Urban Vegetation Modeling 3D Levels of Detail

Master of Science in Geomatics for the Built Environment

by

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TU Delft 3Dgeoinfo

Gemeente Rotterdam

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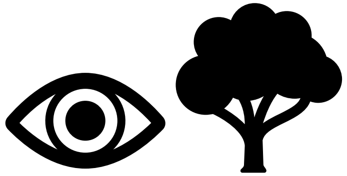
Motivation – Problem Definition

Semantic 3D city models

- Planning
- 3D Simulation
- Backbones
  for smart planning

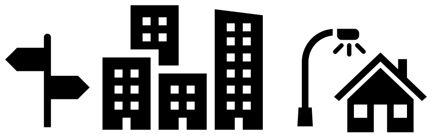


Urban vegetation
in 3D city models
remains symbolic

Motivation – Problem Definition

Standard International
Open Geospatial Consortium (2012)

Motivation – Problem Definition

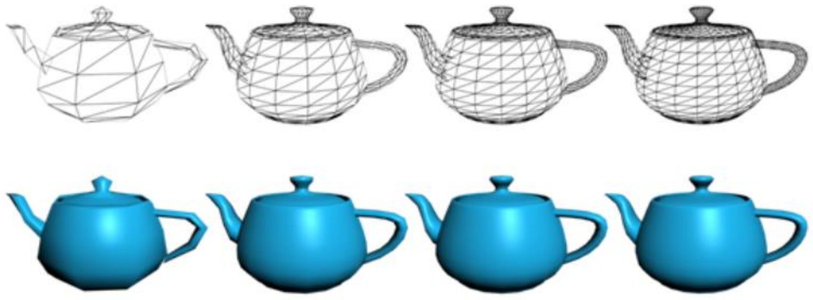


City Objects

CityGML

Level of Detail
(LOD)

3D city models

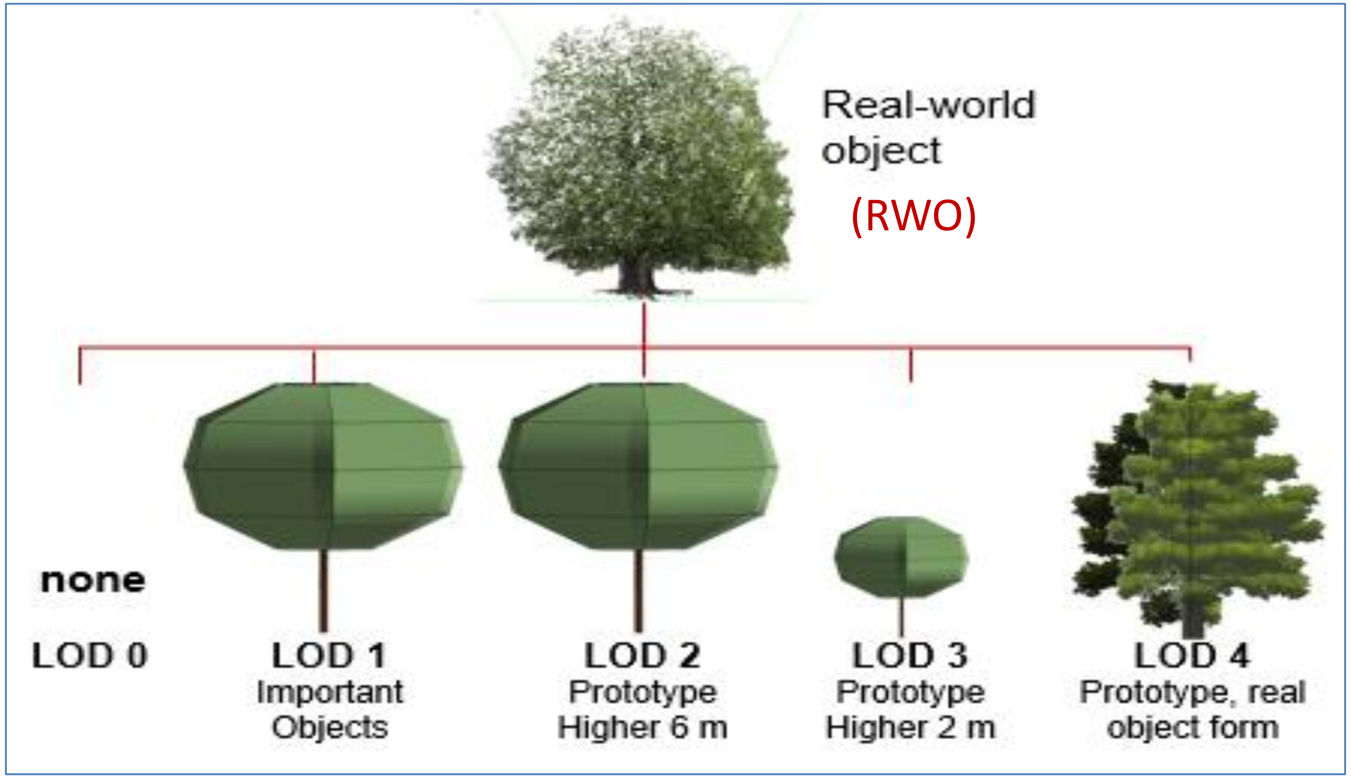


Not only in
geometric aspects
Increasing
Adherence to
real-world object

Low LOD → High LOD

Teapots Source: Jordan Grant (2016)

Motivation – Problem Definition



Terrain Landmark

Decreasing Geographic extents

CityGML's LOD specifications

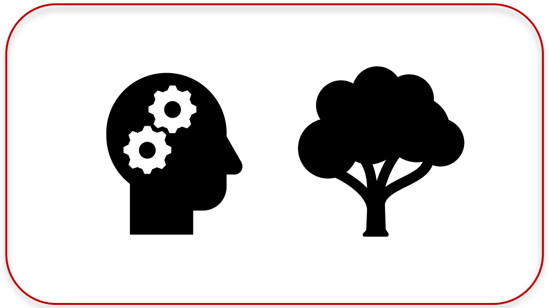
LIMITED for quantitative assessments, spatial analysis, or simulations of the impacts that vegetation has in the urban environment because:

1. Adherence to RWO is very limited
2. Inconsistent and little differentiation
3. Attributes are limited

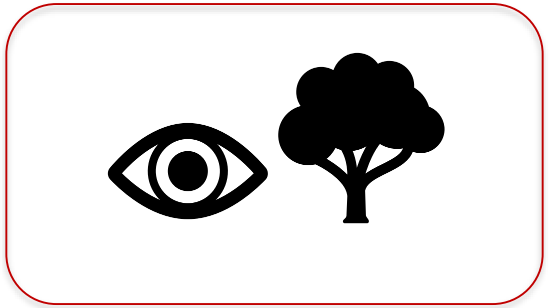
LOD4 source: ESRI-LumenRT (2014)

Research Question

What is the best approach for modeling 3D vegetation features for their use in the built urban environment?



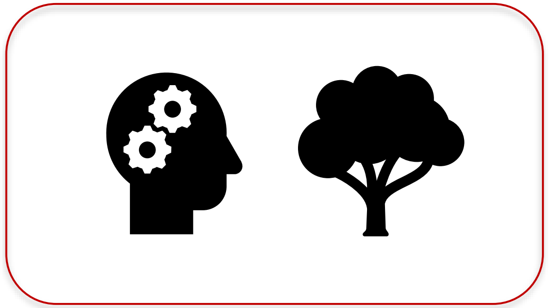
- Quantitative Assessments
- Spatial analysis



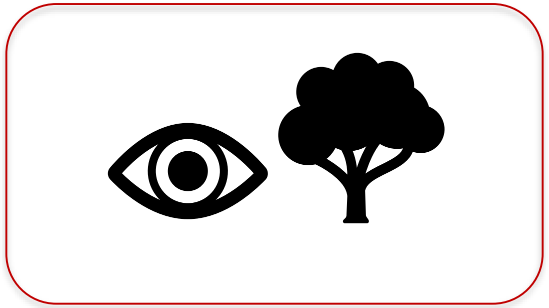
- Visualization
- Presence

Goal

Improve CityGML's vegetation LOD descriptions to
meet demands of current use cases

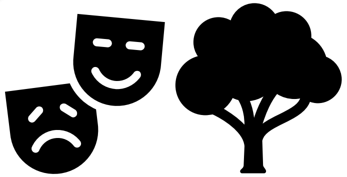


- Quantitative Assessments
- Spatial analysis



- Visualization
- Presence

Relevance - in planning a sustainable urban growth



Role of urban vegetation has changed from aesthetical function

Urban vegetation makes a city livable

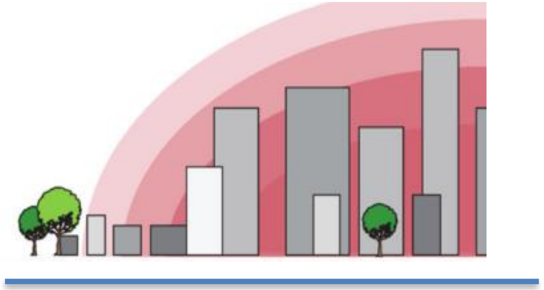
- People live, work, free time:
  - Psychological
  - Medical
  - Social cohesion
  - Reduce crime
  - Recreational
  - Physical activities

Helps mitigating the negative of effects climate change

- Increasing temperatures, Urban heat island effect (UHI)
- Frequent downpours
- Prolonged dry periods

- Ecosystems services (ecoservices):
  - Improves air quality,
  - Captures particulate
  - Stores CO_2
  - Cool surfaces, surroundings
  - Reduce storm water runoff
  - Mitigates power consumption
  - Reduce noise

Relevance - in planning a sustainable urban growth



Today's
urban planning
has two concerns

Due to increasing urban population

Balance
city growth

Resilience &
Adaptation
measures

Continued climate change

Environmentally friendly resource

Urban vegetation
makes a city livable

Help mitigate
negative climate
change effects

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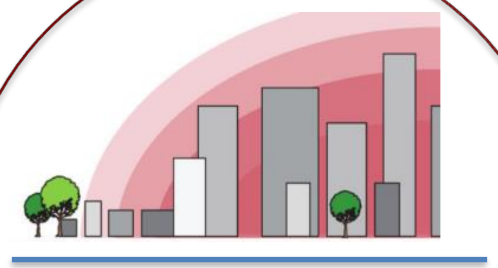
Contribution

- Refined vegetation LOD specifications can help in planning a sustainable urban growth with models that can improve the assessments of vegetation's spatial impacts at different scales,

Refined vegetation LODs



Today's urban planning concern

LOD Related Work: Definition Framework

- Framework for defining LODs of city objects in alignment to CityGML LODs was offered by Biljecki et al. (2014)
- Introduced six **metrics** for specifying geo-datasets LODs
- **Their use** of these metrics was **observed** in analyzed vegetation LOD description approaches
- The **metrics** are **included** in **refined** LOD specifications

LOD Definition Metrics

- IN/OUT **Presence** modelled or not => component granularity
- **Complexity*:*** minimal sizes or lengths, e.g., min. total height
- 0D, 1D, 2D, 3D **Dimensionality:** representation in geometrical primitives
- **Appearance:** material color, textures, or features not geometric nor semantic
- **Spatio-semantic coherence** adds identities (crown, root, etc.) geometric entities, one-on-one basis.
- **Attribute:** additional information e.g. life stage

Related Work: Current Vegetation LODs

Standards

- CityGML
- IMGeo-CityGML
- LOD of Trees

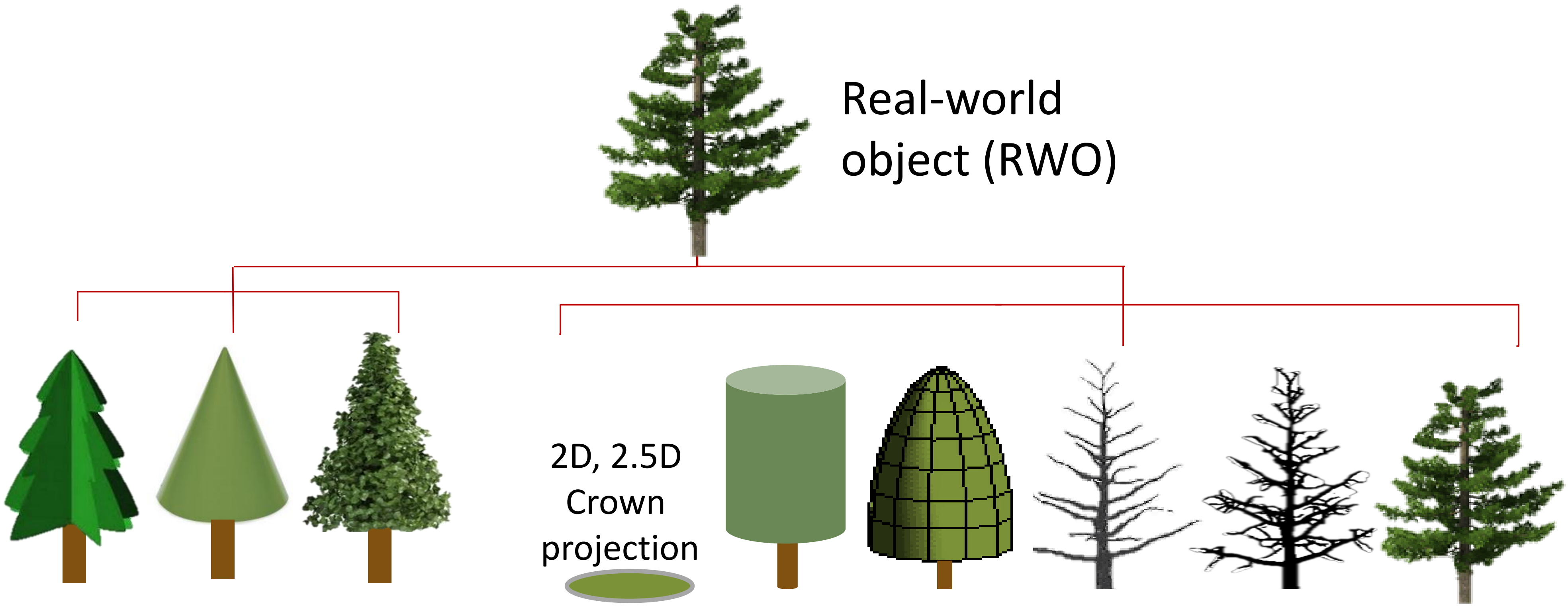
Geometry Focused Academia and Literature

- Level of Tree-detail (LOT)
- LOD and Trees
- Single Tree

Private Co.

- Vertex
- Blom ASA
- ESRI

Implicit and Explicit LOD Examples



Implicit: Prototype, symbols

- Entire object ready to use
- Not based on RWO, can resemble
- 0D or location point

Explicit: Parametric, reconstruction

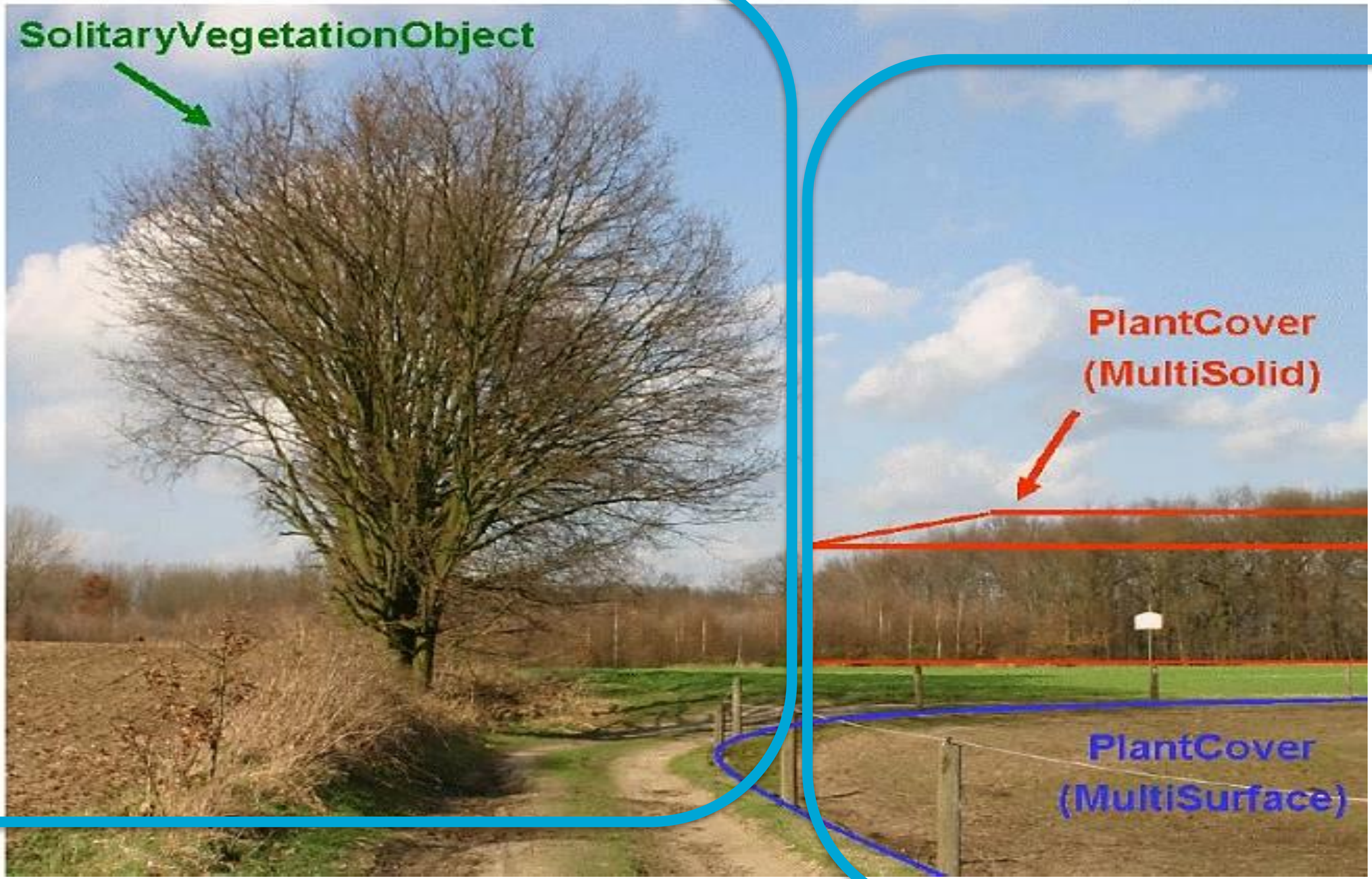
- Use coordinates from RWO, allows separate components
- Multiple dimensions: 2D, 2.5D, 3D

Related Work: CityGML defines vegetation as two objects

SVO

Stand alone

Trees, plants



PC

Communities, groups

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Related Work: CityGML Standard

	LOD0	LOD1	LOD2	LOD3	LOD4
Model scale description	regional, landscape	city, region	city, city districts, projects	city districts, architectural models (exteri-or), landmark	architectural models (interi-or), landmark
Class of accuracy	lowest	low	middle	high	very high
Absolute 3D point accuracy (position / height)	lower than LOD1	5/5m	2/2m	0.5/0.5m	0.2/0.2m
Generalisation	maximal generalisation	object blocks as generalised features; > 6*6m/3m	objects as generalised features; > 4*4m/2m	object as real features; > 2*2m/1m	constructive elements and openings are represented
Building installations	no	no	yes	representative exterior features	real object form
Roof structure/representation	yes	flat	differentiated roof structures	real object form	real object form
Roof overhanging parts	yes	no	yes, if known	yes	yes
CityFurniture	no	important objects	prototypes, gener-alized objects	real object form	real object form
SolitaryVegetationObject	no	important objects	prototypes, higher 6m	prototypes, higher 2m	prototypes, real object form
PlantCover	no	>50*50m	>5*5m	< LOD2	<LOD2
…to be continued for the other feature themes					

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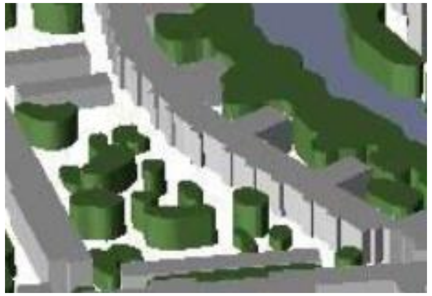
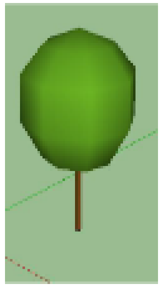
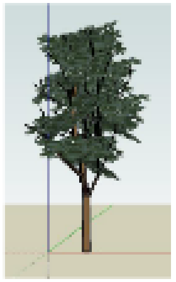
Related Work: Vegetation LODs Extension to CityGML

