POLITIQUE SCIENTIFIQUE FEDERALE - FEDERAAL WETENSCHAPSBELEID

RESEARCH PROGRAMME FOR EARTH OBSERVATION STEREO III

FINAL REPORT

CONTRACT SR/00/363

GARMON

The Garden Monitor - mapping and characterizing gardens using remote sensing

Date: 15/09/2020

For the partnership: Veerle Strosse

1 CONTENT

2 PROJECT INFORMATION

DURATION[1]

01/12/2017 – 30/09/2020

The project was prolonged for the following reasons:

- because of waiting for postdoc at KU Leuven (Promoter P3), because of delay getting visa. This postdoc was needed for the research.
- due to crisis Covid 19 it was difficult to arrange the validation data practically - this validation was necessary for finishing the research.

STAFF / CHANGES IN STAFF[2]

NAMES AND JOB SITUATION AT THE END OF THE PROJECT

KU Leuven

- Jingli Yan – visiting researcher at Precision Agriculture Lab (TU Munich)

3 SUMMARY OF RESULTS[3]

3.1 OVERVIEW OF ACTIVITIES AND ACHIEVEMENTS

WP2 Regional scale mapping of garden characteristics based on airborne imagery:

The aim of this WP was to:

(i) Create a workflow to delineate garden parcels based on regional available GIS data like parcel, building & agricultural datasets and based on an explicit definition of a 'garden'.

(ii) Add garden characteristics based on regional available remote sensing data, in casu the Flanders Green Map derived from summer aerial imagery (40cm spatial resolution), as baseline for comparison with characteristics based on satellite data.

(iii) Produce a garden parcel map of Flanders based on the established workflow.

[1] State whether and why project was prolonged
[2] Per partner
[3] Give a summary of the activities and describe to what extent objectives were met – list problems encountered and how they were solved - lessons learned / experience gained - / - a detailed description of the results can be put in annex

Definition of a garden

A garden can be described as a '*an area set aside for the cultivation and enjoyment of plant and other natural life'**. Two keywords can be derived from this sentence that are used within the Garmon project to construct a definition of a garden: cultivation and enjoyment. Cultivation is the act of adding culture, in this case, to the natural environment. Recreation is a pastime solely for the sake of enjoyment. So a garden is used for cultivation and recreation.

In agriculture areas there is a presence of cultivation but a lack of recreation since the main purpose is the production of food. In forestry and natural areas there is a main purpose of recreation and conservation but there is hardly no cultivation. We assume that in natural and forestry areas there is commonly a lack of buildings. Thus a garden is an area near buildings and lacks cultivation solely for the purpose of production (= agriculture). This definition can work if we look at the concept of garden as inclusive as possible. So within the GARMON project a garden can be a green residential area, a green industrial area (e.g. parking lots of office buildings), semi-public areas (e.g. hospitals), and non-green residential areas (e.g. paved garden with plant containers).

**Garden history : philosophy and design, 2000 BC--2000 AD, Tom Turner. New York: Spon Press, 2005.*

Description of source data

- Large Scale database (Grootschalig Referentiebestand, GRB): The Large-Scale Reference Database (GRB) is a digital topographical reference map of Flanders. The GRB contains only geographical and characteristic information of well-definable, conventionally accepted reference data: buildings, administrative parcels, roads, waterways and railways…. and is periodically (minimal yearly) updated. More information can be found at https://overheid.vlaanderen.be/GRB-Wat-is-het-GRB (in dutch). The objects used in the Garmon- workflow are:
    - ADP: administrative parcels
    - GBG/GBA: buildings and additional building accessories (e.g. overhangs, …). This buildings are within the database classified as *main* or *out* buildings.
    - WBN: road network polygons
    - SBN: railroad network polygons

  Link: http://www.geopunt.be/catalogus/datasetfolder/7c823055-7bbf-4d62-b55e-f85c30d53162
- Agricultural Land Parcel Registration (LBPC): Obligated registration of parcels in agricultural use by farmers for the Department of Agriculture and Fisheries to fulfill their mission: *'contribution to the development of future-oriented agricultural and fisheries policies and quality service to the Flemish agro-food sector'* (https://lv.vlaanderen.be/en). This dataset has a strong link with the European dataset Land Parcel Information System: https://ec.europa.eu/jrc/en/research-topic/agricultural-monitoring and is yearly updated.
  Link: http://www.geopunt.be/catalogus/datasetfolder/47c5540f-bf7c-45fc-9a74-8e60547cde82
- Summer Orthophotos: 3 yearly regional aerial imagery of Flanders with a spatial resolution of 40cm during the summer months (June – September). There is data available for the summers of 2009, 2012, 2015 and 2018.
  Link: http://www.geopunt.be/catalogus/datasetfolder/bdf0a012-459d-42b5-ba43-e2ef655107b9
- Green Map Flanders: regional dataset of Flanders that consist of a multi-level segmentation based semi-automatic classification of above described summer orthophotos into 4 classes: High Green, Low Green, Not Green, Agriculture. There are datasets available of 2009, 2012 and 2015. Because LiDAR (e.g. DHMVII) is not continuously available and originating from 2013-2015 the Green Map is not using DHMVII but a Digital Surface Model derived from the aerial images.
  Link: http://www.geopunt.be/catalogus/datasetfolder/70c663ac-ff3e-4b9a-9867-bb22bbdfcf6d
- Land Cover Map Flanders: regional dataset of Flanders that is based on the GRB dataset, LBPC dataset and Green Map Flanders with data merging and neighborship rules. It further specifies above 4 classes into 9 land cover classes: Buildings, Roads, Railroads, Other Sealed Surfaces, Trees (e.g. High Green), Grass & Shrubs (e.g. Low Green), Agriculture, Other Non-Sealed Surfaces and Water. There are datasets available for 2012 and 2015.
  Link: http://www.geopunt.be/catalogus/datasetfolder/0230a22f-51c0-4aa5-bb5d-0d7eeeaf0ce8

Part (i): creating the workflow

The workflow is established on the municipality of Leuven. A more detailed description of the Leuven area in Flanders can be found in WP3 progress and results. This workflow was built fully empirically but based on the extensive knowledge of the local and regional data and what it contains. No literature study was performed.

Definition of a garden polygon

Following the broad definition of a garden and the description of the source data a straightforward technical definition of a garden can be constructed: *A garden parcel is an administrative parcel (ADP) polygon that contains a building (GBG) polygon and does not overlap with an agricultural (LBPC) polygon.*

Description of the garden polygon workflow

Based on this definition and in interaction with the involved project partners, a more complicated workflow and definition was constructed: *A Garden polygon is an ADP polygon that:*

- *(almost) does not overlap with a LBPC polygon;*
- *contains 1 or more GBG polygons of the main type;*
- *or contains 1 or more GBG polygons of the out type and borders with an ADP polygon that contains 1 or more GBG polygons of the main type;*
- *or does not contain a GBG polygon but overlaps with a BBLOCKS polygon that contains more than 60% ADPs with 1 or more GBG polygons of the main type;*
- *(almost) does not overlap with a SBN polygon;*
- *has been cut by WBN polygons, GBG polygons of the main type or out building type > 20m^2; the 20m^2 is based on the building permission of out buildings.*
- *has been cleaned from slivers.*

The workflow consists of several major steps, starting with all the ADP polygons, they are gradually removed and/or (re)selected in every step. The result of every step can be viewed in Figure 1 to Figure 5. The summer orthophoto of 2015 (described above) is used as a background. In some of the steps more background explanation is given concerning some issues that were encountered. The workflow is worked out using an empirical *look-and-feel* verification feedback loop.

A. Firstly all ADP polygons that overlap with a LBPC polygon are removed. An ADP polygon overlaps and is removed if:
   - the representative point of an LBPC polygon is within the ADP polygon;
   - the polygon intersects with a -16m buffer of an LBPC polygon unless the percentage of intersection surface is less than 0.2%.

B. Secondly the GBG/GBA polygons are used to select ADP polygon from the leftover ADP polygons after step A. An ADP polygon is selected in this step:
    - if it contains a 25cm negatively buffered GBG/GBA polygon of the *main* type;
    - if it is smaller than 5 hectare and contains a GBG/GBA polygon of the *out* type and borders with an ADP polygon that contains a 25cm negatively buffered GBG/GBA polygon of the *main* type.
C. Thirdly, ADP blocks are used to select ADP polygons that are not selected in step B. ADP blocks are the dissolved polygons of all ADP polygons cut out by WBN polygons. Additionally ADP blocks will also not cross waterways, due to the way the ADP polygons are defined within the GRB dataset. They can be described, especially in urban areas, as building block polygons. An ADP polygon is selected in this step if:
    - it lies within an ADP block polygon that contains more than 75% of ADP polygons that contain a 25cm negatively buffered GBG/GBA polygon of the *main* type (first half of step B) or;
    - if it is smaller than 0.5 hectare and lies within an ADP block polygon that contains more than 60% of ADP polygons that contain a 25cm negatively buffered GBG/GBA polygon of the *main* type (first half of step B)
D. In a fourth step from the selected ADP polygons after step C, ADP polygons are removed if they overlap with an 8m negatively buffered SBN polygon; and are cleaned from slivers according to the following attributes:
    - area smaller than $10m^2$;
    - or area smaller than $20m^2$ and length/width ratio larger than 20;
    - or area smaller than $100m^2$ and length/width ratio larger than 30;
    - or area smaller than $500m^2$ and length/width ratio larger than 50;
    - or length/width ratio larger than 100.

    After this the selected and cleaned ADP polygons are cut out by:

    - GBG/GBA polygons of the *main* type;
    - GBG/GBA polygons of the *out* type that touch the border of an ADP polygon or are larger than 20m2;
    - and 5cm negatively buffered WBN polygons.

    Following this step the cut out ADP polygons are cleaned again from slivers according to the following attributes:
    - area smaller than $5m^2$;
    - or area smaller than $10m^2$ and length/width ratio larger than 20;
    - or area smaller than $100m^2$ and length/width ratio larger than 50;
    - or length/width ratio larger than 100.

    This results in Garden ADP polygons.

Figure 1: Summer Orthophoto and ADP polygons (yellow).

Figure 2: Step A: ADP polygons (yellow), LBPC (brown), before (a) and after (b).

Figure 3: Step B: GBG/GBA (red), before (a) and after (b).

Figure 4: Step C: ADP blocks (dark red, only those with more than 60% previously selected ADP polygons are shown), before (a) and after (b).

Figure 5: Step D: cleaning and cut out WBN (grey) & GBG/GBA (red), before (a) and after (b) = final selected Garden ADP polygons. There is no SBN polygon present in this example.

Background explanation on ADP Blocks:

It was found that even in urban areas, the idea of selecting parcels with a building as a means of selecting garden parcels was not enough. This is because in some cases owners own a plot adjacent to their plot with their house and garden and use it solely as an extension of their garden. In the ADP layer this results in polygons without a building that are actually garden polygons. Using neighborhood rules on the parcels itself (*neighbor of*) for selecting these parcels would result in over selecting parcels in more rural areas. Therefor the method of using a broader unit to apply neighborhood rules was needed. The ADP blocks layer was used as a broader unit and the percentage of previously selected ADP parcels was used as a neighborhood rule.

The dataset of the ADP block can also be used as an information unit in between the parcels itself and the border of municipality or administrative area to characterize land cover, e.g. green in gardens. It has the advantage of summarizing information (and the errors within) on a broader scale than the parcel, which in some cases can be too small to potentially add meaningful information from satellites (e.g. Sentinel), but at the same time show potentially meaningful differences within a municipality.

Background explanation on choosing to cut out buildings:

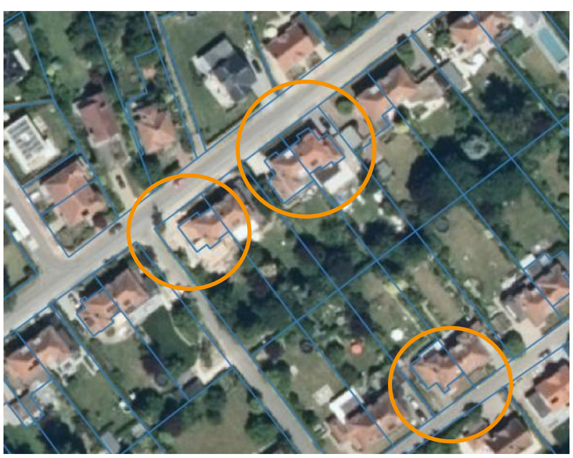


Figure 6: Examples (circled in orange) in an suburban area where within 1 property plot the building is cut out as seperate ADP polygon (blue).

The decision to cut out the buildings from the garden ADP polygons is a result of the following inherent property of the ADP dataset. In some cases a property plot can consist out of two ADP polygons: one surrounding the actual property plot and the other surrounding the building on this plot. This results in two ADP polygons where one is cutting out the other within the same property plot. The reason for this is purely an administrative one. And it is so that it is unpredictable. It could be so that two characteristically similar plots in the same area have a different ADP polygon setup as shown in

Figure 6. This would also result in confusing statistics where two property plots from the same area, with similar characteristics could be characterized very differently when using area weighted percentages.
In co-operation with the involved partners, a technical solution was introduced to firstly detect this issue and try to resolve these kind of setups. Secondly, try to merge them automatically into 1 ADP polygon per property plot. However no viable solution was found as in most cases, the proposed solution created more problems than it resolved. In the end the choice of cutting out all ADP polygons by buildings was found to be the only workable solution.

Validating the garden parcel workflow

The above described workflow to select ADP polygons was used to create a Garden ADP layer for the study area of Leuven. Consecutively this resulting ADP layer was validated for the study area of Leuven. A description of the validation rules as well as the validation results is given below.

I. Sample design
A sample is an ADP polygon. A random stratified selection was performed on the ADP layer in two strata based on the workflow result. This rendered 400 samples:
   - 200 samples coinciding with polygons in the Garden ADP layer
   - 200 samples coinciding with the other (leftover) polygons in the ADP layer

II. Response design
The inclusive definition used within the Garmon project, as described above, was used to evaluate the samples with the use of the reference data (summer orthophoto of 2015 and additional mapping data if needed). The evaluation was performed by 3 operators from the involved Garmon partners and eventually a majority vote was used to group the samples into *reference garden* or *no garden*.

III. Validation result

	Reference			
	Garden	No Garden		
Garden ADP	188	28	216	87.0%
Other ADP	12	172	184	93.5%
	200	200	400	
	94.0%	86.0%		90.0%

It can be seen that the Garden ADP class has a correctness of 87% and a completeness of 94%, which can be considered as useable for an end-user. Still, taken into account the error margins is, as always, an absolute must.

Additionally the Garden ADP layer for the study area of Leuven was *look-and-feel* verified on the usability by the involved partners. It became apparent that an additional classification of the selected Garden ADP polygons based on land use was advisable to have a dataset that can be used in practice. The inclusion of land use information could be helpful to remove some obvious non-garden but green urban areas, like parks and cemeteries for instance. But it can also be used to further classify the selected Garden ADP polygons into e.g. residential, industrial, semi-public, commercial or other land use classifications.
A possible solution for this matter is to use the available land use data available and maintained by involved partners, the so called *Ruimtemonitor* (http://www.ruimtemonitor.be). As of this moment this dataset is the best information available on land use within Flanders. Furthermore it has a guaranteed operation periodical update.

<u>Part (ii):</u> Add garden characteristics based on regional available aerial remote sensing data

The second part of WP2 was to add garden characteristics based on regional available remote sensing data as baseline for comparison with characteristics based on satellite data. In a previous report the Green Map Flanders was proposed as input, but the Land Cover Map Flanders was used instead. The latter is actually derived from the former combined with the GRB dataset and LBPC dataset. This results in more land cover classes and better continuity (more information on this can be found in the reports of both products, available in Dutch through the links found in de source data description).

