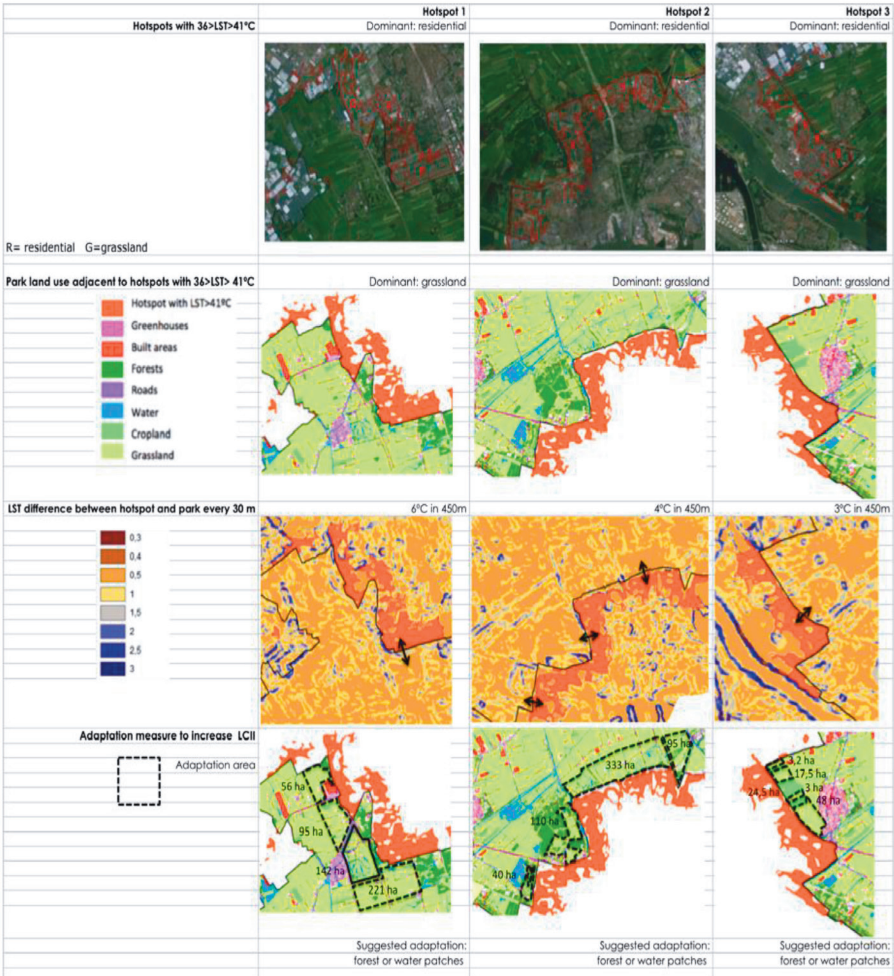

FIGURE 7.19 Diagnosis and adaptation design for hotspots with an LST ranging from 36°C to 41°C.

§ 7.4 Conclusions

The average LST of South Holland provincial parks varies depending on the land use. The average LST increases from 25.9°C for water surfaces, to 31.4°C for forests, 33°C for cropland, 33.1°C for greenhouse areas, 34.9°C for grassland patches and 37.9°C for built areas. Within each land use category, NDVI, imperviousness and patch shape index influence differently their thermal behaviour of the patches. NDVI is inversely correlated to day LST for all categories, imperviousness is correlated to day LST for all areas which do not comprise a significant presence of greenhouses (grassland and built patches) and inversely correlated to LST for areas with a high presence of greenhouses (cropland and warehouses). Finally, LSI varies depending on the nature of the surrounding patches, especially for small patches (built areas, forests and greenhouse areas).

Remote sensing combined with GIS allows identifying the urban hotspots surrounding the parks, identifying the park areas adjacent to these (PAA), their surfaces and their land use, in order to design adaptation measures to increase the cooling capacity of these. In the case of South Holland provincial parks, most of the hotspots surrounding the park are adjacent to grassland patches. The measure to increase the cooling capacity of those patches would consist in a change of land use and or an increase of the NDVI of the existing grassland patches. These suggestions to increase the cooling potential of the parks remain deliberately open in order to allow combining these measures with other spatial planning priorities.

§ 7.5 Discussion

The research questions presented in section 7.1 have been answered, as ultimately, this study provides a methodology to allow the development of design guidelines for the improvement of the cooling capacity of the park perimeter areas over the hotspots surrounding the parks. The provincial parks of such scale surely have a cooling influence in areas and cities located at a greater distance from the park; however, such analysis falls outside the scope of this study. In any case, increasing the cooling capacity of the park edges contributes to increasing the cooling capacity of the park as a whole. The study delves deeper into the specific case of Midden-Delfland provincial park, to illustrate the proposed methodology, which could be replicated in the rest of South Holland provincial parks.

The first part studies how the different land use categories encountered in South Holland parks (grassland, cropland, forests, water surfaces, built areas and industrial areas) present, during heat waves, different thermal behaviours (Indicators -night and day LST- and influencing parameters -average NDVI index, imperviousness coefficient, patch size and patch shape-). It provides an overview of the correlation coefficient of the influencing parameters and the indicators, depending on the analysed land use categories. The influencing parameters are patch characteristics which can be altered through design. Land use and patch characteristics (within each land use category) are the main design categories which have an influence on the thermal behaviour of the park.

The second part of the study aims at identifying park areas adjacent to urban hotspots surrounding the parks, where the implementation of cooling measures (identified in the first section) would contribute to the reduction of the urban heat of the adjacent hotspots. The exercise is carried out for the Midden_Delfland park. The hotspots are identified using Landsat 5TM imagery, the mitigating design measures are proposed for park areas adjacent to hotspots and presenting LST differences with the hotspots, below 10°C. The idea is to use remote sensing and GIS not only to carry out the analysis of the cooling capacity of the park, but also to identify the areas that could benefit from the implementation of cooling design measures. The same technology for the analysis and for the implementation.

