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100K Trees

WP 1 Verification of user requirements & co-creation processes and crowd science

Deliverable No. 1.4: Requirement and recommendations for further adoption of satellite-based support decision tools in an EU market

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List of Acronyms	
CBA	Cost benefit analysis
CPH	Copenhagen
CS	Citizen/crowd science
CSRD	Corporate Social Reporting Directive
EC	European Commission
ESG	Economic, social and governance
EEA	European Environment Agency
GA	General Assembly
GIS	Geographical Information System
HR	High resolution
IPCC	Intergovernmental Panel on Climate Change
MIM(s)	Minimum Interoperability Mechanism(s)
RS	Remote sensing
SOF	Sofia
UC	Use case
UR	User Requirement
VHR	Very high resolution
WP	Work Package

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Executive Summary

This report takes as a starting point the results gathered in Deliverable 1.1 on User Requirements. Here, municipalities expressed demands for GIS mapping providing a comprehensive view of urban tree metrics, including type, location, and vitality. The diagnostic analytics phase, addressing urban challenges like temperature elevations and air quality, aims to optimize green management operations.

The project aims to aid municipalities in predicting future trends using historical data and IPCC scenarios, facilitating nature-based solutions for climate adaptation. The impact analysis focuses on urban cooling, pollution reduction, carbon sequestration, and water absorption, contributing to informed decision-making. Three key use cases— tree maintenance, urban green infrastructure planning, and integration into legal reporting—emerged, with emphasis on the unexpected priority of tree maintenance during co-creation.

To fulfil user requirements, the project acknowledges the need for remote sensing, including LIDAR and aerial surveys, to monitor crown vitality. Anticipating future ESG reporting obligations for private companies, the project aims to secure a 'first mover' advantage. User stories and requirements have informed a set of functional requirements guiding the development teams.

The report explores challenges faced by city authorities in adopting data-driven tools and satellite-based decision support systems and how these relate to the development of the 100KTrees Toolbox. The team has translated user needs and use cases into toolbox functionalities, emphasizing the critical role of satellite data, including Copernicus and VHR data, for scalability. A real-use case with the Municipality of Frederiksberg presents an exciting opportunity for hands-on tool development, requiring careful consideration of spatial resolution and municipal data access.

The upcoming technical and software development stages will resolve detailed aspects of satellite data utilization. The report concludes with the anticipation of the team's plenary meeting in December 2023, where collaboration with Frederiksberg and the challenges associated with developing services for a relatively small urban area will be addressed.

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1 Aim of deliverable

The aim of this deliverable is to provide recommendations for selection of data sources, including satellite data, into the design process of the 100KTrees Toolbox.

The deliverable draws upon the projects earlier deliverable, DEL 1.1 User Requirements, and functions as a guide for the subsequent translation of the user requirements into functional requirements and specifications in delivering data driven services. As such it serves as a stepping stone to bridge development from user input to technical delivery.

1.1 Relation to other Activities

The deliverable 1.4 is central in the transformation process of user inputs to technical delivery and as such it relates to most work packages, especially WP1-4 and WP6 (See figure below). Where the process earlier focused on 'what to develop' (D1.1), the process now moves to describing 'how' to develop. This relates to the models (WP4) and inputs to modelling (WP2 and 3) but it also relates to WP6, especially T6.2 and the relation between data sources and scalability potential, and T6.3 Minimum Viable Product and more complex modelling options.

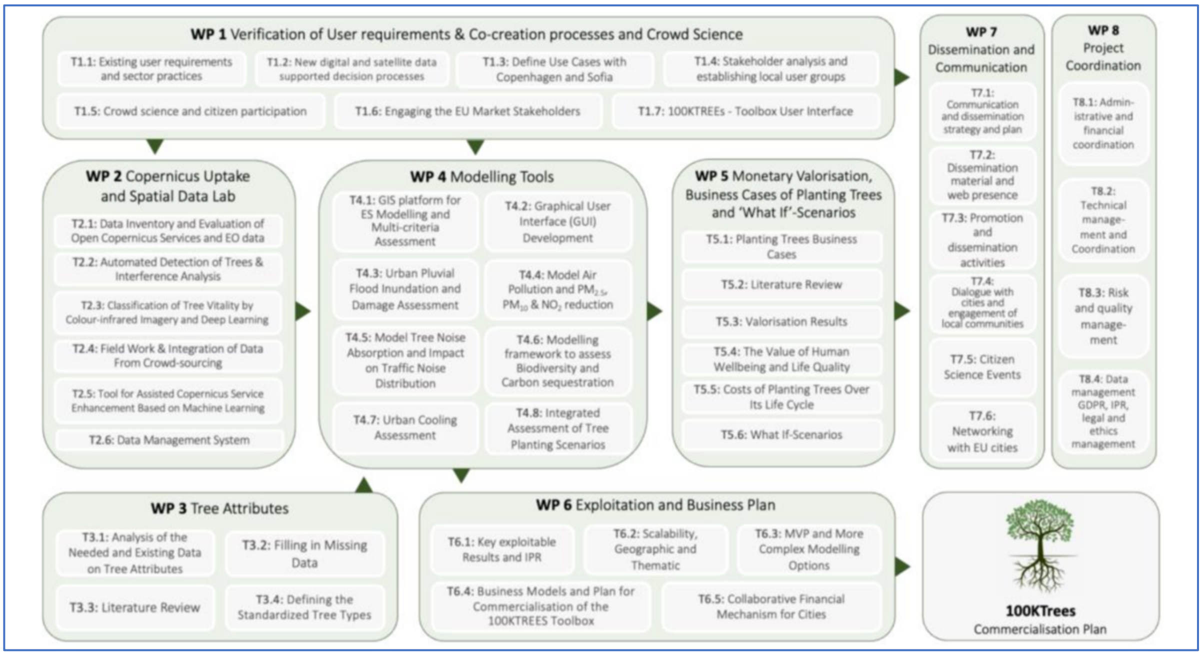

Figure 1 Linkage between WPs in 100KTREEs

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2 Adoption of data driven support tools

Central to the success of the 100Ktrees project is providing a toolbox to stakeholders that fit their needs as customers. Being able to address not the relevant challenges but also the providing a fit to technical and organisational conditions is a must in this regard. Historically, it has been overlooked that the use of data in decision making requires new skills and organisational changes in order to utilise data to an optimum.

