

PlantingSMART: The Parametric Approach for Trees in BIM with Full Lifecycle Application

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Abstract: The purpose of the study is to test the methods of and to evaluate the effects of a proposed parametric modelling approach to developing the individual tree model in BIM software for the full lifecycle application.

Current tree models can't utilize many benefits of BIM, such as clash detection, scheduling, and quantity-take-off. We experiment with a parametric approach towards estimating the shape and growth of trees in a BIM environment with different levels of LoD (Level of Detail).

The selected envelope model allows for a description of a wide range of crown forms, including asymmetric forms for existing trees and symmetric forms for planned trees. It also includes the growth function with specific parameters for overall height, height of clear stem, largest crown diameter, height of largest crown diameter, length, and depth of root, and helps calculate the shapes and volumes in time (age), while describing the morphological traits of a tree specific to its inherent species characteristics.

Apart from the geometry of the model, we define the information required in each design stage and lifecycle phase as a consistent parameter set based on our proposed modelling approach, attempt to standardize for landscape BIM elements.

The proposed envelope model, function, and parameter sets are shown to be effective. We implemented a set of Revit families, including generic models, and a list of species used for teaching in higher education in Switzerland. We successfully performed clash detection, connected to assets for real time visualization, and validated the proposed parameter set by demonstrating the use of the model during the construction phase and handover of the Digital Twin to GIS.

The parametric tree object is an important element in the development of BIM for landscape architects and contractors. It ensures that designers, contractors, suppliers, and clients can use the same object across the entire life cycle for the project. Parametric trees will create a better link between the BIM model and the building environment, and give us the possibility to create intelligent facility management models, also known as digital twin.

Keywords: BIM, parametric tree model, Extract-Load-Translate (ELT), machine operator

1 Introduction

Through a developing experiment, we present a parametric approach towards a full lifecycle application to trees in a BIM environment. We propose a tree with complete and archiving BIM standards and capabilities, which includes crown and roots as solids/mesh for clash detection, parameters for performance analysis, and LoD. It is consistent in classification, and the parameter sets allow for automatic scheduling, age representation, and shapes and sizes specific to species. Its data exchange is on a parameter level rather than a geometry level. Its parameters are concise and correctly describe the shape and growth for existing, generic, and species-specific trees based on parameters and allometric relationships.

The proposed BIM trees are developed for a full life cycle application. It functions well with design optimization, instant rendering, and guidance of machine operators on construction site through developed applications. The attributes of the trees allow for seamless integration between BIM to GIS, and help to make workflow more efficient from design to construction, management, and the Digital twin models.

2 Experimenting with the Parametric Approach

2.1 Method: Parametric Approach to the Tree in BIM

The methods for development of the parametric is as follows:

- 1) Select an envelope that allows for description of asymmetric forms of existing trees, as well as envelopes for a wide range of different species of planned trees, using easy to understand parameters and common allometric relationships.
- 2) Select and define the number of growth functions for calculating shapes and volumes by time (age), and for describing the morphological traits of a tree specific to the characteristics each species.
- 3) Develop a consistent parameter set for trees over their complete life cycle to realize cloud-based BIM synchronization between the files and management using digital twin. We propose parameter sets for proper classification and information collection from the construction site, linking them to models with a unique asset identification ID such as an attached QR/bar code label. We facilitate bidirectional workflows between BIM data and GIS by API-based Extract-Translate-Load (ETL) and snapshot software.
- 4) Test the proposed modelling approach in the Dynamo visual programming environment and Revit family program, develop an app to guide the machine operator at the construction site, and realize a more efficient workflow for the management of smart landscape and smart city architecture.

2.2 Selecting the Algorithm Model for Envelopes of Crowns and Roots

Crown envelopes are the basis for creating crown volumes, and for correct visualization of crown-volume-based performance analysis. They are commonly used in forest measurements and stocktaking (WEISKITTEL 2011). We use the asymmetric hull model originally proposed by HORN (1971) and KOOP (1989), and then extended by CESCATTI (1997), which is defined by using six control points in six directions and two shape factors that control convexity.