IMGeo-CityGML



Extruded PC



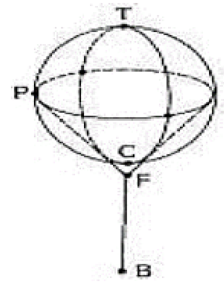


SVO LOD2 SVO LOD3
(Blaauboer et al., 2013)

Highlights

- PC and SVO
- Implicit and explicit parametric model
- Three SVO LODS: (1) 2.5D, (2) 3D SVO, one LOD for each geometry type
- Expandable for each type?
- No differentiation between volumetric or realistic within each LOD

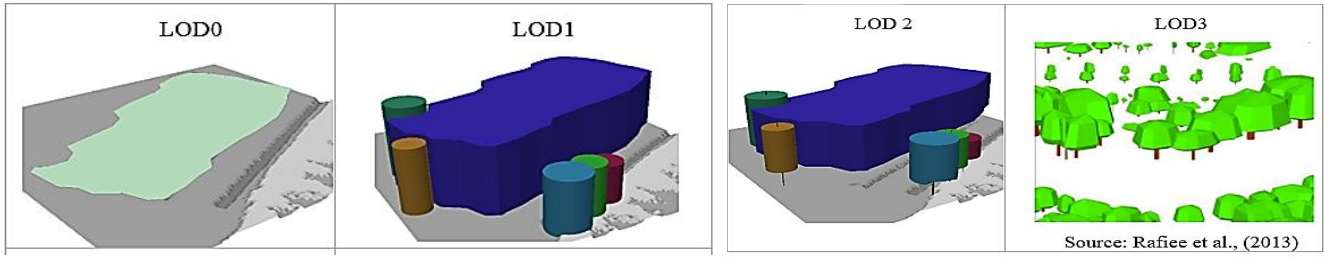
	PC	SVO
Attribute	1. Location on slope (yes/no) 2. Classification by physical appearance and sub-classes.	1. SVO type: Tree/Hedge 2. Explicit geometry parameters (Table 3.4) 3. Condition assessment (Table 3.4)
LOD 0	Extended: footprint polygon in 2.5D as TIN constraint (Figure 3.8).	Extended: SVO-hedge as line, or footprint polygon as 2.5D as TIN constraint
LOD 1	(No extension or change, extrusion of LOD0 surface to avg. height)	SVO-hedge: same as PC LOD1.
LOD 2	Extended: extrusion not restricted to avg. height. Height can vary by area segments or within area	Extended: SVO-hedge as PC LOD2.
LOD 3	No extension or change.	Extended as SVO (either type) with explicit geometry based on parametrical models (Table 3.4)

	ADE- SILVI-STAR	ADE-Assessed Tree
	• Height **T**op • Height **C**rown Base • Height **F**ork • Trunk **B**ase • Crown **P**eriphery • Tree base (not shown)	• Tree ID • Tree Height • Tree Position • Tree Assessed • Tree Safety Value • Tree Safety Measure

SVO parametrical tree model, condition, and risk assessment(Rip & Bulens, 2013)

Related Work: CityGML Vegetation LODs Improvement Proposal

LOD and Trees



Wageningen University (Rip, 2013)

LOD0	SVO	• Points are not applicable to represent
	PC	• Min. size: >250 m in at least one direction • Footprint polygon of vegetation land use type
LOD1	SVO	• Min. size: > 3m. Measured height • Circle as tree crown projection, extruded to avg. height of 10m with avg. radius 5m.
	PC	• Min. size: CityGML 50x50m is to coarse for windbreaks or shelterbelts—Instead, use Dutch land use resolution of 25m in one direction • Polygons outlining tree groups and forest stands extruded to 10 m.
LOD2	Distinguish Individual vertical components and extent: trunk, crown, height and diameters.	
	SVO	• Using measured crown radius and height • Crown radius assigned to 1, 5 or 10 m • Crown: extruded circle to measured height from 3m above ground up to height class ranges*. Extrude from the ground up to 3m. • Trunk: circle radius of 1/20 of crown radius.
	PC	• Min. size: Polygons > 5*5m outlining tree groups and forest stands • Extrude from 1m height to avg. group/stand height
LOD3	SVO	• Detailed crown shapes: top height, horizontal extent, underside crown height. • Attribute deciduous or coniferous. • Tree model according to SILVI-STAR (Table 2.4).
	PC	• Polygons outlining tree groups and forest stands extruded from 1m height to individual heights of trees in group or stand.

Highlights

- Geometry focused
- Only explicit geometry
- No realistic LOD

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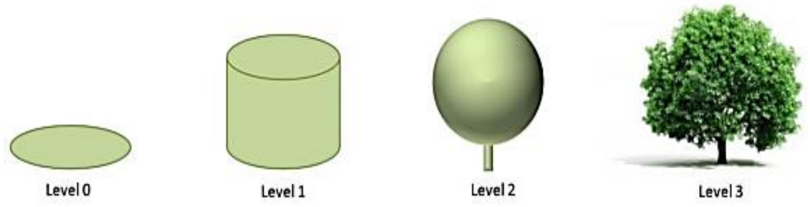
Related Work: Geometry Focused and Academia

Level of Tree (LOT) Detail



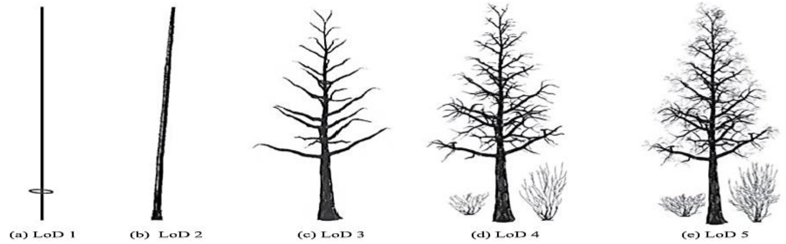
Tree Parameters	LOT-0	LOT-1	LOT-2	LOT-3
Location	√	√	√	√
Height		√	√	√
Crown Width	√	√	√	√
CBH (Crown Base Height)			√	√
DBH(Diameter at Breast Height)			√	√
Density(Crown Volume)			√	√
Leaves Texture				√
Structure				√
Species				√

(Chen, 2013)

Highlights

- 2D SVO
- LOD3 is vaguely specified
- Explicit geometry
- No PC

Single Tree Reconstruction

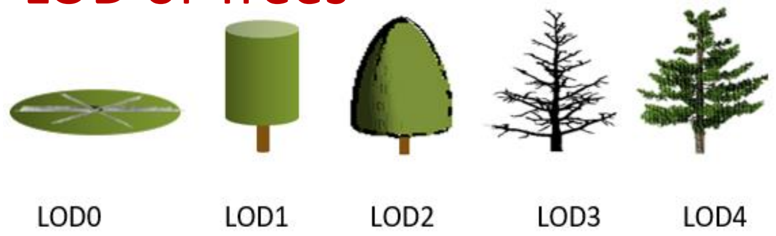


Level	Details	
	Parameters	Predecessor included
LoD 1	• Tree height • DBH	
LoD 2	• Tree position • 3D model of the main stem	LoD 1
LoD 3	• 2nd level branches (directly connected with the main stem)	LoD 1 + LoD 2
LoD 4	• 3rd level branches (connected with the 2nd level branches) • Bushes	LoD 1 + LoD 2 + LoD 3
LoD 5	• Leaves • More details of branches (higher level branches) • More details of bushes	LoD 1 + LoD 2 + LoD 3 + LoD 4

(Liang et al., 2016)

- Reconstruction
- Explicit geometry
- No PC

LOD of Trees



LOD0: The crown projection according to SILVI-STAR that follows the 3D shape of the tree.

LOD1: as LOD0 but with vertical height characteristics such as where the crown starts

LOD2: as LOD1 but reflecting the shape type and properties.

LOD3: as LOD2 with the addition of 1st, 2nd and 3rd grade stem and branch structures

LOD4: LOD3 supplemented with textures of bark and leaves

Wageningen University (Clement, 2013)

- 2D SVO
- Reconstruction
- Explicit geometry
- No PC

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Related Work: Private Companies LODs

Vertex

LOD2 (.1, .3, 1 Km sq.) LOD3 (.1 Km sq.) LOD4 (custom extent) Textured LOD (custom extent)

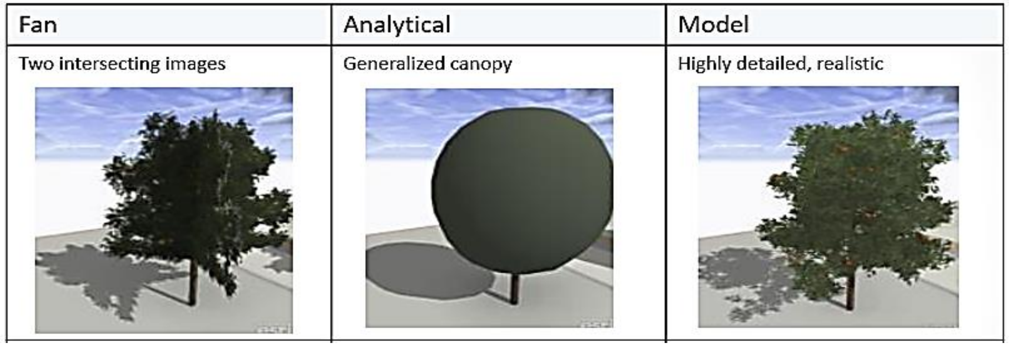
(Vertex Modelling Products, 2017)

Blom ASA

LOD1 LOD2 LOD3 LOD4 Navigation and Pedestrian LOD

(Blom ASA, 2011)

ESRI



3D plant library model usage (ESRI, 2014)

Highlights

- Volumetric, realistic models
- No 2D SVO
- Only implicit
- Differentiated by accuracy and geographic extend
- No PC as object

- Only implicit
- Vegetation part of terrain
- Implicit SVO in application specific LOD

- Billboard, volumetric, realistic models
- Implicit model library
- Differentiated by geographic extend

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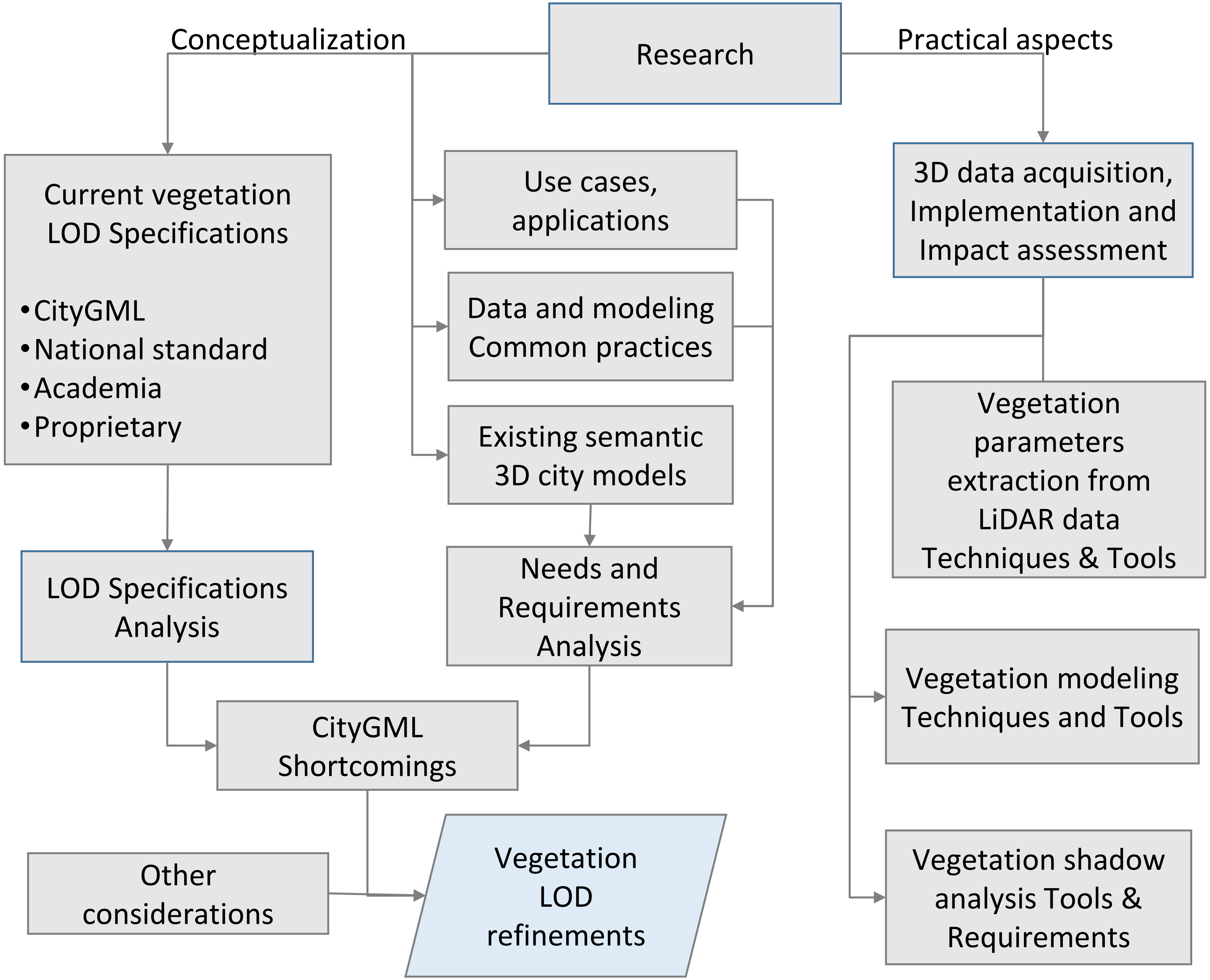
Methodology

- Conceptualization of LOD specifications
- Case study: Shadow assessment of LODs



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Applications that use urban vegetation models and data

- Management, Maintenance and Sustainability
- Urban Planning and Landscaping
- Environmental Policy Making
- Tree Properties Extraction
- 3D City Models enrichment

Application example	Use case
Urban Vegetation Management, Maintenance and Sustainability	1. Track street tree condition, progress and properties 2. Determine the ideal location of cell towers 3. Overhead rail maintenance Models for communication and analysis 1. Plan public work above and below ground 2. Communicate above, below ground topology regulations 3. Analyze tree diversity and distribution
Urban Planning and Landscaping	1. Streetscape spatial requirement estimation 2. Tree root spatial requirement estimation Models for communication 1. Promote sites and projects 2. Solicit collaboration and participation 3. Design alternatives decision making 4. Communicate site renovation /current-future changes Models in simulations 1. Mitigation of UHI from cooling effects of tree canopy 2. Urban vegetation avoided runoff contribution 3. Vegetation morphology and placement for noise reduction 4. Tree placement optimization for cooling houses and parking lots Models for spatial analysis 1. Identification of UHI prone areas 2. Tree shadow impact on solar panels 3. Identification of vegetation and building vertical relationships for urban ecology 4. Underground open space, object distribution assessment
Environmental Policy Making	1. Structure and ecoservices analysis 2. Ecoservices benefits analysis 3. Growth forecast
Tree Properties Extraction	Models 1. Tree crown properties extraction 2. Urban tree allometric model's refinement 3. Tree reflectance and directional light/radiation transmission 4. Tree structure tolerance to storm winds 5. Tree crown evapotranspiration estimation
3D City Models enrichment	Models 1. Vegetation models for 3D datasets enrichment 2. Inventory tree properties and data query

Vegetation Data Needs

- Track condition, risk status, maintenance
- Assess horizontal and vertical distribution
  - Location, parameters: height and width param
- Assess planting feasibility
  - Above, below ground :
    - Project structural change
    - Spatial requirements – parameters for calculations, e.g. volumes
  - Environmental issues
    - Canopy properties, tree type, species
- Data as input to simulations
  - Object-based parameters
  - Crown properties
  - Other objects: buildings
  - 2D, 2.5D canopy projection

Simulations:

- HUI tree structure optimization
- Noise and water runoff mitigation
- Tree and urban forest structure analysis
- Ecoservices assessments
- Forecast ecoservices

Application example	Use case
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Use Cases Vegetation Data Needs (summary 1)

- Track condition, risk status, maintenance
- Assess horizontal and vertical distribution
  - Location, parameters: height and width param
- Assess planting feasibility
  - Above, below ground :
    - Project structural change
    - Spatial requirements – parameters for calculations, e.g. volumes
  - Environmental issues
    - Canopy properties, tree type, species
- Data as input to simulations
  - Object-based parameters
  - Crown properties
  - Other objects: buildings
  - 2D, 2.5D canopy projection

Use Case needs of vegetation data (parameters, attributes)

- Condition, status
- Above and below ground calculations, estimations, e.g., volumes,
- Input to simulations
- Bottom up parameters acquisition
  - SVO object and crown properties
  - needed assessment applications

Most Required Vegetation Models

Multiple dimensions, adherence in **appearance/aesthetics and form**:

- **Visualizing, communicating**
  - Designs – realistic with variations
  - Topology, link information
- **Visual analysis**
  - Sustainability
  - Space availability

Multiple dimensions and **adherence in form**:

- **Input to simulation**
- **Analyze spatial** relationships,
- Assess **impacts** to surroundings:
  - Basic height, width
  - implicit SVO models
  - Components
    - Crown, Root
- **Reconstruction** models
  - Extract data

Application example	Use case
Management Maintenance and monitoring of trees in public space	1. Track street tree condition, progress and properties 2. Determine the ideal location of cell towers 3. Overhead rail maintenance Models 4. Plan public work above and below ground 5. Communicate above, below ground topology regulations 6. Analyze tree diversity and distribution
Urban Planning and Landscaping	7. Streetscape spatial requirement estimation 8. Tree root spatial requirement estimation 9. Mitigate negative effects of climate change 10. Urban vegetation avoided runoff contribution Models 11. Promote sites and projects 12. Solicit collaboration and participation 13. Design alternatives decision making 14. Communicate site renovation /current-future changes Models for simulations 15. Vegetation morphology and placement for noise reduction 16. Tree placement for cooling houses and parking lots Models for spatial analysis/impact to surrounding objects 17. Identification of UHI prone areas 18. Identification of vegetation and building vertical relationships for urban ecology 19. Underground open space, object distribution assessment
Environmental Policy Making	Trees and urban forest… 20. Structure and ecoservices analysis 21. Ecoservices benefits analysis 22. Growth forecast Models for spatial analysis/impact to surrounding objects 23. Tree shadow impact on solar panels
Tree Attribute and Properties Extraction	24. Urban tree allometric equation refinement 25. Tree reflectance and directional transmission 26. Tree structure tolerance to storm winds 27. Tree crown properties extraction 28. Tree crown evapotranspiration estimation
3D city Models	29. Modeling for 3D datasets enrichment 30. Inventory tree properties and data query

Use Cases Most Required Vegetation Models (summary 2)

- **SVO** Models for different needs:
  - Visualization, communication
  - Spatial analysis, impact to surrounding,
  - Input to simulations
  - To extract data (hard/not measurable)

- **Components** LODs also needed

- SVOs with **multiple:**
  - **Dimensionalities** 2D, 2.5D and 3D,
  - **Adherence** in **appearance** and **form**
    - Realistic variations
    - Basic height, width
    - implicit
    - Parametric
    - Reconstructed (crown, trunk, branches)
- **Components** with
  - Crown: adherence in form (type, species) and properties
  - Root: spatial requirements
  - Trunk: volume- model - biomass