Gartner, the consultancy company, was perhaps the first to formalise how the digital transformation can be described in phases. Their perspective is the business sector while cities, a main stakeholder for 100Ktrees, share many of the same steps, they also have other considerations relating to transparency and political accountability that come into play especially in the realms of automated decision making. As a framework to understand adoption of data driven support tools in an EU context the Gartner model remains relevant. Especially, as it stresses the organisational difficulty in advancing, and therefor also that service provision (i.e. the 100KTrees Toolbox) needs to fit at each stage in order to be relevant.

Gartner describes the digital transformation process as a journey that involves developing a nuanced understanding of various analytics stages that illuminate the past, diagnose the present, predict the future, and prescribe optimal actions. This evolution is encapsulated in the four key stages of analytics: Descriptive, Diagnostic, Predictive, and Prescriptive.

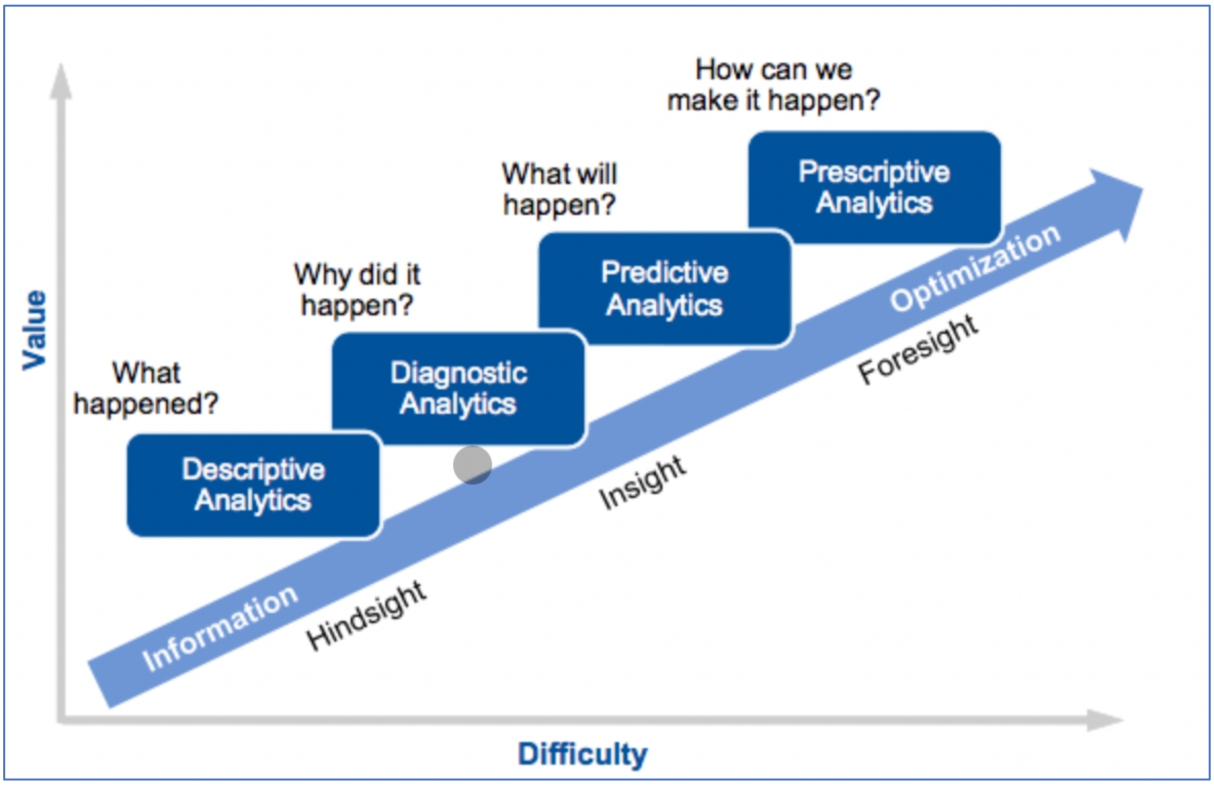

Figure 2 The Gartner Digital Transformation phases[1]

[1] Source: www.computd.nl/demystification/4-levels-of-data-maturity/

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2.1 Descriptive Analytics

The foundational stage of descriptive analytics starts by asking 'what'. In this phase, data is utilized to articulate and understand past events, offering insights into historical conditions or performance.

The 100KTREEs team has covered the 'what' for the municipalities during the co-creation process of elaborating the user stories, and their requirements, where we investigated their pains and gains in a green management context. This includes the issues they have faced in the past and their foresight regarding the information they will require in the future to tackle urban climate change. In relation to 100KTrees descriptive analytics involves examining the number of trees, trees per type, location of trees, etc., enabling an overview of the tree situation in the city through GIS mapping (i.e. with layers of information for the trees).

2.2 Diagnostic Analytics

Moving beyond the historical narrative, diagnostic analytics delves into the 'why' behind the data. This stage involves uncovering the root causes of issues or occurrences identified in the descriptive phase.

Through the 100KTREEs survey (initial questionnaire), the team have illuminated the 'why' aspects – e.g. they are interested in urban trees, the planting of new trees and hence this project. For 100KTrees diagnostic analytics include the understanding of the reasons behind many of issues faced in urban environments, e.g. local temperature elevations, air quality and pollution levels, etc. Armed with this knowledge, organisations can optimize their green management operations to mitigate challenges or enhance efficiency.

2.3 Predictive Analytics

According to Gartner's model organizations mature in their analytical journey, they can move on to predictive analytics, where the focus shifts to anticipating future trends and events based on historical data. In the context of 100KTrees, predictive analytics involves the ability to predict future climate pattern forecasts on the basis of IPCC scenarios. This aspect will be covered by the scenario analysis and tree planning component of the 100KTREEs toolbox. This foresight will empower the planning departments to allocate resources effectively, ensuring optimal staffing levels, or planting trees in hot spots in time to grow sufficient crown diameter over the long term (10-20 years).

2.4 Prescriptive Analytics

Last is the most valuable form of analytics; prescriptive analytics. This segment of analytics revolves around prescribing decisions and actions to the organisation. These include automated decisions of e.g. allocation and location planning for NBS and urban greening maintenance from preference inputs such as costs and CO2 emissions. This project will most definitely support our users in such planning and decision-making processes. Our analyses regarding the impact of new trees on urban cooling, pollution, carbon sequestration, noise and water absorption will inform their decision making, while the cost benefit analyses and business case assessments for new urban trees will give a more balanced view of the pros and cons of expensive tree planting.