For symmetrical tree shape, the parameter set can be aligned with parameters used in forestry and tree nurseries. These include total height of the tree ($HT = P1.Z$), clear stem height or height to the base of the live crown ($HLBC = P2.Z$), spread or largest crown radius ($LCR/2 = P3.X, P4.Y, -P5.X, -P6.Y$), and the height of largest spread or crown radius ($HLCR = P3-6.Z$).

The shape parameters can be considered as constant over the life of a tree and inherent to the species. Thus, the shape of the crown at a specific age can be calculated as a rotational object by the lower and upper heights, and the largest crown radius and the height of the largest crown radius can be spread as a function over time using species related parameters. The model can be extended to root systems as well, based on information of typical root forms and allometric parameters describing the relationship between crown and root (KOOP 1989).

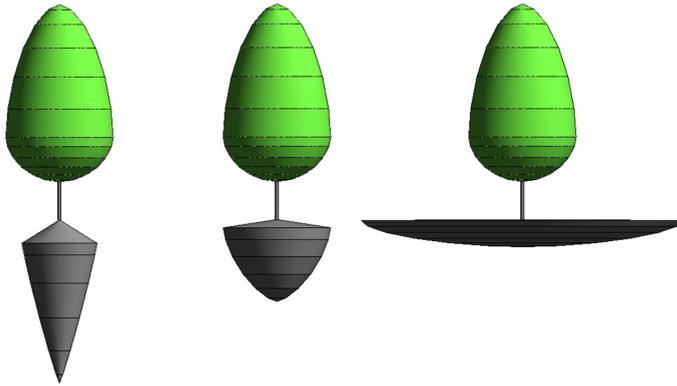


Fig. 1: Typical root forms based on parameters for ultimate depth, ratio crown radius to root radius and one single form parameter

2.3 Selecting Algorithms and Parameters for Describing Tree Growth

The change in the size of an individual over time can generally be described using growth functions (BURKHART & TOMÉ 2012). They are often based on Von Bertalanffy's hypothesis, which expresses the rate of growth of an organism as the difference between anabolic rate (constructive metabolism) and catabolic rate (destructive metabolism). Most of them express an S-shaped curve between the initial and final size (the lower and upper asymptotes), a lag phase, an accelerated growth rate until their time of maximum growth (inflection point), and finally a slowed growth rate upon approaching the final size. We selected the Chapman-Richards growth function, one of the most popular models for describing the growth of various trees and forest stand growth variables, such as tree and stand height, diameter at breast height, basal area, and volume. Using a site index to describe the quality and availability of resources, we can estimate the final height of a tree based on its given location (i.e., expressing differences between optimal conditions in a park, limited open surfaces in urban settings, or soil depth over underground car parks).

In the Chapman-Richards function, the curve starts with germination and has only three parameters. This function can be further re-parametrized for direct interpretation of important characteristics of observed growth patterns. Here is the function:

$$h(t) = h_{\max} * (1 - \exp(-K/t(d^{d/(d-1)})))^{1/(1-d)}$$

$$\text{with inflection point } t_i = \ln(1/(1-d))/K * d^{d/(d-1)}; h(t_i) = h_{\max} * d^{1/(1-d)}$$

Table 1: Explanation of variables in the function

Parameter	Function (meaning)	Interpretation
h_{\max}	Upper asymptote	Adult value
K	Slope at inflection	Maximum relative growth rate
t	Time at inflection	Age at maximum growth
$d^{1/(1-d)}$	Proportion of upper asymptote at inflection	Relative value at maximum growth

As growth estimation has long been established through yield tables in the forestry industry, we have a reliable base for the estimation of tree growth in an urban environment. The curve can be fitted using an iterative nonlinear regression obtained from known values. As we often have empirical knowledge about the parameter h_{\max} , K , and t_i , we can determine the shape parameter directly.