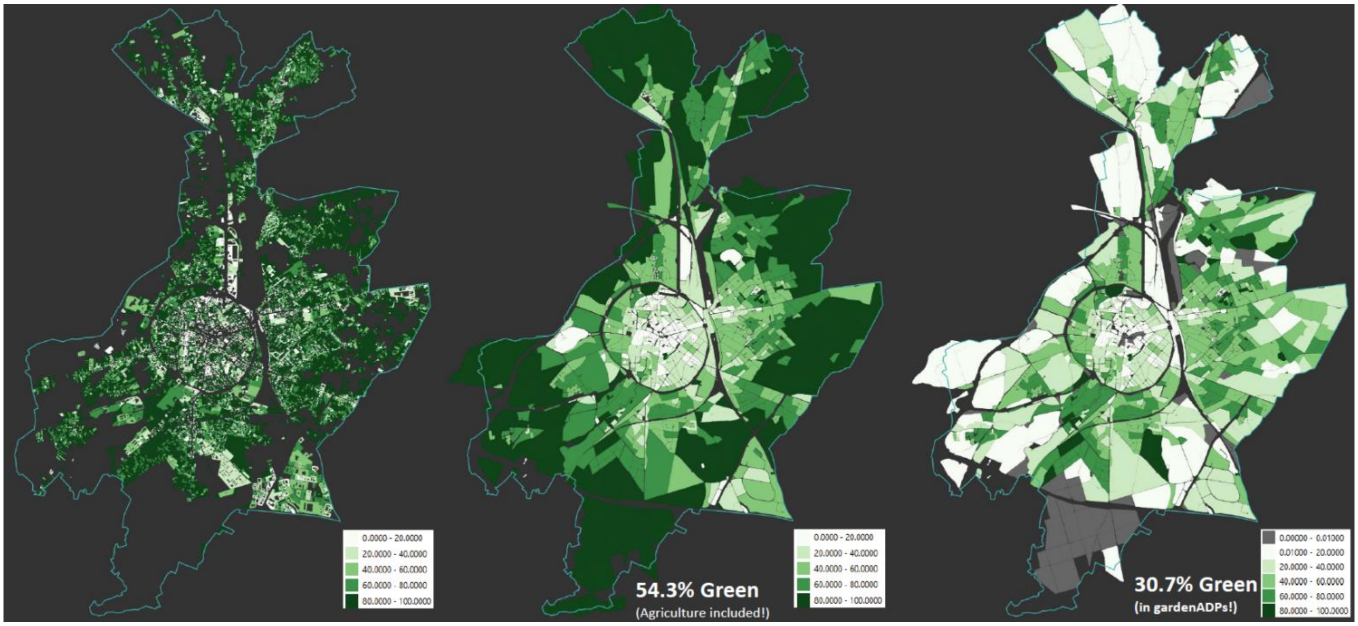
Together with the involved partners the following garden attributes per parcel were defined:

- GRB dataset attributes: ID, GVDV (= date of inclusion in database) and Capakey (=cadaster code);
- Area: the size of the parcel
- %LGreen: percentage of low green which is the sum of percentages of the classes *Grass & Shrubs* and *Agriculture* from the Land Cover Map;
- %HGreen: percentage of high green which equals the percentage of the class *Trees* from the Land Cover Map;
- %AFGDKT: percentage of sealed surfaces which is the sum of percentages of the classes *Buildings*, *Roads*, *Railroads* and *Other Sealed Surfaces*;
- %ONAFGDKT: 100 - %AFGDKT.

Next to this the ADP Blocks dataset was also used to calculate attributes based on the Land Cover Map Flanders. The following attributes were agreed upon:

- GRB dataset attributes: ID and GVDV (= date of inclusion in database);
- Area: the size of the parcel
- %LGreen: percentage of low green which is the sum of percentages of the classes *Grass & Shrubs* and *Agriculture* from the Land Cover Map;
- %HGreen: percentage of high green which equals the percentage of the class *Trees* from the Land Cover Map;
- %AFGDKT: percentage of sealed surfaces which is the sum of percentages of the classes *Buildings*, *Roads*, *Railroads* and *Other Sealed Surfaces*;
- %ONAFGDKT: 100 - %AFGDKT
- %GrdLG: weighted mean of %LGreen in Garden ADP polygons within the ADP block polygon;
- %GrdHG: weighted mean of %HGreen in Garden ADP polygons within the ADP block polygon.

The information on greenness per garden ADP and in the ADP blocks is shown in Figure 7 for the study area of Leuven.



% Green per Garden ADP = %LGreen + %HGreen

% Green per ADP Block = %LGreen + %HGreen

% Green in Garden ADP per ADP Block = %GrdLG + %GrdHG

Figure 7: Greeness per Garden ADP and ADP blocks for the study area of Leuven based on the Land Cover Map Flanders.

Background explanation of a technical issue that needs resolving:

In the case of the Garden ADP result, a technical issue has arisen concerning the capakey attribute and cutting the GBG/GBA polygons out of the ADP polygons. Several single part polygons with the same capakey should be dissolved to multipart polygons with one capakey and a summation of the other attributes as discussed with the involved partners.

Part (iii): Producing a Garden Map of Flanders

The following topics were handled in the last part of WP2:

- Research on what to do with the need of *land use* information within the garden parcel map together with involved partners;
- Resolving a technical issue where some single part polygons need to be dissolved;
- Production of the garden parcel map based on the above workflow;
- Validation of the garden parcel map following the same sample and response design as described in the progress report.

Research on what to do with the need of *land use* information within the garden parcel map together with involved partners.

Land use information can be crucial for users to determine if a parcel is relevant in their definition. This is the case since in the GARMON project a broad definition of garden was used, while in some cases the user might only be interested in f.e. gardens in a residential context. Together with the involved partner *Departement Omgeving*, the 'Landgebruikskaart' data was researched for adding land use information to the final dataset. This is dataset is maintained by this department and published as open data through the application *Ruimtemonitor* (http://www.ruimtemonitor.be). As of this moment this dataset is the best information available on land use within Flanders. Furthermore it has a guaranteed periodical update.

The 'Landgebruikskaart ' map (LGK) shows the actual land use for each 10m cell within the Flemish Region for different reference years (at this moment 2013 and 2016). The concept of land use refers to the actual use of land for specific human activities such as housing, industry and services, recreation, ... or crops, such as arable farming, grass cultivation, ... or natural vegetation, such as forest, shrubs, ... The actual land use of a site is not necessarily identical with the legal zoning plan destination of the site. Land can be intended as a residential area, but effectively used as grassland or arable land. This map does not contain any information about the planned use. The actual land use, as shown on this map, has been compiled on the basis of the 4 data levels of the 'land use database '. More specifically, this is done by combining and aggregating a number of categories from the different data levels of this land use geodataset. For more details on the creation of the underlying 'land use file' (with 4 data levels), see the report 'Land use and land take in Flanders, state 2016', which can be found at https://www.milieuinfo.be/dms/d/d/workspace/SpacesStore/56a309c7-504c-479e-853c-3e9d2d441425/landgebruik_ruimtebeslag_toestand2016.pdf (in Dutch). This results in a Land use map with 18 classes (see legend Figure 8)

A simplification or reclassification of the 18 classes was considered but it was decided not to implement mainly because of recognizability for the user since the LGK classes are considered well known. The 10m raster data was linked to the vector based Garden ADP map in the following steps:

- The modus of LGK classes was calculated per Garden ADP polygon considering all LGK pixels completely within the polygon;

- for Garden ADP polygons which are too small to have at least 1 pixel completely within its border, the representative point[4] was calculated and the class of the corresponding LGK pixel was obtained;
- the LGK class of a Garden ADP polygon was then obtained by its modus and if not available by its representative point. It is added to the result as an attribute: LGK.

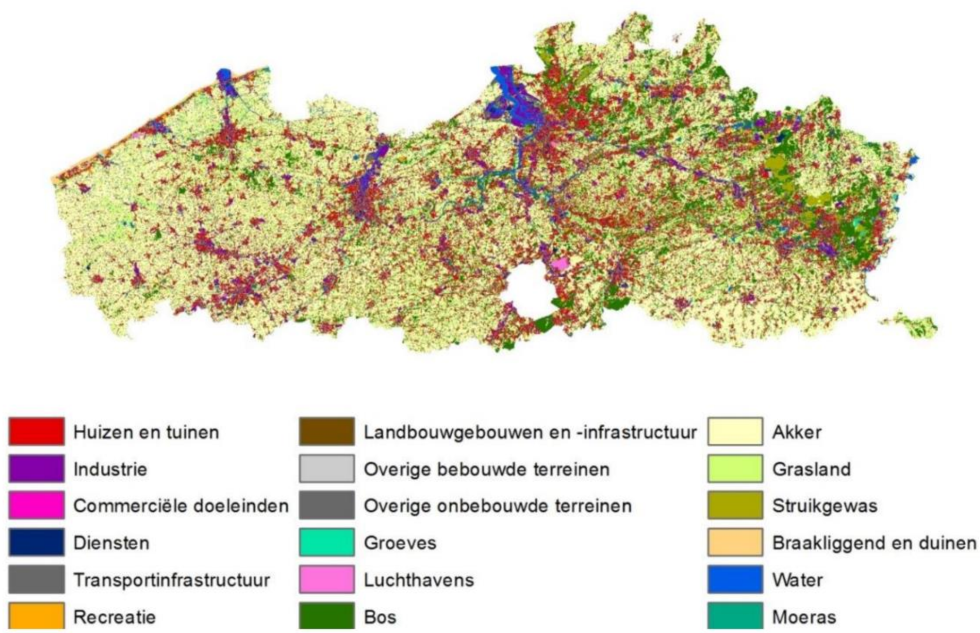


Figure 8: Landgebruikskaart 2016 (LGK) data for the region of Flanders.

[4] This is a point close to the centroid of a polygon but guaranteed within the border of the polygon: https://shapely.readthedocs.io/en/latest/manual.html#geometric-objects .

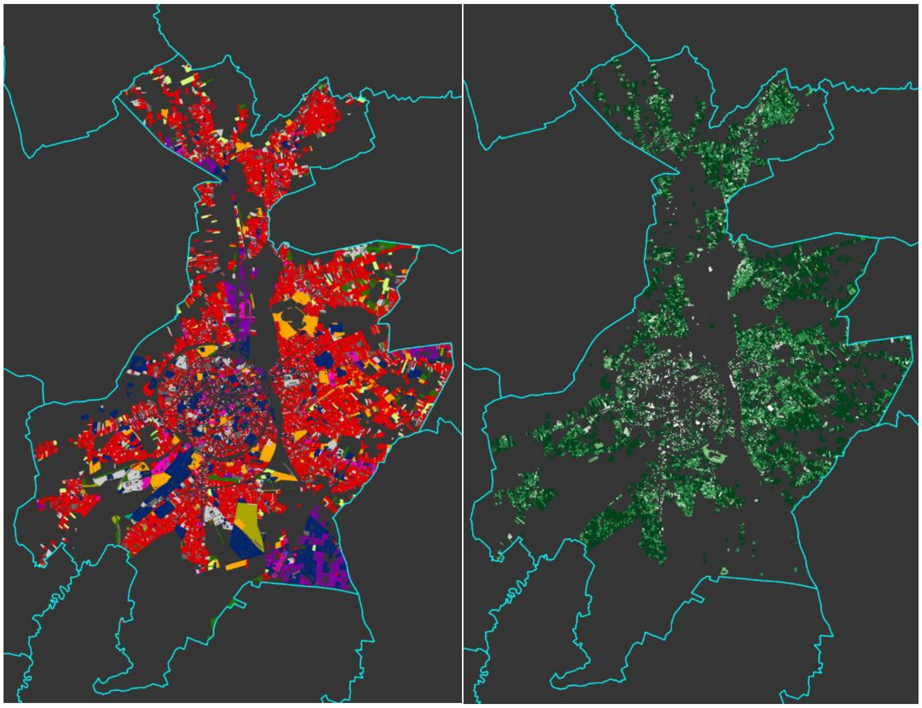


Figure 9: Garden ADP polygons of the city of Leuven according to Landgebruikskaart 2016 (LGK) classes (left), and all Garden ADP polygons of the city of Leuven with the residential class (= Huizen en Tuinen) according to % Green.

Figure 9 show the result of the addition of LGK information to the Garden APD dataset for the study area: the city of Leuven.

Resolving a technical issue where some single part polygons need to be dissolved.

A user request was to create multipart polygons according to their CAPAKEY (=cadaster code). While writing the previous activity report, there were still some single part polygons left with the same CAPAKEY. By reviewing the workflow code a simple coding error was found and resolved before using the workflow code to produce a regional ADP Garden dataset.

Production of the garden parcel map based on the above workflow.

The previously described workflow expanded with addition of the LGK attribute was used to produce a regional ADP Garden dataset. Next to this a regional ADP blocks dataset was also produced. The unit of production was the municipality. In Flanders there are currently 300 municipalities. This resulted in:

- 300 MunicipalityNameADPgrdn.shp files (and .shx &.dbf files):
    - GRB dataset attributes: ID, GVDV (= date of inclusion in database) and Capakey (=cadaster code);
    - Area: the total size of the parcel (= sum of parts);
    - P_LG: percentage of low green which is the sum of percentages of the classes *Grass & Shrubs* and *Agriculture* from the Land Cover Map;
    - P_HG: percentage of high green which equals the percentage of the class *Trees* from the Land Cover Map;
    - P_A: percentage of sealed surfaces which is the sum of percentages of the classes *Buildings*, *Roads*, *Railroads* and *Other Sealed Surfaces*;
    - P_OA: 100 – P_A;
    - nPARTS: number of parts the polygon consists of;
    - LGK: the land use class of the polygon according to the Landgebruikskaart 2016 in text format.
- 300 MunicipalityNameADPblocks.shp files (and .shx &.dbf files):
    - GRB dataset attributes: ID and GVDV (= date of inclusion in database);
    - Area: the size of the block;
    - P_LG: percentage of low green which is the sum of percentages of the classes *Grass & Shrubs* and *Agriculture* from the Land Cover Map;
    - P_HG: percentage of high green which equals the percentage of the class *Trees* from the Land Cover Map;
    - P_A: percentage of sealed surfaces which is the sum of percentages of the classes *Buildings*, *Roads*, *Railroads* and *Other Sealed Surfaces*;
    - P_OA: 100 – P_A;
    - P_GrdLG: weighted mean of %LGreen in Garden ADP polygons within the ADP block polygon;
    - P_GrdHG: weighted mean of %HGreen in Garden ADP polygons within the ADP block polygon.

Validation of the garden parcel map following the same sample and response design as described above.

The above result was validated according to the following description:

I. Sample design
A sample is an ADP polygon. A random stratified selection was performed in two strata based on the workflow result. This rendered 1197 samples:
    - 504 samples coinciding with polygons in the Garden ADP layers
    - 693 samples coinciding with the other polygons in the ADP layer.

II. Response design
The inclusive definition used within the Garmon project, as described in the progress report, was used to evaluate the samples with the use of the reference data (summer orthophoto of 2015 and additional mapping data if needed). The evaluation was performed by 3 operators from the involved Garmon partner, *Departement Omgeving*, and eventually a majority vote was used to group the samples into *reference garden* or *no garden*. It was found, during the validation, that the broad definition used within the Garmon project made it not easy for the operators to make a decision, as this definition does not necessary overlap with what is generally perceived as garden. This coincides with the findings of the *look-and-feel* validation performed on the study area of Leuven which resulted in a need for adding land use information to the Garden ADP polygons. Some other difficulties were handled like:
    - Parcels with mixed use, e.g. agricultural parcels with a small part occupied by farmhouse and garden and a larger part occupied by fields or grassland or sport terrains with leftover areas that could be seen as garden according to the broad definition. For these mixed parcels, the percentage of usage was taken into account. If more than 50% was not used as a garden it was referenced as *no garden*.
    - The Agricultural Land Parcel Registration (LBPC) layer was also used when in doubt if an agricultural parcel is used for production instead of recreation.
    - When in doubt if a large garden could be a public park, the benefit of the doubt was given to the garden unless it was clearly a public terrain based on the interpretation of orthophoto imagery. Scale was a definitive factor in this decision.
    - Green plots between the runways of an airport were considered as *no garden*, although they could be caught by the inclusive definition of garden. These specific areas should be identified by the 'Landgebruikskaart' as an airport plot.
    - Some doubt existed about the interpretation of vacant lots. Following the inclusive definition, most of them were indicated as *garden* (especially when they lie between built-up plots),

III. Validation result

a. Overall

	Reference			
	Garden	No Garden		
Garden ADP	402	102	504	79.8%
Other ADP	57	636	693	91.8%
	459	738	1197	
	87.6%	86.2%		86.7%

It can be seen that the Garden ADP class has a correctness of 80% and a completeness of 88%, which is considerably lower compared to the validation of the study area in Leuven (87% and 94%). This is however to be expected when upscaling workflows to a larger area. A correctness of 80% can be considered as marginally useable for an end-user. But taking into account the error margins is an absolute must when using the results globally (e.g. in surface calculations). For everyday usage the dataset can for example be used as starting point to create a more detailed garden map on the local level (e.g. municipality) but should not be used as a 'truth' map.

b. Per land use group

Adding land use information makes it possible to look at the performance of the workflow on the level of groups of LGK classes. On the level of separate LGK classes it was not possible since it would result in too much samples to validate and oversampling in certain classes, because there are simply not many Garden ADP polygons in these certain classes (e.g.Water). The following groups were made, based on the content of the classes and making sure there are enough samples per class:

- *Agricultural*; *Akker* (Field), *Grasland* (Grassland) and *Landbouwgebouwen en -infrastructuur* (Agricultural buildings and infrastructure): this group relates to agriculture and should not have a lot of Garden ADP polygons. Mistakes are mostly due to misregistration in the LBPC layer (temporal or geographical).
- *Nature*; *Bos* (Forest), *Struikgewas* (Shrubs), *Moeras* (Marsh) and *Water* (Water): this group relates to natural land uses (beside *Bos* they can be described as land cover classes). This group is expected to have lower performance mainly due to edge or neighboring errors. In contrast to the agricultural group there is no clear layer to delineate area used for natural land uses. It is based on the presence of parcels with buildings or the neighborhood of those parcels.
- *Work & Recreation*; *Industrie* (industry), *Commerciele doeleinden* (commercial uses), *Diensten* (services) and *Recreatie* (Recreation): this group should have ADP parcels denoted as garden parcels due to the broad definition used within the GARMON project. It is expected to have a moderate performance mainly due to higher presence of large parcels with mixed use or the presence of public parks and such in the *Recreatie* class.
- *Habitation*; *Huizen en Tuinen* (houses and gardens) and *Overige bebouwde en onbebouwde terreinen* (other built and unbuilt terrains): this group should mainly consist out of parcels denoted as garden. The performance in this group is expected to be high due to relation of the presence of buildings rules.
- *Other*; *Transportinfrastructuur* (transport infrastructure), *Groeves* (quarries), *Luchthavens* (airports) and *Braakliggend en Duinen* (wasteland and dunes): a small group of leftover classes that normally should not contain any parcels denoted as garden, but there are due

to misregistration (transport, quarries) or the broad definition of garden (airports). The amount of samples in the leftover group ended up low in comparison with the other groups.