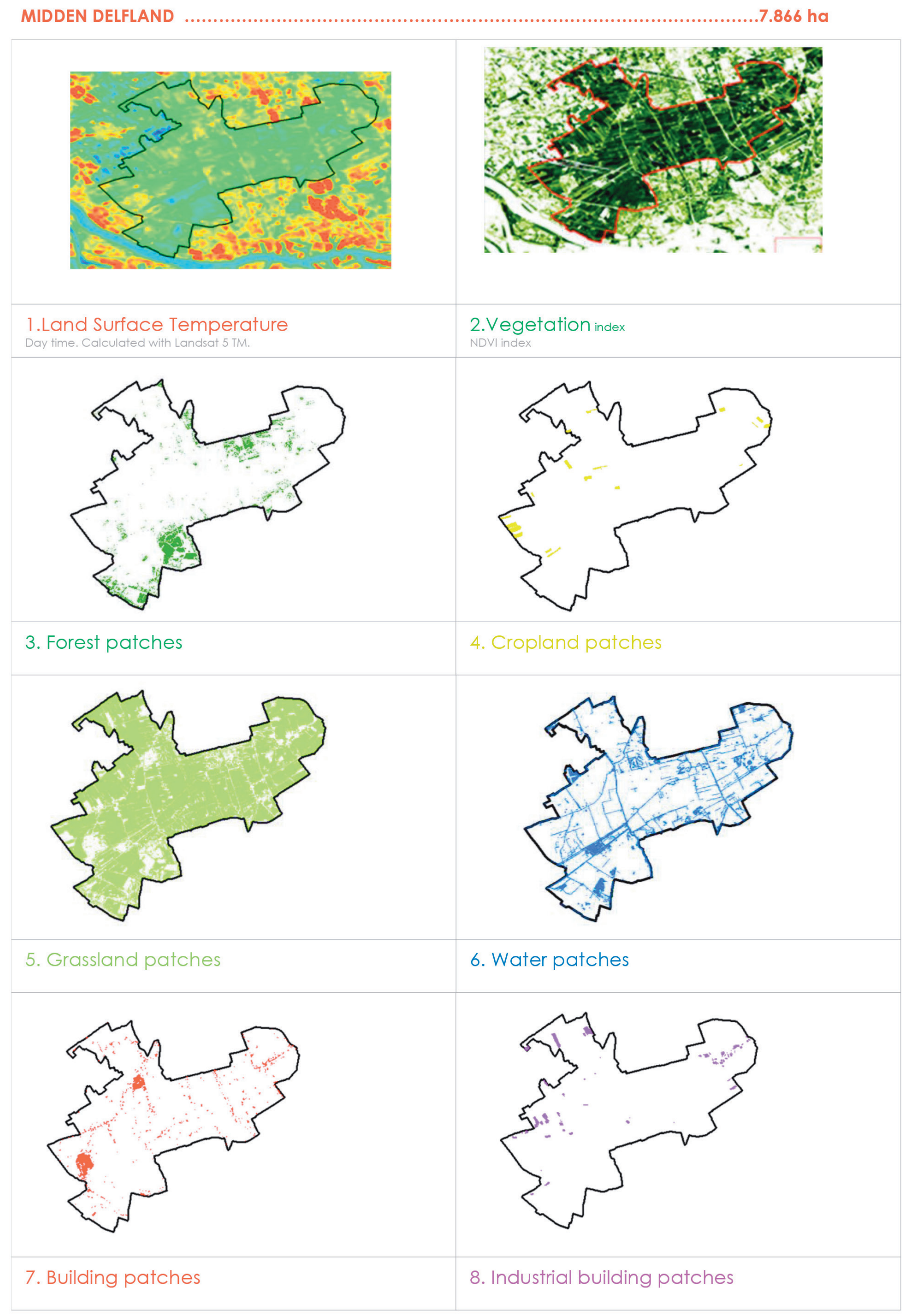

FIGURE 7.20 Midden-Delfland analysis schemes

FIGURE 7.21 Duin, Horst en Weide analysis schemes

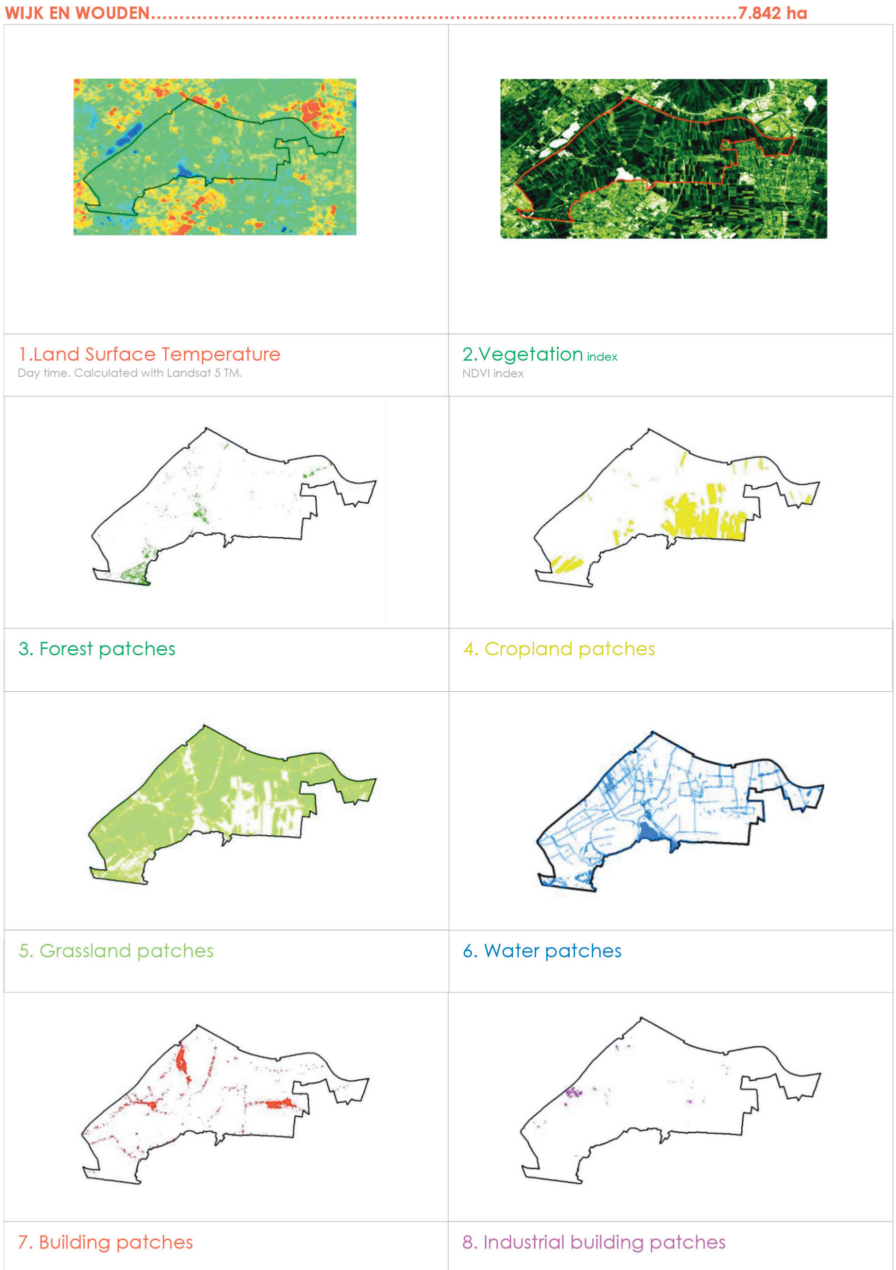

FIGURE 7.22 Wijk en Wouden analysis schemes

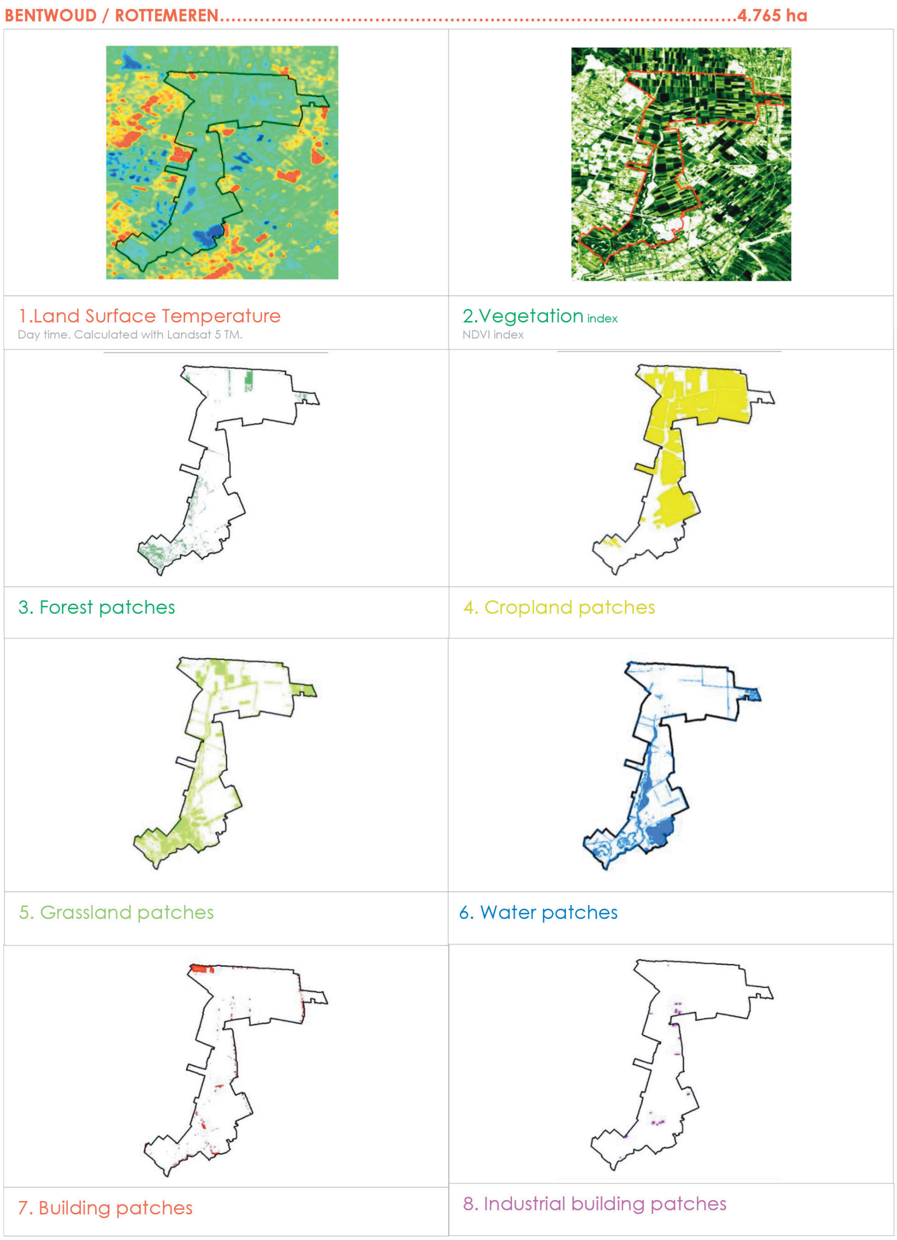

FIGURE 7.23 Bentwoud/Rottemeren analysis schemes

HOLLANDS PLASSENGEBIED..10.658 ha

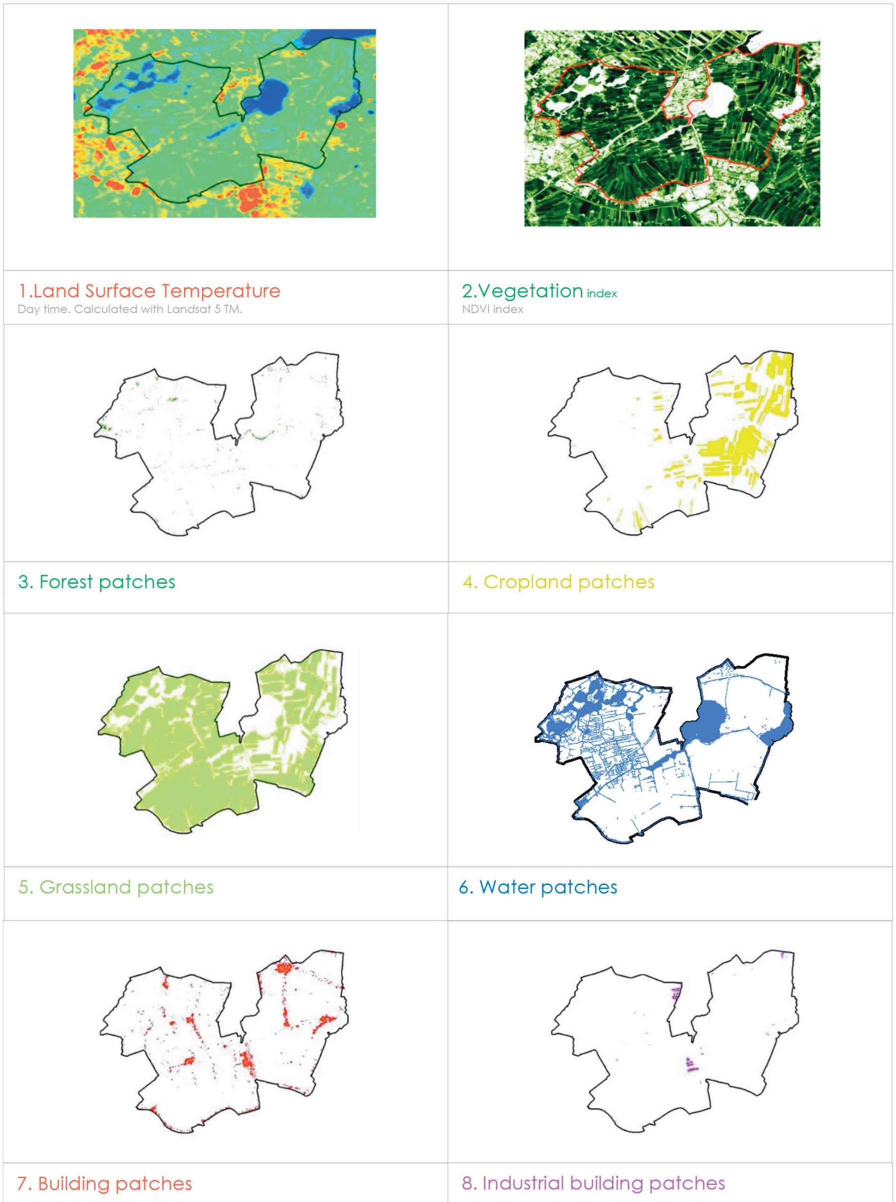

FIGURE 7.24 Hollands Plassengebied analysis schemes

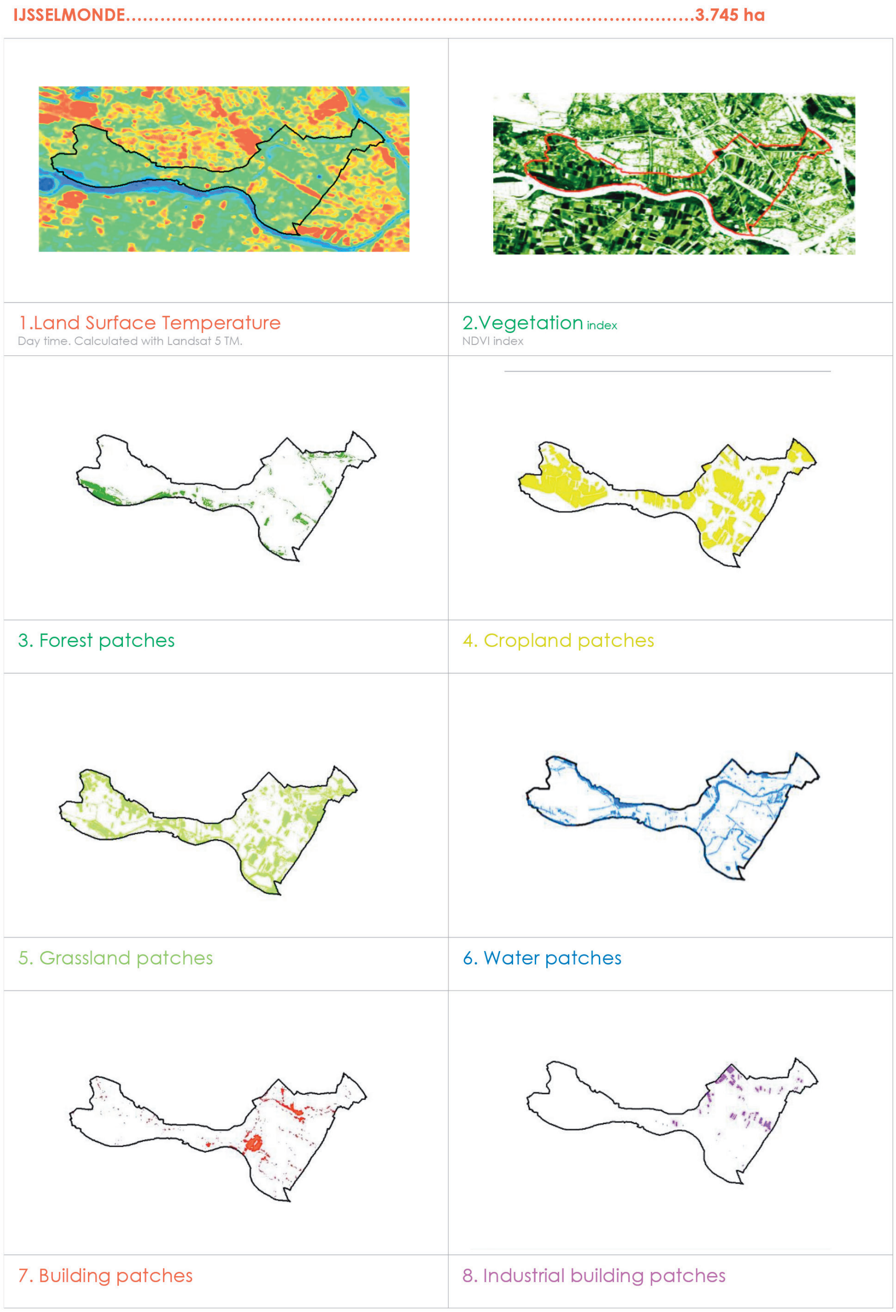

FIGURE 7.25 Isselmonde analysis schemes

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8 Conclusions

§ 8.1 Answering the research questions

This thesis answers the overall question if the use of satellite imagery could help analysing the UHI in the Netherlands and suggests mitigation actions that can be implemented in the existing urban contexts of the cities, regions and provinces assessed. In order to answer this main research question a number of sub questions were formulated and studied from a theoretical perspective in part A: method. The investigation carried out in part A was used as a basis for the assessment of the urban heat in three specific case studies in the Netherlands in part B: results (Figure 8.1).

Subquestion 1: SCALE

How would the implementation of the 1920´s regionalist premises of Geddes and Mumford affect the UHI phenomenom?

Subquestions 2: TOOLS

What satellite imagery and remote sensing processing techniques could be used for the heat island assessment at supra-urban scale?

Subquestion 3: STRATEGIES

What representation and mapping strategies could we use to ensure the proposed measures are accurate enough to actually make a difference and open enough to be compatible with the rest of elements?

PART A: METHOD.