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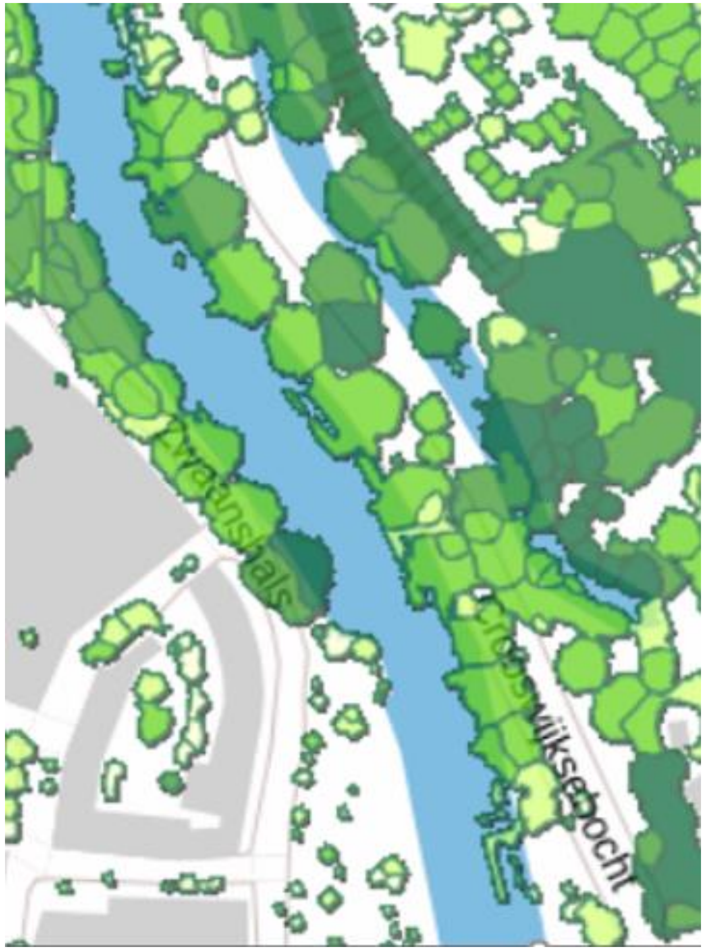
Common Practices

0D data for location (Maintenance Public Work in Rotterdam, 2016);

1D data for rows of trees along roads; (Clement et al., 2013)



2D or 2.5D tree crowns from Boomregister.nl

Public 3D City Models

Cities around the world with open CityGML datasets

https://www.citygml.org/3dcities/

dataset	country	year	Building LOD	other classes	textures	acquisition	CityGML version	notes
Berlin	Germany	2013	LOD2		true		2.0	Released in 2015
Brussels	Belgium	2014	LOD2	Building	false		1.0	
Dresden	Germany	2009	LOD1/LOD2/LOD3		Partially		1.0	
Dutch cities	Netherlands	2016	LOD1	Terrain and many other	false		2.0	A few Dutch cities generated with 3dfier
Hamburg	Germany	2017	LOD1 and LOD2			Cadastre footprints + LiDAR	2.0	
Helsinki	Finland	2016	LOD2		true		2.0	
Linz	Austria	2011	LOD2		false		1.0	
Lyon	France	2012	LOD2	Terrain, water			2.0	
Montréal	Canada	2009	LOD2	terrain (TIN in CityGML format)	true	Photogrammetry	1.0	The LiDAR dataset of the same area is also available
New York City (by TUM)	United States	2015	LOD1	Roads, lots, parks, water, terrain	false	Photogrammetry in combination with existing public 2(.5)D datasets	2.0	article with details
New York City by DoITT	United States	2016	LOD2		false	Cadastre footprints + LiDAR	2.0	buildings are modeled with thematic surfaces in LOD2, however, for most buildings the geometric shape is LOD1
North Rhine-Westphalia (state)	Germany	2016	LOD1+LOD2		false	Cadastre footprints, LiDAR, aerial images. LOD1 is derived from LOD2 models with average roof height (details here)	1.0	Enormous datasets that covers whole NRW (NRW is the most populated state in Germany) Cities included: Düsseldorf, Essen, Oberhausen, Köln, Bonn and

Found 2 datasets with vegetation with billboard representations

16 CityGML datasets, 10 open 3D datasets not in CityGML

Use Cases Most Required Vegetation Models (summary 2)

- **SVO** Models for different needs:
  - Visualization, communication
  - Spatial analysis, impact to surrounding,
  - Input to simulations
  - To extract data (hard/not measurable)

- **Components** LODs also needed

- SVOs with **multiple:**
  - **Dimensionalities** 2D, 2.5D and 3D, **0D, 1D**
  - **Adherence** in **appearance** and **form**
    - Realistic variations
    - Basic height, width
    - Implicit volumetric (proprietary LODs), billboard models
    - Parametric
    - Reconstructed (crown, trunk, branches)
- **Components** with
  - Crown: adherence in form (type, species) and properties
  - Root: spatial requirements
  - Trunk: volume- model - biomass

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Vegetation LODs Analysis

- LOD specifications
  - vs LOD definition metrics (6)
  - CityGML specifications:
    - Geographic extent
    - Accuracy
- 1. How are they specified?
- 2. Requirements
- 3. Differentiation
- 4. Relationships

	Standards			Geometry focus			Proprietary		
	CityGML	**IMGeo-CityGML**	**LOD of Trees**	**LOD and Trees**	**LOT**	**Single Tree**	**Vertex**	**Blom ASA**	**ESRI**
Veg. LODs / All LODs (36/40)	4/5	3/4	5/5	4/5	4/4	5/5	4/5*	4/5**	3/3
Veg. objects described:	2	3	1	2	1	1	1	1	1
Geometry type:	I	B	B	E	E	E	I	I	I
Dimensionality	0D 2.5D 3D	0,1D 2D 2.5D 3D	2D 2.5D 3D	2.5D 3D	2D 2.5D3D	2.5D 3D	0D	0D	0D
Feature Complexity									
Appearance									
Component granularity									
Semantic granularity									
Geographical extent									
Accuracy by LOD									
Accuracy by object									
Vegetation data timeliness									
Attributes									
Temporal									
Underground									
Topology									
Maintenance: condition, risk									
Requirements									
Builds on previous LOD									
Optional SVO in LOD0									
Optional additional LODs									
Optional object components									
Optional attributes									
Can mix LODs									

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Results Summary from LODs specification approaches analysis

- All mostly geometrical LOD descriptions
- Two modeling approaches
- CityGML's shortcomings = Implicit modeling weaknesses

CityGML and Implicit Modeling	Explicit Modeling
SVO centric	
Weakness	Strengths
• No SVO in LOD0	• Include SVO at LOD0
• 0D only • No components	• Multiple dimensionalities • Parametrical modeling
• Adherence: - as appearance at high LOD - weak at mid and high LOD	• Adherence progresses • Align better to buildings LODs
• Differentiation: minimal in appearance for highest LOD, feature complexity in Ht	• Differentiation: component granularity, dimensionally feature complexity when specified
Strengths	Weakness:
• LODs not dependent • Minimal requirements, flexible • Lower cost required for acquisition, realization, computing and storage resources	• LOD build on previous • Specific requirements at each • Higher cost of acquisition, realization, computing and storage resources

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To Refine LOD Specifications

- Which specifications meet identified needs?
  - No one approach does
  - * For implicit modeling approaches to meet identified needs => Need to incorporate some explicit modeling LODs
  - Missing LODs/specifications for * = *shortcomings*

- Improve CityGML's SVO LOD specifications => address *shortcomings*:
  - Add explicit modeling LODs
  - Strengthen specifications using LOD definition metrics
  - Specifications: consistent, discrete where possible (not vague)
  - Other considerations (covered later in LOD descriptions

Use Cases Most Required Vegetation Models (summary 2)

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    - Realistic variations
    - Basic height, width
    - Implicit volumetric (proprietary LODs), billboard models
    - Parametric
    - Reconstructed (crown, trunk, branches)
- **Components** with
  - **Crown**: adherence in form (type, species) and properties
  - **Root**: spatial requirements
  - Trunk: volume- model - biomass

Start

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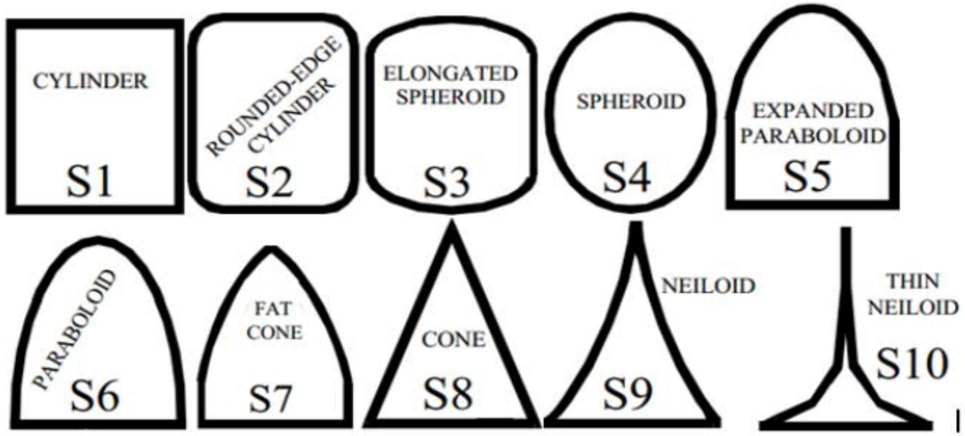
Coder Crown Shapes

- Searching for SVO descriptions of forms to reflect type or species
- Coder, 2000 crown shapes used in forestry and ecology to estimate crown volumes

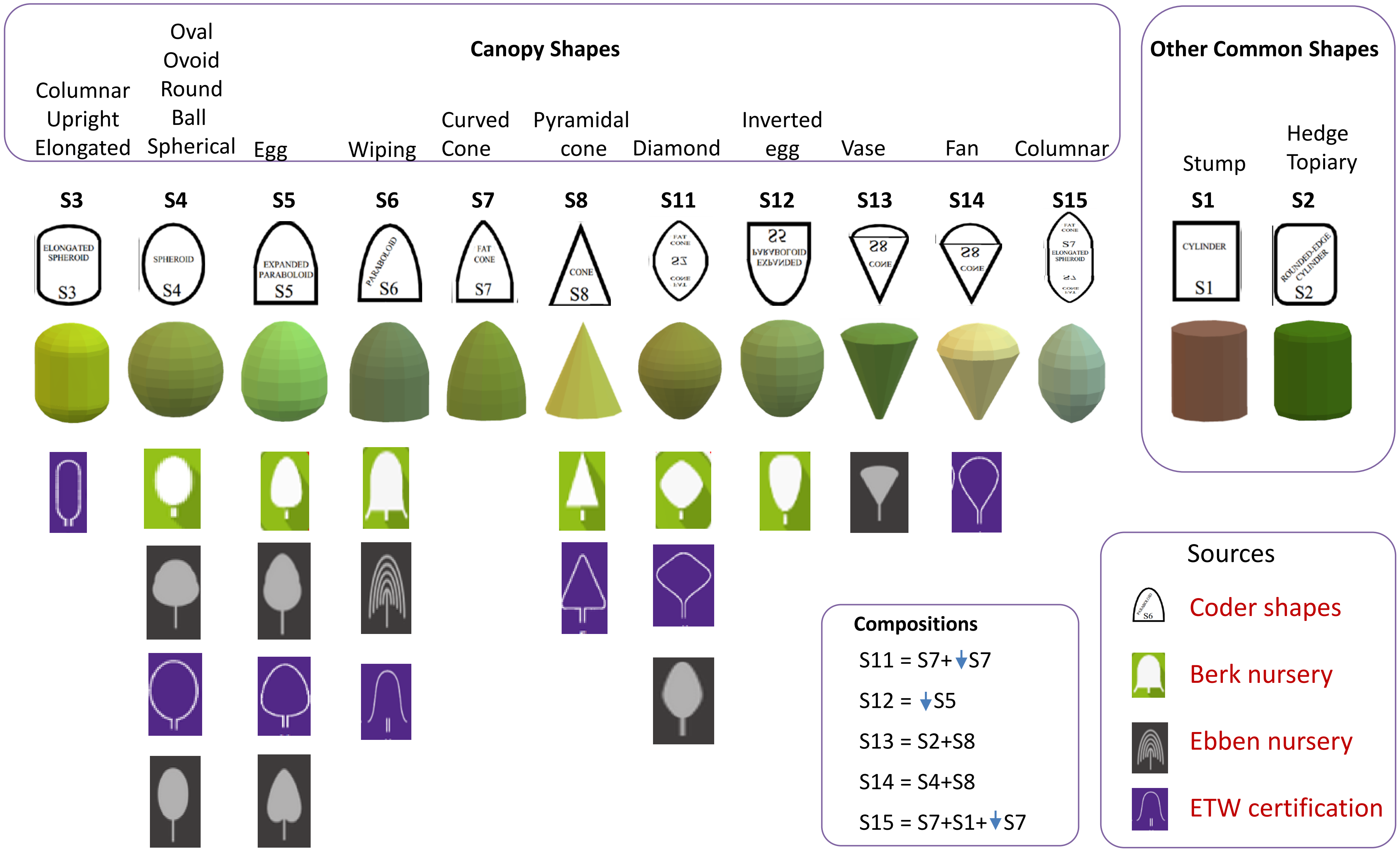


shape number	shape value	shape formula	shape name
S1	8/8 (1.0)	(Crown Diameter)^2 x (Crown Height) x (0.7854)	CYLINDER
S2	7/8 (0.875)	(Crown Diameter)^2 x (Crown Height) x (0.6872)	ROUNDED-EDGE CYLINDER
S3	3/4 (0.75)	(Crown Diameter)^2 x (Crown Height) x (0.5891)	ELONGATED SPHEROID
S4	2/3 (0.667)	(Crown Diameter)^2 x (Crown Height) x (0.5236)	SPHEROID
S5	5/8 (0.625)	(Crown Diameter)^2 x (Crown Height) x (0.4909)	EXPANDED PARABOLOID
S6	1/2 (0.5)	(Crown Diameter)^2 x (Crown Height) x (0.3927)	PARABOLOID
S7	3/8 (0.375)	(Crown Diameter)^2 x (Crown Height) x (0.2945)	FAT CONE
S8	1/3 (0.333)	(Crown Diameter)^2 x (Crown Height) x (0.2619)	CONE
S9	1/4 (0.25)	(Crown Diameter)^2 x (Crown Height) x (0.1964)	NEILOID
S10	1/8 (0.125)	(Crown Diameter)^2 x (Crown Height) x (0.0982)	THIN NEILOID

idealized crown shapes. right: volume formulae (Coder, 2000)

Crown Forms/shapes Descriptions

- Many sources, many names for same shape
- Extended Coder, crown shapes (S1 to S8) with other shapes found sources (S11 to S15)



idealized crown shapes. Bottom: volume formulae (Coder, 2000)

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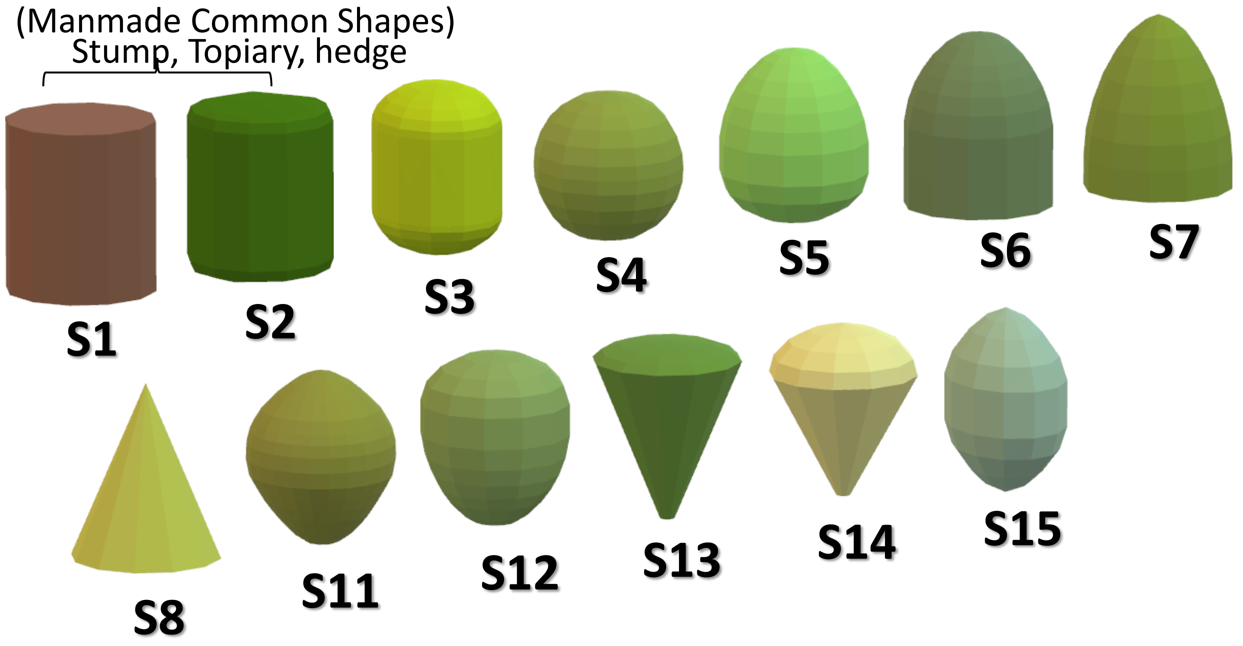
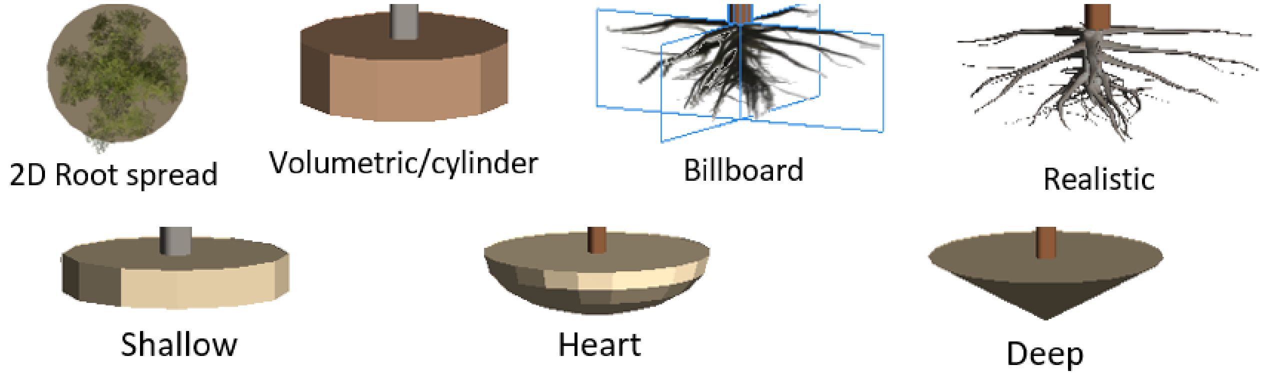
Crown

- Need: Crown adherence in form (type, species)
- Universal shapes
- For all SVOs not only trees
- Name harmonization



Root

- Need: Spatial requirement
- Volume estimation methods provided
- Parameter terminology harmonization
- Visualization options



Non-cylinder and 2D are from ESRI Germany

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Refined SVO LODs

Introduce

- Improve CityGML's LODs
- High LODs can expand with further sub-levels
- SVO components descriptions
  - Expandable crown shapes
- Underground descriptions
- Harmonized:
  - Crown shapes description, terminology
  - Root parameters

Specifications

More than geometric, consistent, clear

- Dimensionality
- Component granularity
- Feature complexity
- Appearance
- Semantics
- Attributes

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Refined SVO LODs (Cont.)

With specifications:

- All datasets can be represented by at least one LOD including underground
- Modelers or users of 3D city models can tell:
  - What LOD is possible based on the data I already have?
- For acquisition:
  - What data is required for a LOD?
  - Which LOD can be used to obtain data needed for an application?