The results per land use group can be found in the following tables:

	Reference			
Agriculture	Garden	No Garden		
Garden ADP	31	13	44	70.5%
Other ADP	7	382	389	98.2%
	38	395	433	
	81.6%	96.7%		95.4%

	Reference			
Nature	Garden	No Garden		
Garden ADP	23	49	72	31.9%
Other ADP	8	121	129	93.8%
	31	170	201	
	74.2%	71.2%		71.6%

	Reference			
W & R	Garden	No Garden		
Garden ADP	111	18	129	86.0%
Other ADP	28	36	64	56.3%
	139	54	193	
	79.9%	66.7%		76.2%

	Reference			
Habitation	Garden	No Garden		
Garden ADP	215	6	221	97.3%
Other ADP	11	48	59	81.4%
	226	54	280	
	95.1%	88.9%		93.9%

	Reference			
Other	Garden	No Garden		
Garden ADP	22	16	38	57.9%
Other ADP	3	49	52	94.2%
	25	65	90	
	88.0%	75.4%		78.9%

	Reference			
wo. Other	Garden	No Garden		
Garden ADP	380	86	466	81.5%
Other ADP	54	587	641	91.6%
	434	673	1107	
	87.6%	87.2%		87.4%

The *Agricultural* group has a 95% overall accuracy which is quite high, but the Garden ADP class in agricultural areas has an moderate completeness (82%) but a low correctness (70%). This means according to the validation there is almost a 30% chance the map will denote a parcel as garden whereas according to the reference they are not.

The *Nature* and *W&R* group both have a low overall accuracy but for different reasons. In the nature group there is a poor correctness (32%) of the Garden ADP class: this means that there are more samples denoted as garden whereas they are not a garden according to the reference. In most cases these samples are classified wrongly due the neighborship of parcels containing buildings. In the W&R group there is poor correctness in the Other ADP class: in many cases parcels classified as Other ADP parcels are actually garden parcels according to the reference. More than half of these samples are classified wrongly due to their overlap with negatively buffered SBN layer polygons (see step 4 of the workflow). In fact these are e.g. railroads that overlap with industrial terrains (in harbors). An unexpected result which was not accounted for while developing the workflow for the study area, but removing the rule would result in buffer parcels between gardens and railroads being classified as Garden ADP parcels. And more importantly, the completeness of the Garden parcels (80%) is marginally usable.

The *Habitation* group has a high overall accuracy and the completeness (97%) and correctness (95%) for the Garden ADP class, while those of the Other ADP class are usable to marginally usable. The recommendation on the use of the Garden ADP map posed in the overall validation section is still valid but it's good to know the workflow performs good in the habitation group, which is in many cases the focus area of users.

The *Other* group (airport, roads, railroads, quarries, dunes and wastelands) was expected to not contain any garden parcels and yet almost 28% of the samples in this group are referenced as garden (according to the broad definition). It's possible to remove all ADP parcels of this group, if the user chooses to, but the effect is marginal, illustrated by the cross table denoted with *wo. Other*.

The results of the validation can be used for targeting problems and focus possible future improvements on the workflow. But there will always be a tradeoff between the correctness and completeness of the two classes.

WP3 Mapping of garden characteristics based on satellite imagery:

The aim of this WP was to evaluate:

(i) To what extent satellite imagery can provide or add similar information on garden composition compared to the Land Cover Map Flanders (see WP2: description of source data). Recall that the Land Cover Map Flanders is derived from the Large Scale database (GRB) and Green Map Flanders which in turn is based on periodically taken summer aerial imagery/orthophoto's (40 cm spatial resolution).

(ii) To what extent satellite imagery can provide complementary information on garden composition compared to the Land Cover Map Flanders .

In order to test the added value of spatial resolution and multi-sourced remote sensed data sets for urban greenspace mapping, we developed and compared several object-based classification schemes and tested them on the city of Leuven, Belgium. Our results demonstrated the clearly added value of spatial resolution, green phenology and also three-dimensional structure to detailed urban greenspace mapping. Pleiades satellite imagery achieved similar mapping accuracies to orthophotos when either applied alone or in combination with additional remotely sensed layers. Overall classification accuracy increased with roughly 20% when 3D information and green phenology (derived from a summer and winter SPOT image) was added to the single summer Pleiades image (2015). By adding information on green phenology it also became possible to distinguish evergreen from deciduous vegetation.

Classification designs

Our study was directed toward to ten classification schemes to test the added value of spatial resolution, greenspace phenology and three-dimensional structure to garden land cover monitoring. First we conducted three classifications only using SPOT-6 satellite imagery acquired in August, 2015 (referred to as scheme a, Figure 1-a), Pleiades-1A satellite imagery of June 2015 (referred to as scheme b, Figure 1-b), and orthophotos of June 2015 (referred to as scheme c, Figure 1-c) respectively to examine the capacity of a single remotely sensed imagery in garden land cover mapping. For scheme a to c, the spectral, spatial and textural features were the only information applied to the corresponding classification schemes. Subsequently we performed additional classifications by combining a winter and summer Sentinel-2 NDVI image scene (referred to as scheme d, Figure 1-d) and SPOT-6 (referred to as scheme e, Figure 1-e) with the Pleiades image. We further combined 3D structure information (derived from a nDSM) with the Pleiades image (referred to as scheme f, Figure 1-f) and with the orthophotos (referred to as scheme g, Figure 1-g)*. In scheme d and e, the phenological variations were mainly used to separate deciduous and evergreen species, while in scheme f and g the nDSM was introduced to identify the high and low greenspace. Finally we included remotely sensed imagery, green phenology, and three-dimensional structure in new classifications (referred to as scheme h, i and j, Figure 1) to test the performance of multi-source remote sensing imagery in land cover mapping.

**Note that classification scheme g corresponds to the data basis used to generate the Flanders Green Map and is here thus used as our reference/baseline map.*

Classification procedures

An Object-Based Image Analysis (OBIA, Benz et al., 2004; Blaschke, 2010) was selected to produce the following land cover classes, Deciduous Trees (DT); Deciduous Grass (DG); Evergreen Trees (ET); Evergreen Grass (EG), and Others (OT). OBIA can accurately delineate ground object boundaries, and also introduces much more spectral and spatial features to identify ground objects than pixel-based approaches, especially for higher spatial resolution remote sensing images (Li et al., 2013). During the OBIA classification, we first applied a multi-resolution segmentation (MRS) algorithm to generate image objects levels. After that, we separated spectrally and texturally shaded objects and unshaded objects using thresholds of mean value of brightness and mean red band derived from the Pleiades imagery, as the higher spatial and spectral resolution of Pleiades imagery contribute to higher separation accuracy than that of SPOT-6 imagery. Subsequently vegetated objects, indicated by NDVI and mean Blue reflectance, were extracted from shaded and non-shaded objects. Note that we applied exactly the same features but different thresholds for shaded and non-shaded objects, e.g., NDVI for vegetated objects in shaded area (0.13) and non-shaded areas (0.24). After obtained the vegetated objects, further classifications of greenspace classes (HD, LD, HE, LE) were performed in all ten classification schemes. The flowcharts for classification schemes were described in Figure 2, and the thresholds for features were listed in Table 1.

Finally we also compared the results of our satellite-based workflow with the garden composition map derived from Land Cover Map Flanders (cf. Section WP2)

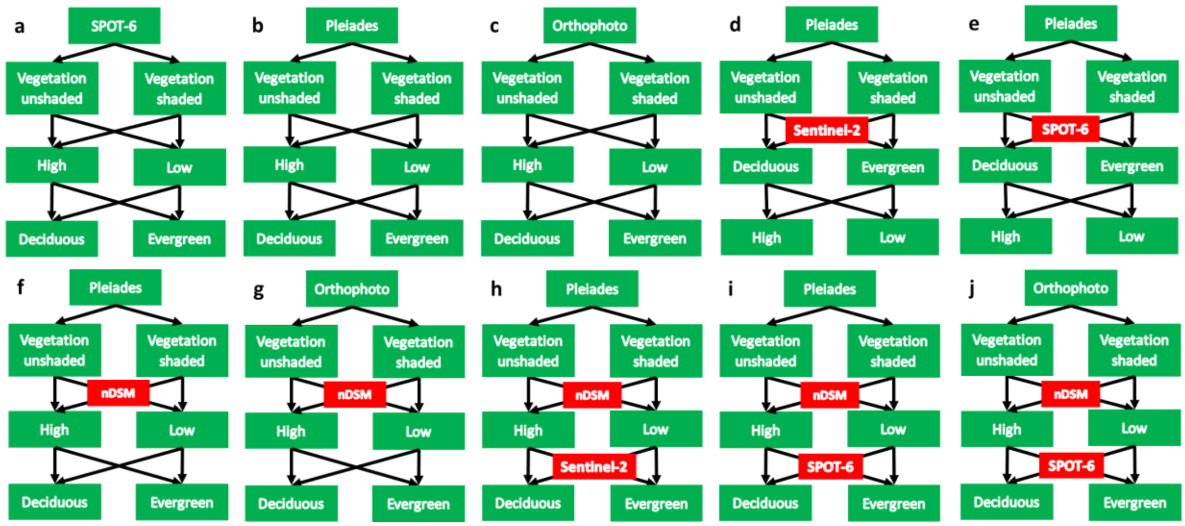


Figure 1. The flowchart of classification scheme designs. a-c: classification with a single remotely sensed imagery; d-e: classification with additional time-series satellite imagery; f-g: classification with additional LiDAR; h-j: classification with additional both time-series satellite imagery and nDSM.

Validation

We collected 3314 ground samples across our study area for both training and validation of the different classification schemes. All ground samples were collected from 30 public plots of 100x100 m^2 and 198 private gardens (Figure 2-a and 2-b), and they subsequently were digitalized to patches based on the 40 cm spatial resolution orthophotos. The accuracy assessment consists of "sample validation" and "coverage evaluation". The "sample validation" was conducted based on ground samples collected from the field campaigns, and was performed for the whole study area (Figure 2-c). 1314 samples were used for generating confusion matrixes and to calculate Kappa coefficients for all five produced green maps.

In contrast, the "coverage evaluation" were only performed within 198 investigated private gardens (with the mean green coverage of 71.2%) to further analyse the percentage cover differences of greenspace and functional types between produced green maps and in-situ observations, at three analytical units (garden parcels, building blocks and garden parcels in building blocks, Figure 2-d).

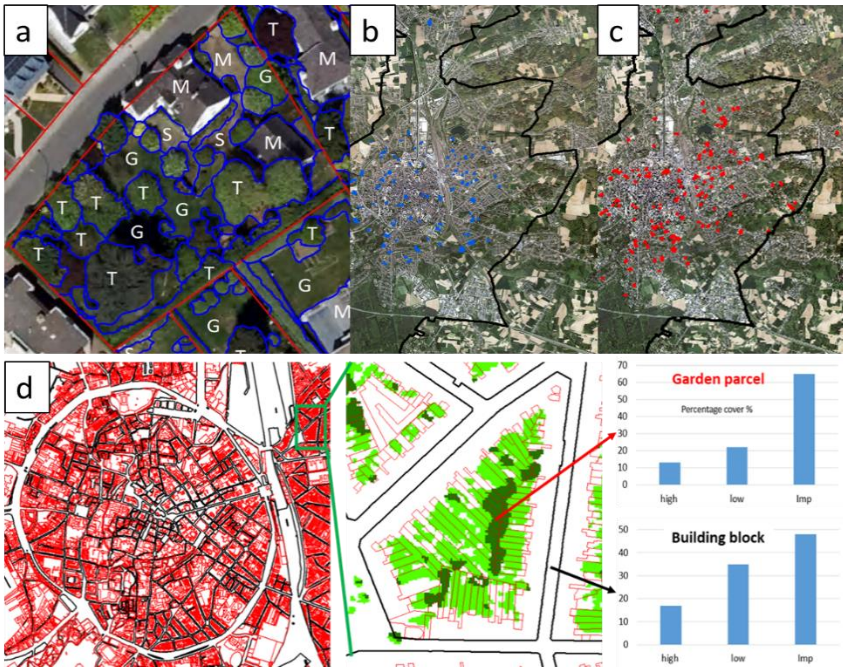


Figure 2. The example of manually delineated patches (a); 100 random selected segmented image objects for object validation (b); 1314 samples for sample validation (c); and the analytical units for coverage validation (d).

Results

Building on the produced green maps and investigated private gardens, we summarized the results into the following four sections. Firstly we evaluated the performance of object-based segmentation compared to manually delineated objects; secondly demonstrate the added value of spatial resolution of remotely sensed imagery in recognizing garden land cover; thirdly we quantified the added value of multi-source data (three-dimensional structure and green phenology) contributing to identify green functional types; and finally we demonstrated the NDVI variations derived from time-series Sentinel-2 imagery to monitor the long-term phenology.

Evaluation of segmentation accuracy

Generating accurate segments as close to the true situation as possible, is a crucial preconditions to an high-quality object-based image analysis. To evaluate the performance of segmentation, we randomly selected 100 segmented image objects produced from the segmentation using only the Pleiades image. We subsequently calculated objects size and %overlap compared to the manually delineated objects (Figure 3). According to Figure 4, the patch sizes derived from segmentations (OBIA based) and manual delineations were very similar. Figure 4-c suggested that all segmented objects had a minimum overlap with its manual delineated counterparts of at least 75%. The average overlap percentage was 90.17%, and 56 of the 100 objects achieved a %overlap higher than 90%. The segmentation evaluation suggested a reasonable accuracy of segmented objects, which provide a reliable basis for the following classification procedures.

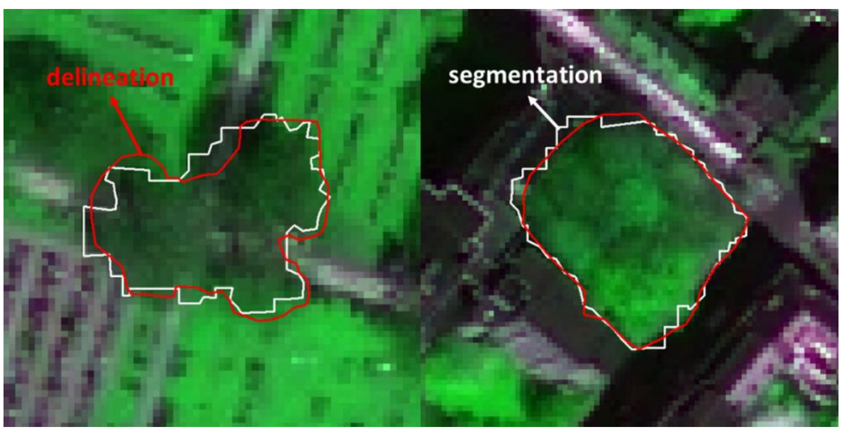


Figure 3. The examples of greenspace patches produced by manual delineation (red line) vs automated object-based segmentation (white line).

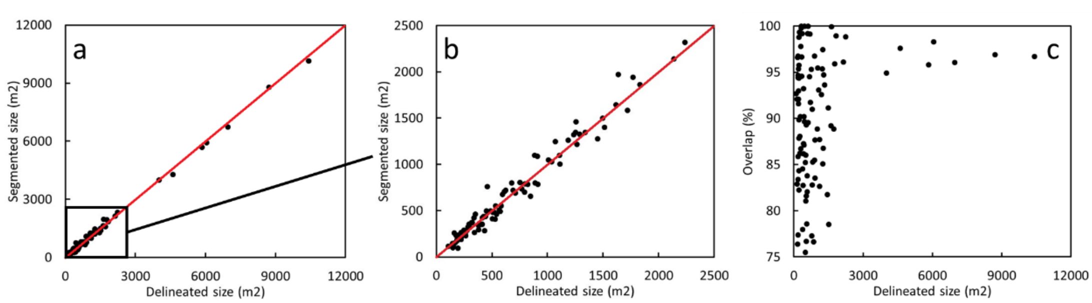


Figure 4. The differences of segmented and manually delineated objects. a-100 random selected objects; b-the image objects less than 2500 m^2; c-the overlap percentages of selected objects.