For 100KTrees and the use of satellite data, it is important to stress the increase in the level difficulty as an organisation moves from one phase to another. Use of data for descriptive analysis involves few data sets and will often be carried within one department of an organisation. Moving up to involves more data but often also working across departments and systems where complexities of data models,

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data quality, and standards come into play. The Framework of Minimal interoperability Mechamisms, MiMs (see D 1.1) is one European attempt to standardise data and data models to ease adaptation of data.

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3 100Ktrees Use cases

In course of D1.1 the process of identifying user requirements from main stakeholders have been condensed into 3 main use cases:

1) Planning urban green infrastructure
2) Maintenance of trees
3) Integration to legal reporting

Each of the use cases consist of a series of single user requirements that in the end will be translated into technical functionalities. By adding the perspective of Gartner the conditions for these functionalities become apparent and it is possible to map dependencies of data and necessary integration in order to be able to provide a Toolbox with services that are relevant in many cities across a European Market.

The illustration below maps the user requirements that we received from stakeholder representatives to each stage of the maturity ladder. Each step illustrates the addition of complexity of data sources.

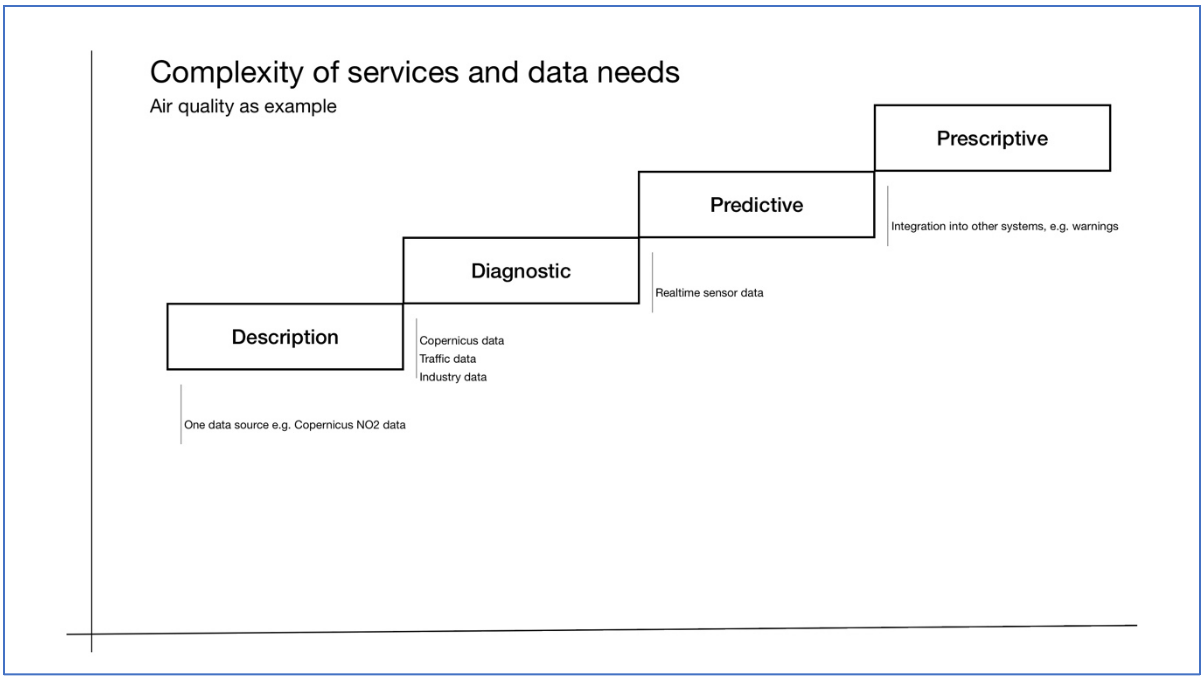

Figure 3 The Gartner model applied to the air quality parameter in the 100KTrees.

The mapping above is based upon inputs from Copenhagen and Sofia. In order for the toolbox to provide services that can be applied to many European cities it is important to ensure that for each use case have the necessary data input at all levels. It is essential to build each service level with the next levels in mind or at least be aware of the necessary data pipeline.

While the model is generic it raises a number of reflection points for the development of the toolbox; as the functionalities become more and more mature (illustrated by moving to the right along the x axis) the delivery of Toolbox services also become more complex as the services rely on more and data sources that may need to be integrated from outside sources into the toolbox. In the illustrative case of air quality, moving from a description where Copernicus data are used to describe, to diagnostics by adding local data on traffic, industry sources or number of wood stoves etc. Moving up to prescriptive and forecast may need streams of real time data and thereby a completely different data set up. For a

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toolbox, that ideally will work across European cities these different data sets may come in different formats or resolutions, that may infer large coding city specific efforts in order to scale. In the development of the 100KTrees Toolbox a balance needs to be determined between detailed services to ability to scale from more standardised data sets.

3.1 Monitoring and Legal reporting

During the collection of User requirements a shared challenge was aired during workshops and interviews: the integration of tree data into monitoring frameworks. For municipalities the reporting scheme of climate plans were mentioned; for companies a more vague articulation of reporting needs surfaced between the workshop participants from housing associations and private companies that relates to the forthcoming introduction of monitoring regulation in the form of the Corporate Social Reporting Directive, including the European Sustainability Reporting Standards and the Taxonomy. The team has evaluated this as an opportunity to provide a new service that few tree management toolbox's have ready.

All companies within the scope of the Corporate Social Reporting Directive (CSRD) will need to report on ESG performance based on their adherence to 12 European Sustainability Reporting Standards—which consist of two overarching standards, five environmental standards, four social standards and one governance. Companies meeting two of the following three conditions will have to comply with the CSRD:

- €50 million in net turnover.
- €25 million in assets.
- 250 or more employees.

The legislation comes into force per 1 January 2024.

European Sustainability Reporting Standards (ESRS)[2] specifies what companies shall use to carry out their sustainability reporting[3].