Limitations

- Does not include PC
- Use cases, not an exhaustive list
- As per scope
  - Acquisition is point cloud centric
  - Mainstream, open source tools

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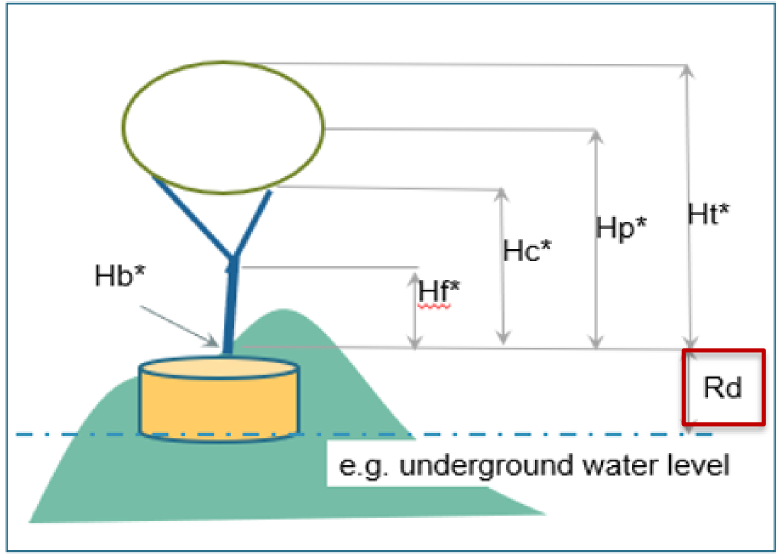
Refined LODs

Specifications:

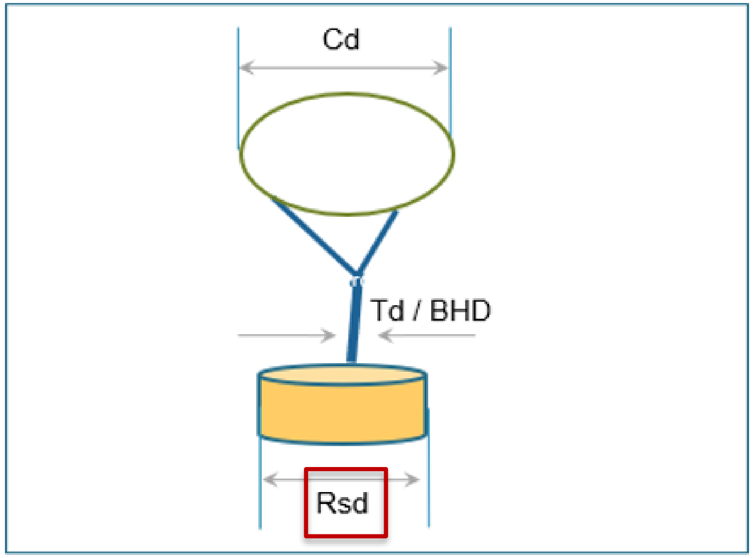
Parameters:

- Adopt explicit tree model
- Add root parameters

Vertical Parameters



Horizontal Parameters



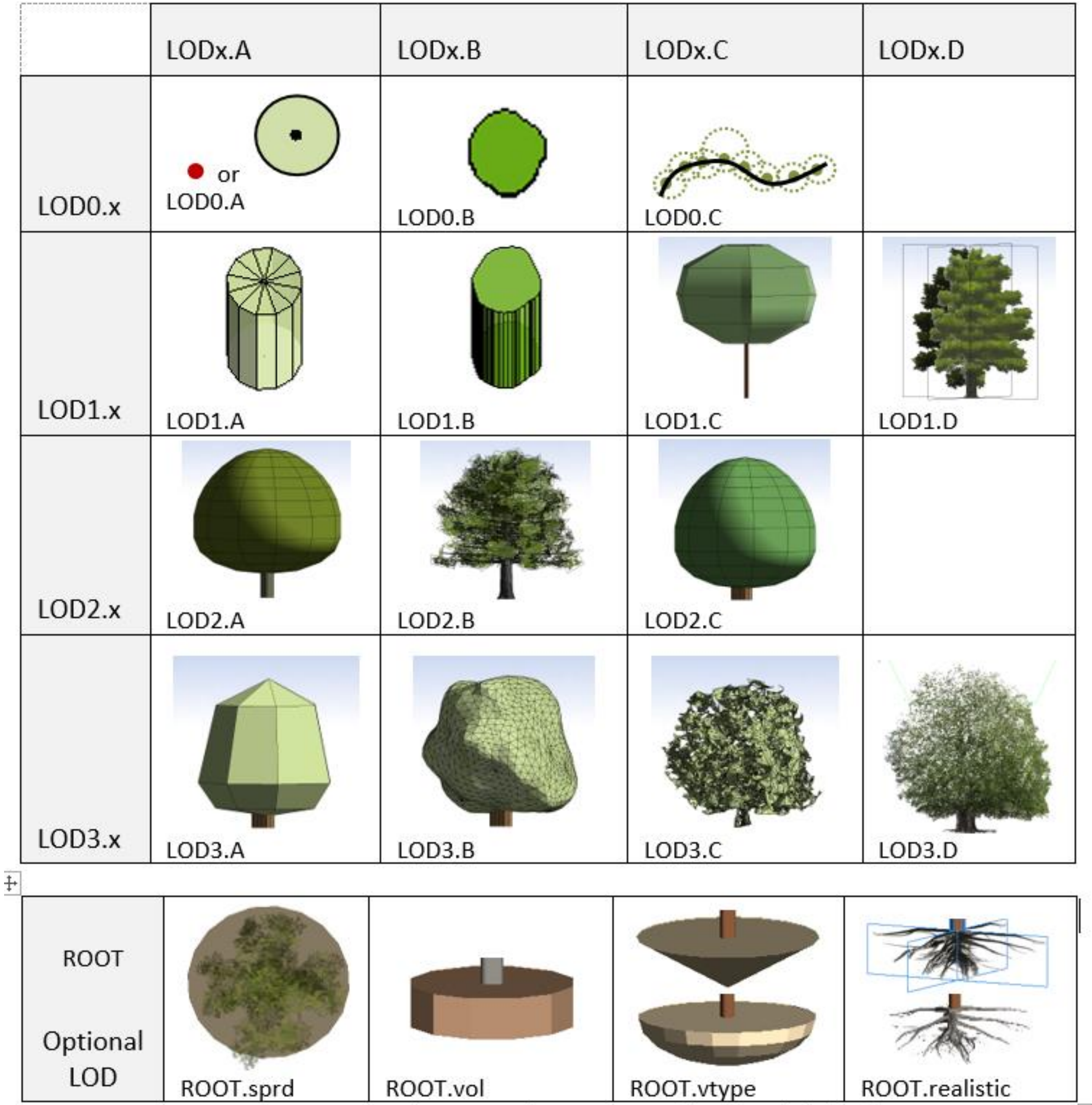
Ht*	Tree top relative to Hb
Hb*	Baseline or elevation
Hp*	Height at crown widest perimeter
Hc*	Crown base height
Hf*	First fork height
Rd	Root depth

Cd	Crown or 2D dripline diameter
Cr	Crown radius
Td	Trunk diameter/Breast height diam. (BHD)
Rsd	Root spread diameter

* SILVI-STAR tree model parameters (Koop, 1989)

Refined LODs

- 4 LOD families + Sub-levels
- Adherence increase
  - x family and x sublevel
- Adherence in:
  - geometry, component, attributes, appearance
- Specifications in other 6 LOD definition metrics
- Families align with CityGML's
- Root LODs
  - Optional
  - Not aligned to any SVO LOD



LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

Refined LODs

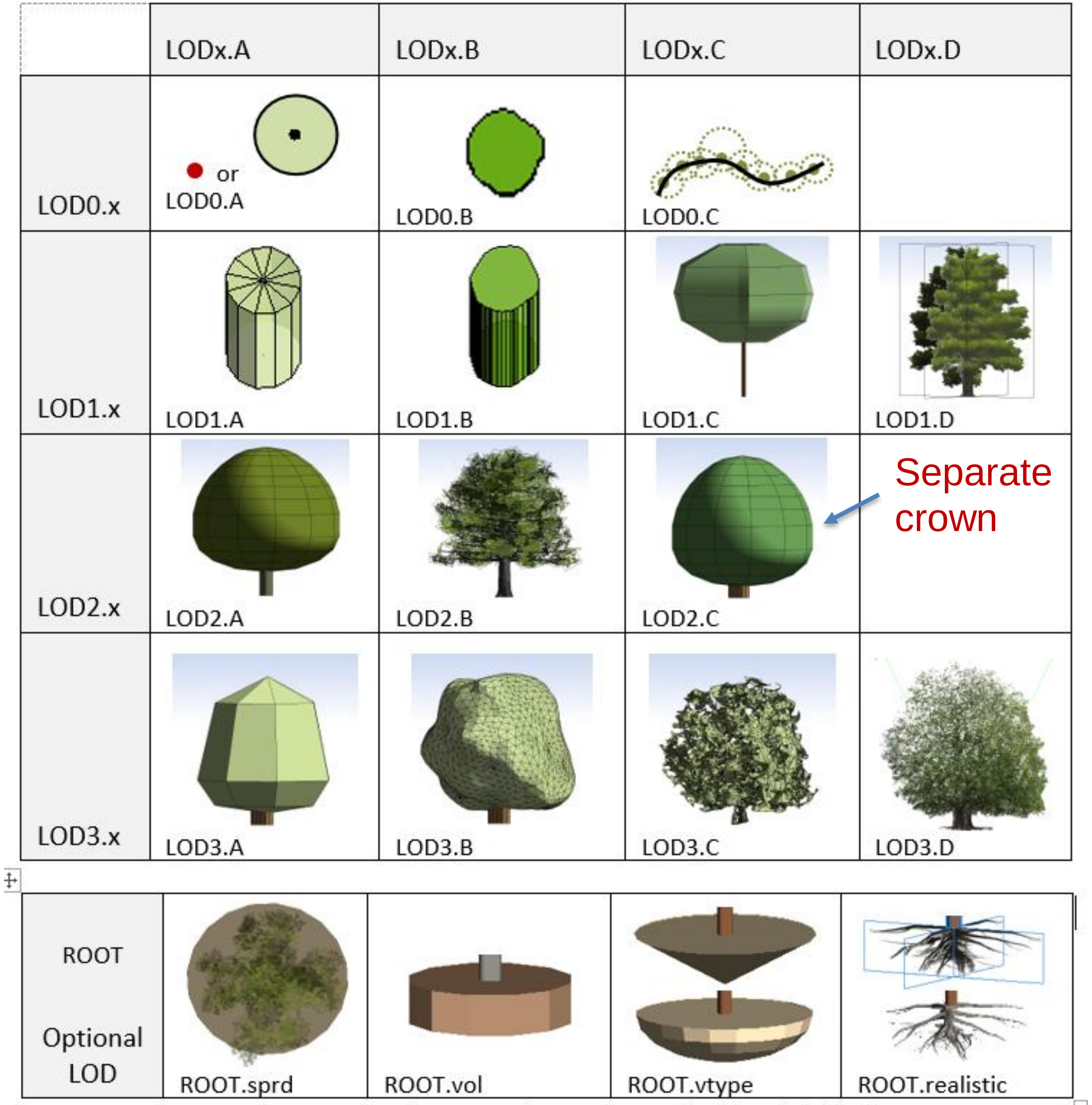
SVO in terrain LOD0
0D, 1D, 2D/2.5D, support GIS operations

- Height, width adherence, extrusion, implicit
- Distinct LODs

- Species/genus adherence, implicit
- Implicit tree/crowns (S1-S15)

- Crown adherence, explicit +
- Highest cost of acquisition, storage

Root (optional, exchangeable):
- projection • volume • implicit



LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

Use Cases Most Required Vegetation Models (summary 2)

- **SVO Models** for different needs:
  - Visualization, communication
  - Spatial analysis, impact to surrounding,
  - Input to simulations
  - To extract data (hard/not measurable, directly)
- **Components LODs** also needed

- SVOs with **multiple:**
  - **Dimensionalities** 2D, 2.5D and 3D, **0D, 1D**
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- **Components** with
  - **Crown**: adherence in form (type, species) and properties
  - **Root**: spatial requirements
  - Trunk: volume- model - biomass

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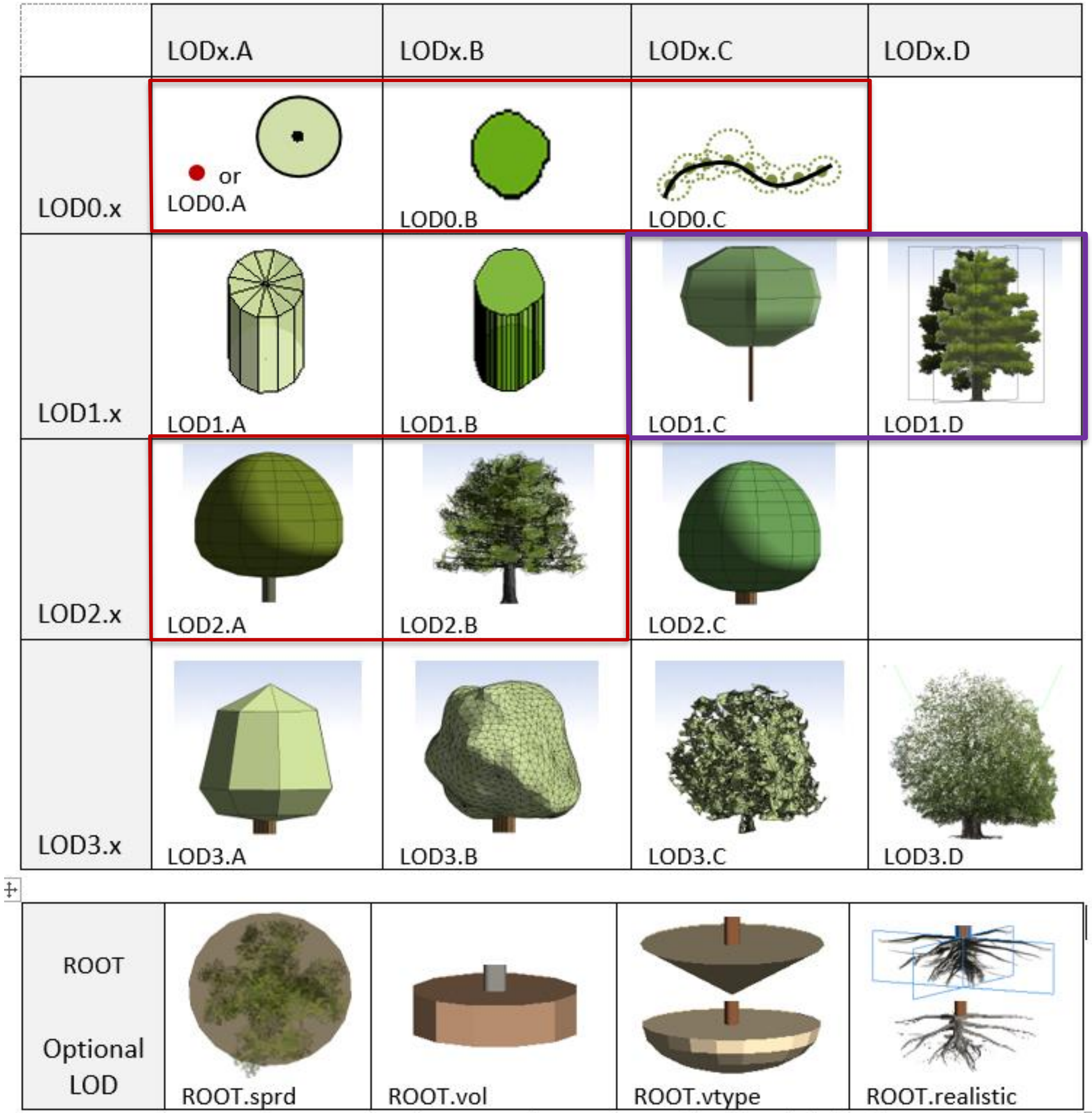
Refined LODs

- **SVO Models** for different needs:
  - Visualization, communication
    - In public 3D City Models, and proprietary LODs
  - Spatial analysis, impact to surrounding,
  - Input to simulations
  - To extract data (hard/not measurable, directly)
- **Components LODs** also needed



LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

Refined LODs

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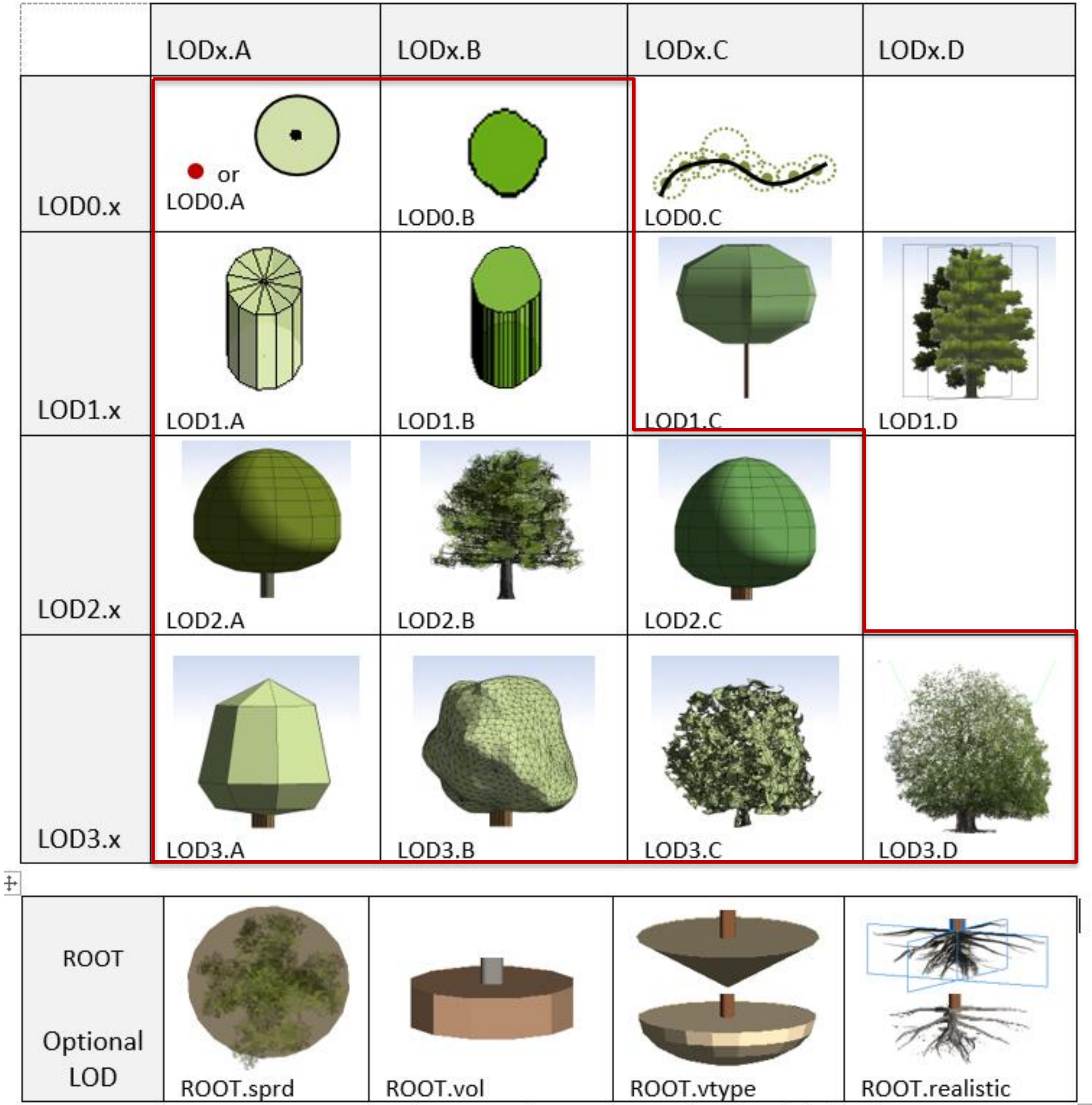