The added value of increased spatial resolution

In order to investigate the added value of increased spatial resolution, we first compared the classified accuracy of the derived green maps, and then compared the high and low green fraction between green maps and garden inventories at three scales across private gardens to building blocks.

Table 1. The confusion matrixes of green maps produced from our classification schemes.

	scheme a	scheme b	scheme c	scheme d	scheme e	scheme f	scheme g	scheme h	scheme i	scheme j
OA	61.79	67.12	69.41	73.29	76.86	79.22	80.37	82.19	87.29	90.26
Kappa	0.475	0.548	0.581	0.632	0.682	0.716	0.731	0.755	0.825	0.866

a (Classified)	Reference H_D	H_E	L_D	L_E	OT	UA
H_D	**254**	12	17	106	21	61.95
H_E	14	**51**	8	18	11	50.00
L_D	22	9	**69**	18	16	51.49
L_E	101	10	17	**314**	24	67.38
OT	34	7	10	27	**124**	61.39
PA	59.76	57.30	57.02	65.01	63.27	

b (Classified)	Reference H_D	H_E	L_D	L_E	OT	UA
H_D	**281**	12	12	85	20	68.54
H_E	11	**55**	6	15	9	57.29
L_D	15	6	**76**	20	10	59.84
L_E	95	11	23	**332**	19	69.17
OT	23	5	4	31	**138**	68.66
	66.12	61.80	62.81	68.74	70.41	

c (Classified)	Reference H_D	H_E	L_D	L_E	OT	UA
H_D	**295**	11	9	93	16	69.57
H_E	10	**57**	8	11	8	60.64
L_D	13	9	**81**	17	8	63.28
L_E	88	8	17	**338**	23	71.31
OT	19	4	6	24	**141**	72.68
	69.41	64.04	66.94	69.98	71.94	

d (Classified)	Reference H_D	H_E	L_D	L_E	OT	UA
H_D	**313**	15	4	69	16	75.06
H_E	14	**56**	3	8	12	60.22
L_D	11	5	**79**	21	6	64.75
L_E	64	9	25	**372**	19	76.07
OT	23	4	10	13	**143**	74.09
PA	73.65	62.92	65.29	77.02	72.96	

e (Classified)	Reference H_D	H_E	L_D	L_E	OT	UA
H_D	**331**	8	20	40	11	80.73
H_E	5	**59**	6	23	4	60.82
L_D	45	4	**78**	12	4	54.55
L_E	34	15	13	**388**	23	82.03
OT	10	3	4	20	**154**	80.63
	77.88	66.29	64.46	80.33	78.57	

f (Classified)	Reference H_D	H_E	L_D	L_E	OT	UA
H_D	**349**	20	11	27	14	82.90
H_E	32	**57**	6	7	3	54.29
L_D	9	2	**81**	38	4	60.45
L_E	22	6	19	**396**	17	86.09
OT	13	4	4	15	**158**	81.44
	82.12	64.04	66.94	81.99	80.61	

g (Classified)	Reference H_D	H_E	L_D	L_E	OT	UA
H_D	**355**	22	7	18	15	85.13
H_E	39	**58**	5	5	1	53.70
L_D	6	2	**82**	51	4	56.55
L_E	17	4	25	**401**	16	86.61
OT	8	3	2	8	**160**	88.40
	83.53	65.17	67.77	83.02	81.63	

h (Classified)	Reference H_D	H_E	L_D	L_E	OT	UA
H_D	**355**	9	15	28	12	84.73
H_E	17	**63**	5	4	5	67.02
L_D	8	5	**84**	25	4	66.67
L_E	32	9	11	**414**	11	86.79
OT	13	3	6	12	**164**	82.83
PA	83.53	70.79	69.42	85.71	83.67	

i (Classified)	Reference H_D	H_E	L_D	L_E	OT	UA
H_D	**374**	9	5	22	8	89.47
H_E	12	**68**	6	3	2	74.73
L_D	8	2	**96**	13	5	77.42
L_E	27	7	11	**435**	7	89.32
OT	4	3	3	10	**174**	89.69
	88.00	76.40	79.34	90.06	88.78	

j (Classified)	Reference H_D	H_E	L_D	L_E	OT	UA
H_D	**391**	8	5	11	5	93.10
H_E	10	**70**	2	3	3	79.55
L_D	4	5	**101**	9	3	82.79
L_E	15	4	10	**447**	8	92.36
OT	15	19	13	17	187	88.50
	92.00	78.65	83.47	92.55	90.31	

Scheme a	**SPOT-6**
Scheme b	**Pleiades**
Scheme c	**Orthophoto**
Scheme d	**Pleiades + Sentinel-2**
Scheme e	**Pleiades + SPOT-6**
Scheme f	**Pleiades + nDSM**
Scheme g	**Orthophoto +nDSM**
Scheme h	**Pleiades + nDSM + Sentinel**
Scheme i	**Pleiades + nDSM + SPOT-6**
Scheme j	**Orthophoto + nDSM + SPOT-6**

	OA	**Kappa**	**User's accuracy**				**Producer's accuracy**			
			H_D	H_E	L_D	L_E	H_D	H_E	L_D	L_E
scheme a	61.79	0.475	61.95	51.52	50.36	67.38	59.76	57.30	57.02	65.01
scheme b	67.12	0.548	68.37	57.89	59.84	69.17	66.12	61.80	62.81	68.74
scheme c	69.41	0.581	69.58	60.64	63.28	71.31	69.41	64.04	66.94	69.98
scheme d	73.29	0.632	75.05	60.22	64.75	76.07	73.65	62.92	65.29	77.02
scheme e	76.86	0.682	80.73	60.82	54.55	82.03	77.88	66.29	64.46	80.33
scheme f	79.22	0.716	82.90	54.29	60.45	86.09	82.12	64.04	66.94	81.99
scheme g	80.37	0.731	85.13	53.70	56.55	86.61	83.53	65.17	67.77	83.02
scheme h	82.19	0.755	84.73	67.02	66.67	86.79	85.35	70.79	69.42	85.71
scheme i	87.29	0.825	89.47	74.73	77.42	89.32	88.00	76.40	79.34	90.06
scheme j	90.26	0.866	93.10	79.55	82.79	92.36	92.00	78.65	83.47	92.55

Table 2. The percentage cover difference and distribution frequency between green maps and referenced garden inventory regarding functional types.

	scheme a	scheme b	scheme c	scheme d	scheme e	scheme f	scheme g	scheme h	scheme i	scheme j
Green cover	-14.01	-10.12	-9.33	-8.91	-8.24	-7.79	-7.02	-6.28	-5.53	-4.68
SD	16.22	11.84	10.35	11.04	10.72	9.83	9.11	7.98	7.65	6.74
±10	70.81	74.71	77.24	80.76	82.45	85.53	86.48	88.14	89.52	89.97
High Deciduous	-29.55	-26.87	-24.18	-22.06	-19.32	-17.15	-14.72	-11.55	-9.06	-8.13
SD	26.28	22.12	19.36	16.87	16.45	16.23	14.75	11.64	10.52	9.83
±10	57.44	61.17	62.22	66.23	69.38	72.26	74.91	77.63	81.81	82.24
High Evergreen	37.36	33.71	31.97	28.11	24.54	22.49	19.04	16.15	13.63	12.75
SD	39.51	34.44	32.63	32.45	27.37	24.11	23.42	19.31	18.59	16.31
±10	48.38	52.55	55.17	58.38	61.57	62.16	63.06	66.24	70.21	71.55
Low Deciduous	-35.19	-31.03	-29.21	-25.36	-22.92	-20.36	-19.21	-17.33	-13.19	-11.71
SD	34.18	30.48	32.09	26.77	25.87	22.33	21.65	17.02	18.23	14.76
±10	51.61	56.12	58.51	62.81	64.37	66.45	68.14	73.96	76.47	75.83
Low Evergreen	27.12	24.59	24.37	22.79	19.16	17.53	15.77	13.48	11.22	10.15
SD	30.24	26.83	23.96	24.55	23.31	21.27	18.25	18.55	15.13	13.43
±10	60.84	63.47	65.27	70.01	74.83	76.26	78.35	80..94	83.65	84.91

The accuracies of the produced green maps clearly improved with increasing spatial resolution from 61.8% for scheme a, to 67.13% for scheme b, to 69.41% of scheme c (Figure 5 and Table 1). Additionally the differences of greenspace coverage reduced from 13.06% for scheme a to 9.33% for scheme c (Figure 6; Table 2). Further, the improved overall accuracies and greenspace coverages were consistent with the differences in spatial resolution between the three remotely sensed imagery. Those findings demonstrate the contribution of spatial resolution to more accurate green maps.

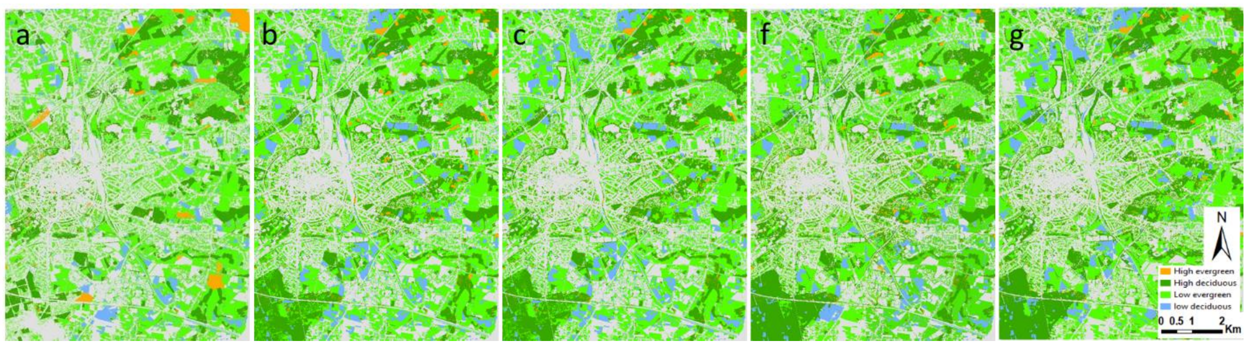


Figure 5. The green maps derived from classification scheme a (a); scheme b (b); scheme c (c); scheme f (f); scheme g (g).

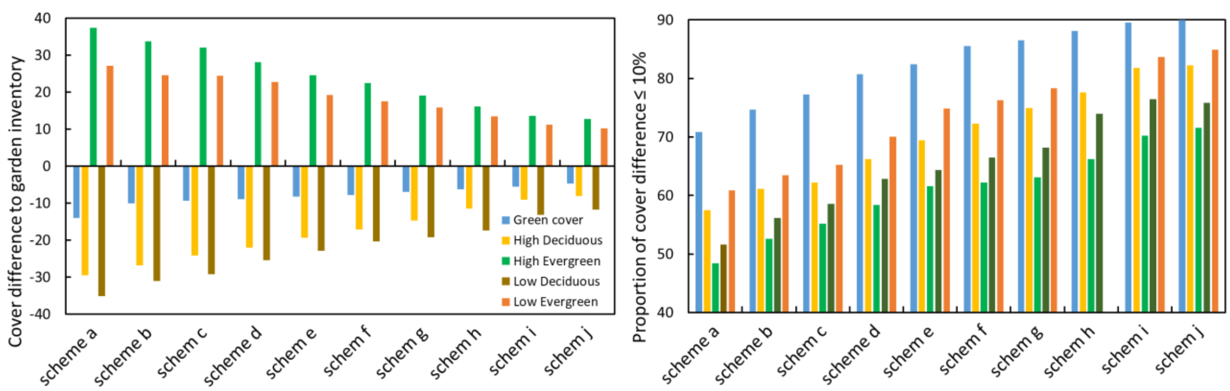


Figure 6. The percentage cover difference and distribution frequency between green maps and referenced garden inventory regarding functional types.

According to the confusion matrixes, the least accurate class was high evergreen, followed by low deciduous, while the most accurate one was low evergreen. A higher level of confusion occurred between high deciduous and low evergreen. 284 of the 369 high deciduous objects were misclassified into low evergreen, and 284 of 383 low evergreen objects were misclassified into high deciduous for schemes a to c (Table 1). Although the green maps generally "under-classified" deciduous objects and inversely "over-classified" evergreen objects, for more than 70% of the gardens the mapped error in greenspace coverage was less than 10%. Concerning the greenspace coverage to investigated private gardens, the high evergreen achieved the largest coverage differences (37.36% to 31.97%) while low evergreen were the smallest (27.12% to 24.37%), and at least half gardens achieved the differences of coverage less than 10% for all green functional types (Table 2). When we focus only on improved high green in Table 3, the height information derived from the nDSM contributed to more than 15% of improvement in overall accuracy which clearly shows the added value of 3D structural information.

Furthermore, quite similar accuracies were observed from scheme g and the garden composition map derived from the Land Cover Map Flanders as produced in WP2. These similar accuracies indicate that Pleiades (+ height info, potentially this info can be derived from STEREO pairs of Pleiades) is a viable alternative to the garden composition map derived from orthophotos.

Table 3. The confusion matrixes of produced green maps regarding high green and low green.

	scheme b Pleiades	scheme c Orthophoto	scheme f Pleiades + nDSM	scheme g Orthophoto + nDSM	LCF Land Cover Flanders
OA	72.15	74.05	87.6	89.27	90.03
Kappa	0.547	0.576	0.797	0.826	0.837

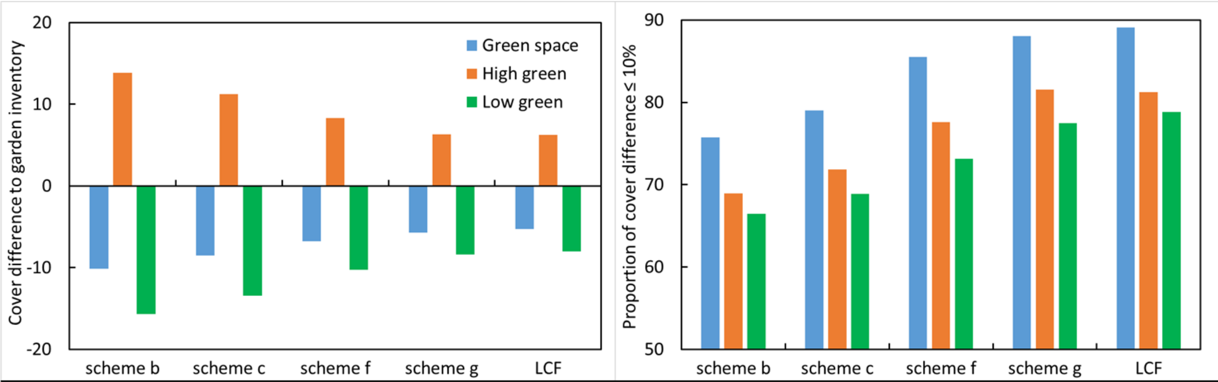
scheme b		Reference			UA%
		High green	Low green	Other	
Classified	High green	**359**	118	29	70.98
	Low green	127	**451**	29	74.3
	Other	28	35	**138**	68.65
PA%		69.85	74.67	70.41	

scheme c		Reference			UA%
		High green	Low green	Other	
Classified	High green	**377**	119	24	72.52
	Low green	114	**455**	31	75.83
	Other	23	30	**141**	72.68
PA%		73.34	75.33	71.94	

scheme f		Reference			UA%
		High green	Low green	Other	
Classified	High green	**459**	50	18	87.1
	Low green	38	**535**	21	90.07
	Other	17	19	**157**	81.34
PA%		89.28	88.58	80.1	

scheme g		Reference			UA%
		High green	Low green	Other	
Classified	High green	**465**	42	16	88.91
	Low green	37	**548**	20	90.58
	Other	12	14	**160**	86.02
PA%		90.47	90.73	81.63	

LCF		Reference			UA%
		High green	Low green	Other	
Classified	High green	**471**	40	14	89.71
	Low green	33	**551**	21	91.07
	Other	10	13	**161**	87.5
PA%		91.63	91.23	82.14	



Coverage of green map – Coverage of garden inventory

	scheme b Pleiades	**scheme c** Orthophoto	**scheme f** Ple.+nDSM	**scheme g** Ortho.+ nDSM	**LCF** Land cover Flanders
Green space (%)	-10.12	-8.51	-6.79	-5.68	-5.27
SD	11.84	8.79	6.93	6.74	6.85
±10	75.71	79.04	85.53	88.07	89.11
High green (%)	13.84	11.26	8.29	6.32	6.26
SD	17.24	14.76	11.14	7.92	8.19
±10% (%)	68.95	71.83	77.57	81.53	81.24
Low green (%)	-15.71	-13.43	-10.25	-8.38	-8.02
SD	14.32	15.74	13.61	10.75	9.93
±10% (%)	66.47	68.87	73.13	77.46	78.82

Figure 7. The percentage cover difference and distribution frequency between green maps and garden inventory regarding high and low green.