[2] https://finance.ec.europa.eu/regulation-and-supervision/financial-services-legislation/implementing-and-delegated-acts/corporate-sustainability-reporting-directive_en

[3] https://ec.europa.eu/finance/docs/level-2-measures/csrd-delegated-act-2023-5303-annex-1_en.pdf

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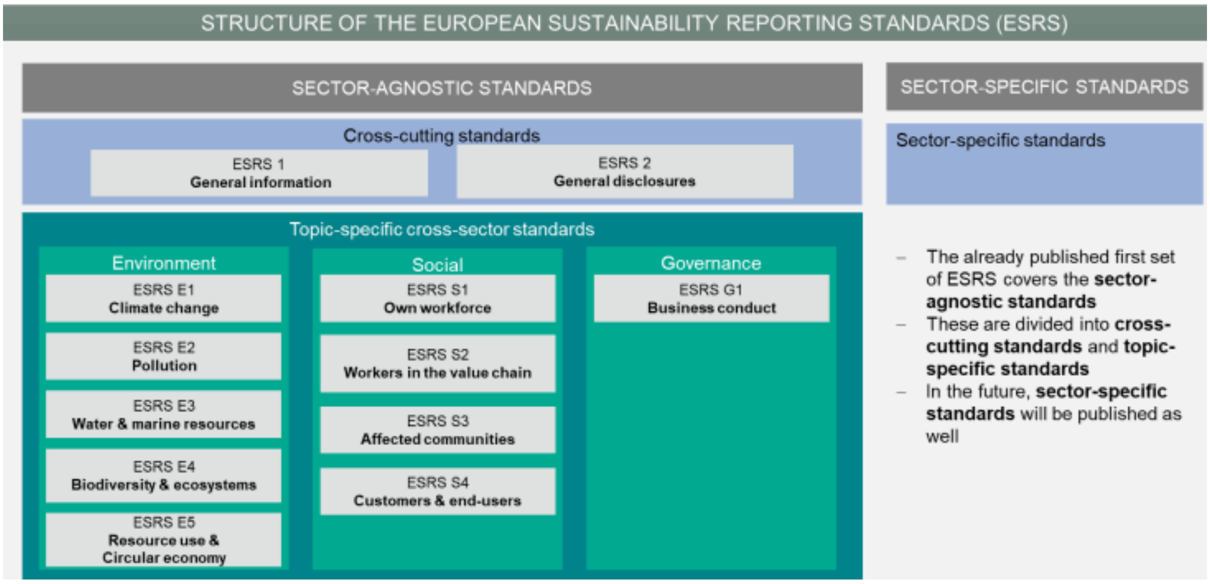

Figure 4 ESRS[4]

How does sustainability reporting impact 100KTREEs? Since it is a brand-new legislation and reporting standards are still under development, it is difficult to say exactly how planting trees and investing in urban biodiversity can be used in ESG reporting. However, it is certain that large property owners (within the scope of CSRD) will have to report on sustainability related to their properties including environmental impacts. In this respect, trees and greening can be part of the CO2, air quality and water balance accounts or credits.

The business case of ESG reporting will be further elaborated in D5.2.

3.2 Use Case from Frederiksberg

During discussions with Frederiksberg Municipality an opportunity to cooperate on a concrete development has been aired. The opportunity involves the re-development of Frederiksberg Hospital from public hospital to a new neighbourhood of mixed commercial and residential areas. The hospital will be decommissioned by the end of 2026 as part of a general process to modernise the Danish health care system.

The political process has started and a consortium of architectural companies lead by Effekt has won the public tender to develop a full development plan that will need political approval by end 2023. Hereafter, the municipality will produce a new set of local plans for the area in time for the expected deployment starting in Q1 2027.

The majority of existing buildings will be modernised into residential use and will be complemented with new buildings. The area will be designed as a green oasis where a network of paths connects to the neighbouring areas. At present, the hospital grounds include old trees and these are to be maintained although a number of them will be substituted as part of the building process. It is this planning element 100KTrees have the opportunity to be engaged in and provide input to the local plans and the final design.

[4] Source: https://www.efrag.org/lab6?AspxAutoDetectCookieSupport=1

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Figure 5 Excerpt from the Master planning ambition of Frederiksberg Municipality. The plan can be viewed [here.]

Trees are an integral part of the plans. Below is a rendering of the imagined end result with new and old buildings in the background, together with new and existing trees and paths in between. The 100KTrees project has been asked to develop together with Frederiksberg Municipality a process for the optimal positioning of trees and buildings, including positioning of new trees and positioning of new buildings to existing trees.

To the development of the 100KTrees Toolbox a design process together with Frederiksberg Municipality will provide a hands-on opportunity. In the plans are considerations of sustainability and climate change. The ask is to provide optimal locations for trees and buildings that favour protection in the winter months to save energy and mitigation of heat islands in the summer and together with landscape designers use the Toolbox to create attractive microclimates. New trees are to be selected to support biodiversity. The ask includes considerations for environmental protection of wind and noise and to include a cost benefit analysis that includes socioeconomic projections for the municipality.

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The project team is considering this as an initial use case and is evaluating pros and cons. The benefits to the project include:

- Working directly with problem owners and their project partners to get 360 perspective of how the 100KTrees Toolbox shall work in context with real challenges
- A market driven perspective of getting a prioritisation of most important functionalities first
- Getting a real use case 'under the belt' to build on to getting next customers
- Putting data collection and market needs in sync.

The cons include:

- The project could lose the city master planning perspective as the focus is to optimally locate within a given area where conditions in general might be suboptimal
- A focus on short term delivery rather than developing more general applicable solutions
- A tendency to disregard inputs received from other types of potential clients where the market may be larger.

In general the opportunity is sharpening the definition of the toolbox boundaries inside the project team.

3.3 Moving from the Use Cases to Toolbox Development

To recap, user stories focus on customer value with a built-in imprecision meant to encourage communication, while use cases focus on interactions between the user and the Toolbox system. The use cases integrate the requirements into a comprehensive package that describes the interaction of the user with the system. Use cases can be best illustrated in a diagram – see figure below for the 100KTREEs use cases.