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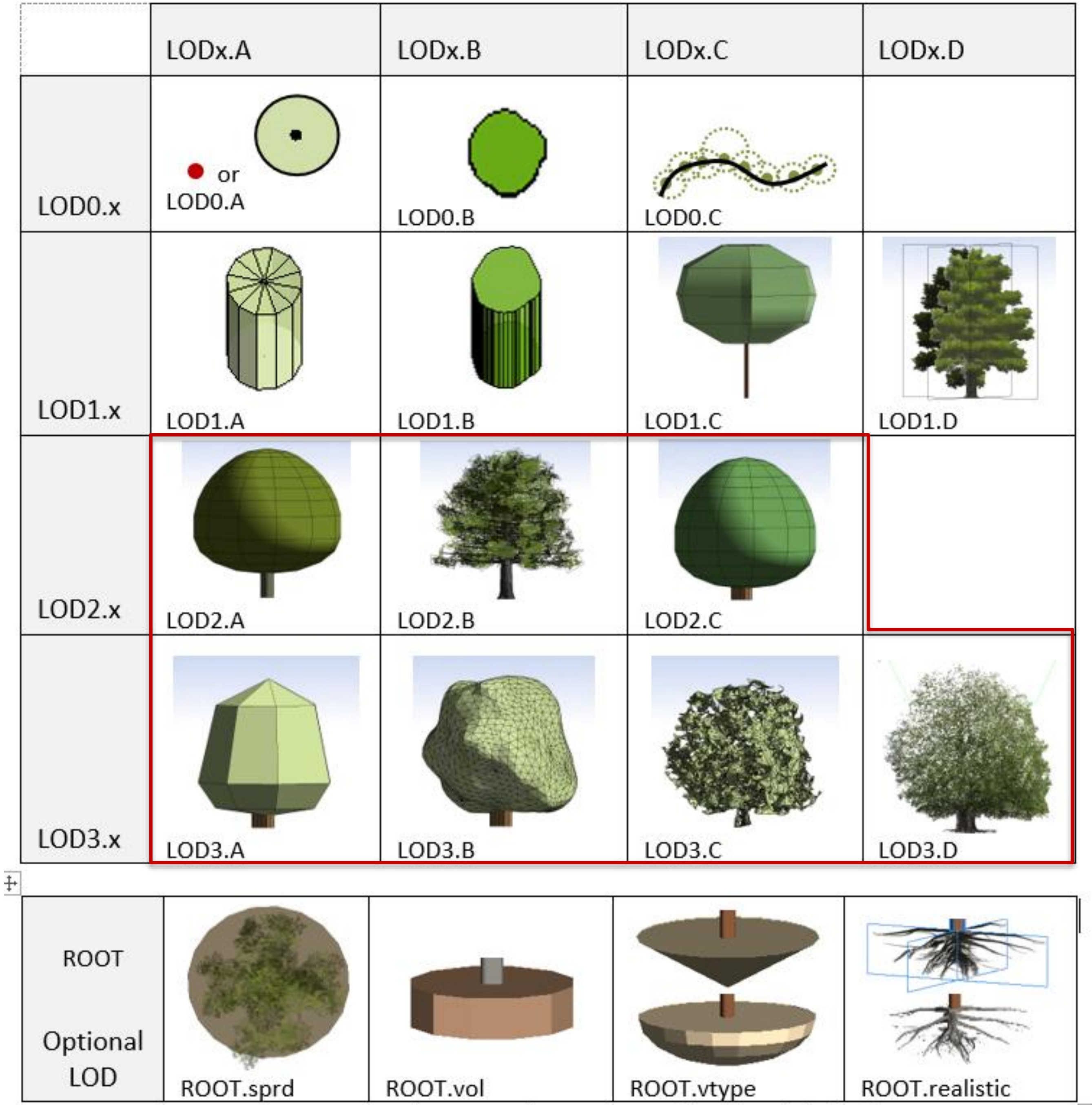

LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

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Refined LODs

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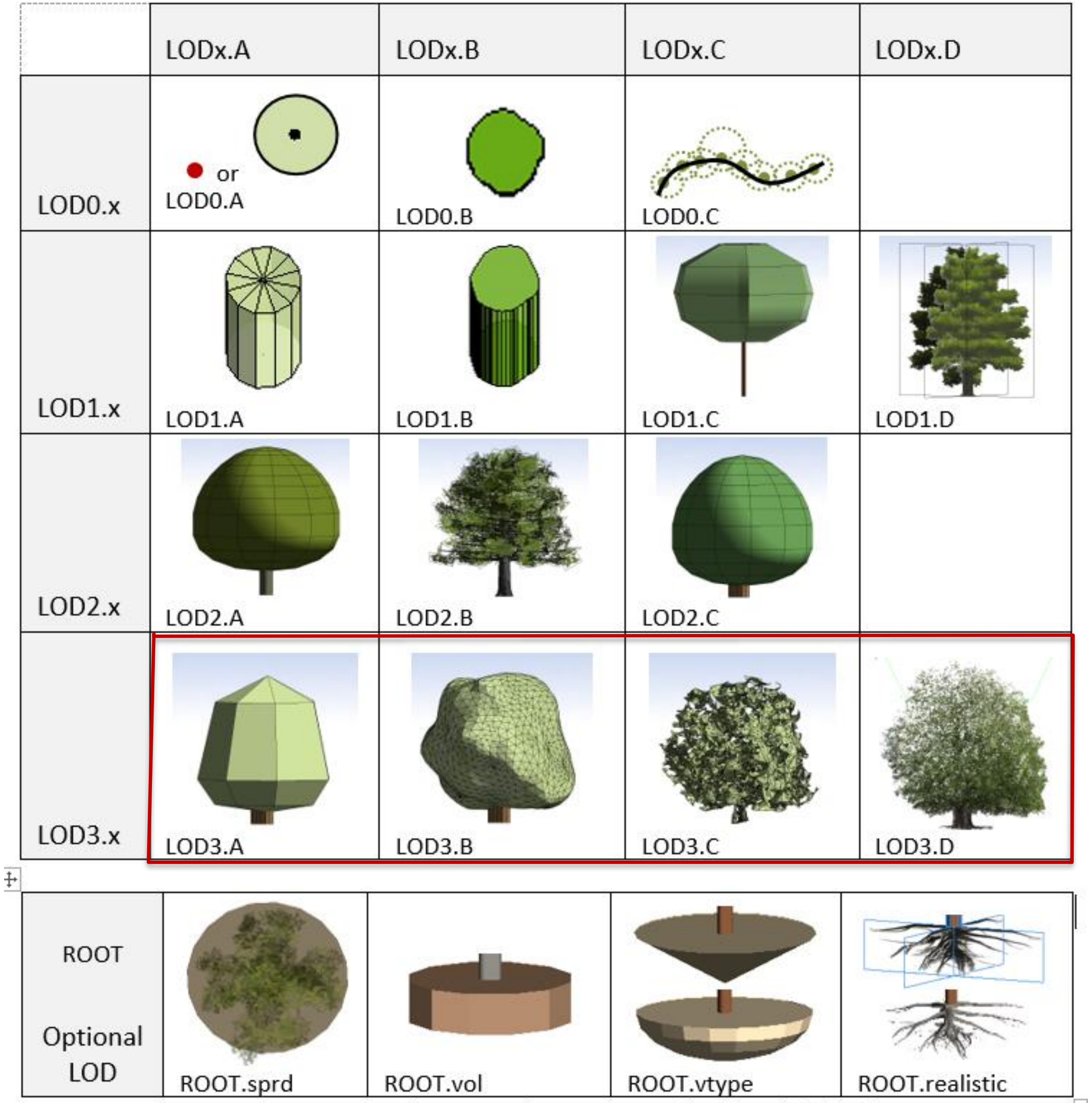

LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

Refined LODs

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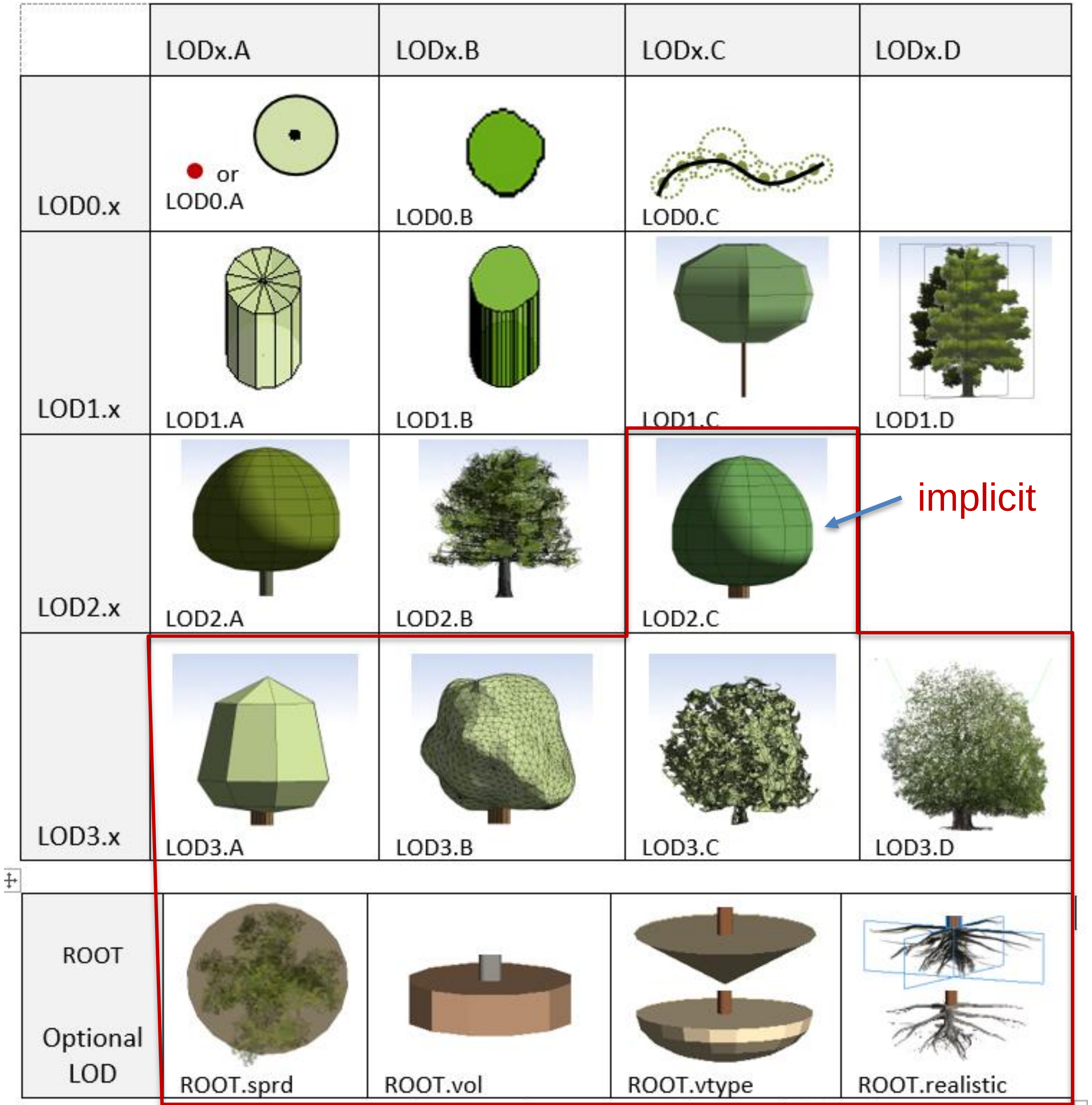

LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

Consideration - Other

- Acquisition techniques and demand in resources
  - horizontal feature complexity specifications (alternative)
  - High LOD considered regardless of automation or manual
- Accuracy
  - Not in LOD specifications
  - Recommendations given based on acquisition
- Geographic extents
  - LODs are independent but aligned to CityGML's
- Data availability or little resources
  - Standard dimension ratios provided

Refined LODs

Specifications:

1. Geometry type:
   a. Explicit, coordinate based
   b. Implicit
   c. Set by User
2. Dimensionality
3. Component granularity
4. Feature complexity
5. Appearance
6. Semantics
7. **Attributes**
   1. Minimum required
   2. Extended list

Minimum Required

	LOD0.x	LOD1.x	LOD2.x	LOD3.x
Min. attributes	• Type • *Application specific attributes*	LOD0's and ... • Class • Usage • Significance • *Application specific*	LOD1's and ... • Species • Crown shape • Life stage • Condition • *Application specific*	• Same as LOD2 • *Application specific attributes*

Extended

Type of attribute	Attribute	Description examples
Parameters	**Hb**	Baseline or elevation
	Ht+	Tree top relative to Hb
	Cd+	Crown diameter or dripline contour diameter
	Td/ BHD+	Trunk diameter/Breast height diam. (DBH)
	Hc+	Crown base height relative to terrain elevation
	Hp	Height at crown perimeter
	Hf	First fork height
	Rd	Root depth (see Underground attributes)
	Rsd	Root spread diameter (max.)
Crown Properties	**Crown shape**	S1 – S15 shape numbers
	Crown light exposure+	Sun exposure
	Percent crown missing+	Crown volume missing
	Crown Condition/dieback+	Estimate of dead branches
Temporal Properties	**Life stage**	Seedling/Young/Adult/Mature/Ending
	Growth rate per Yr.	
	Foliage fall/sprout/bloom	Month of year
Status	**Significance**	Endangered/monument/historic/none
	Condition	Excellent, good, fair, poor, dead, plagued
	Plan	(To be) cut/replanted/replaced/moved
Classifications	**Type**	(Semi)Deciduous/(semi)Evergreen
	Class	Tree/Hedge/shrub
	Species+	Latin name
	Usage	Shadow/Erosion/Water run-off /Wind block
Underground	Vertical distance limitation	e.g., underground water, rock bed level, none
	Max root volume	
	Root type	Shallow, heart, deep
Topology	Distance to building+	
	Direction to building+	
Land related	land use+	
	Percent tree cover+	Percent to nearest 5%
Application specific	E.g.: Maintenance - height class	Tall, medium, small

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Results – Case Study
What impact do LODs have in analysis in a practical implementation?

Each LOD produced different estimations

- Change in LOD => different shadow means and distribution
- Differentiated LODs
- Model type: Volumetric => overestimation, others underestimated
- Lower LOD provided insights => max. shadow reach, distribution

Limitations

- Shadow reference was the highest LOD3.C.
  - reconstruct not successful, inconsistent point cloud density
- Shadow was not validated with field data
  - Interested in differences, assessment model basic shadow only
- Not simulated with SVO types (deciduous or not)
- Not simulated impact from seasonal foliage and sun path changes

Findings – Case study

- Confirmed broad spectrum of LODs meet different needs
- Multiple LODs choices useful in different ways:
  - Lower LOD provided insights
  - higher LOD, cost-trade offs based on RWO's crown
  - Crown LODs, choose based on RWO's crown properties:

	Hundred SVOs	Few
Regular crown LOD2.x	Implicit + forms adherence LOD2.x implicit crown shape, LOD2.C	
Irregular crown LOD3.x	Parametric	convex hull reconstruction
Crown density LOD2.x, LOD3.x	implicit realistic	non-convex reconstruction

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Findings – Case study (Cont.)

Based on implementation of LODs for case study

1. Process not straight forward
2. No one procedure workflow, procedure or tool

Both *acquisition* technique and *demand in resources* influence:

1. Which LOD can be implemented
   - LOD1 (Ht, Hb easier), LOD0.B (dripline contour), LOD2.C & Parametric (Hc, Hp harder)
2. Accuracy of attributes from point cloud:
   - Ht, Hb vs. Hc, Hp; Cd vs. dripline,
   - DBH, location, Rsd, Rd, crown properties, <= calculated or manual

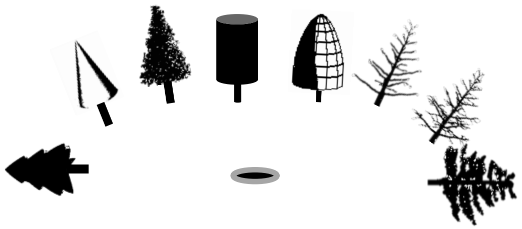
Findings LODs Approaches Analysis

- PC ignored focus mostly on SVOs
- Explicit and implicit specifications complement e/o
- *Acquisition* technique and *demand in resources* impacted which LOD is/not specified:
  - Implicit specified and adopted in Standards and Proprietary
  - Explicit models with higher cost,
    - Only in IMGeo-CityGML and suggested in literature
    - Recently, higher demand, better technology
    - High adherence LODs
      - Meet needs
      - High impact => accuracy of ecoservices assessments

Conclusions

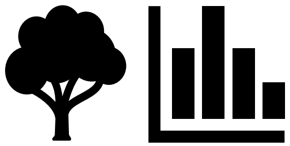
Q. *What is the best specification approach for modeling 3D vegetation features for their use in the built urban environment*

A.

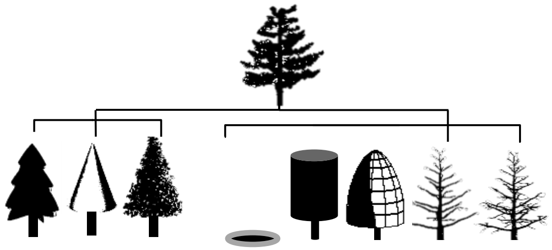


Broad LOD spectrum

Meet different requirements



Models and Data of varying dimensionality & adherence



Both geometry types, combines strengths

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Conclusions

Based on: LODs analysis, use cases, common practices, most used models, and case study

Q. *What is the best specification approach for modeling 3D vegetation features for their use in the built urban environment*

A.

Specifies components

Specifications > geometric aspects

Multiple dimensionality, clear feature complexity, appearance, semantics, attributes

$

Include high adherence LODs

Push technology to meet needs

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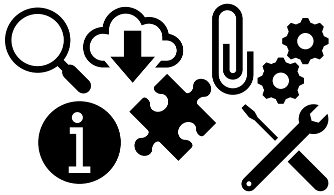
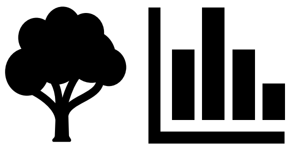
Conclusions

Other

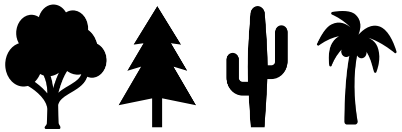


- Fragmented procedures, no one place/tool
- Techniques, algorithms, tools in different places

Push developers to provide user friendly tools



Urban veg. data is key input for urban environmental assessments



SVO reconstruction key for data urban vegetation

Recommendations

Standardization of LODs

would encourage software developers to fulfil demand

Standardization or guidelines in acquisition of SVO data from LiDAR

Would increase use of open LiDAR data for SVO modeling

Guidelines of LOD implementation

Would generate more homogeneous datasets

Further Work – Vegetation LODs

- **How can CityGML store and retrieve introduced components/features, together with** non-geometric aspects, i.e., semantic, appearance, attributes

- Do **PC LODs** descriptions need of improvement? How is different PC defined if share the same footprint, e.g., multiple strata?

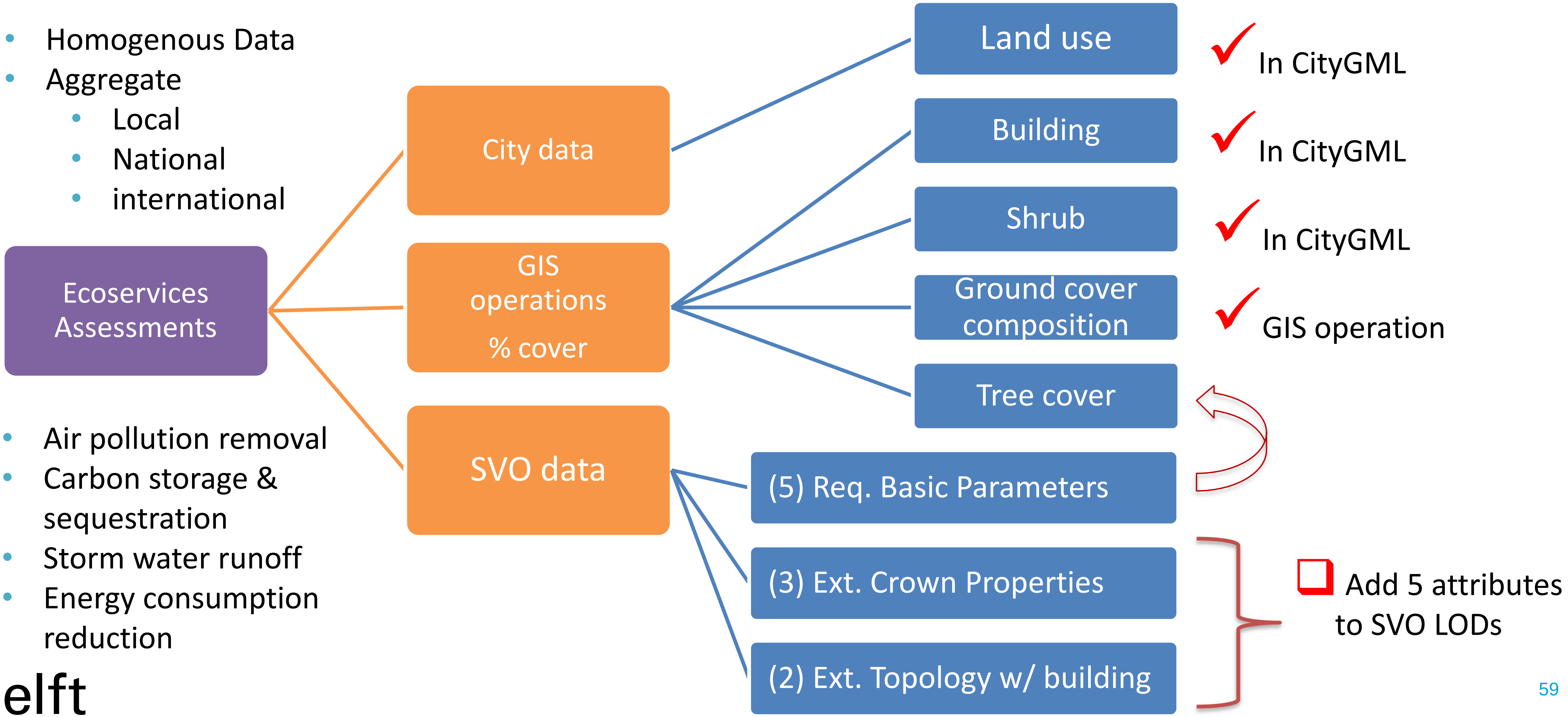
- **Define LOD3.x Sub-level or leave to practitioners to define? Impacts harmonization?**
  - Parametric with more perimetry crown points at different heights as sub-levels?
  - Different number of triangles in convex hull or non-convex hull as sub-levels?
  - Reconstruction LOD ⇔Standardize reconstruction of SVO for trunk, branches volume estimation?