To further evaluate these green maps, we also compared the greenspace coverage of our green maps to the in situ garden inventory performed in 180 private gardens. As suggested by Figure 7 and Table 3, all green maps underestimated the greenspace coverage compared to the garden inventory because they failed to identify some shaded green spaces. Although very high spatial resolution satellite imagery may achieve reasonable accuracy in extracting greenspace (8.51%-10.12% differed to garden inventory and more than 75% of garden parcels achieved the percentage cover differences less than 10%, Table 2), it was insufficient to identify more greenspace information, such as making a difference in functional types (evergreen vs deciduous). With respect to functional types, the green maps always over-classified high green, while always under-classified low green. The misclassifications were partially explained by the fact that shaded grass patches shared the same boundaries as the tree canopies and were thus classified as trees, which led to the over-estimation of high green and under-estimation of low green.

The added value of three-dimensional structure and green phenology

The classification schemes in which 3D structure information was included (scheme f and g) achieved at least 10% improvements when compared to using only optical remote sensing data (scheme b and c) (Table 1 and 3). When in addition information on phenology is included in the classification schemes (scheme d and e), at least 6% accuracy gain is achieved compared to using a single remote sensing image in the classification (scheme b and c) (Table 1). The confusion matrices revealed that misclassifications mainly occurred between high and low green when applying only phenology information, whereas confusion between deciduous and evergreen dominated when only using a single optical image combined with 3D structure information. In addition, the confusion matrixes also suggested that within the same context adding three-dimensional structure information to the classification scheme was more efficient than adding information on green phenology (79.22% of scheme f vs 76.86% of scheme e). In contrast to the nDSM and the Pleiades image, the coarser spatial resolution of SPOT-6 imagery both had more possibilities of mixing land cover type and of introducing more shadow due to the inherent capture angle of the SPOT-6 satellite sensor. Moreover, only two SPOT images were available for this study and were not sufficient to capture the full phenology. Therefore, a higher accuracy can be expected if we can introduce more scenes of SPOT imagery or replace them to a higher spatial resolution satellite imagery.

The best accuracies though were obtained for the classification schemes that combined both multi-temporal optical imagery and 3D structural information: 90.26% (scheme j) (Table 1). These findings all clearly suggested the added value of multi-source data sets in recognizing high and low green.

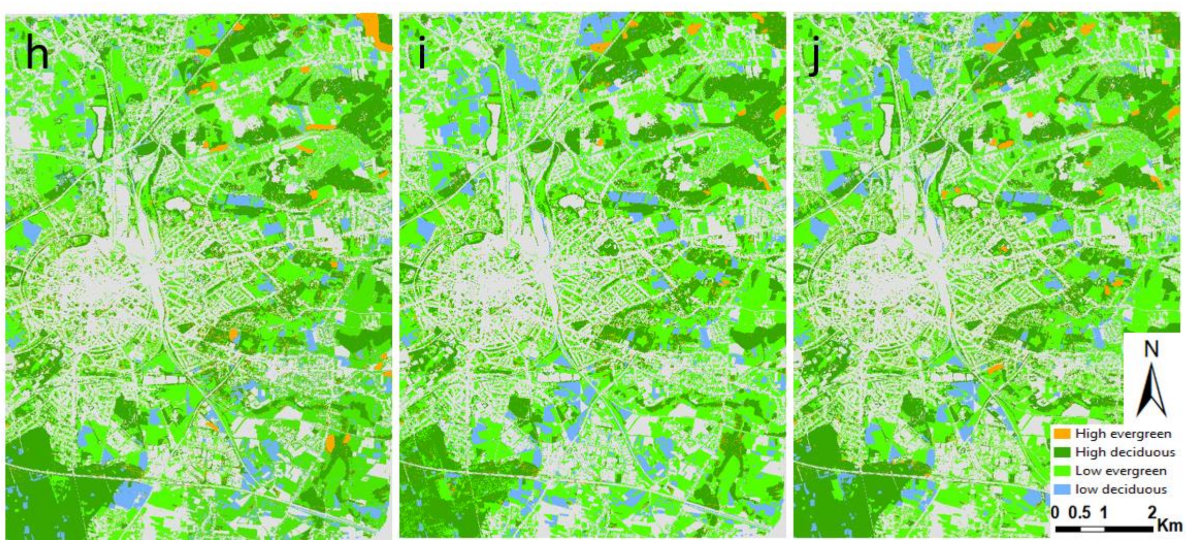


Figure 8. The green maps derived from classification scheme h (h); scheme i (i); scheme j (j).

The overall accuracy of 82.19% produced from scheme h (using Pleiades + nDSM + time series of Sentinel 2) was slightly better than 80.37% of scheme f (Pleiades + nDSM), but less accurate than 87.29%

of scheme i (Pleiades + nDSM + SPOT6). This can be explained by: 1) the acquisition date difference between Pleiades-1A and Sentinel-2 imagery. We used the Sentinel-2 imagery of 2019 to represent the phenological variations, as mostly imagery of 2015 were unavailable or offline from platform (https://scihub.copernicus.eu/dhus/#/home). The land cover changes occurred during these four years may cause more misclassifications; 2) the spatial resolution difference. The coarser spatial resolution of Sentinel-2 imagery to Pleiades-1A imagery (multi-band of 10m vs 2m) would mix the land cover landscapes failing to recognize ground objects at smaller spatial scale as Pleiades imagery. Additionally the geometrical issues caused by spatial resolution difference also aggravated the lower accuracies; 3) spatial variations in classified accuracy. The classification achieved better performance in suburban and rural areas than urban area, because larger greenspace patches are less sensitive to spatial resolution, while the heterogeneous urban core area needs very high resolution imagery. Meanwhile our validation samples in urban gardens were mostly located in complex land cover contexts. Therefore, for accurately urban land cover mapping, the high spatial resolution remote sensing imagery are a crucial premise.

Figure 6 and Table 2 shows the cover differences of functional types compared to the reference data of 198 gardens. From scheme a to scheme j, the differences of greenspace coverage to investigated gardens consistently decreased from 14.01% to 4.48% for scheme f, and all functional types followed a similar decreasing accuracy trend. Among the functional types, the high deciduous and low evergreen classes achieved higher accuracy than the other two green types (Table 2). Meanwhile the most improved types (high evergreen and low deciduous) were exactly the least accurate type in accuracy assessments. More specifically, high evergreen achieved 20.96% of improvement from 33.71% (scheme b) to 12.75% (scheme f), followed by 19.92% of low deciduous from 31.03% to 11.71%. The percentage cover differences within 10% also varied among functional types ranging from 48.38% to 60.84% (scheme a), but from 71.55% to 84.91% (scheme j). The increments of four functional types varied from 19.1% for high evergreen to 24.71% for low deciduous, which is consistent with the confusion matrixes in which evergreen classes generally achieved the lower accuracies (Table 2). Additionally for all schemes high evergreen was usually "over-classified" in urban areas, while low deciduous was probably "under-classified" in rural area. This can partly be explained by the fact that the less-brightly shaded objects had higher chances of confusing with evergreen objects, and the higher occurrence of shading objects further aggravated the confusions in urban areas.

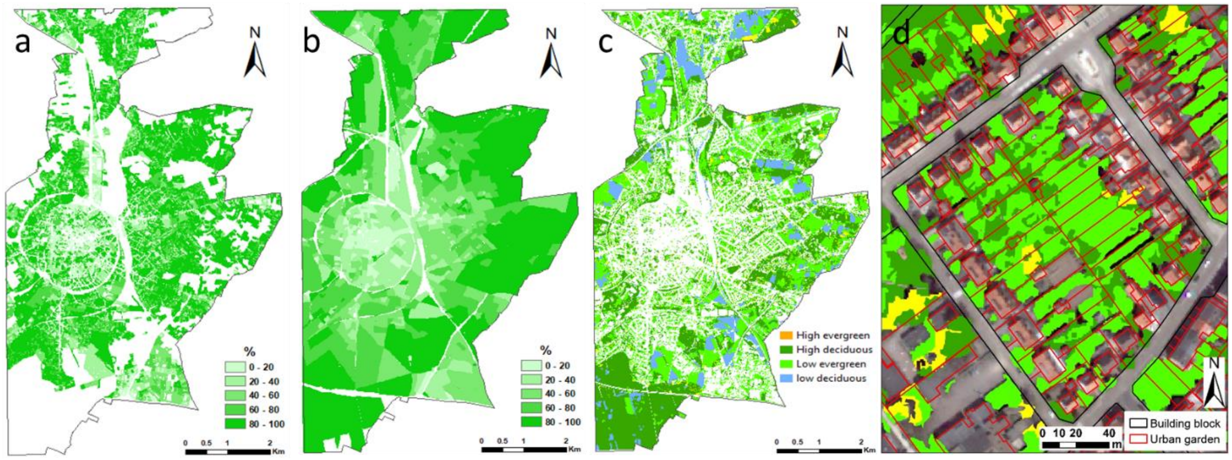


Figure 9. The greenspace coverage within private gardens (a), building blocks (b), and the spatial variations of green functional types (c) within building blocks and private gardens (d).

To evaluate the capacity of Pleiades satellite, we further compared the greenspace results from Pleiades and nDSM (scheme g) to the reference map (Land Cover Flanders). As suggested by Table 3, these two green maps achieved very similar accuracies legitimizing the comparison between scheme g and land cover flanders. According to Figure 8 and 9, the green map from Pleiades and nDSM was less vegetated than the land cover flanders by 4.38% at garden parcel scale and 3.42% at building block scale.

Greenspace landscape dynamics of residential gardens

Finally we demonstrate the potential of Sentinel-2 time series to monitor garden dynamics. We use NDVI time series built from Sentinel 2 imagery from January 2019 to May 31 2020. After only including the imagery with a cloud coverage of less than 10%, in total 42 Sentinel-2 imagery were analysed in our study. The annual greenspace dynamics were clearly observed from the seasonal NDVI variations. The higher mean NDVI values generally occurred during May to August, while the lower mean NDVI values occurred during December to February (Figure 10). Further research is needed to fully explore the potential of Sentinel2 in garden monitoring and research.

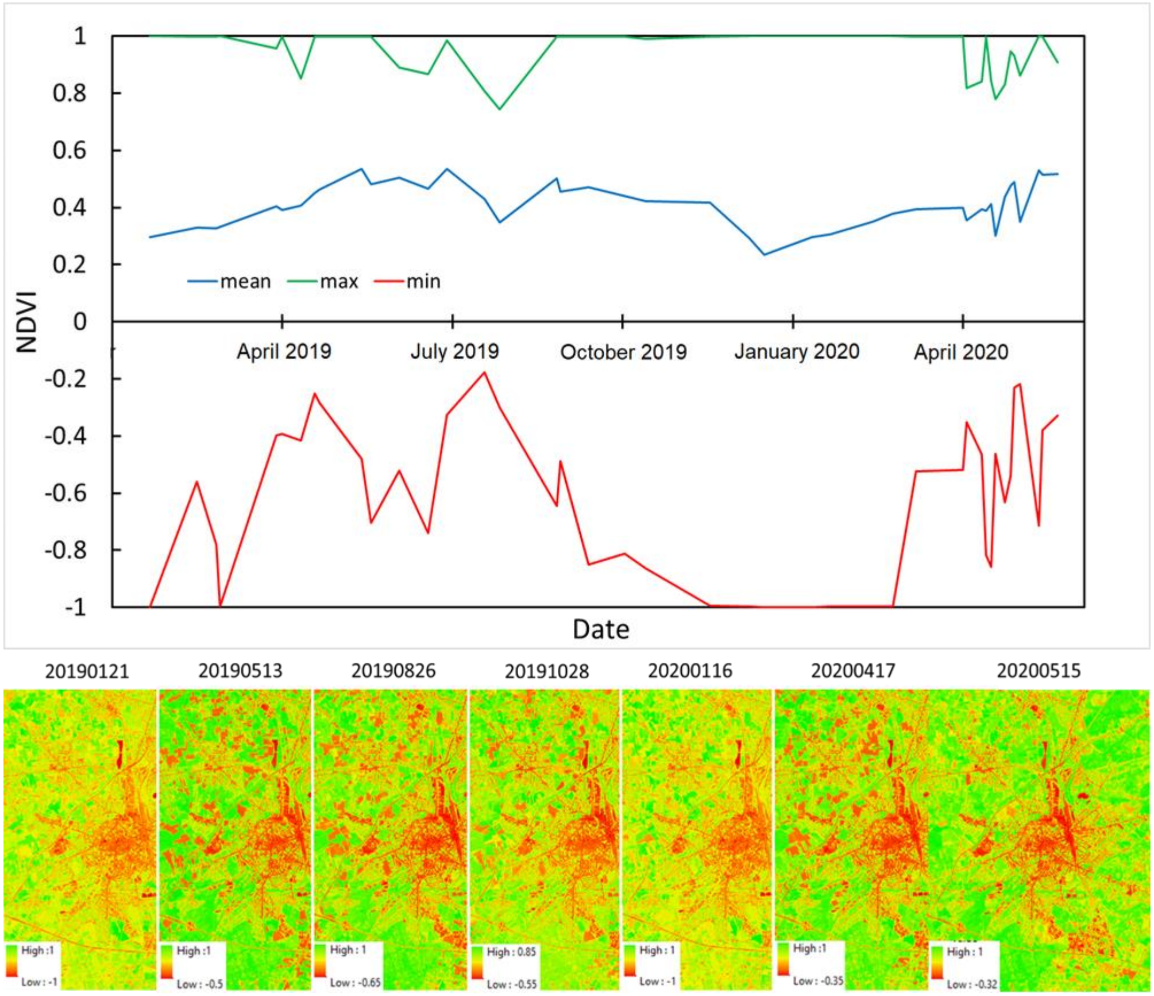


Figure 10. The NDVI variations (mean, max and min value) derived from time-series Sentinel-2 imagery sensed from January 2019 to May 2020.

More detailed technical details on the methodology applied in WP2 can be found in **Section 9**.

3.2 REALISATION OF OBJECTIVES

WP2 Regional scale mapping of garden characteristics based on airborne imagery:

The aim of this WP was to evaluate:

(i) Create a workflow to delineate garden parcels based on regional available GIS data like parcel, building & agricultural datasets and based on an explicit definition of a 'garden'.

(ii) Add garden characteristics based on regional available remote sensing data, in casu the Flanders Green Map derived from summer aerial imagery (40cm spatial resolution), as baseline for comparison with characteristics based on satellite data.

(iii) Produce a garden parcel map of Flanders based on the established workflow.

A workflow was created to delineate garden parcels and a garden parcel map of Flanders was produced. Garden characteristics, %High Green and %Low Green, were added based on regional available remote sensing data, in casu the Land Cover Map Flanders instead of the Green Map Flanders for clarity and continuity reasons. The former is actually used a source for the latter and is also used by the involved user partner *Departement Omgeving* in the periodical production of the 'Landgebruikskaart' data. The Garden Parcel Map Flanders product was validated and the Garden ADP class was found to have a correctness of 80% and a completeness of 88%. A correctness of 80% can be considered as marginally useable for an end-user. Taking into account the error margins is an absolute must when using the results globally (e.g. in surface calculations). For everyday usage the dataset can for example be used as starting point to create a more detailed garden map on the local level (e.g. municipality) but should not be used as the 'truth' map.

WP3 Mapping of garden characteristics based on satellite imagery:

The aim of this WP was to evaluate:

(i) To what extent satellite imagery can provide or add similar information on garden composition compared to the Land Cover Map Flanders (see WP2: Description of source data). Recall that the Land Cover Map Flanders is derived from the Large Scale database (GRB) and Green Map Flanders which in turn is based on summer aerial imagery/orthophoto's (40 cm spatial resolution).

(ii) To what extent satellite imagery can provide complementary information on garden composition compared to the Land Cover Map Flanders.

Our analysis revealed that high resolution satellite imagery (in our case Pleiades) could provide garden composition maps that are in line with those generated from orthophotos. It was further demonstrated that by including 3D information in the classification scheme the classification accuracy (especially from the high and low vegetation class) further increased. Finally we could demonstrate that adding multi-temporal satellite imagery (SPOT, Sentinel2) further improved the classification of the high and low green classes but in addition allowed to classify additional functional green types (evergreen vs deciduous).