Tools and **strategies** to allow a **mutliscale** and mulidisciplinary assessment of the heat islands UHI

	CHAPTER	CONCLUSIONS
SCALE. Description of regionalists principles that would help reduce the UHI.	CHAPTER 3 (ARTICLE 2)	**Regional.** Enhancing and preserving large-scale regional geographical natural and/or green elements, has a positive impact on heat island reduction.
		City. Urban containment policies, contributes to the reduction of heat island effect.
		Neighbourhood. Green open blocks suggested.
TOOLS . Revision of parameters and mapping possibilities of satellite imagery combined with GIS for UHI assessment.	CHAPTER 4 (ARTICLE 3)	Modis 11A1 + GIS
		Landsat 5TM+ GIS
STRATEGIES. Revision of four catalyzing mapping strategies (Game-board, Rhizome, Layering and Drift) and how these could help integrate UHI considerations into the broader urban planning plans.	CHAPTER 4 (ARTICLE 3)	Gameboard. Preliminary overall assessment. Identification of disciplines/priorities intervening
		Rhizome. Integration of the influences of the "actants" identified during the game-board phase, relating one to the other and suggesting open and combinable actions.
		Layering:physical overlap of the different layers of maps identified in the two previous phases
		Drift phase would represent the final translation of the maps into specific routes for citizens.

FIGURE 8.1 Overall thesis structure

PART B: RESULTS.

Heat island **case studies** in The Netherlands: remote sensing assessment and adaptation proposals

CHAPTER	CONCLUSIONS
CHAPTER 7 (ARTICLE 6)	Measures to enhance natural cooling capacity of South Holland provincial parks. Affect land use, size and shape index.