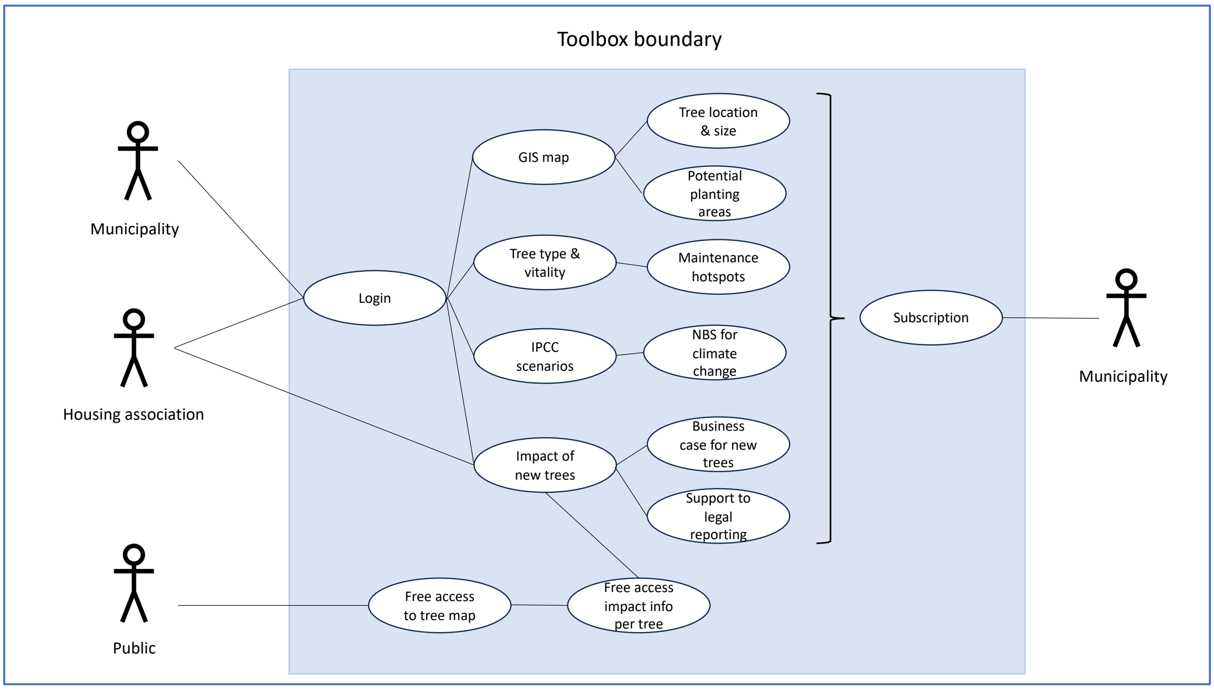

Figure 6 Diagram of 100KTREEs use cases

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The logical next step, after clarifying the use cases, is to define the functional requirements of the system, or in our case, the toolbox. While use cases focus on the user's goals and needs, the functional requirements focus on the system's/toolbox's functionality and behaviour. The functional requirements of the system focusses on detailed system specification with a tendency towards more detailed specification, and those for the 100KTREEs toolbox are presented in the next chapter.

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4 Functional Requirements of 100KTREEs toolbox

In this chapter the focus shifts from the demand side (users and user organisations) to the supply side - i.e. how does the 100KTREEs team collate information and develop tools that will help the municipalities/city authorities to better manage their urban trees, as well as support their decision-making concerning planting new trees.

A key step for 100KTREEs in developing such a toolbox and information services to meet the requirements of our users, is the translation of their user requirements (UR) into functional requirements of the system the team will develop. Functional requirements are defined as:

'Functional requirements are product features that developers must implement to enable the users to achieve their goals. They define the basic system behaviour under specific conditions.'

Thus, the functional requirements form the link between what the users have requested, and what the toolbox/information providers need to develop for them. During this process of translation UR into functional requirements, consideration should also be given to the technical solution that is needed in each case and whether these solutions are technically feasible or not. In addition, another filter is needed to identify the UR that so not fall within the remit of this project.

4.1 Summary of functional requirements for planning

The starting point for translations of the UR into functional requirements was the grouping of similar UR. These groupings are a good indicator of how many times this UR was mentioned during the co-creation workshops. This in turn is used to give priority ratings (high, med, low) to the functionalities that the team needs to develop.

4.1.1 High priority

The table below give a good overview of the high priority functional requirements, as well as a brief explanation of how these will technically be achieved – and which combination of satellite data, airborne RS (photogrammetry, LIDAR) and in-situ data, will be utilized.

Some base functionalities were not specifically mentioned by the user, but are essential for the more complex services that the users have requested – these have been identified by <u>underlining</u> in the table.

Topic/ UR	Functional requirement	Technical solution	Additional comments
Tree repository			
	Land cover, land use map of city	Base GIS layer	
	Database of tree locations	3D visualisation of trees e.g. from LiDAR or stereo imagery; VHR for trees below 2,5m in height	

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Topic/ UR	Functional requirement	Technical solution	Additional comments
	Tree vitality	10 m resolution with NDVI data for higher temporal resolution, complemented with aerial images (RGBI) 5-20cm GSD and in-situ (fieldwork/CS)	Single tree level requires VHR commercial data with cost implications
	Annual tree mapping	Reliant on annual LIDAR/orthophoto campaigns by city authorities	Delay in detection of new trees, delay until tree reaches 2 m canopy min
	Change detection	10 m resolution with Copernicus data	Detection of single tree changes will require VHR data
Planning of NBS/city greening			
	Tree locations & seasonal tree vitality	LIDAR for initial tree locations (inventory) and tree vitality information at least twice per year	See above – possible at 10 m resolution with NDVI
	Map spots available for new trees	Overlay tree map with AQ, heat islands, noise, env indicators to identify area where trees could be useful @ 10 m resolution on annual basis Inputs from city regarding ID of candidate spaces	Could we offer less than 10 m resolution? ⇒ Need GIS inputs from municipalities to ID candidate muddy/brown areas, parks, streets without ground infrastructure, parking areas, etc.
	Show potential planting maps to individuals or organization that are willing to donate money/trees	Public access to maps of spots available for new trees	
	On map of planting spots calculate distance to middle of road	Interference analysis with tree database + street elements	
	On map of planting spots calculate distance to underground infrastructure	Ingest map of underground infrastructure	⇒ This map can only be provided by the municipality