Overall, the combination of the summer Pleiades image with an nDSM resulted in an overall accuracy of >85%, a Kappa of around 80% and users and producers accuracy of >80%. Accuracies of >80% are in line with what is generally considered to be good quality land cover map accuracies useful for policy support (Foody, 2002[5]). What's more the accuracies derived using the Pleiades imagery is in line with the

[5] Foody (2002). Status of land cover classification accuracy assessment. Remote Sensing of Environment, 80, 185-201

accuracies achieved by the current operational work flow of the Land Cover Map Flanders (WP2), a map which is considered useful for policy support. To conclude please find below a summary table with the objectives, deliverables and an indication to what extent each of these have been achieved:

WP2: Regional scale mapping of garden characteristics based on airborne imagery	
Deliverables D2.1 a methodology to map the location and size of gardens D2.2 a methodology to map different garden components, e.g. calculation of area of and ratio's between different garden cover components (trees, grass, low green, sealed surface, and water) Extra deliverable not included in the contract: D2.3 Produce a garden parcel map of Flanders based on the established workflow	All objectives and deliverables within this WP have been realized
WP3: Mapping of garden characteristics based on satellite imagery	
Deliverables D3.1 a methodology to map the location and size of gardens derived from Pleiades/Sentinel2	This did not seem feasible after all. Delineating gardens can only be done based on GIS operations using data on buildings, road extents, Using standard GIS operations on data layers including spatial and property boundaries. In Flanders we have all these data layers (up to date) so in WP2 we developed a workflow to delineate gardens using such a GIS workflow.
D3.2 a methodology to map different garden components, e.g. calculation of area of and ratio's between different garden cover components (trees, grass, low green, sealed surface, and water) derived from Pleiades/Sentinel2	This deliverable/objective has been partly achieved. We developed a workflow for characterizing garden composition based on a combination of Pleiades, seasonal SPOT images and a nDSM derived from airborne LiDAR and could demonstrate that this workflow delivered mapping accuracies

D3.3. integrated garden maps combining info from WP2 & WP3	comparable with the current Land Cover Map Flanders (cf. WP2). Yet, the original plan was to develop and test the workflow on seasonal tri-STEREO Pleiades images allowing to derive info on reflectance, phenology and 3D from Pleiades. The data could however not be delivered within the timeframe of this project. The analysis of Sentinel showed promise for assessing temporal dynamics in vegetation cover in gardens but its coarse resolution made the data unfit to be applied in smaller gardens. Further research is needed to explore the potential of Sentinel in the context of urban green mapping. It was clear that there is a high potential to combine the seasonal variety of satellite data with periodical high resolution data (Aerial images, LiDAR) in a garden monitoring scheme related to landcover and land use information. At local or parcel level more detailed information from eg citizens is an added value. At a regional level the use of "building blocks" is sufficient to develop a general garden policy for Flanders.

Overall we can conclude that we were able to develop a proof of concept garden map for Flanders in which we could delineate garden parcels with an acceptable accuracy and map garden composition in terms of %high green, %low green and %imperviousness also with an acceptable accuracy.

We further demonstrated that object-based classification of Pleiades (+ nDSM) results in a comparable accuracy in terms of garden composition. And by adding seasonal SPOT images we could demonstrate that we could in addition to high and low green also differentiate between evergreen and deciduous vegetation covers. This latter is important for studying the ecosystem service provisioning of urban green.

Yet an important note is here that we were not able to fully explore the potential of Pleiades as we did not have access to seasonal tri-stereo Pleiades images.

3.3 PROBLEMS ENCOUNTERED AND SOLUTIONS

WP2 Regional scale mapping of garden characteristics based on airborne imagery:

The main problem we've encountered was during upscaling the workflow to the regional level. A loss of accuracy was to be expected but not by the encountered amount. There are two reasons for this:

- the subjectivity of the definition of what is a 'garden' which we tried to overcome by broadening and objectifying the definition;
- and the heterogeneity of the landscape in Flanders being very fragmented.

The former was partly successful for translating the de definition in workflow algorithm rules but will make it more difficult to explain the definition to the users which became clear during the validation by the involved user partner *Departement Omgeving*.

Although there might be some room for improvement to overcome the latter, there will always be a trade of between correctness and completeness for the end product. Meaning that altering the workflow to overcome certain problems in certain areas will always result in creating other workflow problems in other areas. It is therefore important to give attention to explain this aspect of remote sensing to the user so the expectations will better match the results.

WP3 Mapping of garden characteristics based on satellite imagery:

We encountered several problems during the realisation of the objectives, but finally we have solved them or find alternative solutions:

1) requested satellite imagery not delivered/available

We planned to use time-series tri-stereo Pleiades imagery in our case study, however, due to the unexpected atmospheric conditions, the potential date sets still has not been delivered. Therefore we finally applied a DSM derived from available airborne images (orthophotos) to replace the DSM which we originally wanted to derive from the Pleiades stereo pairs themselves. Further we used time-series of SPOT imagery to replace time-series of Pleiades. We also intended to monitoring NDVI variations using continuous Pleiades imagery. As an alternative we now derived the NDVI variations from SPOT and Sentinel-2 imagery instead.

2) Spatial resolution and geometrical issues

The multi-source data sets used in our study have different spatial resolutions - 1m for the DSM, 2m for Pleiades, 6m for SPOT, and 10m for Sentinel-2 – causing geometrical mismatches. To solve this, we applied object-based image analysis to perform the land cover mapping. Moreover, the geometrical correction became even more crucial during the preprocessing aiming to integrate such various data sets. To increase the image quality and decrease the geometrical dislocation, we first resampled the pixel size of SPOT and Sentinel imagery to 2m. In addition, we selected more tie points and control the RMSE under 0.5 pixel during the geometrical corrections.

3) Shading effects in urban area

Shadow has been recognized an critical issue in urban green mapping, particularly for high spatial resolution imagery. Some of the previous studies just simply masked out the shaded area, and only classified the unshaded area. In our study we kept the shaded area but applied a different features/thresholds contrast to them in the OBIA approach compared to the unshaded areas. Although the shaded areas might produce more misclassifications than unshaded area, whereas in general our treatment to shaded area were more close to reality.

3.4 LESSONS LEARNED

- High resolution satellite time series analysis provides potential for continuous monitoring of gardens in a heterogeneous landscape like Flanders. Yet, data availability (free of charge) and good weather conditions remain a point of attention and additional validation and calibration studies need to be performed to fully explore the added value of satellite imagery. Deep learning approaches are a promising avenue but further research is needed in this perspective.
- 3D structural information has been shown to be crucial for urban vegetation mapping. Yet, data availability so far fully relies on airborne flight campaigns. Timely data is therefore not a sinecure. The potential of deriving DSM's from tri-stereo pairs of Pleiades could be a viable

alternative but could not be explored within the frame of this project (due to the lack of data available) but should be further explored in the future.

- It stays important to match the expectations of users and policy makers and the reality of the quality of remote sensing products. Users should be helped on how to use the data, either as a starting point for more detailed mapping or the monitoring of indicators. The former might be done with developing user tools so the resulting map can be integrated in a manual workflow. The latter by explaining the importance of validating and the use of error margins in the calculations of statistics.

3.5 INTERACTION WITH STAKEHOLDERS - SOCIETAL IMPACT[6]

- We contacted nearly 200 garden owners during field campaigns to collect validation data. During the recruitment phase and the measurements itself we sensed that most citizens do care about their gardens and are engaged to participate in our project, knowing they contribute to research on the benefits of gardens to the local quality of life in urban environments.
- Somers, B., Van Valckenborgh, J., Van der Linden, S., Yan, J., Steenberghen, T., Strosse, V. (2020). 'Naar een tuinenkaart voor Vlaanderen'. Oral presentation on the 'citizen science in de tuin - online symposium Mijn Tuinlab'.
  3 December, 2020 (> 70 participants)

3.6 USE OF BELGIAN RS INFRASTRUCTURE AND INSTRUMENTS

- We made use of Pleiades imagery (more info about the image data used can be found in Section 9)

3.7 UPTAKE OF RS BY NEW USERS

- Within the Flemish scientific community the availability of a detailed garden map opens new opportunities. In this perspective KU Leuven is currently preparing project proposals in the

[6] Include minutes last user meeting in annex

frame of the following calls: ‘Internal KU Leuven financing’, ‘H2020 Green Deal’, ‘H2020 LIFE project’, ‘VLAIO TETRA’. The focus lies on how to unlock the climate potential of the garden complex. The garden map will be a key aspect of the proposals. For more info on ongoing projects making use of the GARMON results see section 7.

4 PERSPECTIVES FOR FUTURE RESEARCH

WP2 Regional scale mapping of garden characteristics based on airborne imagery:

- Use the validation to pinpoint problem areas and improve the workflow for application on a regional scale.
- Research other sources of information that is regionally and periodically available to either improve the operational workflow or add characteristics to the ADP garden parcels.

WP3 Mapping of garden characteristics based on satellite imagery:

- Test the performance of classifications using the DSM derived from the tri-stereo Pleiades satellite imagery, and compare to green map produced from orthophotos. Such data sets have more operational power since it will be available every week or month for the whole Flemish territory.
- Evaluate the potential of time-series Pleiades satellite imagery to provide information on green phenology, and compare to Sentinel-2 imagery. Such data sets are more efficient in identify urban green composition and landscapes related to urban ecological process.

5 STEERING COMMITTEE

5.1 REPORT OF THE LAST STEERING COMMITTEE

See Attachment

bijlage3_GARMON_StCom_12122019.pdf

5.2 FEEDBACK TO STEERING COMMITTEE

• The Steering Committee recommends to focus on methods and data which are best suited to eventually upscale the approach to the whole of Flanders and provide a clear justification of the rationale for selecting them. To that end, the communication and information exchange between both project partners may need to be intensified.

A: We appreciate this suggestion and will take this into account during further analysis. Since the last steering committee we evaluated the potential of Sentinel 2. Results are presented above.

• In view of the difficulties in acquiring Pléiades imagery, the team should carefully consider whether to explore the Pléiades tri-stereoscopic research track

A: Good point. The tri-stereoscopic images are still under acquiring/reprocessing. So far we have not received any updates on new available images but we fully agree that this is a recommended future research track. Meanwhile, we changed the previous classification designs, replaced the CHM derived from the LiDAR data with a DSM derived from Orthophotos, to explore the added value of 3D informations in garden mapping.

• Once a garden map is produced, a layer of uncertainty should be added. This will allow the team to better see where the method fails and thus helps improving it.

A: In a follow-up project we will perform a thorough Flanders-wide evaluation of the garden maps based on citizen science data and we will at that time create an uncertainty layer.

• The report referred to other publications in the text, but the list of references was not given. Please add the list of references next time.

A: Apologies for this oversight. The reference list is added below:

Anders NS, Seijmonsbergen AC, Bouten W, 2011. Segmentation optimization and stratified object-based analysis for semi-automated geomorphological mapping. Remote Sens Environ 115, 2976-2985.

Baatz M, Schäpe A, 2000. Multiresolution segmentation-an optimization approach for high quality multi-scale image segmentation. In: Strobl, J., Blaschke, T., Griesebner, G. (Eds.), Angew. Geogr. Info. verarbeitung. Wichmann-Verlag, Heidelberg, 12-23.

Benz UC, Hofmann P, Willhauck G, Lingenfelder I, Heynen M, 2004. Multiresolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information. ISPRS J Photogramm Remote Sens 58, 239-258.

Blaschke T, 2010. Object based image analysis for remote sensing. ISPRS J Photogramm. Remote Sens 65. 2-16.

Laben CA, Brower BV, 1998. Process for Enhancing the Spatial Resolution of Multispectral Imagery Using Pan-Sharpening. US Patent 6, 011, 875.

Breiman L, Friedman JH, Olshen RA, Stone CJ, 1984. Classification and Regression Trees. Wadsworth International Group, Belmont, CA.

Dragut L, Csillik O, Eisank C, Tiede D, 2014. Automated parameterisation for multi-scale image segmentation on multiple layers. ISPRS J Photogramm. Remote Sens 88, 119-127.

Laliberte AS, Browning DM, Rango A, 2012. A comparison of three feature selection methods for object-based classification of sub-decimeter resolution UltraCam-L imagery. Int J Appl Earth Observ Geoinform 15, 70-78.

Li XX, Shao G, 2013. Object-based urban vegetation mapping with high-resolution aerial photography as a single data source. Int J Remote Sens 34, 771-789.
Yuhendra, Alimuddin I, Sumantyo JTS, Kuze H, 2012. Assessment of pan-sharpening methods applied to image fusion of remotely sensed multi-band data. Int J Appl Earth Observ Geoinform 18, 165-175.
Prasad AM, Iverson LR, Liaw A, 2006. Newer Classification and Regression Tree Techniques: Bagging and Random Forests for Ecological Prediction. Ecosystem 9(2), 181-199.
Pu RL, Landry S, 2012. A comparative analysis of high spatial resolution IKONOS and WorldView-2 imagery for mapping urban tree species. Remote Sens Environ 124, 516-533.
Qian YG, Zhou WQ, Nytch CJ, Han LJ, Li ZQ, 2020. A new index to differentiate tree and grass based on high resolution image and object-based methods. Urban For & Urban Green, https://doi.org/10.1016/j.ufug.2020.126661.
Zhou, WQ, Huang, GL, Troy, A, Cadenasso, ML, 2009. Object-based land cover classification of shaded areas in high spatial resolution imagery of urban areas: a comparison study. Remote Sens Environ 113, 1769-1777.

• According to the authors, Lidar data of DHMVII (2015) improved the results significantly, yet Lidar are not periodically available (see page 19). Height of vegetation may not change so fast, with respect to the vegetation classes used. Would it be worthwhile to test if the 2015 DHMVII can still improve the classifications of 2016 and 2017, with some extra rules on large changes, maybe as an alternative/in addition to using DSMs from Orthophotos (see page 24)?

A: We used DHMVII of LiDAR to replace the DSM from tri-stereo images because the delay of delivery of tri-stereo images. To more accurately evaluate the capacity of DSM of tri-stereo images, we decided to test the performance of DSMs derived from multi-stereo Orthophotos (*available every three years for the whole Flemish territory; quite similar to Pleiades at spatial and spectral features*) in our following step. Further research should indeed evaluate the potential of a Pleiades derived DSM (but as said the data was not made available for this project).

• On page 17, the authors write they converted remaining patches into points. How?

A: After removing the sampling patches used for training in our study area, we just convert patches (polygons) to points (one polygon to one geometrically centered point) in ArcMap.
As suggested during the steering committee meeting we will however improve the validation strategy in our work plan by replacing point-based validation with object-based validation. Therefore, we will remove the conversion process in final report.

• Page 17, on accuracy assessment: Why only use one out of four points for accuracy assessment (of the points that were not used for training and not excluded from study area)? Why collect so many samples if these were not used?

A: We understand that the more validation samples the better. But the majority of samples locate in central region of Leuven city, which leads to an aggregation of validation samples in central Leuven. In addition, 800 validation points are enough considering the size of the study area. In our final analysis as reported in this final report we increased the number of training samples, and use more validation samples for object-based validation.

6 DESSIMINATION ACTIVITIES

6.1 SCIENTIFIC PAPERS

PUBLISHED[7]

NA

SUBMITTED

Yu, K. et al. (in preparation). Greenspace mapping in residential gardens using optical remote sensing. Landscape and Urban Planning.

6.2 POSTERS

NA

6.3 SOFTWARE

NA

6.4 DATA ACCESS[8]

Based on the results and its validation that the 'garden map' cannot be seen as the 'truth' map the advice is that on local (e.g. municipaliy) level it can be a starting point to create a more detailed garden map. Therefore at this moment the dataset is more likely to be seen as a dataset provided by the Department Omgeving for the more high-end users. Therefore it will not yet be published as an open data set. On the other hand, the map with the building block statistics can be published as an open data set.

6.5 OTHER TYPES OF OUTREACH

Somers, 2019. Uw tuin in de strijd gegooid tegen gevaarlijke hittegolven. Het Nieuwsblad, 1 juni 2019 [newspaper article]

Somers, B., Van Valckenborgh, J., Van der Linden, S., Yan, J., Steenberghen, T., Strosse, V. (2020). 'Naar een tuinenkaart voor Vlaanderen'. Oral presentation on the 'citizen science in de tuin - online symposium Mijn Tuinlab'. 3 december, 2020 (> 70 participants)

[7] Full bibliographic reference, including doi – separate conference papers

[8] Give to link of data repository where project data can be accessed by the community.

Steegen, Van Steenberghe, Somers, 2020. Bereken je tuinscore met "Mijn tuinlab": "Er ligt een enorm potentieel in onze achtertuinen". Vrt Nieuws, 24 april 2020

[https://www.vrt.be/vrtnws/nl/2020/04/24/mijn-tuinlab/?fbclid=IwAR3rTvw5xxQQDFd27tW6xqV_bzOG4o1tW38lLVn1RiudShe_5dY9xJsesNI]

6.6 COLLABORATION WITH OTHER BELSPO PROJECTS

NA

7 NEW PROJECTS AND INTERNATIONAL COLLABORATIONS STARTED (PARTLY) BASED ON RESULTS OF THIS PROJECT

- Leuven.cool: an initiative of the KU Leuven research group of PI Somers in collaboration with the city of Leuven and the non-profit organization Leuven2030 that strives for a climate neutral city – we enrolled a network of autonomous weather stations in person's gardens and will use the green maps derived in the Garmon project to evaluate the impact of green infrastructure on urban heat stress (www.leuven.cool).