CHAPTER 6 (ARTICLE 5)	Forecasted growth of medium size North Brabant cities will not aggravate the UHI per se. The design (albedo, greenery, ..), thus neighborhood typology, will have a larger impact.
CHAPTER 5 (ARTICLE 4)	City centers have a worst thermal behaviour than post war residential neighborhoods (with open residential blocks). Measures to improve city centers heat accumulation suggested.

§ 8.1.1 SCALE. How would the implementation of the 1920´s regionalist premises of Geddes and Mumford affect the UHI phenomenom?

Contemporary urban planners are generally not empowered to act at a regional scale, and thus are often not concerned by that larger supra-metropolitan scale, which seems critical to address the global challenges faced by existing urbanisation patterns, and for which remote sensing is best suited. Geddes and Mumford 1920´s regionalist principles can be divided in two main categories: territorial design principles and urban containment principles.

At the territorial scale, enhancing and preserving large-scale regional geographical natural and/or green elements (thus reinforcing the "sense of place and concept of nature" suggested by the 1920's´ regionalists) is still a very appropriate and much used approach to maintain quality of life at a regional scale. Reaching a regional balance between population, resources, vegetation, and animal life represents the greatest challenge. From an UHI perspective, the measures that are part of "sense of place and the concept of nature" are often prescribed to mitigate the UHI effect. In chapter 7, the cooling capacity of the different land uses found in South Holland provincial parks was studied, in order to promote enhancement measures that would increase the natural cooling capacity of the areas of the park adjacent to hotspots.