- **Species** identification is important, extracting species from LiDAR data is needed

- Is **generalization and aggregation** applicable to **PC, groups of SVOs**, and perhaps only SVO crowns at certain scales?

Further Work: Ecoservices LOD or ADE?

- City and vegetation data harmonization for ecoservices assessment



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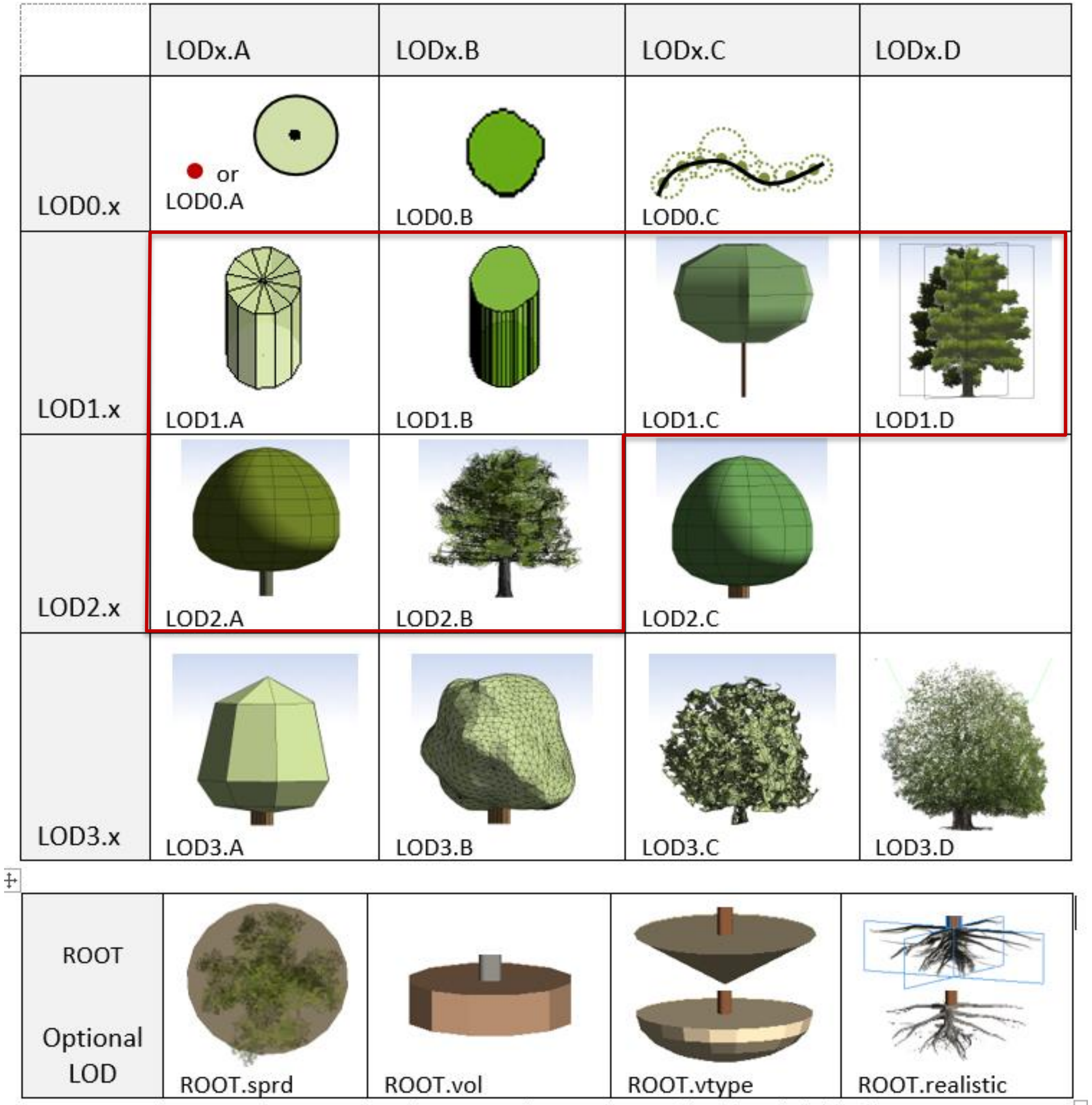
Questions?

Recap CityGML LODs

- Prototypes/implicit any of these in
  - LOD0: no vegetation
  - LOD1: *important*
  - LOD2: Height > 6 m.
  - LOD3: Height > 2 m.
  - LOD4: realistic form
- No distinction besides heights

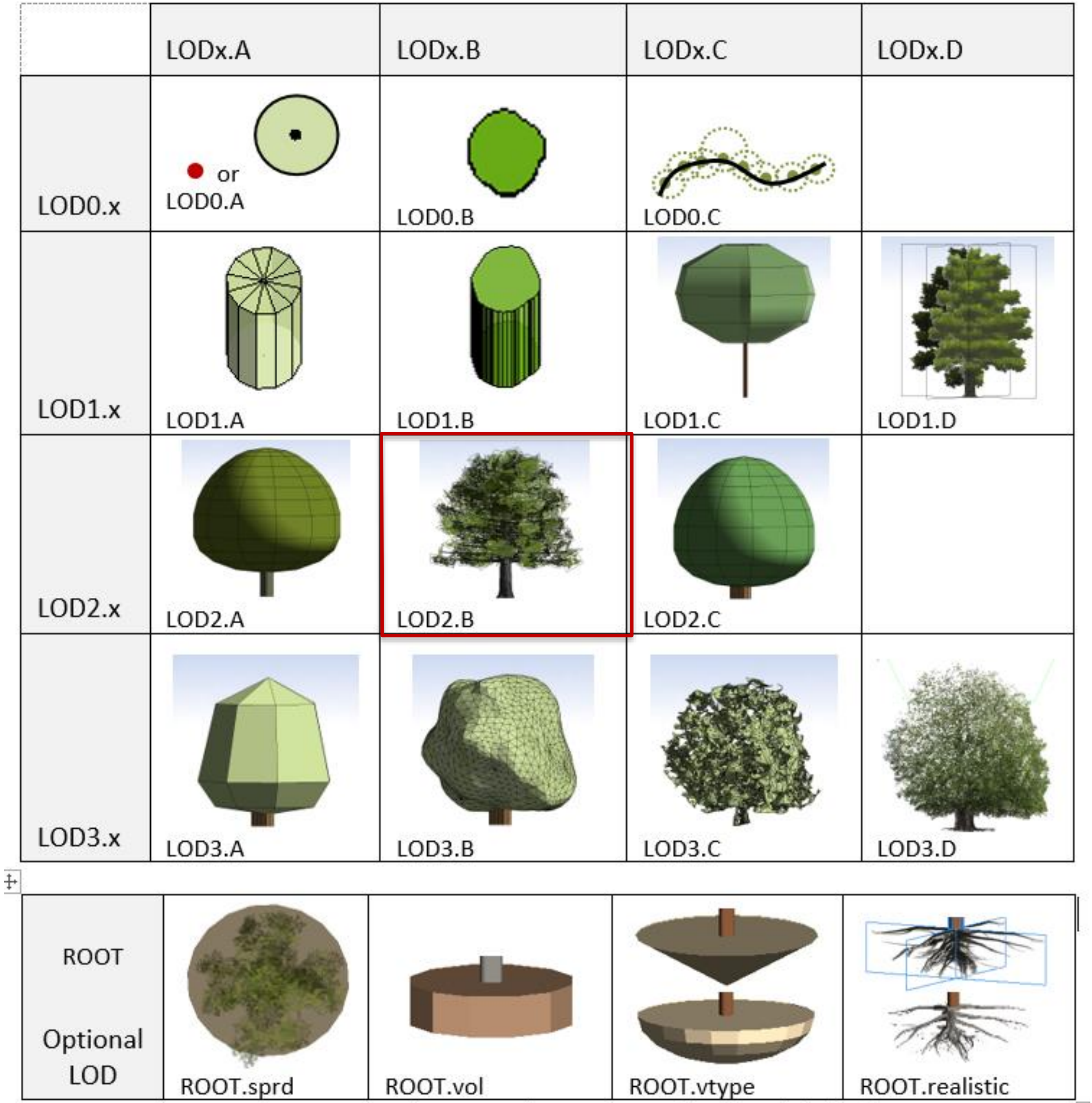


LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

TU Delft

Recap CityGML LODs

- Prototypes/implicit
  - LOD0: no vegetation
  - LOD1: *important*
  - LOD2: Height > 6 m.
  - LOD3: Height > 2 m.
  - LOD4: realistic form
- Appearance differentiation

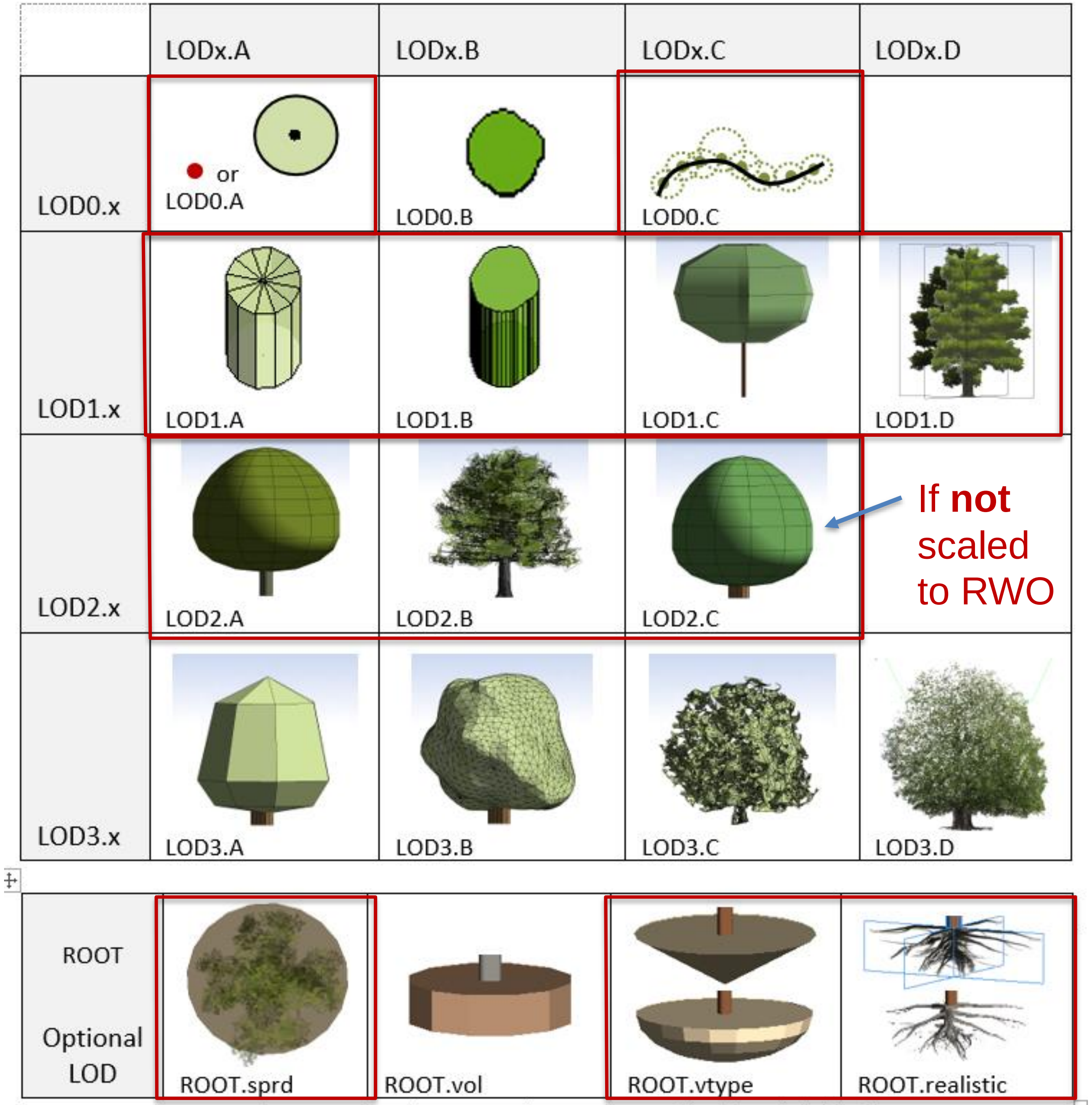


LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

Refined LODs

Acquisition and IT Resources demand

- Low, process hundreds of SVOs
  - Basic parameters and implicit models
- Higher, manual intervention, process hundreds of SVOs
  - Point cloud data, specialized software, expertise
- High manual, process few SVOs
  - Point cloud data, specialized software, expertise

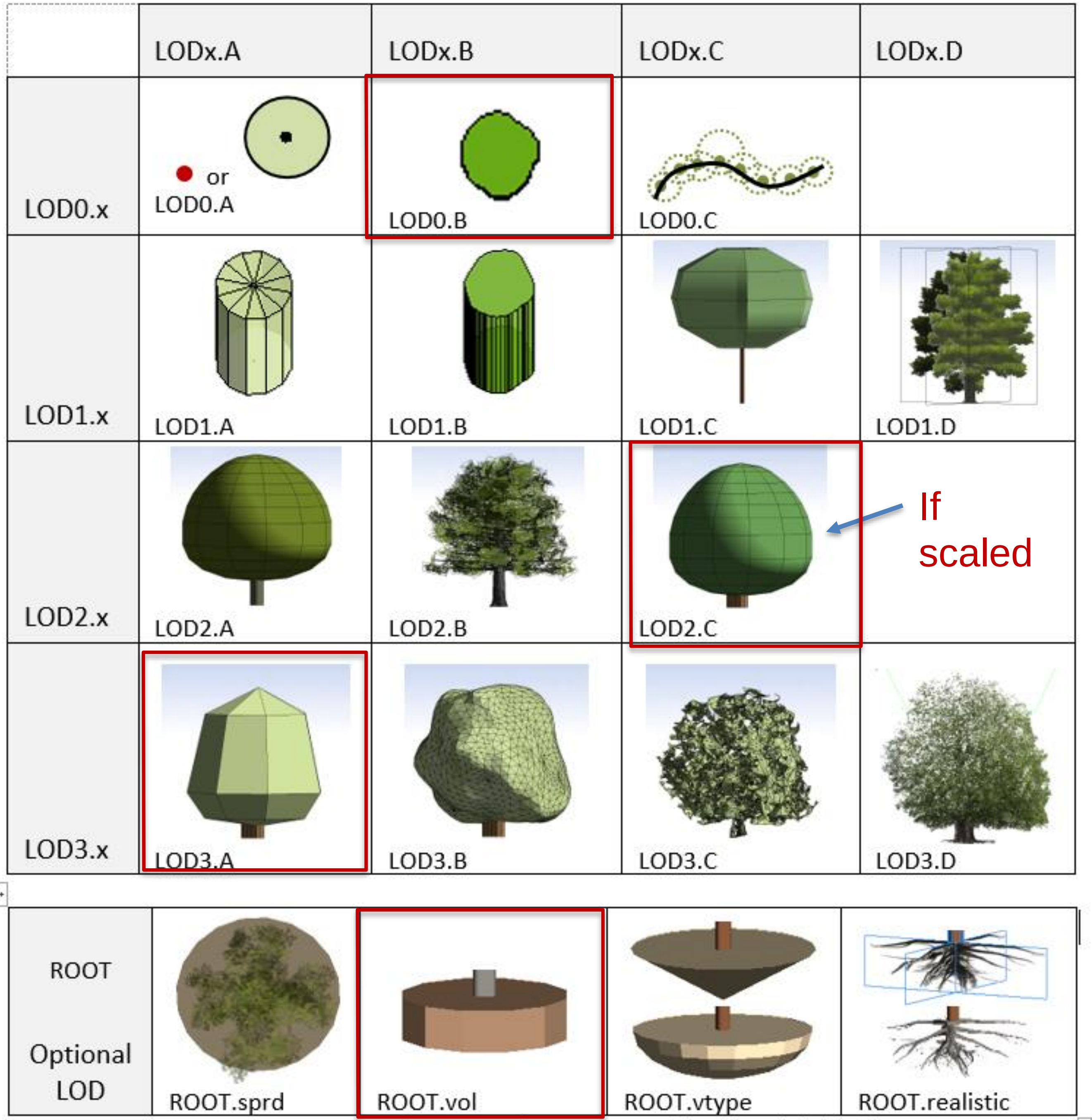


LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

Refined LODs

Acquisition and IT Resources demand

- Low, process hundreds of SVOs
  - Basic parameters and implicit models
- Higher, some manual intervention, process hundreds of SVOs
  - Point cloud data, underground data, specialized software, expertise
- High, manual, process few SVOs
  - Point cloud data, specialized software, expertise