- Mijn Tuinlab (financed by EWI Flanders, 175.000 euro) – development of a citizen science webplatform for performing citizen science projects on gardens. More info: https://www.ewi-vlaanderen.be/oproep-citizen-science/mijn-tuinlab-onderzoek-de-achtertuin

8 COPY OF PUBLISHED PAPERS

NA

9 ADDITONAL INFORMATION[9]

Details concerning methodology WP2

Study area

Leuven is one of the largest city in Flemish region of Belgium with total area of 56.63 Km^2 and population of more than 100 thousands (Federal Ministry of Home Affairs, 2018). In addition, Leuven is also an integrative part of the “Flemish Diamond”, which is consisted of four agglomerations taking up four corners of an abstract diamond shape (Brussels-Ghent-Antwerp-Leuven). The “Flemish diamond” locates in the heart of western Europe, and the scattered appearance of the urban structure was the typical feature of the middle ages, concentrating high-quality industrial, commercial, and residential activities. The greenspace of Leuven city mainly consists of public parks, agricultural lands, forests, and private gardens. The prefectural city has a total greenspace of 3713 ha, which covers 64.6%, but unevenly spatial distributed across the city (https://www.vlaanderen.be/, 2015). The suburban area outside the “ring road” is featured by lower building density but larger-size agricultural lands, whereas the compact urban area circled by the “ring road”, where featured by higher building density and smaller-size private garden mosaics (Figure 11). Moreover, the average greenspace coverage of urban gardens is only 26.7%, with the average size of 366 m^2. Therefore, the intensified heterogeneous urban landscape in Leuven city would be a great area to quantify the added value of multi-source remote sensing date sets in urban green mapping.

[9] Detailed description methodology, statistics, reports, …

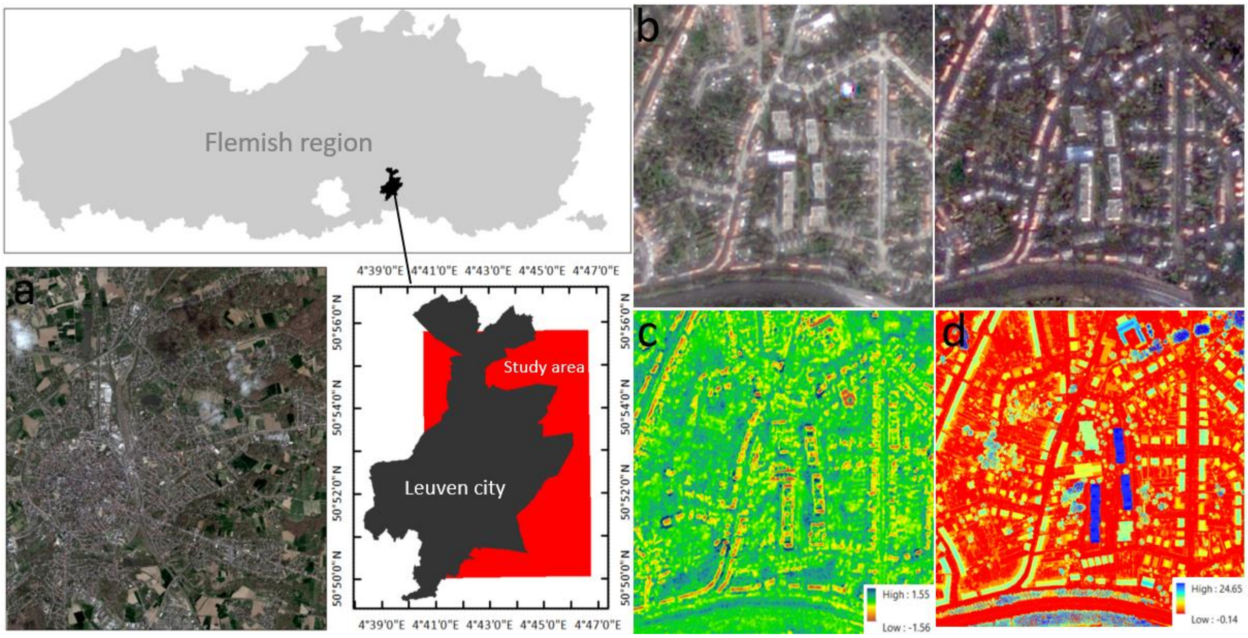


Figure11. The study area and example of satellite imagery (a-Pleiades imagery; b-SPOT imagery acquired in September and January), NDVI difference derived from time-series SPOT imagery (c), and Digital Surface Model (DSM, d).

Remote sensing data

Four scenes of high-resolution remotely sensed imagery, 42 Sentinel-2 imagery and one normalized digital surface model (nDSM) were introduced into our case classifications. One of the satellite imagery was from Pleiades-1A satellite acquired on June 5, 2015 (Figure 1-a). Pleiades-1A satellite, launched in December, 2011, captures high-resolution imageries in one pass at large areas (up to 106 km2), as well as locates an ground object within one meter of its physical location. Pleiades-1A satellite provides a spatial resolution of 0.5 meter for panchromatic (480-830nm) and 2 meters for multispectral (Blue:430-550nm; Green:490-610nm; Red:600-720nm; Near Infrared:750-950nm) with daily revisit. Another two were SPOT-6 satellite imagery acquired on January 7, 2015 and August 29, 2015, respectively (Figure 1-b), which were used to demonstrate the phenological variations. SPOT-6 satellite, launched in September, 2012 and then joined the Pleiades constellation (1A and 1B) in 2014. SPOT-6 satellite is capable of imaging the earth with a spatial resolution of 1.5 meters at panchromatic band and 6 meters at multispectral bands (Blue:455-525nm; Green:530-590nm; Red:625-695nm; Near Infrared:760-890nm) with up to 750 scenes per day per satellite.

Sentinel-2 is a European wide-swath, high-resolution, multi-spectral imaging mission. The full mission specification of the twin satellites flying in the same orbit but phased at 180°, is designed to give a high revisit frequency of 5 days at the Equator. The twin satellites of Sentinel-2 provides continuity of SPOT and Landsat-type image data, contribute to ongoing multispectral observations and benefit applications such as land management, agriculture and forestry, disaster control, humanitarian relief operations, risk mapping and security concerns. Sentinel-2 carries an optical instrument payload that samples 13 spectral bands: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution. Among them, band 4 is the red band, and band 8 is the near infrared band, then NDVI=(band 8-band 4)/(band 8+band 4). Based on the advantages, in total of 38 Sentinel-2 imagery sensed from January 1, 2019 to May 31, 2020 were collected (https://scihub.copernicus.eu/dhus) when only keep the ones that cloud coverage was less than 10%. Finally, the digital photographic aerial images were sensed in the summer flying season during June 17 to July 1, 2015 with a ground resolution of 40 cm, and subsequently the production of an Orthophoto mosaic with a ground resolution of 40 cm. The Orthophoto mosaic was available in the form of a true color composite (RGB) and a color infrared composite (CIR) (https://www.vlaanderen.be).

The Pleiades-1A and SPOT-6 imagery were orthographic calibration-ready standard products obtained under cloudless conditions. A series of preprocessing steps, including internal sensor geometry correction, removal of optical distortions, scan distortions and line-rate variations, and band registration, were performed by the vendor (Airbus Defence and Space Intelligence). Afterwards we applied the Gramm-Schmidt (GS) algorithm (Laben and Brower, 1998) in ENVI 5.3 (http://www.harrisgeospatial.com) to pan-sharpening the multispectral bands as GS algorithm produces better spectral quality and maintain original spectrum of imagery (Yuhendra et al., 2012). Then geometric corrections were also conducted in ENVI 5.3 through selecting more than 100 pairs of tie-points with controlling the RMS under 0.5, using the airborne Orthophoto as the reference map. Geometric corrected SPOT-6 imagery were then applied to represent the phenology through developing a phenological metric-NDVID (Figure 1-c). NDVID was the difference value between NDVI (Normalized Difference of Vegetation Index) value of SPOT imagery acquired in September and that of acquired in January. NDVI was calculated as: NDVI=(NIR-RED)/(NIR+RED), where NIR was near infrared band, and RED was red band.

The normalized Digital Surface Model (nDSM) at the spatial resolution of 25 cm were derived from an airborne LiDAR dataset (Figure 1-d). The point cloud were collected in Summer 2015 by Aerodata Surveys Nederland BV (https://www.geobusiness.nl/leden/aerodata) featuring an average point density of 15 points/m2. The processing procedures using LAStools software includes detection and removal of noisy returns, detection of ground returns, creation of DTM through interpolation, derivation of all non-ground returns and creation of a CHM by extracting the maximum height for each cell.

Image segmentation

A MRS algorithm embedded in eCognition Developer (www.geospatial.trimble.com) was applied to generate hierarchical image objects (Figure 12). MRS is a bottom-up segmentation that consecutively merges pixels or existing image objects into bigger objects based on a relative homogeneity criterion (Baatz and Schäpe, 2000; Benz et al., 2004), which measures how homogeneous an image object is within itself. Three key parameters, scale, shape, and compactness, can be modified to control the homogeneity (Anders et al., 2011; Blaschke, 2010). Larger scale parameters result in larger segmented objects, vice versa, whereas a larger scale possibly causes “under-segmentation” through generating image objects mixing several land covers, while too small scale leads to “over-segmentation” of a fragmented landscape. Once a scale parameter was identified, the color and shape were modified to refine the shape of the segments. Differing to a “trial and error approach” of validating the quality of segmented objects through visual inspection, we performed the Estimation of Scale Parameter (ESP; Dragut et al., 2014) as ESP is more efficient and objective compared to common used visual inspection (Pu and Landry, 2012). The ESP automatically segments the image with fixed increments of scale parameter, and calculates Local Variance (LV) for each object level obtained through segmentation, and also assesses the dynamics of LV using a measure called Rate of Change (ROC). The peaks in the ROC-LV graph indicate the object levels at which the image can be segmented in the most appropriate manner (Dragut et al., 2014). Results from ESP suggested three potential scale parameters (25; 55; 90; Figure 12) for the target land cover classes, e.g., scale 25 for greenspace, 55 for green functional types, and 90 for water and impervious surface. In addition, the value of shape, which equals 1 minus that of color, determines how much weight (0-1) was placed on shape when generating segmented objects. Most works have found that more meaningful objects would be extracted with a higher weight for the color criterion (Herold et al., 2002; Laliberte et al., 2004; Zhou et al., 2009). The parameter compactness is a shape-related factor, which determines the compactness or smoothness of segmented objects (Pu and Landry, 2012). Finally, we generated a three-level hierarchical image objects using scale parameters as suggested by ESP (25, 55, 90 as scale; 0.1/0.5 as shape/compactness) for classification schemes with equally weighted remote sensing layers.

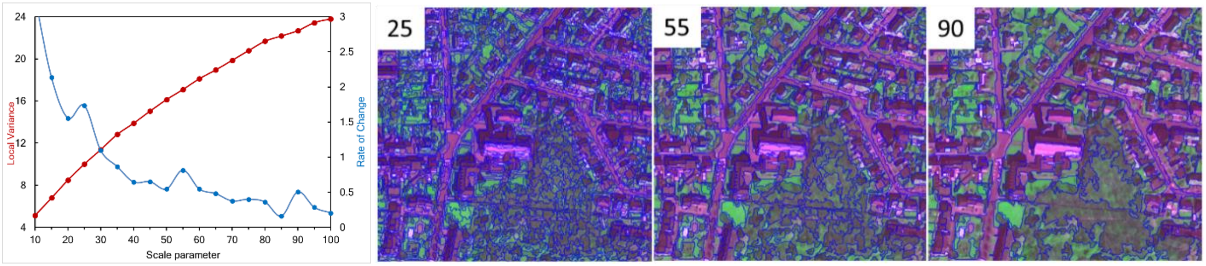


Figure 12. The segmented examples using the scale parameters indicated by ESP.

Classification using single Pleiades-1A imagery (scheme a to c)

For recognized vegetation objects, we first applied Tree-Grass Difference Index (TDGI, expression= -Log(canny)+Brightness, Qian et al., 2020) to separate high green (trees and shrub) and low green (grass). Then Classification and Regression Tree (CART) was conducted to differentiate the deciduous and evergreen objects. CART is a non-parametric classification method making no assumptions regarding the underlying distribution of values of the predictor variables, and also identifies splitting variables based on an exhaustive search of all possibilities (Breiman et al., 1984; Laliberte et al., 2012). A total of 2000 training samples (not equally distributed by land cover types) were randomly selected from the study area based on the field campaigns recording location and land cover types. Then the potential features were analysed and selected according to the similarity of features (the overlap of feature ranges was less than 50%). Finally, 16 selected features were included in CART to generate decision tree separating green functional types (Figure 13).

For shaded areas, we separated shadow objects into tree shadow (shadow caused by trees) and building shadow (shadow caused by buildings), as they were too distinct in spectrum and shape characteristics to apply the same thresholds when identifying greenspace under them, e.g., building shadow are generally darker color and larger size than tree shadow. Therefore, the shaded objects with area greater than 400 pixels ($100m^2$) and brightness lower than 24 were classified into building shadow, and the rest were tree shadow. In addition, the more boundaries of an object shared with vegetated objects, the higher possibilities of the object belongs to vegetated objects. Then shaded greenspace was extracted from the two shadow types with combinative use of NDVI (0.13 for tree shadow, 0.08 for building shadow) and relative border to vegetated objects (0.5). Afterwards the shaded greenspace were separated using the same features as in unshaded greenspace, but different thresholds (Table 5).

Table 5. Features and thresholds used in classifications for classes.

Class name (object level)	Feature (threshold)	Class name (object level)	Feature (threshold)
Unshaded area (25)	Brightness(36); Mean Red (387)	**Shaded area (25)**	Brightness(27); Mean Red (332)
		Tree & Building shadow (55)	Area(100 m2); Brightness(24) Relative border to green (0.5)
Unshaded green (25)	NDVI (0.24); Mean Blue (445)	**Shaded green (55)**	NDVI (0.13) in tree shadow NDVI (0.08) in building show
High & low green (55)	-Log(canny_NIR)+Brightness (51.24)	**High & low green (55)**	-Log(canny_NIR)+Brightness (36.81)
Deciduous & evergreen (55)	Mean NIR (236); Ratio G/R(1.34); Hue-R_G_B (0.21)	**Deciduous & evergreen (55)**	Mean NIR (197); Ratio G/R(1.15); Hue-R_G_B (0.16)
High deciduous & evergreen (55)	Ratio G/R(1.52); GLCM-H_NIR(0.14); GLCM-H_G(0.19); Hue-R_G_B (0.31)	**High deciduous & evergreen (55)**	Ratio G/R(1.29); GLCM-H_NIR(0.06); GLCM-H_G(0.12); Hue-R_G_B (0.22)
Low deciduous & evergreen (55)	Mean NIR (279); Ratio R/NIR (0.56); Hue-G_R_NIR (0.23); GLCM-H_NIR (0.1)	**Low deciduous & evergreen (55)**	Mean NIR (234); Ratio R/NIR (0.46); Hue-G_R_NIR (0.14); GLCM-H_NIR (0.08)
NDVID (55)	0.23; 0.35	**NDVID (55)**	0.13; 0.22
nDSM (55)	3 meters	**nDSM (55)**	3 meters

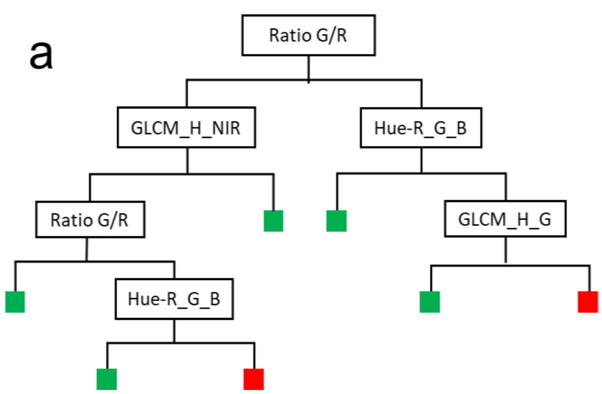


Figure 13. The decision trees result from CART. a-decision tree for high deciduous and high evergreen; b-decision tree for low deciduous and low evergreen. The green square indicates the target class; while the red square indicates the other class.