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Topic/ UR	Functional requirement	Technical solution	Additional comments
Monitoring of city greening			
	Change mapping of env. indicators	visualisation of 'change mapping' on an annual basis for AQ, noise, heat islands, biodiversity, (flood attenuation)	Flood attenuation is never mentioned by users
Air Quality			
	Air quality map at 2 m resolution	Satellite data complemented with in-situ measurements to inform models of urban typologies	
	Estimate air quality improvements due to trees	Through modelling	
Noise abatement			
	Noise map at 2m, night and day levels	Land cover/use map (street map) plus in-situ sensor data or OSM data	
	Estimate extent of noise abatement by trees	Through modelling	
Cooling impacts			
	Map city temperature & identify heat islands	Satellite data (30m) plus in-situ sensors (2 m)	Requires ingestion of downscaled climate data for cities
	Visualise cooling due to trees	Modelling of tree cooling impacts	
	Estimate value of reduction in heat islands by trees	Through modelling	
Biodiversity			
	Estimate value of increased biodiversity due to trees	Through environmental indicator and modelling	
Tree maintenance - *NEW*			

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Topic/ UR	Functional requirement	Technical solution	Additional comments
	ID of trees that need maintenance	Map changes in tree vitality from orthophotos Visualisation of CS inputs on toolbox map	Identify hotspots for tree deterioration from satellite – send fewer fieldworkers to add CS data
	Number of trees that need maintenance	Part of annual tree inventory	
	Plan and schedule tree maintenance	Tree management system	Option for future toolbox
Flood attenuation			
	(component of NBS for climate change adaptation)	Modelling of water retention by tree roots	Copenhagen is especially concerned about increasing cloud bursts in the future due to climate change
Valorisation			
	Benefits to private landowners	Estimate number of trees (output of tree database) and calculate overall value of trees on private lands	Municipality needs to provide cadastre map showing private land
	Calculate the CO2 sequestration of trees in the city	Estimate number of trees and calculate CO2 sequestration	
	Calculate the socioeconomic outcomes of trees	Calculate the overall value per 'standard' tree, multiplied by number of trees	
Scenario planning			
	Risk assessment of heat islands in view of climate change	Utilize IPCC scenarios for increases in city temperatures Modelling of tree cooling effects	
	Impact of tree planting on env indicators	Scenario map based on what temporal basis (ideally every 2 years, mandatory every 5 years)	For users the priority indicators are: AQ, temperatures, biodiversity, noise, in that order.

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Topic/ UR	Functional requirement	Technical solution	Additional comments
	CO_2 sequestration of trees in the city	Number of trees and modelling of CO_2 sequestration (simple visualisation of value)	Valuable inputs to city's climate plan
	Impact of trees during different seasons	Database of tree types Bi-annual mapping of pollen levels, fruits, leaf litter, etc.	Allowing city officials to anticipate and address potential political objections, e.g. trees in danger of falling. However, the public are concerned about tree felling with no replacement.
	CBA of replacing parking areas with trees	Calculate loss of parking income, citizen inconvenience vs overall benefits of number of possible trees	Requires 'standard' space needed per tree
	Impact of single tree on temperature, noise, humidity, air quality	Modelling on single tree level	Results on single tree level will be negligible

Table 1 Summary of high priority functional requirements for 100KTREEs

4.1.2 Lower priority

This category includes user requirements that were only mentioned by a single user, or are not currently technically feasible, and thus has been given lower priority. This does not mean that these user requirements will be ignored, but rather that they will be supported as far as possible by the MVP (minimum viable product) that will be developed.

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Topic/ UR	Functional requirement	Technical issues	Additional comments
Planning of NBS/city greening			
	ID suitable type of trees for planting	Database with potential tree species (and their requirements)	e.g. Univ. of Sofia has such a database
	Differentiate between soft canopy (trees planted on grass) vs hard canopy (planted on paved areas/streets)	Mapping of surface under trees Sealed or unsealed surfaces modelled for water run-off and carbon sequestration	VHR satellite data is required during the winter season Differential modelling of soft and hard canopies for temperature, noise, humidity and AQ, not included. Inclusion of humidity levels are under consideration
	ID muddy areas	Detection of bare soil	
	Share knowledge of local landscapes	Database of tree locations and tree vitality Public access to green space visualisation	
Scenario analysis			
	Different tree planting formations for air pollution and cooling	Differential models for street trees and pockets of trees	Trees formation is considered in model (straight line, Z-shape, groups)

Table 2 Summary of lower priority functional requirements for 100KTREEs

4.1.3 Out of scope

Some interesting issues came up in the discussions with the users at the co-creation workshops, but that the team has deemed to be outside of the scope of the project. However, this have been included in our assessment and are shown in the table below, as some of these topics could be considered for future expansion of the functionalities offered by the 100KTREEs toolbox.

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Topic/ UR	Functional requirement	Technical issues	Additional comments
Urban planning			
	Land management to prevent accidents and ensure safety	Tree vitality mapping can support land management, but cannot assess safety	Tree safety can ONLY be assessed by tree inspections
	ID who is responsible for green management of city zones	Only the city authorities have access to this information	
	Propose greening alternatives to street trees	Requires information on and modelling for shrubs, vertical gardens, etc.	Option for future development
	Impact of solitary trees, soft canopy, greenery on wind in areas around buildings	We have NOT considered wind modelling in urban areas	Current partners do not have this expertise.
	ID of land value	Mapping of green areas can support this, but is not the only factor that determines the price of land	
	Minimise investment in compensatory landscaping	Balance between trees increasing land/asset value and cost of extra trees	
	Training for urban green management	100KTREEs toolbox can support the green management, but this is far broader in scope than the objectives of the project	

Table 3 List of functional requirements for 100KTREEs that currently are out of scope

4.2 Recap of User survey

As explained in D1.1 (Report on user requirements for adopting satellite data supported in planning, budgeting, investment decisions), the team devised a stakeholder questionnaire with the aim of gathering information about the stakeholders in advance of the co-creation workshops. It is worth reconsidering the responses to this questionnaire as a reminder of what the users stated at the start of the project.

For the foreseen 100KTREEs services and toolbox, the survey showed that the priorities for information required – in descending order of importance – was as follows:

1. Socio-economic modelling and valuation of the impact of the trees/planted areas (including the extent of carbon offset)
2. Impact of trees and greenery on 20–30 year scenarios of expected change in temperature & Impact of trees and greenery on 20–30 year scenarios of expected change in precipitation

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3. Create tree planting scenarios with planting costs & socio-economic valuation.

While priorities for toolbox features were revealed to be as follows – again in descending order of importance:

1. Location of possible spaces for planting of new trees & Socio-economic modelling and valuation of the impact of trees/planted areas
2. Cost benefit for the city
3. Maintenance and planning/alerts of planted areas &
4. Impact on real estate prices
5. Monitoring of the state and health of the trees/planted areas.