The urban containment concept set forward by the regionalists includes elements such as garden cities, limiting the size of the cities, implementing density thresholds and greenery standards, and suggesting interventions at neighbourhood scale. Attempts to limit the growth of the cities' actual footprint are still relevant in present times. In chapter 6, the relationship between the surface temperature and the size of the cities was analysed for several medium-size cities in North Brabant. For the analysed cities, the size was not a determining factor, instead, high albedo did contribute to the reduction of the surface temperature.

The greenery standards applied in garden cities are far from what is realistic in current cities. However, the materialisation of residential blocks interspersed with greenery did find a broad acceptance. From a UHI perspective, in The Netherlands postwar neighbourhoods with green open residential blocks present lower surface temperatures than city centers, as highlighted in chapters 5 and 6.

Overall most key elements of the regionalist concept are still very much relevant today and would indeed help to reduce the impact of the Urban Heat Island. The garden city idea requires a revision.

§ 8.1.2 TOOLS. What satellite imagery and remote sensing processing techniques could be used for the heat island assessment at supra-urban scale?

Remote sensing retrieves mainly land surface information and thus allows mapping surface urban heat islands (SUHI). There are two main categories of urban heat islands: the air temperature urban heat island (UHI) which concentrates in the air temperature difference and the surface urban heat islands (SUHI) which measures the surface temperature difference. They have different behaviours and patterns. The SUHI hits its peak during daytime, when the sun is still shining, reaches up to 15°C difference (EPA, 2015), whereas UHI reaches its peak after sunset, when warm urban surfaces start radiating the heat absorbed during the day towards the atmosphere, registering air temperature differences of up to 12°C.

Air temperature seems a more relevant indicator of human comfort than surface urban heat island. However, retrieving consistent air temperature data in the urban environment is a challenge. In the particular case of the Netherlands, the KNMI meteorological stations are all located in the rural environment, precisely to erase the influence of urban heat in the temperature retrieval. Consistent surface temperature data can be mapped using satellite imagery. Even though the spatial pattern of UHI and SUHI differs (Dousset and Gourmelon, 2003), many climatologists use land surface temperature to assess the urban heat accumulation behaviour (Price, 1979; Roth et al., 1989; Parlow, 2003; Van Hove et al., 2011; Yuan and Bauer, 2007; Cao et al., 2010; Li et al., 2011; Zhou et al., 2011; Choi et al., 2012). Moreover, remote sensing also allows mapping parameters that influence the urban thermal behaviour, such as albedo, vegetation index, imperviousness, storage heat flux, latent heat flux and sensible heat flux.

For urban planners the principal limitation of remote sensing lies in the fact that even though aerial view provides a very comprehensive overview of cityscapes and landscapes, these must be complemented by the analysis of other tangible (street level views, pedestrian flows...) and intangible parameters (economic activity, social cohesion...). However, the most important challenge for urban planners is to be able to turn these accurate and precise images into maps. Satellite imagery per se cannot be taken as true record of reality. First, the selection of scale and frame are critical and then the way in which the information is filtered and represented also plays an important role. Mastering the use of software to treat satellite imagery becomes critical for urban planners to be able to integrate these into design.

ENVI is a geospatial software designed by Exelisvis (Exelis Visual Information Solutions, 2016) to process and analyse any kind of satellite imagery. The combination of ENVI and GIS allows for the greatest integration between the available raster and vector information. There is a third type of software consistently needed to work with satellite information. These are the programs that atmospherically and geometrically correct the raw satellite imagery. The geometrical correction is needed in order to be able to transpose the information retrieved from the curved surface of the earth into a two-dimensional image. The atmospheric correction is needed because the satellites retrieve the radiation emitted by the surface of the earth through the atmosphere. The radiance retrieved is somehow distorted due to the composition of the atmosphere (humidity, chemical content). Atmospheric correction software "erase" the effect of the atmosphere from the retrieved radiance through the use of certain atmosphere composition models which vary, depending on the latitude and longitude, on the season and on whether the image captures a rural or an urban environment.

The satellite images themselves, can be downloaded through the US Geological Survey Global EarthExplorer (USGS EarthExplorer, 2016), such as Landsat or Modis. Landsat 5TM and Modis 11A1 satellite imagery were used for the case studies developed in chapter 5, 6 and 7. Landsat has a resolution of 100 m and Modis of 1 km. Land surface temperature, heat fluxes and albedo can be mapped using Landsat imagery (100 m resolution) and processing it in ATCOR (Atmospheric & Topographic Correction, 2016), which allows not only completing the geometric and atmospheric correction of the images but also calculates the before mentioned parameters. Albedo, NDVI and imperviousness are physical characteristics of the built environment which can be addressed and improved. Measures to improve albedo, NDVI and imperviousness can be simulated and quantified. Satellite imagery product Modis 11A1 (1 km resolution) contains a layer where land surface temperature (day and night averages) and albedo are already processed and calculated. In this study the authors have only focused in the use of open source satellite imagery which have enough resolution to assess the SUHI at a city and regional scale. There are high-resolution satellite imagery which provide a more accurate analysis, however these are not open-source.

Studies carried out in Basel by Parlow reveal that heat fluxes might be more relevant indicators of the UHI phenomenon than day-time surface temperature patterns (Parlow, 2003). Remote sensing imagery can be used as a basis for mapping heat fluxes. The energy balance equation for radiant energy absorbed by heat fluxes can be written as (Asrar, 1989): Rn = G + H + LE, where Rn is the net radiant energy absorbed by the surface; G is the storage heat flux, i.e. the energy dissipated by conduction into the ground or into the building materials; H is the sensible heat flux, that is the energy dissipated by convection into the atmosphere (its behaviour varies depending on whether the surface is warmer or colder than the surrounding air); and LE is the latent heat flux, that is the energy available of evapotranspiration.

Albedo is an index that represents surface reflectance. It is strongly related to urban heat. Increasing the albedo of roofs and pavement reduces their surface temperatures. When a surface has an albedo of 0, it means that it does not reflect any radiation whereas an albedo of 1 means that all the incoming radiation is reflected by the surface to the atmosphere. In European cities the average albedo is around 0.20 (Taha, 1997). Increasing the surface albedo from 0.25 to 0.40 could lower the air temperature as much as 4°C (Taha et al. 1988).

Normalised difference vegetation index is typically used to calculate vegetation index. It can be mapped after calculating NDVI. If Landsat is used, both NIR and VIS are bands of the satellite imagery. If Modis is used, NDVI is included as one of the satellite products.

The vegetation index can be considered as a relevant indicator for urban heat studies. Several studies show that minimum air temperatures and vegetation indexes (more specifically the Normalised Difference Vegetation Index – NDVI) are correlated: there is a linear relationship between the difference of urban and rural NDVI and the difference of the urban and rural minimum air temperatures (Gallo et al. 1993). In rural environments, heat fluxes can be expressed as a function of the vegetation index (Choudhury et al., 1994; Carlson et al., 1995).