Classification integrating multi-source date sets (scheme d to h)

In classification schemes d and e, NDVID derived from Sentinel-2 and SPOT-6 satellite imagery were introduced into classification scheme b as an auxiliary layer to recognize the green functional types. We first divided the vegetated objects into three groups (deciduous, mixed greenspace, and evergreen) according to NDVID values. The vegetated objects were classified into evergreen trees when NDVID < 0.23 (0.13 for shaded objects for NDVID from SPOT-6), and were classified into deciduous trees when NDVID > 0.35 for unshaded objects (0.22 for shaded objects). Those objects that NDVID between 0.23 and 0.35 for unshaded objects (0.13 < NDVID < 0.22 for shaded objects) were classified as mixed greenspace (Figure 5-a). Then the mixed greenspace were separated into deciduous and evergreen using the same features listed in Table 1. Finally, the classified deciduous and evergreen objects were further classified to high green and low green using feature TDGI (-Log(canny)+Brightness) respectively. But for classification schemes f and g, high green and low green were first identified with break point of 3 meters of nDSM (Figure 13-b), then high and low green were separated into deciduous and evergreen respectively using the same features listed in Table 1. With respect to classification scheme h to j, both nDSM and NDVID were applied to remotely sensed imagery.

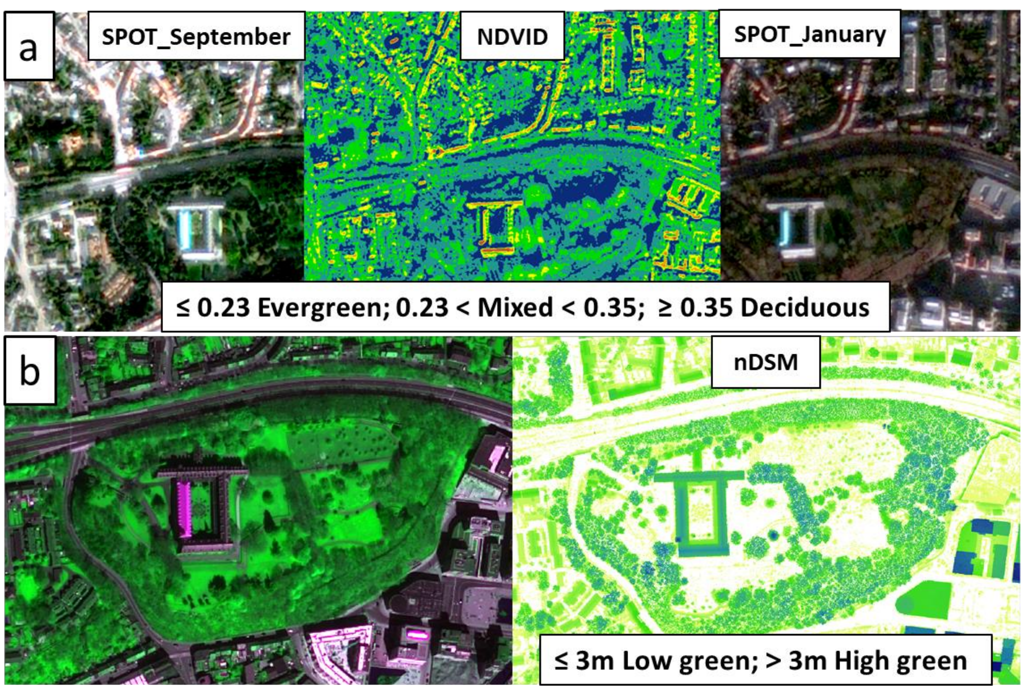


Figure 14. The examples of applying green phenology and three-dimensional structure to classification schemes.

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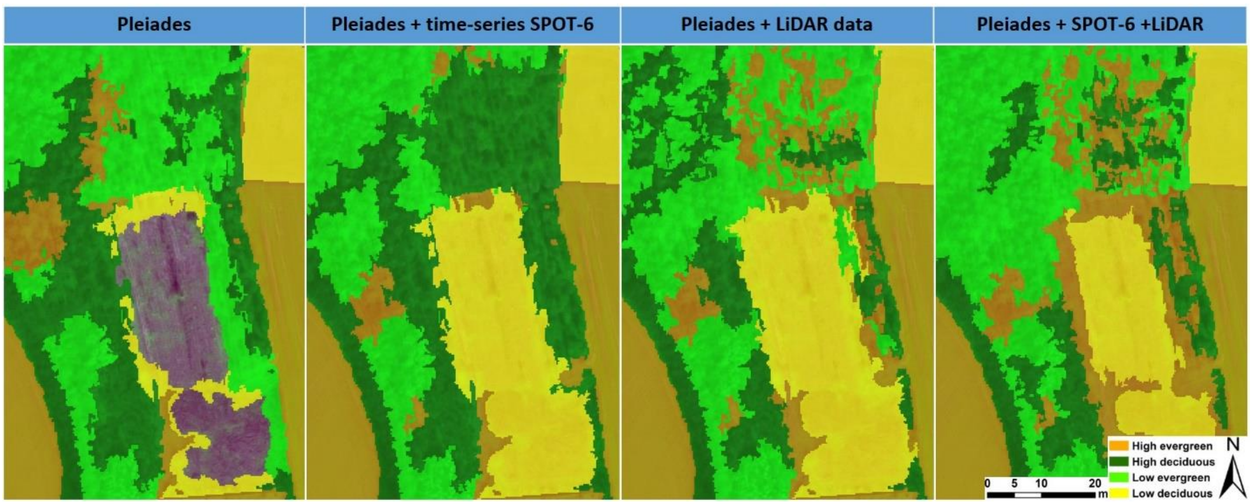
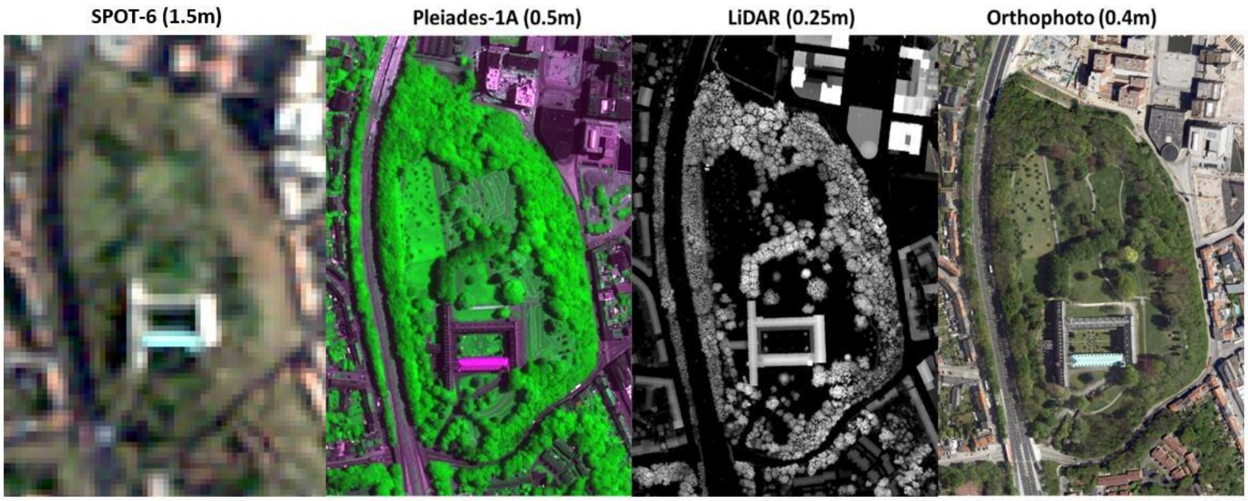
10 PROJECT ILLUSTRATIVE MATERIAL[10]

1. improvements in green mapping result from additional layers

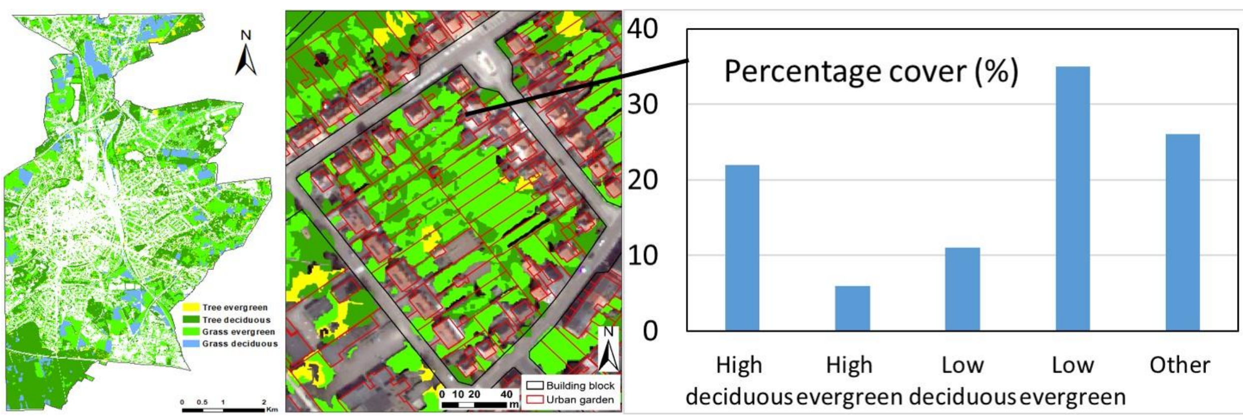


[10] In attachment by Wetransfer or ftp link; high resolution photographs of field campaigns, graphs and maps. You may also provide us with pictures of the team members if so wished. By sending us photographs, you agree that BELSPO can use them for its websites and other forms of communication.

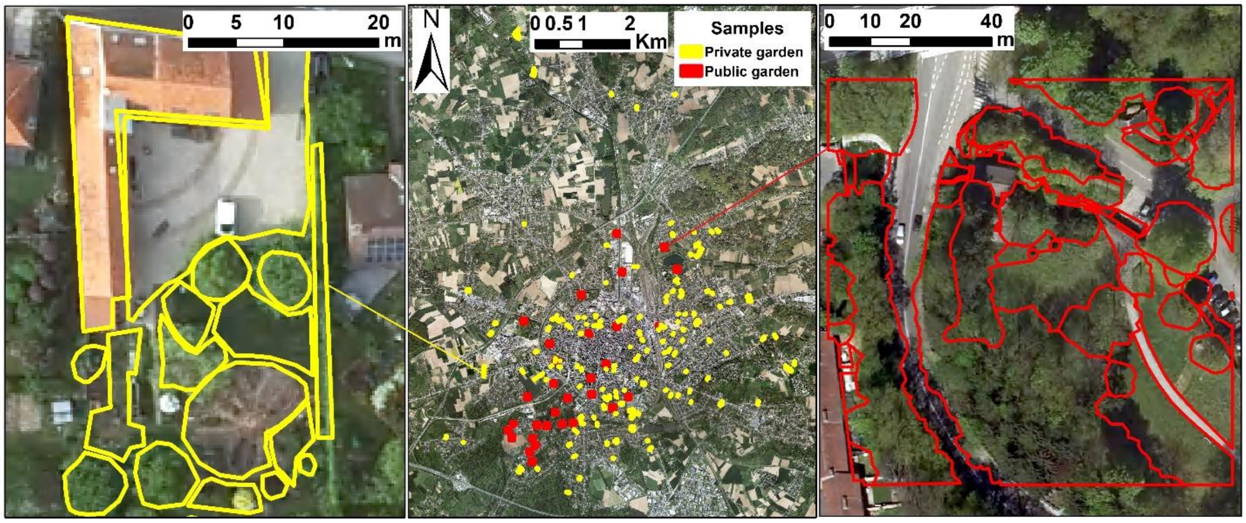
2. data sets used



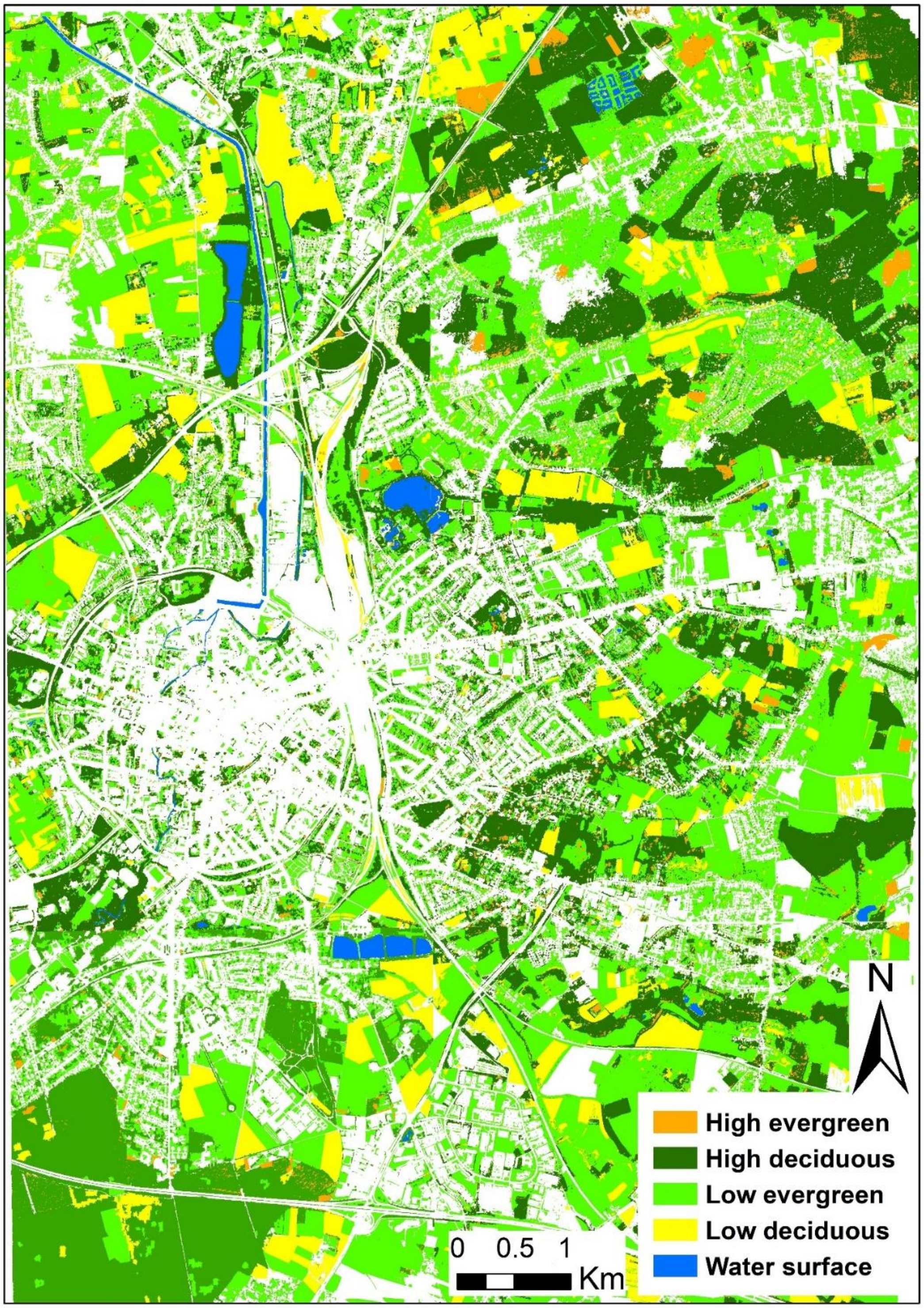
3. evaluation of garden greenspace



4.manual delineations of ground samples



5.example of green maps




N
0
0.25
0.5
1
Km
Green Map
High Green
Low Green

11 PROJECT SHEET (separate form)[11]

bijlage1_GARMON_Project-sheet-final.pdf

12 PROJECT WEBSTORY (separate form) [12] [13]

bijlage2_GARMON_webstory_25112020.pdf

13 Attachment

- **Report of the last Steering Committee** (separate document)

Last steering Committee (stuurgroep 12/12/2019) :
bijlage3_GARMON_StCom_12122019.pdf

- **Final results – presentation** (separate document)

Last internal steering group department (stuurgroep 07/10/2020) :
bijlage4_GARMON_Stuurgroep_DepOmgev_07102020.pdf

- **Evaluation** (by departement Omgeving)

Cooperation with the research team went smoothly. Some presentations about the added value of the satellite images could have been clearer. Another point for attention is that during the course of the research, quite a lot of personnel deployment was required from the client (especially for data validation), which should have been clearer from the start.

- **Concrete plans for using the outcome of the project within the Flemish administration (by departement Omgeving)**

The data from the GARMON report will be incorporated into RURA 2.0 (Ruimterapport Vlaanderen), under the chapter on Natural Capital, part gardens. In combination with data from MijnTuinlab, an analysis will be made in relation to the Flemish gardens. The Leuven case may possibly serve as an illustration. In addition, the final results will also be presented to relevant governments and stakeholders. At local level - such as cities and municipalities - the results can make a possible contribution to supporting green policy.

[11] Form available on project management website
[12] Form available on project management website
[13] Story for broader audience on interesting aspect of project, e.g. fieldcampaign, cross border cooperation

Some results such as the garden statistics per building block will be distributed as open geodata. The Flemish Administration engages itself to create updates from both geographical outcomes ('probable gardens' and 'building blocks with garden statistics') on a regular basis.