These are all reflected in the functional requirements above, with special emphasis on 20-30 year scenarios, i.e. the IPCC predictions. Keeping these responses in mind, we can safely state that the extracted functional requirements are meeting all the information priorities set out by the users. The next step in the project is to develop these functionalities for the 100KTREEs toolbox.

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5 Adoption of satellite-based support decision tools

Satellite-based decision tools (e.g., through ESA Copernicus data) provide a cost-efficient and effective pathway to support urban planning, presenting an array of opportunities to address environmental challenges while enhancing city landscapes. By harnessing high resolution and up-to-date satellite data, informed decision-making can be empowered through dynamic and scalable insights into urban ecosystems, tree cover, air quality, and climate variables.

Satellite data provides a scalable means to maintain an up-to-date overview of green/blue infrastructure at cityscape level to underpin spatial decision making. Assessing trends in time series (for instance trends in vegetation growth or surface water dynamics, trends in surface temperatures, trends in tree cover, etc.), identifying hot spots (for instance concentrated green or grey areas, heat pockets, etc.) and conducting predictive scenario-based models to experiment with predicted impacts in a coherent and scalable way are some of the key strengths of satellite-based tools.

In a nutshell, some of the key benefits of adopting satellite-based tools to support urban decision-making processes include:

1. **Enhanced Precision and Detail:** Satellite tools offer high-resolution data, enabling detailed mapping of urban greenery, tree cover, and spatial features. This precision aids in accurately identifying suitable locations for tree planting, optimizing green spaces, and facilitating informed spatial planning decisions.
2. **Real-Time Monitoring and Analysis:** These tools provide near-real-time data updates, allowing for continuous monitoring of urban landscapes at cityscape level. Such monitoring enables prompt responses to changes, ensuring adaptive and dynamic planning processes aligned with evolving urban needs.
3. **Comprehensive Data Insights:** Satellite imagery captures diverse urban features, including potentially tree species, tree location, canopy cover, land use patterns, and environmental conditions. Integrating this comprehensive data allows for multifaceted analyses, fostering a holistic understanding of urban ecosystems and their interactions.
4. **Informed Decision-Making:** Access to detailed and timely data supports evidence-based decision-making in urban planning. It assists authorities in identifying optimal locations for tree planting, managing green spaces, mitigating environmental risks, and creating resilient urban environments.
5. **Sustainable Urban Development:** Leveraging satellite-based tools facilitates the development of sustainable urban landscapes. It enables the preservation of green spaces, enhances biodiversity, mitigates climate risks, improves air quality, and contributes to the overall well-being of urban populations.

However, challenges persist, particularly in terms of cost barriers for accessing higher resolution data to address the limitations in spatial and temporal resolutions of freely available datasets, and the complexities of integrating diverse data sources. Overcoming these barriers necessitates balancing cost considerations, user expectations, technological advancements, and the seamless integration of varied datasets for optimised and impactful urban planning.

5.1 Evaluation of availability and quality of data sources

Availability of high quality free and open data (such as through the Copernicus Sentinel programme) has undeniably transformed access to geospatial information, by providing a new scalable framework to conduct timely and coherent urban monitoring. However, free and open data has inherent limitations, particularly in terms of spatial resolution presents a challenge in urban environments. While these datasets provide valuable insights for urban planning and environmental monitoring, their spatial resolution (10+ meters), may not capture the granular details essential for more detailed analysis and

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modelling, especially in densely populated urban environments. The spatial resolution constraints of free and open satellite data limit the application potential and accuracy in identifying small-scale urban features which are useful for nuanced decision-making at local levels.

In contrast, higher resolution commercial satellite data, with spatial resolutions up to 30 cm, or aerial imagery with spatial resolution 2-20 cm, offers unparalleled detail. This finer granularity enables precise mapping of individual trees, smaller green spaces, and urban infrastructure elements, enhancing accuracy and informed decision-making in various urban planning aspects at very local level. However, while the increasing competition in the commercial downstream sector has driven down costs, commercial satellite imagery is still relatively costly to acquire, posing financial barriers for smaller municipalities or organizations with limited budgets. Moreover, managing and processing higher resolution data requires substantial computational resources and storage, adding to the challenges of utilisation.

The VHR2021 dataset, introduced by the European Environment Agency (EEA), represents Very High-Resolution (VHR) imagery acquired in 2021. It provides coverage with optical data optical for 39 European States in 2-to-4-meter resolution. Its use holds potential as a cost-efficient means to address imitations related to spatial resolution in cities that doesn't have high resolution alternatives (e.g. through aerial imager) however, it has significant temporal limitations as it is currently only updated once every three years. Hence, it does not provide a data foundation sufficient for monitoring dynamic changes in urban environments.

In essence, while free and open data democratises access to valuable geospatial information which enables comprehensive synoptic insights at cityscape level, end users must carefully weigh the inherent limitations of lower resolution alternatives against the potential benefits and costs of utilising higher resolution commercial satellite imagery. This strategic evaluation is pivotal in optimising data utilization to address the intricate demands of urban planning and environmental monitoring effectively.

5.2 Scalability to other cities

The opportunities provided through satellite-based tools provides new avenues for transcending city boundaries, catering diverse urban landscapes through a unified and coherent approach. The main benefit of free and open data, such as through the Copernicus programme, lies in its expansive coverage, standardized accessibility, and multifaceted applications, offering a robust foundation for scalable urban planning tools that can adapt to diverse city landscapes, integrate seamlessly with varied administrative systems, and enable the fusion of multi-source data, thereby fostering interoperability and facilitating informed decision-making processes across a spectrum of urban environments worldwide.

Many cities already have archives of very high-resolution aerial imagery or commercial satellite data, and for the ones that doesn't, commercial satellite data is readily available and accessible for any urban area, at an added cost. Hence, while the backbone of satellite-based services could, and should, be based upon free and open data for dynamics near real time monitoring, they should be flexible to integrate existing or acquired higher resolution data alternatives as needed.

Lastly, scalable tools leveraging free and open data should continuously evolve, incorporating feedback and lessons learned from diverse city implementations. This iterative approach supports continuous improvement, allowing these tools to remain adaptable and relevant across a broad spectrum of urban settings using open data sources.