2.4 Developing Consistent Parameter Sets for the Whole Life Cycle of Trees

Extending the dataset to consider information exchange throughout the whole lifecycle is a key benefit to using BIM in a collaborative environment. Efficient information exchange requires certain information in certain formats to be delivered to the client and project partners at key points during the project lifecycle as data becomes available.

We propose a parameter set based on the UK Product Data Template for COBie, with additional parameters to aid in proper classification. Due to the lack of IFC standards in landscape architecture, we also include national classification systems (eBKP for Switzerland, Uni-classes, or OMNIClasses).

We also propose additional parameters for information collection during the construction process, including parameters for the contractors, procurement, installation, quality checks, and commission information. With a standardized parameter set, this data can be digitally collected. Construction data are usually recorded in a relational database, and the link between the models and the database is established through a unique asset identification ID.

The reliable asset tracking system with unique identifiers is the key to successfully implement a cloud-based BIM synchronization system and for facilitating smooth handovers to facility management. The asset tag can be an attached QR/bar code label or an RFID tag used for scanning and tracking.

2.5 BIM Data Integration for GIS-based Landscape Facility Management Using Digital Twin

After construction is completed, the tree in BIM is to be setup for its maintenance using the digital twin modelling system. Because landscape facility management using digital twin is mostly based on a GIS system, seamless integration between BIM to GIS is critical. The display of GIS information within BIM is already well established. However, the integration of BIM information within GIS still requires a three-step process. First, the required content gets extracted from the BIM system and stored outside the source in an intermediate format like IFC, CSV file, or Excel. Second, these data are translated into a schema readable by GIS. This task often involves removing missing or outlying data, converting variable formats, and even more important translation between coordinate systems. Finally, the data are 'loaded' into the GIS software.

More seamless integration can be achieved using the Extract-Load-Translate (ELT) process. Standard API allows for reading of content from a snapshot of the BIM system data, and waits for translate data for use as native content. As the creation of the snapshot can trigger an automatic refresh/update on the GIS, ELT preserves the connection back to the BIM system and can facilitate bidirectional workflows.

3 The Implementation in Dynamo and Revit Families

The implementation step applies the parametric approach by experimenting with it in Dynamo and Civil 3D. We focused on Revit and created two all-purpose generic families, one for existing trees with asymmetric crowns and one for new trees with symmetric crowns. With a growing number of parameter sets, we organized such information in a database and established a connection with an existing plant database.

3.1 Testing Algorithm and Parameters in Dynamo

Dynamo is a visual programming environment from Autodesk for Revit and Civil 3D. We developed a set of Dynamo scripts for testing the asymmetric hull model and the Chapman-Richards growth function. The Dynamo environment allows immediate visual control of the results, allowing experimentation with different parameters and algorithms.

It showed that the asymmetric hull and Chapman-Richards growth function can be implemented into the design software from Autodesk with reasonable effort.

We found that we need different parameters of the growth functions for height, height of clear stem, largest crown diameter, height of largest crown diameter, and root depth, as they vary more widely in their characteristics. Roots reach closer to the maximum depth much faster than the crown reaches its maximum height. For many species, the spread relative growth rate lags behind the height relative growth rate in younger trees, but in mature trees, the height growth rate is relatively small as the spread continues. The spread of the roots can be related more closely to the spread of the crown than the root depth.

3.2 Developing Revit Families

In accordance with the requirements for defining the LoD in BIM standards we developed three families.

1) Family for existing trees using asymmetric hull

This model is based on 6 geometric controlling points for the crown and 2 shape parameters: the height of clear stem and diameter at breast height (DBH). The six points and two shape parameters can be interactively adjusted, and a Dynamo script creates and updates the complex form of the crown envelope and stores it as a solid/mesh inside the Revit family. The critical root zone (CRZ) is derived from the DBH and crown drip line ($CRZ = DBH * 12$ or the crown drip line, whichever is bigger).

Attached is the information from the arborists (number (id), common and Latin name, protection class, health, remove/remain/credited) for preparing tree protection plans and tree survey tables with mitigation measures.