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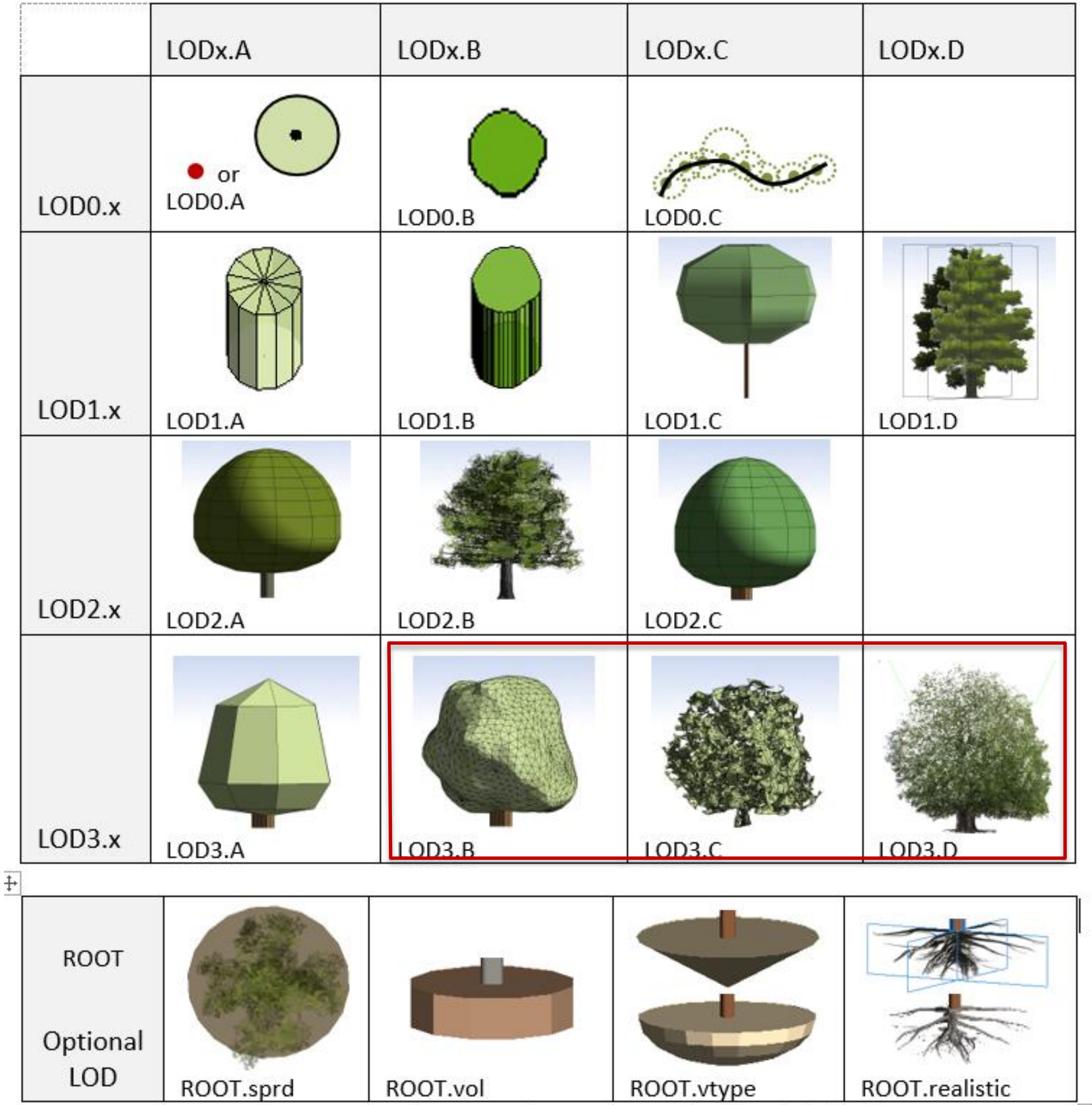
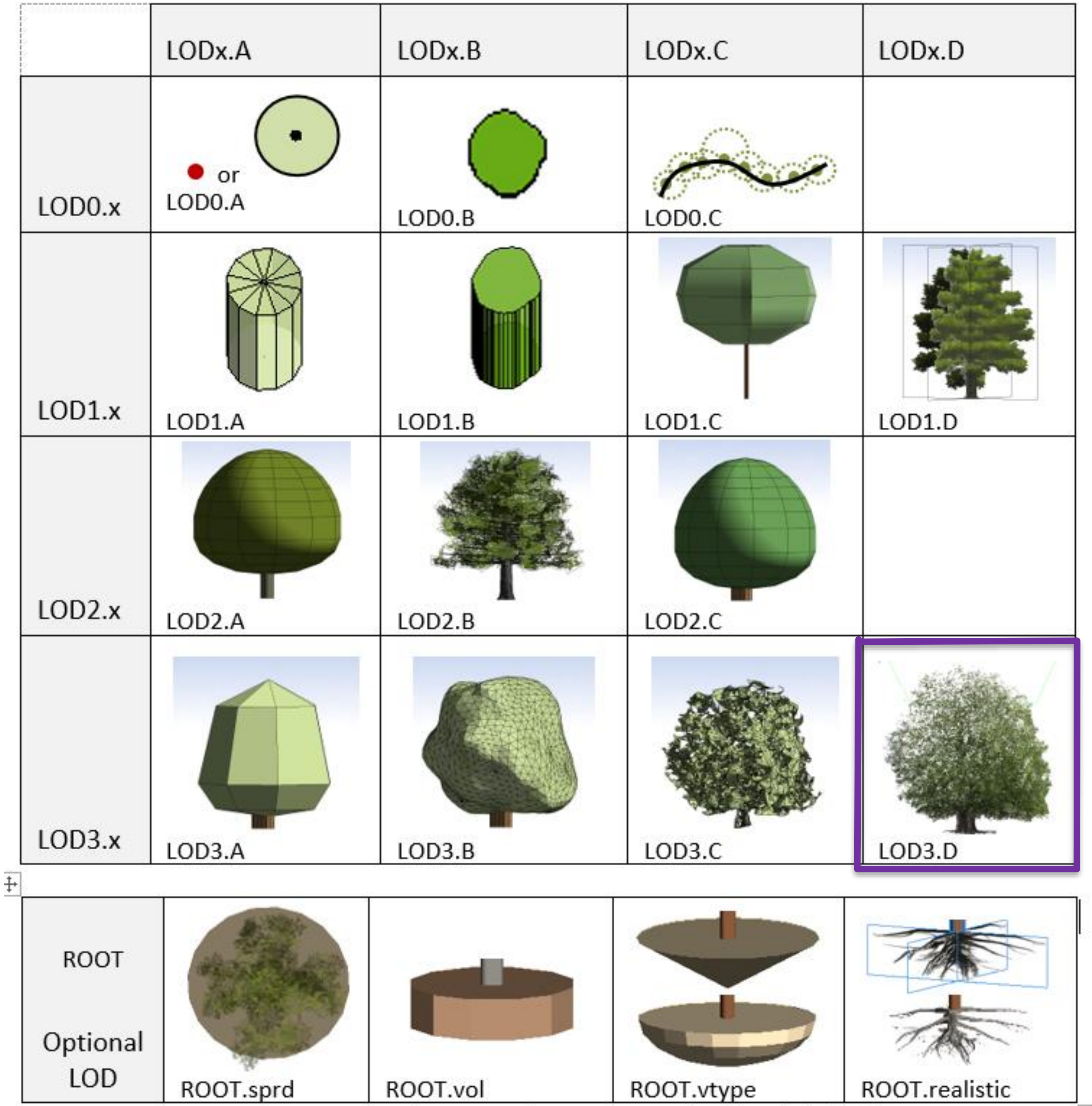


LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

Refined LODs

- **SVOs** with **multiple:**
  - **Dimensionalities** 2D, 2.5D and 3D, 0D, 1D
  - **Adherence** in **appearance** and **form**
    - Realistic variations
    - Basic height, width
    - Implicit - volumetric, billboard models
    - Parametric
    - Reconstructed (crown, **trunk, branches)**
- **Components** with
  - Crown: adherence in form (type, species) and properties
  - Root: spatial requirements
  - **Trunk**: volume- model - biomass



LOD1.D, LOD2.A and LOD2.B and some roots are library models (ESRI)

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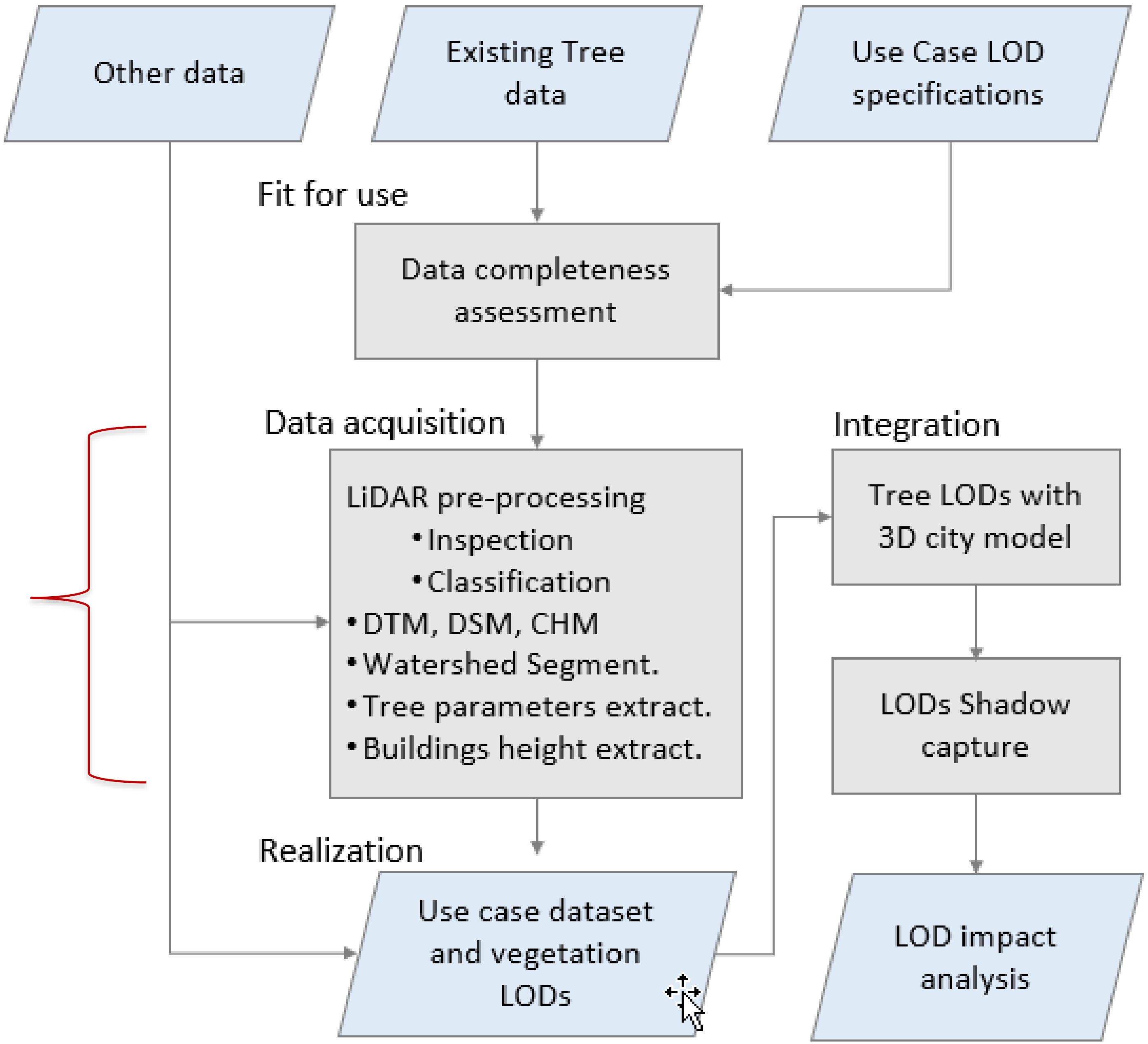
Methodology

- Case study: Shadow assessment of LODs

Acquisition techniques and demand of resources: computing, storage, software tools, expertise



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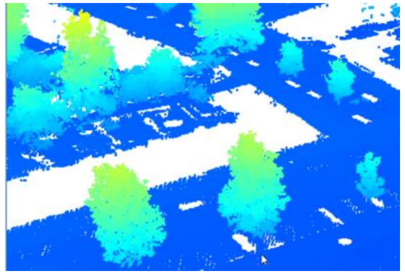
Methodology - Case study: Shadow Assessment of LODs

- Scope
  - Started in an internship with the 3D project team in the municipality of Rotterdam
- Tools
  - Use existing mainstream software tools used at the municipality, and
  - Open source tools, as much as possible to:
    - further develop process
    - integration with other 3D projects.

Methodology - Case study: Shadow Assessment of LODs

Data:

- The municipality of Rotterdam tree inventory
  - Trees managed and maintained by the municipality
- LiDAR data as the main 3D spatial data source
  - Aerial LiDAR data from 2015-2016 of 30 points m^2 in city areas
  - Mobile LiDAR data from 2014 of 358 points m^2
  - Digital terrain model (DTM) from LiDAR 2015-2016; 50 cm cell size



- Vector 2D data
  - Administrative boundaries for clipping areas
  - Large scale topographic vector data, BGT 1:1K for building segmentation
- Satellite photograph
  - NEO Netherlands Space Office (2017) from 15/5/17 for segmentatio
- 3D vegetation model library
  - ESRI-LumenRT an E-on product.

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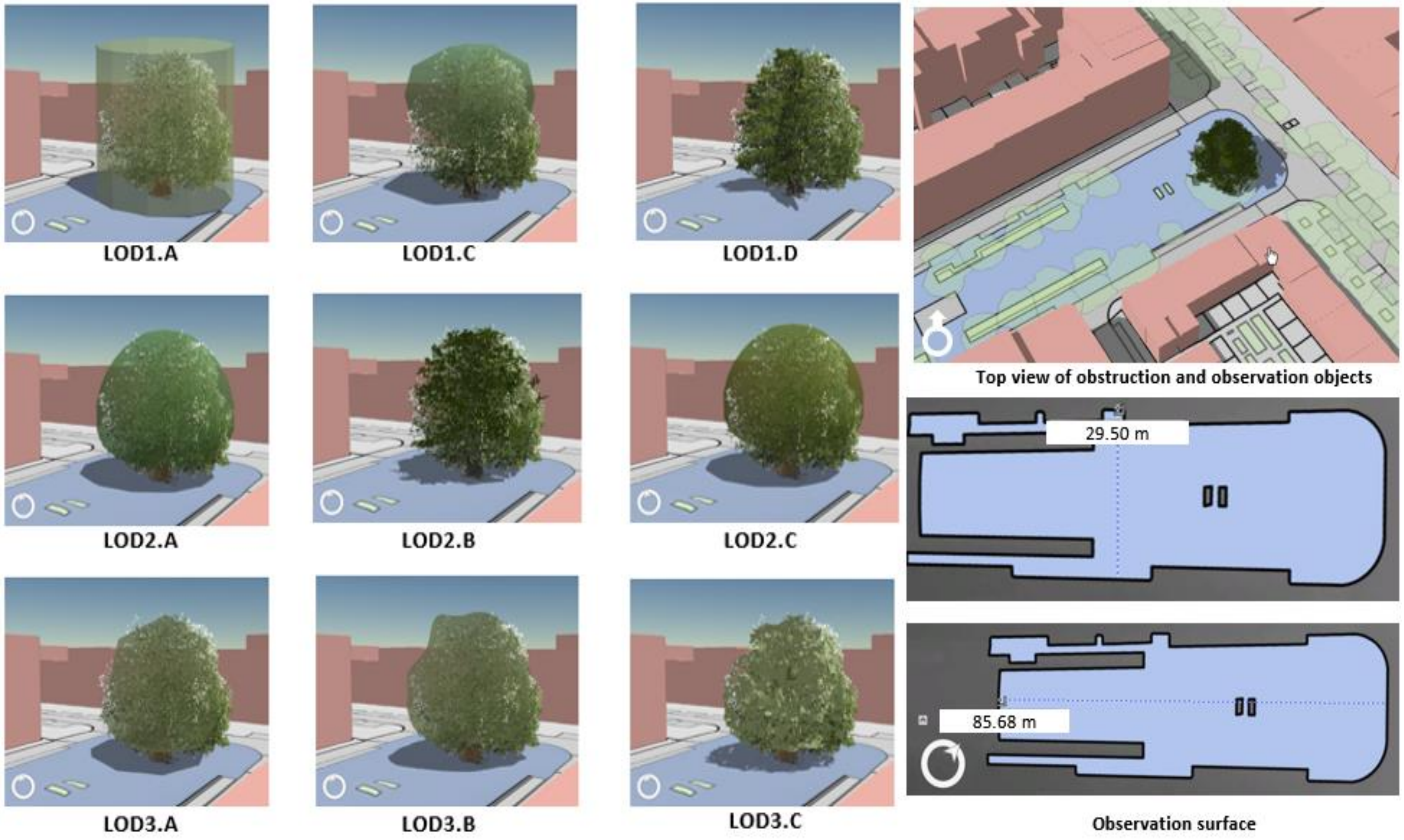
Shadow Analysis

Aesculus hippocastanum with Tree ID: 70562 in Burgemeester Hoffmanplein and Van der Takstraat



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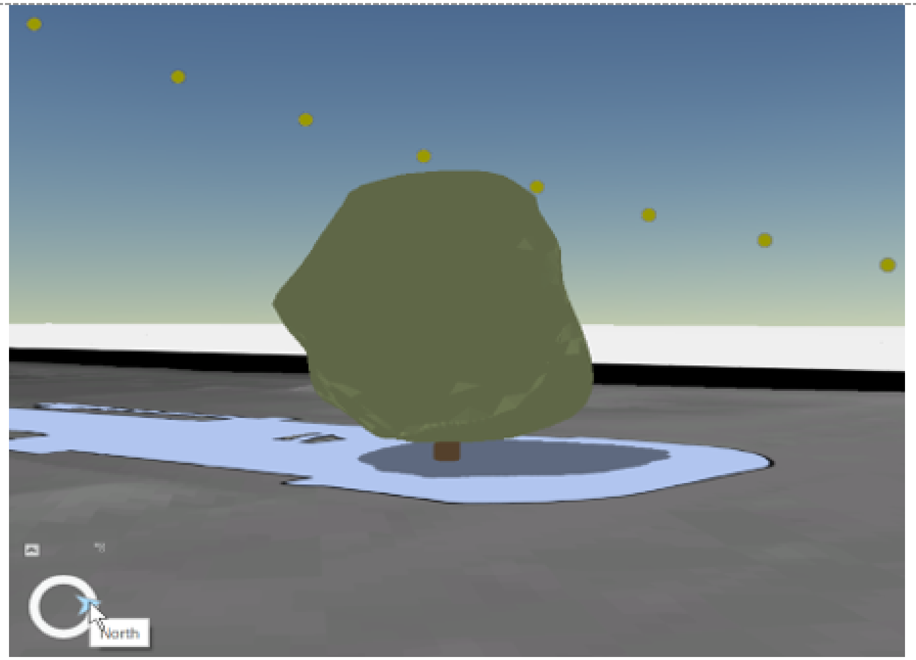
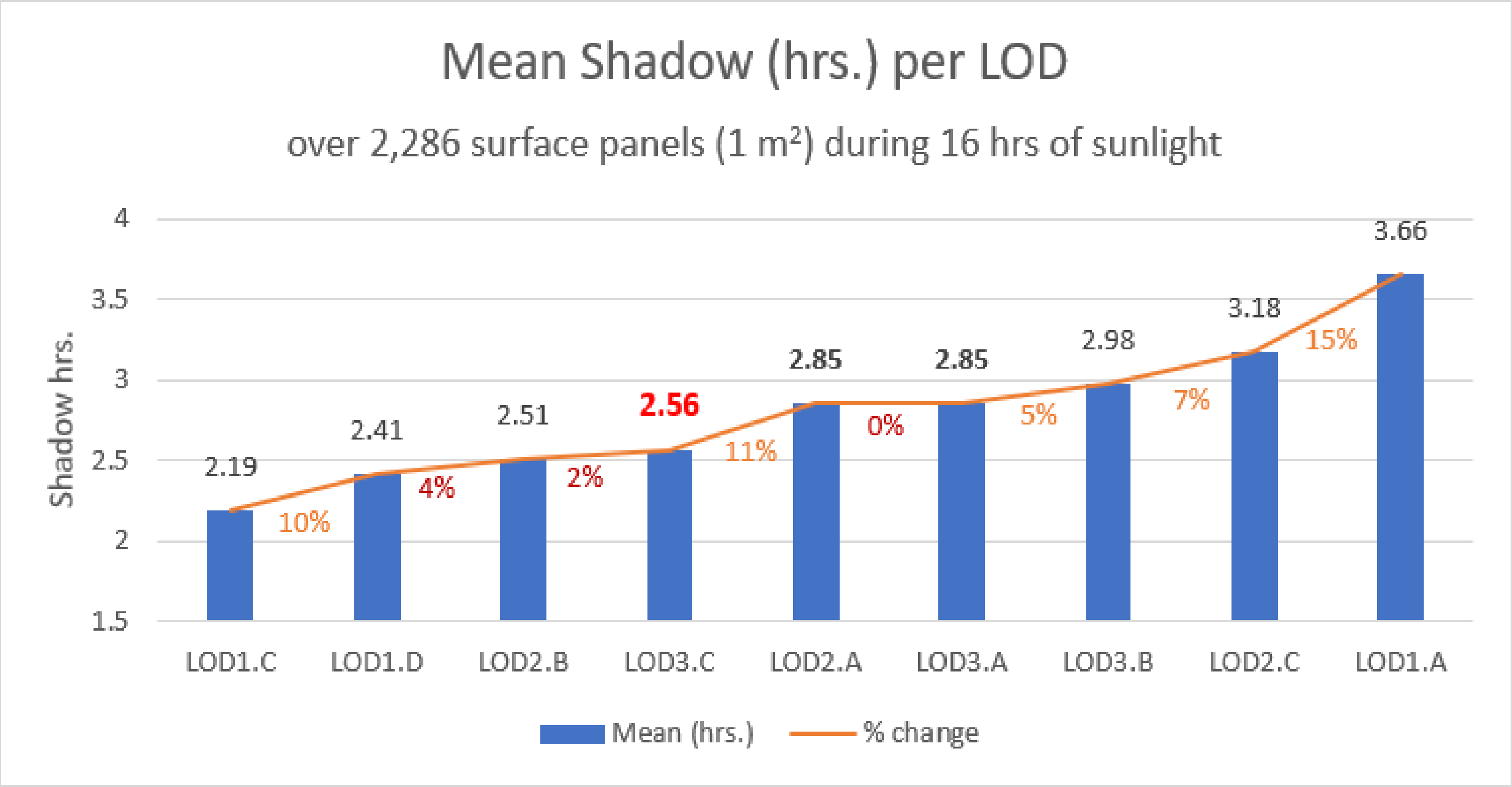
Shadow Analysis Setup