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5.3 Recommendations for adoption of satellite-based support decision tools in 100KTREEs

Satellite data and satellite derived products holds significant potential to underpin and enhance the capabilities of the 100KTREES toolbox. The integration of such approaches however requires a comprehensive approach that encompasses several key elements. One critical aspect involves the seamless integration and synthesis of diverse satellite-based datasets and products, remote sensing technologies like photogrammetry and LIDAR, and on-ground measurements. This integration facilitates the creation of a robust spatial data framework, incorporating land cover and land use maps, land surface temperature data, tree inventories and other relevant datasets – as well as capabilities to apply satellite data to continuously update these datasets.

While Copernicus and similar free and open data sources provides a scalable and efficient foundation for the majority of baseline assessments needed within the toolbox, the limitations in terms of spatial resolution are recognised, particularly when considering the need for more detailed satellite based single-tree-level analysis. Therefore, incorporating existing aerial imagery or VHR satellite data, where such is available, along with the capacity to enhance the toolbox through acquiring new VHR satellite data when existing data is unavailable, becomes essential for supporting precise mapping aspects such as individual tree mapping.

Moreover, ensuring scalability across multiple cities and geographical areas is crucial for geographical expansion and commercialisation of the toolbox. Tailoring the toolbox to suit diverse urban landscapes and their unique requirements necessitates a comprehensive understanding of the variability inherent in municipal spatial data infrastructure. This adaptability involves accommodating a spectrum of spatial resolutions, diverse data formats, and structural variations. Alternatively, it entails the capability to conduct standardised, detailed baseline assessments as needed. Integrating satellite data serves as an ideal framework for establishing automated and standardized methodologies to perform new baseline mapping or refine existing spatial data using the latest satellite imagery in an automated way.

Capacity building also stands as a crucial pillar for efficient integration of satellite data or derived products. Investing in stakeholder education and generic training/information material is critical to create the foundational understanding of satellite-based data products, including their application potential and inherent limitations. Clear and transparent communication about such cost benefits is critical in order to leverage potential of the satellite-based capabilities within the toolbox, to effectively foster its sustainable and widespread use.

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6 Conclusions

The municipalities are requesting the 100KTREEs project team the development of data driven tools for urban tree management, which falls within the remit of their climate adaptation plans. Thus, they are facing the digital transformation and the phases of the Gartner process. Through our user engagement and adoption of the co-creation methodology, we have captured their work 'pains and gains' in a green management context. This in turn has led us to understand their information requirements for: an overview of the urban tree situation throughout the city through GIS mapping (i.e. with layers of information for the trees), including data on the number of trees, trees per type, location of trees, and crown vitality. Our survey elucidated the reasons 'why' – e.g. they are interested in the planting of new trees and hence this project. For 100KTrees, the 'diagnostic analytics' phase of Gartner includes the understanding of the reasons behind many of issues faced in urban environments, e.g. local temperature elevations, air quality and pollution levels, etc. Armed with this knowledge, organisations can optimize their green management operations to mitigate challenges or enhance efficiency.

The project also supports then in anticipating future trends and events based on historical data, and the inclusion of IPCC scenarios will also municipalities to predict future weather conditions and plan nature-based solutions accordingly, especially with regard to planting trees in 'quality of life' hot spots (e.g. heat islands, high pollution and noise levels, poor air quality) in time to grow sufficient crown diameter over the long term. Though the impact analysis, this project will most definitely support our users in such planning and decision-making processes. The impact of new trees on urban cooling, pollution, carbon sequestration, noise and water absorption will inform their decision making, while the cost benefit analyses and business case assessments for new urban trees will give a more balanced view of the pros and cons of expensive tree planting.

The team has identified three key use cases for 100KTREEs:

1) Planning urban green infrastructure
2) Maintenance of trees
3) Integration to legal reporting

The first use case is close to what the team envisaged at the stage of proposal writing, and thus is well in hand. The maintenance of trees was not initially foreseen as part of the project, but it emerged as high priority for our users during co-creation. Thus, it is an aspect of urban green management that the toolbox needs to support as far as possible. It is clear that the vitality and health of a single tree can only to a certain extent be monitored by satellites, and that the team needs to put more emphasis on airborne remote sensing (LIDAR, aerial surveys, etc.) and in-situ monitoring (fieldwork and CS) to achieve a higher level of tree detail. The team still needs to investigate the extent to which 100KTREEs can support legal ESG reporting and this will be done in WP5. For the moment there is no obligation on public authorities to carry out ESG reporting in contrast to private companies. As we would like to target private companies (real estate, housing associations, etc.) with our toolbox in the future, we are anticipating this use case to get 'first mover' advantage in the market.

Through a thorough analysis of the user stories and requirements, the team now has a defined list of functional requirements to guide the development teams regarding satellite data, RS, in-situ and modelling. There is a clear coincidence with the toolbox priorities highlighted by our user survey.

Our users have obviously not expressed their needs for satellite data – this is something the team has to interpret from the temporal and spatial aspects of their information requirements. The use of satellite data, Copernicus and VHR data, is key to the scalability of the 100KTREEs toolbox to other cities in Europe and the world, and yet at the same time it is clear that this data has to be significantly complemented by other data and tools for our purposes. Some more detailed aspects of the utilization

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of satellite data by the toolbox still need to be resolved, but that is all part of the next stage of the project, i.e. the technical and software development.

In this report we have given an overview of issues faced by our users, initially focussing on city authorities and municipalities, in their adoption of data driven tools and satellite-based decision support systems. This has helped the team to formulate the user requirements and use cases into the functionalities that our toolbox needs to offer. In parallel, the team has considered the data sources & modelling needed, as well as the advantages and limitations of satellite-based data.

Very recently, a very good opportunity has arisen for the 100KTREEs project. The Municipality of Frederiksberg, is about to rejuvinate a large municipal district that falls under their jurisdiction, and which entails the planting of a significant number of trees to create a lovely, balanced environment for the new inhabitants. This opportunity will involve close collaboration with the Frederiksberg municipality and the engineering company responsible for the rezoning. At first glance, this 'real use case' seems like an excellent fit for the project and a great opportunity to develop hands-on tools for Frederiksberg that will be utilised imminently. As exciting as this opportunity would seem, the team needs to face the challenge of developing services for a relatively small urban area (compared to the overall size and scale of Copenhagen) with the planned spatial resolution of our data and models. This use case will also rely heavily on municipal data being made available to the team (e.g. cadastre, underground infrastructure, planned location of buildings). This will be discussed in detail at the team's next plenary meeting in December 2023.

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