Imperviousness makes a strong contribution to urban heat. Imperviousness seals the surface, it prevents water from evaporating, and hinders the growth of vegetation, in this way it prevents solar radiation from being converted into latent energy. Impervious surfaces have in addition, the capacity to store heat during the daytime. The heat that is stored in this process is then released at night.

The influence of other factors such as sky view factor (SVF) does not seem to be clear. Some studies find a clear correlation between SVF and nocturnal UHI (Svensson, 2004; Unger, 2004), while in other cases the correlation is not so clear (Blankenstein and Kuttler, 2004). In any case the 3-dimensional analysis of the areas is often critical to ensure that the effect of the building radiation is also taken into consideration.

§ 8.1.3 STRATEGY. What representation and mapping strategies could we use to ensure the proposed measures are accurate enough to actually make a difference and open enough to be compatible with the rest of urban planning priorities?

Since urban heat is often not the only priority to be addressed during the planning process, the need to find integrative and catalysing mapping strategies becomes even more crucial. The incorporation of these parameters and tools into open and integrative large scale urban plans can be done through the use of game-board, rhizome, layering and drift. Game-board is the strategical analysis to be carried out in order to understand which are the "driving forces" affecting the process – game-board mapping strategy has been used to set forward the driving forces influencing the design of South Holland provincial parks in chapter 7 – rhizome is used to define the representation of all aspects (including abstract considerations) that condition the process -this mapping strategy was used to connect the existing neighbourhood categories and the surface thermal clusters in chapter 6-, layering describes the mapping phase which displays the overlap of the different strategies that could be used to reduce urban heat – it was applied in chapter 5 to provide an overview of the parameters influencing urban heat in the six Dutch cities analysed – and finally drift is used as a tool to guide citizens to fresher areas during heat waves. These catalysing mapping categories would allow integrating among others critical climatologic parameters such as urban heat. Heat related parameters (such as heat fluxes, land surface temperature, albedo, NDVI and imperviousness) are mapped at supra-regional scale through the use of satellite imagery.

The catalysing mapping strategies allow reinterpreting the information unfolded by these powerful tools ensuring they to not lead to static prescriptions, but instead they reveal inspiring connections and information, which triggers interactions between actants, parameters and systems.

§ 8.1.4 Could the use of satellite imagery help analyse specifically the urban heat in the Netherlands and suggest mitigation actions implementable in the existing urban contexts of the cities, regions and provinces assessed?

In this PhD thesis remote sensing has been used in three different studies: firstly for the UHI assessment in the city centers of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch, secondly for the analysis of factors influencing the formation of UHI at neighbourhood and city scale in medium-size cities in North Brabant and third to study how to increase the cooling capacity of Midden-Delfland South Holland provincial park.

UHI assessment in the cities of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch

- Remote sensing was effectively used to identify urban heat hotspots in areas where there is a lack of micro-measurements. Storage heat flux was used as an indicator for the identification of urban areas with a high tendency to accumulate heat. Storage heat flux can be mapped using Landsat 5 TM imagery and processing it in ATCOR 2/3 and ENVI 4.7.
- Landsat 5TM processed in ATCOR 2/3 and ENVI 4.7 allowed defining mitigation strategies to reduce urban heat in the identified hotspots. The mapping of vegetation indexes, land surface temperature, coolspots and albedo, allowed identifying areas where to implement more vegetation, areas where wind corridors (connecting hotspots to coolspots) could be created and areas where to increase the reflectance of the materials (to improve the albedo) in the six analysed city centers.
- The layering mapping strategy was used to display the analysis of the different parameters and strategies in the 6 case studies.
- The same satellite imagery was used to estimate the surface of bituminous flat roofs and of clay sloped roofs within the hotspots, in order to calculate a high level estimation of the mitigation effect of the increase of albedo of those surfaces.
- Ultimately remote sensing was used to provide a customised UHI assessment for the cities of The Hague, Delft, Leiden, Gouda, Utrecht and Den Bosch:

UHI assessment of North Brabant medium-size cities

- Remote sensing and GIS were used to map and calculate average night LST, albedo, NDVI, imperviousness and surface of 21 medium-size cities in the region of North Brabant. Further a regression analysis was carried out to understand how these parameters affect the night-time LST. The purpose was to incorporate UHI-related aspects into the design guidelines for the identified future growth areas of medium-sized cities in North Brabant, as these aim to contribute to sustainable development, but do not incorporate yet any urban heat considerations.
- GIS was also used to carry out an “unsupervised cluster classification” of the three most relevant parameters affecting UHI (albedo, NDVI and imperviousness) in order to map and identify the main 6 thermal clusters in the cities of the region. The combined classification of the surface thermal clusters with the existing “urban living environment” categories, has allowed us to come up with a new classification for the development of design guidelines for existing and growth areas which take into consideration the UHI phenomenom.

UHI assessment for South Holland Provincial parks

- First remote sensing and GIS was used to map and calculate the average night LST, day LST, NDVI, imperviousness, size of the patch and shape index for the six most relevant land use categories present in South Holland provincial parks. Then a regression analysis was carried out to understand which factors had a greater influence on day LST.
- GIS was used to carry out an unsupervised classification of day LST, NDVI and imperviousness and obtained 5 surface thermal clusters in South Holland provincial parks (that can be assimilated to water surfaces, trees & bush areas, green grassland patches, warm grassland patches and finally urban and bare soil zones).
- In the second part of the study the authors identified the urban hotspots surrounding the Midden-Delfland park (areas with surfaces larger than 10 ha and average LST above 42°C, and areas with average LST above 36°C with connecting lengths above 1,500 m) and they identified Park Adaptation Areas (PAA) within the park (areas with less than 10°C difference with the hotspots) in order to suggest measures to improve the cooling capacity of those PAAs, based on the conclusions of the first part of the study (measures consisting mainly in a change of land use within the park, or in the increase of NDVI, reduction of imperviousness).

§ 8.2 Interpretation of the results and conclusions in a wider context

The three main characteristics of this research are the scale, the tool, and the mapping strategy.

The scale is the regional one which is key for the urban/rural balance, so critical to ensure sustainable urbanisation patterns at all levels (thus not only to prevent the formation of the UHI effect).

The tool is remote sensing combined with GIS which is key not only for the UHI assessment, but which provides real time accurate information on existing urban environments, unfolding information of any part of the globe and capturing "invisible" wavelengths, allowing also to look back in time (and thus to trace and map) changes since the 1980s (when consistent satellite imagery became available), and finally enabling the treatment of these images (to allow calculation of indexes, surface cluster classifications, completion of regression analysis…). Remote sensing combined with GIS is a very powerful tool not only for the UHI assessment, but also for the overall urban planning purposes. Aerial imagery can be obtained through satellite imagery or through images retrieved on board of airplanes, or drones. The use of drones for many different disciplines is proliferating, and even though its operation is not yet legally regulated in any country, they can potentially revolve the urban data collection mechanism, offering infinite possibilities. In such context, the present research gains particular relevance.

The mapping strategies suggested (game board, rhizome, layering or drift) are also key for integrative urban plans, as the risk of overspecialisation is precisely to forget the integration, the priorisation, the cross connections.