Sun Position Settings	
Observation surface	Pedestrian area (colored in blue)
Elevation	Noordereiland's DTM
Time zone	Amsterdam (UTC+ 01:00) including daylight savings time
Date	June 21st, 2017; longest day
Period	5:18 AM to 10:06 PM
Time interval	30 minutes

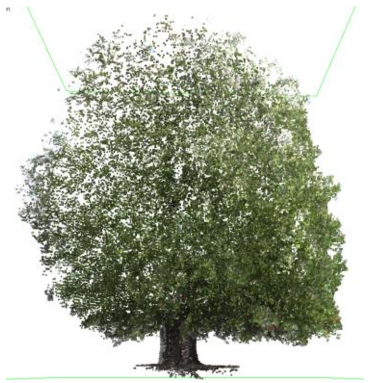


- Aesculus hippocastanum, obstacle surface
- Pedestrian surface, observation surface in blue
- Sun positions on sky and NW sunset
- North cardinal direction points to the right

Shadow Analysis Results



- Longest day: 16 hrs. daylight: June 21, 2017
- LODs of an Aesculus hippocastanum
- Hours of shadow captured by 2,286 panels surface



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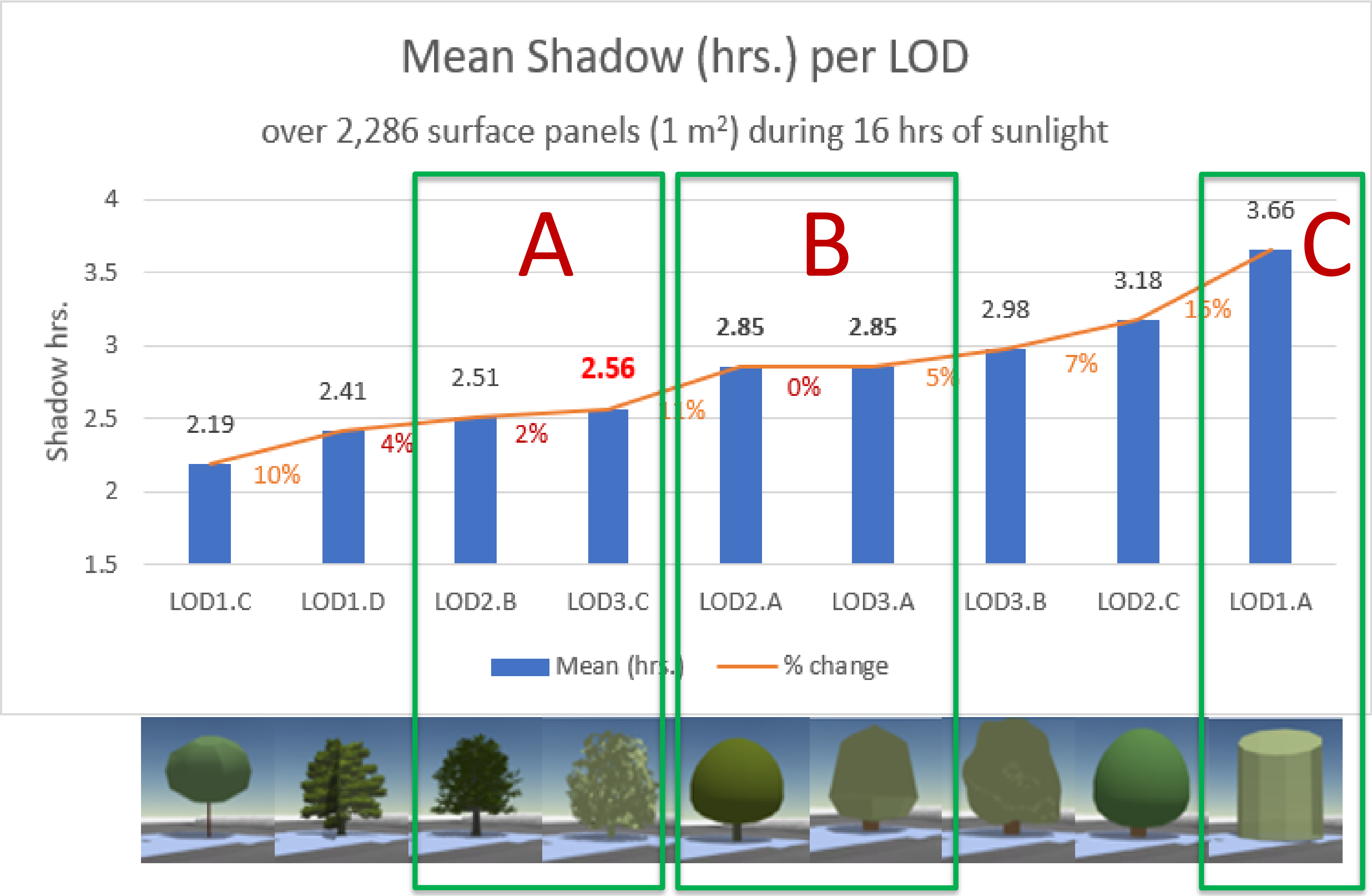
Shadow Analysis Results



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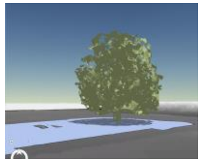
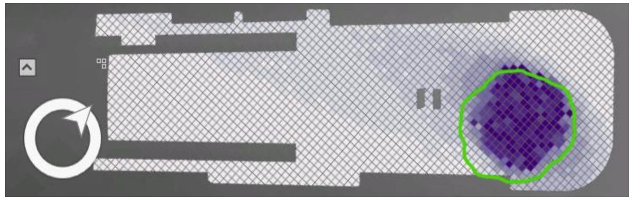
Findings Shadow Analysis

A

Difference = Test (LOD2.x) – Base (LOD3.C)

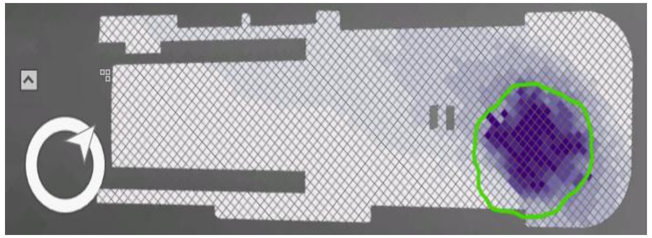
LOD3.C



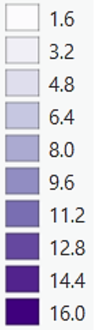


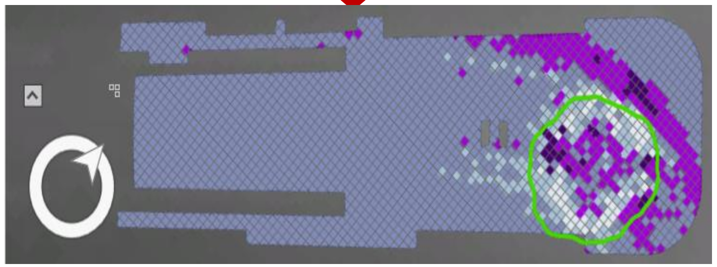
Mean = 2.56 hrs.

LOD2.B

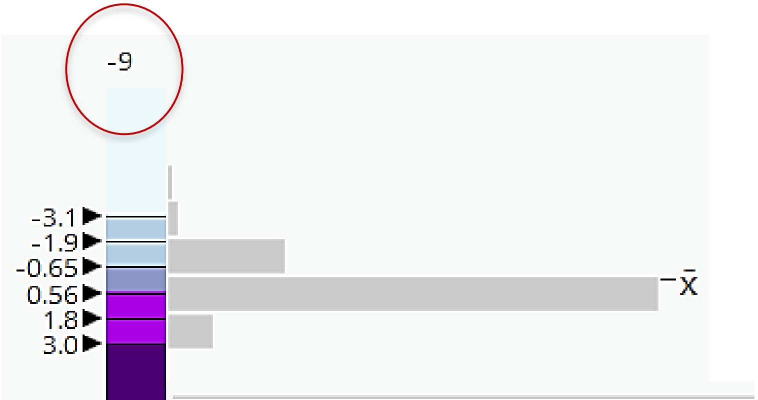


Mean = 2.51 hrs.





- Close match of implicit of same genus
  - Not so similar if irregular crown
  - RW crown shape is fairly regular



Statistics

Count	2286
Minimum	-9.00
Maximum	8.50
Mean	-0.05
Standard deviation	1.21

Findings Shadow Analysis

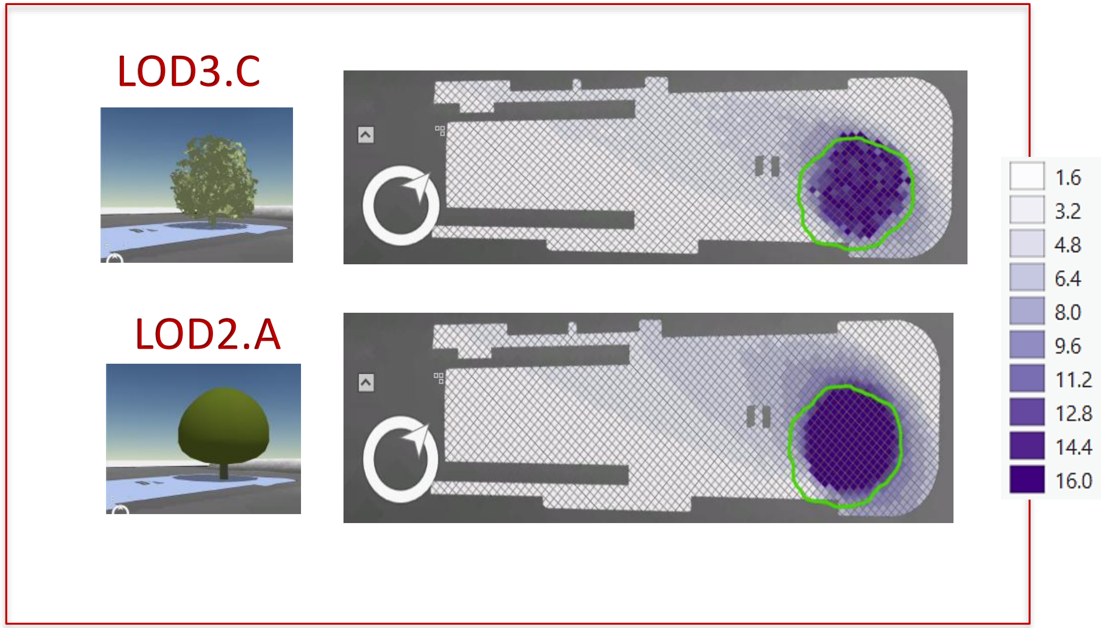
- Although LOD2.A and LOD3.A produced **same mean hrs.** of shadow, it depends where on the surface
  - Max and min. shadow hrs. differ, e.g., when compared with highest LOD

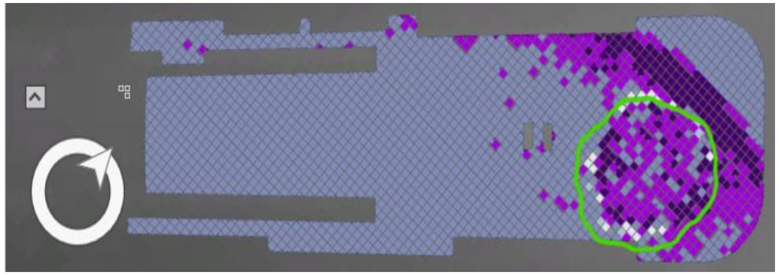
Difference = Test (LOD2.x) – Base (LOD3.C)

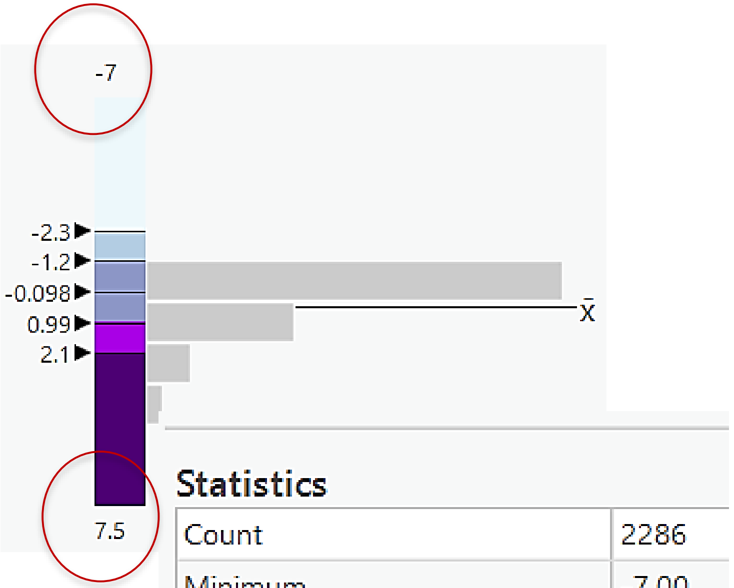
B

Mean = 2.56 hrs.

Mean = 2.85 hrs.







Statistics

Count	2286
Minimum	-7.00
Maximum	7.50
Mean	0.45
Standard deviation	1.09

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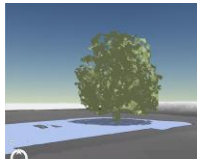
Findings Shadow Analysis

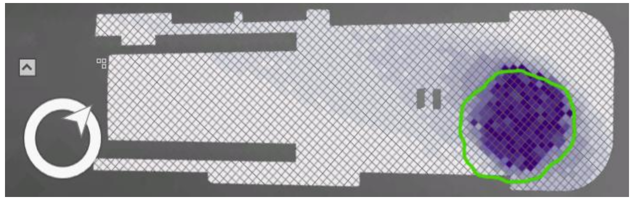
Difference = Test (LOD2.x) – Base (LOD3.C)

B

Mean = 2.56 hrs.

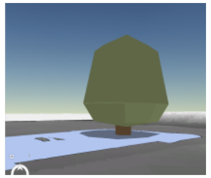
LOD3.C

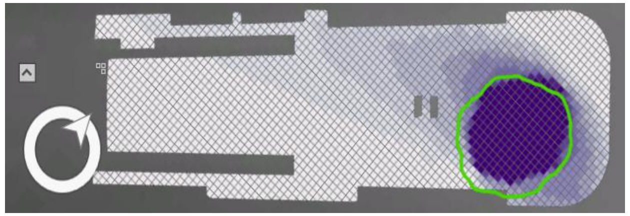


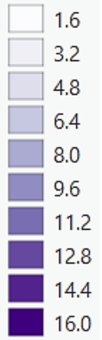


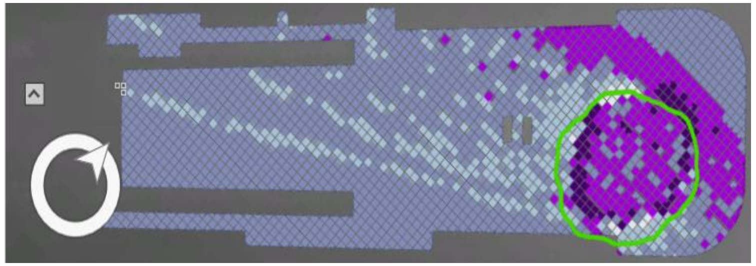
Mean = 2.85 hrs.

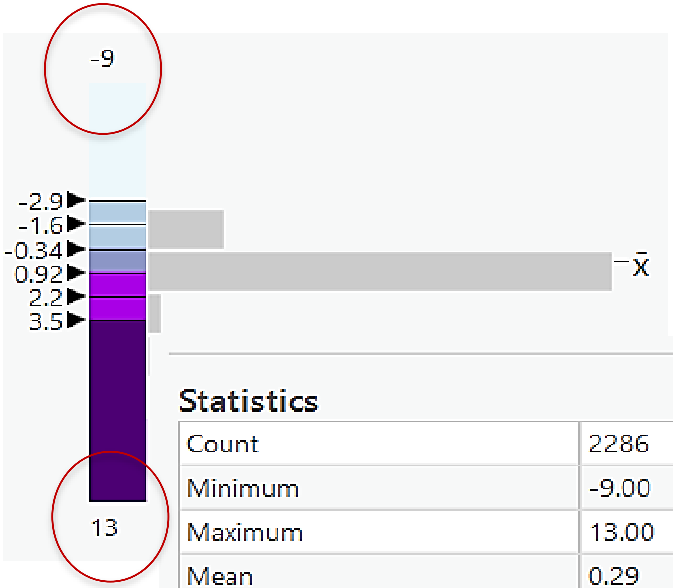
LOD3.A











Statistics

Count	2286
Minimum	-9.00
Maximum	13.00
Mean	0.29
Standard deviation	1.27

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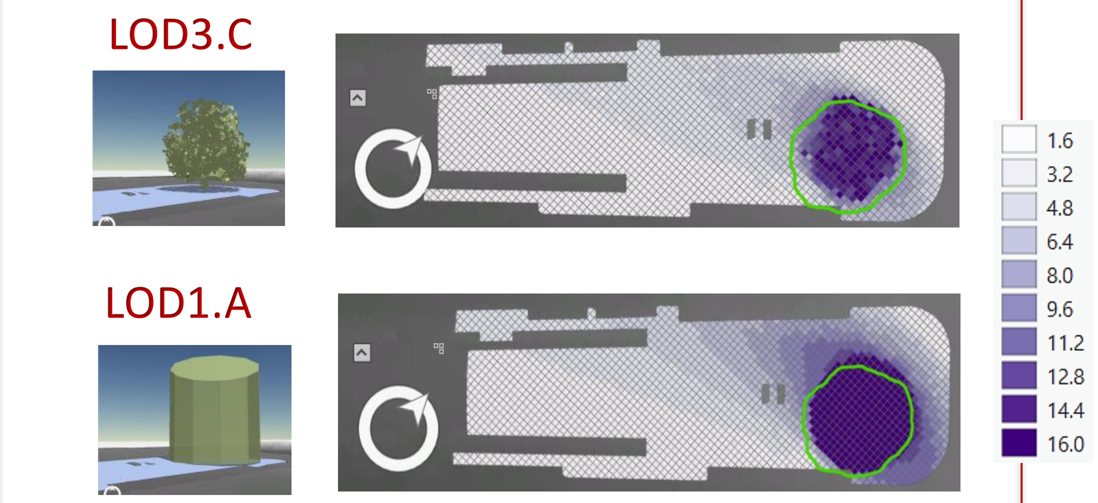
Findings Shadow Analysis

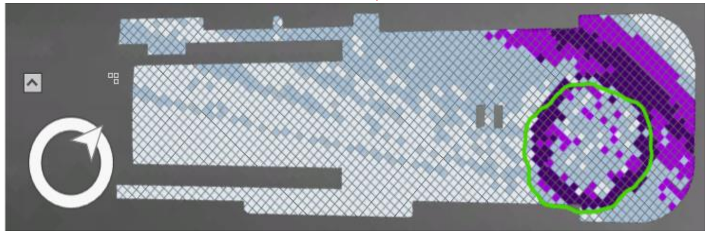
Difference = Test (LOD2.x) – Base (LOD3.C)

C

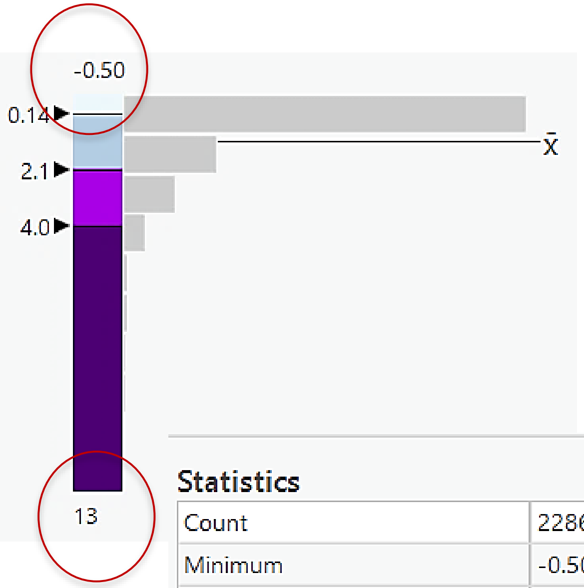
Mean = 2.56 hrs.

Mean = 3.66 hrs.





- Cylinder best extreme case to assess maximum shadow spread



Statistics

Count	2286
Minimum	-0.50
Maximum	13.00
Mean	1.10
Standard deviation	1.92

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