§ 8.3 Discussion

§ 8.3.1 Climatologist tools for the urban planning practice

Even though urban planners should aim for producing integrating plans, the urban planner cannot be an expert in all disciplines of mobility, sociology, economy, climatology… The urban planner needs to be able to retrieve input from different experts, and build up integrating proposals from there. In principle, the urban planner should not necessarily have a specific command of the tools used by climatologists, sociologists, transportation engineers… However, some of the instruments used for the assessment of those specific disciplines, have proven to have wider applications, which can be used for a more general assessment by urban planners. This is the case of remote sensing, which is often used by climatologists, to study (for example) in depth the Urban Heat Island phenomenon, but which can also be used by urban planners for a more superficial assessment of the phenomenon, more oriented towards the development of design adaptation guidelines, rather than focusing on the accuracy of the retrieved measurements. The depth and accuracy of the climatological assessment produced by urban planners is inevitably not comparable to the ones issued by climatological experts. In that sense it is important to remind the different purposes of these two disciplines. Climatologists aim at having the most accurate insight of the phenomena themselves, while the focus of urban planners is on developing spatial planning guidelines to reduce the effect of the phenomena and which are flexible and compatible with other urban planning priorities. The use that those two disciplines make of certain tools is therefore not the same.

§ 8.3.2 Resolution limitations

Landsat 5TM is an appropriate tool to assess urban heat accumulation at city scale due to the resolution of its spectral bands: 30 m for bands 1 to 7, and 120 m for band 6 which is resampled to 30 m. However, in this study Landsat 5 TM was also used to quantify and assess on the phenomenom at neighbourhood scale. The resolution of Landsat 5TM for material discrimination is a little rough. Nonetheless, the purpose of the surface estimations is to provide a high-level quantification of the mitigation effect of the proposed measures, therefore a certain degree of inaccuracy in the surface quantification and qualifications should be acceptable. Furthermore, the objective of these studies is not only to quantify the mitigation effect of the measures, but also to suggest a methodology that could also be replicated with finer resolution satellite imagery, allowing more accurate surface classification results.

MOD11A1is the other satellite imagery used in the studies included in this research is a satellite imagery product issued by MODIS and has a resolution of 1,000 m, which is considerably coarser than Landsat 5TM, and thus only used for large surface assessments (whole city assessments).

§ 8.3.3 Remote sensing limitations for UHI assessment

In principle, satellite imagery provides surface temperature assessment only (even though there are some algorithms that allow the calculation of air temperature based on LST, and some software that calculate the sky view factor based on Landsat satellite imagery), which can be considered as a limitation. Overall parameters related to the neighbourhood structure (sky view factor, wind, shadow...) as well as factors such as anthropogenic heat emissions should be the object of another study to determine to what extent they influence the formation of the UHI. The present research focuses on suggesting measures to improve the surface cover behaviour. The same urban structures can considerably improve their thermal behaviour only modifying their surface covers.

§ 8.3.4 Replicability of the study

The studies presented in this PhD research can be replicated with a basic remote sensing and climatological knowledge and only require a certain command of the two main software utilised (ENVI 4.7 and ATCOR 2.3). One critical item is the selection of the satellite imagery, which should preferably be retrieved during a heat wave, and on a cloudless and windless day.

The satellite imageries used for this research are Landsat 5 TM and Modis 11A1 (open source), however the same exercise can be performed with finer resolution satellite imagery, thus obtaining more accurate results.

§ 8.3.5 The challenge of redefining the regional scale balance nowadays

Even though revisiting the regionalist principles is inspiring for the creation of spatial planning guidelines for reducing the heat island in new urban developments, it is important to highlight that these are precisely only applicable in certain contemporary scenarios. Thus Mumford's concept of "reversal" is often no longer valid in the current context, since in the last 100 years automobile technology has in most cases only accentuated the ravages caused by the 19th century city that Mumford described in the 1920's, and thus in that sense the recovery of the garden city principles in an existing metropolis no longer seems feasible. He referred to that "reversion phase" as "neotechnics". Thus a new contemporary form of regional balance should be explored by urban planners, one that is compatible with existing metropolis. That is, on the one hand, one that is compatible with the minimum infrastructure required to operate and supply (food, material and human transportation) these megalopolises, which rely up to a certain point on intensive road and air traffic – with their corresponding CO_2 and heat emissions – and one that on the other hand is also compatible with (or that mitigates) existing unbalanced urbanisation and growth patterns (high density, sprawl…).

§ 8.4 Outlook

Existing urbanisation patterns seem unsustainable, both from a global metabolism perspective and from a local liveability angle. 54% of the world's population resides in urban environments (UN, 2014), cities occupy 3% of the Earth's land and account for 60-80% of total energy consumption and 75% of carbon emissions (UN, 2016). The world´s urban population will experience an increase of 2.45 billion inhabitants by 2050. Urban planners need to come up with measures to retrofit existing urban structures, and to plan urban growth to accommodate the new dwellers. The magnitude of the UHI is such that during the heat wave of 2003 it generated over 30,000 excess deaths in Europe, and still it is only one example of an urban climate phenomenon resulting from unbalanced design arrangements. New development patterns need to be investigated to ensure a natural balance at local and global scales, which will be reached through the reinforcement of the cohesion at the intermediate scale that is the regional scale.

§ 8.5 Societal Impact

Innovative solutions at a large scale require on the one hand urban planners to assume responsibility and control over the interventions at an infrastructural and regional scale to ensure a coherence between the interventions suggested at neighbourhood, city and regional scales; on the other hand the incorporation of appropriate technology (here remote sensing) and mapping strategies (game board, rhizome, layering and drift) is critical to be able to assess with coherence at this larger scale.

§ 8.5.1 Reinterpretation of technology

In a world ruled by technology, urban planners are often tempted to specialise in one of the disciplines they are supposed to integrate and adopt the tools and instruments specific to that specific field for a greater specialisation, forgetting their main original mission which consists in developing "a holistic urban vision". This research study aims at suggesting the incorporation of a cutting edge technology – remote sensing analysed and processed with ENVI 3.4, Atcor and GIS – combined with catalysing mapping strategies into the urban planners field in order to use technology as an integrator of fields, parameters, inputs, processes and actants. Scientific input is as relevant as the sociological, cultural, economic and political context, thus urban planners maps need to reflect any on-going debates, contradictions and/or challenges and scientific input should not be treated as compulsory, irrefutable truth. Somehow the regionalists already anticipated the importance of the debate of the integration of the scientific input into the urban planning discipline when Mumford denounced the use of science to narrow the depth of the urban planning discussion (Luccarelli M, 1995) for the defence of his Regional Plan of New York and Its Environs (RPNY) (GLP, 1932).

§ 8.5.2 Connection with existing realities

Beside analysing and assessing on the impact of urban heat, and potential mitigation actions, the three studies that were carried out within the framework of this dissertation, establish a connection with the existing realities of the neighbourhoods, cities or regions analysed, in order to try to obtain the maximum impact and relevance for the affected municipalities and provinces analysed.

In the article "The Urban Heat Island Effect in Dutch City Centers: Identifying relevant indicators and first explorations" (Echevarria Icaza et al, 2016c), the study carries out a comparative analysis of several Dutch cities, which have similar city centre structures, and for which it could be interesting to share knowledge, actions and experiences. The purpose of the comparative study is to increase the societal impact, to promote a dialogue between the different municipalities, and to help them benefit from each other experiences.

In the article "Surface thermal analysis of North Brabant cities and neighbourhoods during heat waves" (Echevarria Icaza et al., 2016b), the analysis carried out aimed at estimating the impact of planned future urban developments for the Province of North Brabant (Provincie Noord-Brabant, 2010) in the formation of urban heat. The purpose was thus to assess whether the location of the future growth areas, which are all adjacent to existing small and midsize cities, would per se worsen the UHI effect in those cities or not. The Province of North Brabant had used the "ladder for sustainable urbanisation" developed by the Dutch Ministry of Infrastructure and Environment to compare the urban development needs with the options to restructure nearby derelict areas prior to delimiting the "growth areas", however this tool does not include UHI considerations. The intention of this article was to take into consideration the existing spatial planning context, so to consider existing plans of the province and existing considerations taken into consideration so far ("ladder for sustainable urbanisation"), in order to generate a study connected to the reality of the analysed area.

Finally in the article "Using satellite imagery analysis to redesign provincial parks for a better cooling effect on cities. The case study of South Holland" (Echevarria Icaza et al., 2016a) also picked up the fact that the spatial vision of the province of South Holland ("Structuurvisie Zuid-Holland") – to which the six analysed provincial parks belong – does not specifically take into consideration the UHI phenomenon, which is surprising since South Holland is the densest province of the Netherlands, and thus the most affected by the UHI in absolute terms (CBS, 2006). The article on the South Holland provincial park aims at providing tools to the province, to ensure the parks preserve and enhance their natural cooling properties.

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Curriculum Vitae

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Professional qualifications

2003	**Architect.** Delft University of Technology, Faculty of Architecture (TU Delft, Bouwkunde), Netherlands. Graduated in with distinctions 9/10. Selected for the Archiprix competition.
2007	**Urban planning in Developing Countries**.. Specialisation course at the Architecture School of the Technical University of Madrid, Spain.
2008	**LEED AP**. Leadership in Energy and Environmental Design Accredited Professional.
2011	**MRICS.** Accepted as Member Royal Institution of Chartered Surveyors
2012	**Remote sensing** professional accreditation. 11th edition of "Remote sensing applied to the environment" course at Teruel University.
2017	**PhD defense**. Urban and regional heat island adaptation measures in The Netherlands. TU Delft.

Languages

English.	TOEFL and American High School Diploma Washington DC.
Dutch.	Eerste, twede, derde ronde Delftste Method. TBM TU Delft.
French.	French International Baccalauréat, with distinctions.
Spanish.	Mother tongue.

Scholarships

2000-01 Erasmus scholarship. Ecole d´architecture Victor Horta. Brussels. Belgium.

Research work

2003	**URBEST**. European urban Best Practices. European project, for the selection and presentation of Urban Planning Best Practices, at the International Institute for The Urban Environment. Delft.
2003	**COST 16**. Improving the Quality of Existing Urban Building Envelopes. Participation in the European project COST 16. Presentation of graduation project. Collaboration with ir. Leo Verhoef at the renovation department of Delft University of Technology, Faculty of Architecture (TU Delft, Bouwkunde), Netherlands.
2004	**Sustainable regulation for the municipality of Tres Cantos** (Madrid). Member of the team in charge of developing the regulation for the mentioned municipality.
2011	**Climate Proof Cities Program**. PhD research.

Publications

- ECHEVARRIA ICAZA, L. Open and transferable architectonic interventions for high rise dwelling blocks. Archiprix 2004. The best plans by Dutch students. 010 Publishers, 2004. 48-50
- CPC RESEARCHERS. Climate Proof Cities - Final Report. 2015.
- GARACHANA R.; ELIZALDE J.; HIGUERAS GARCÍA E.; DIAZ-PALACIOS S; GIL J.; CASANOVA M.; ECHEVARRÍA ICAZA L. Texto Definitivo Ordenanza Municipal de Urbanización y Edificación Bioclimática. Ayuntamiento de Tres Cantos. Junio 2004.
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explorations. In Implementing Climate Change Adaptation in Cities and Communities, 2016. LEAL FILHO, W.; ADAMSON, K.; DUNK, R.; AZEITEIRO, U.M.; ILLINGWORTH, S.; ALVES, F.; Eds.; Springer International Publishing AG: Cham, Switzerland, 2016c.

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- LEAL FILHO W.; ECHEVARRIA ICAZA L; NEHT A.; KLAVINS M.; MORGAN E.A. Coping with the impacts of Urban Heat Islands A literature based study on understanding urban heat vulnerability and the need for resilience in cities in a global climate change context, In Journal of Cleaner Production, 2017, , ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2017.10.086.http://www.sciencedirect.com/science/article/pii/S0959652617323806

Conferences

SEPT 2013	GEODESIGN SUMMIT EUROPE in Geofort The Netherlands Presented study on UHI in The Netherlands.
SEPT 2015	5th WORLD SUSTAINABILITY FORUM in Basel Switzerland Presented study on the integration of heat parameters in urban plans.
SEPT 2015	WORLD SYMPOSIUM ON CLIMATE CHANGE ADAPTATION in Manchester. Presented study on UHI in Dutch city centers.

Work relevance

2003	GRADUATED WITH DISTINCTIONS at TU Delft (Eervolle vermelding).
2013	AWARDED with "EMEA Going beyond awards" prize.
2017	ARTICLE (Echevarria Icaza et al., 2016d) selected by the French Ministry (Ministère de la Transition Ecologique et Solidaire and Ministère de la Cohésion des Territoires) to be on the COP21 webpage (2015 Paris Climate Conference) http://www.cdu.urbanisme equipement.gouv.fr/ecosystemes-terrestres-a24821.html

Work

NOW FM ARQUITECTOS. CBRE. MADRID.SPAIN

Head of the Occupier **Project Management** team

Sustainability consultancy work

Project in Paris. France. LEED ® EB - Gap analysis of the building. Total built area:11,000m²

Project in Paris. France. LEED ® CI. Certification process. Total built area: 2,175m².

Project in Milan. France. LEED ® CI. Gap analysis of the building. Total built area. 1,980 m².

2004 TAU PLANIFICACIÓN TERRITORIAL

Sustainable Regulation for the Urban Design and Architecture of the Spanish Municipality of Tres Cantos. Member of the professional team which developed the regulations.

2002-04 THE INTERNATIONAL INSTITUTE FOR THE URBAN ENVIRONMENT

Member of the **URBEST project** team in charge of selecting the European sustainable best practices.

2001-02 MOLENAAR EN VAN WINDEN.DELFT.NETHERLANDS

Wooden pavilion in the forest. Netherlands.Basic and execution project of a wood cabin in the forest.

Library in Holland. Netherlands. Basic project of a library in Wassenar.

Housing project. Netherlands.Housing project in the Netherlands.

2000-01 ART AND BUILD. BRUSSLES. BELGIUM

RTL contest. Belgium. Contest for RTL offices in Belgium.

Project for the renovation of Shell building in Brussels.