2) Generic tree with basic forms (symmetric) and basic growth characteristics.

This family looks at symmetric crowns based on height, diameter, clear stem height, root depth, and allometric coefficients (relative position of largest diameter, Height/DBH, Root/Crown, two shape parameters for the crown, one shape parameter for root). This family comes with common types for planning (i.e. slow growing, medium height, narrowly conical evergreen broadleaf tree) with associated parameter sets. The appearance of foliage for summer and autumn, and clear stem height can be adjusted in each instance. The referenced size is that of a 25-year-old tree.

3) Species type tree

The species-specific information is defined using its common and Latin names, the characteristic size and growth (25 years reference size, ultimate size, growth rate, shape factors, allometric coefficients) links to plant databases, available nursery stock sizes, construction requirements, and yield.

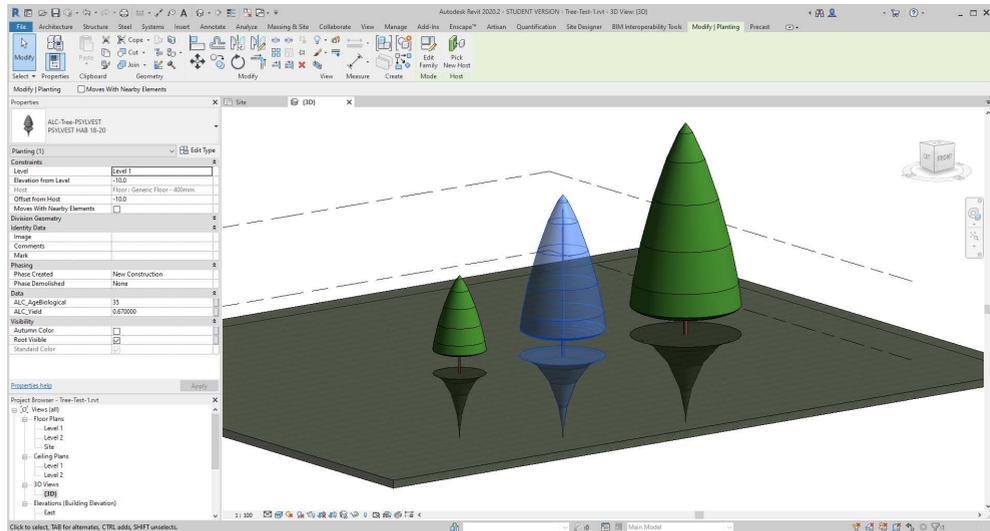


Fig. 2: Revit species type tree with parameters in different ages

3.3 Developing an App for the Guidance of Machine Operators on the Construction Site

The application was developed with Autodesk's cloud platform Forge, using services and APIs for accessing drawings uploaded to BIM360. The viewer is embedded in a standard web browser, and design automation API was used for updating the BIM model with the information collected from the construction site. All data exchange between different mobile devices are handled with nodejs and javascript, and the viewer extensions handling the overlay of the BIM model, label decoding, and real-time positioning information are coded in javascript.

3.4 Workflow for the Management of Smart Landscape Architecture and Smart City

As this is the prototype, we demonstrate a manual ELT approach extracting tree data from Revit with Dynamo and exporting it to a CSV file. The file is loaded and translated using GIS (QGIS) software, and there it is overlaid with other spatial information (a point cloud). Then, by using an API-based ETL, the snapshot is created by uploading or syncing a Revit drawing on the BIM360 server. With the Forge 'model derivate' API we can directly query the Revit file and access all information related to the trees and push them as JSON into the QGIS API.

4 Results

Through experimentation, it has been verified that the proposed parametric approach with a consistent property set can create tree models that work throughout the complete life cycle of a tree. We have built more than fifty tree species using this parametric approach. These smart tree models have BIM functions that include real-time visualization, clash detection, and automatic mechanical applications. The tree species include: *Acer campestre*, *Alnus glutinosa*, *Alnus incana* 'Aurea', *Acer platanoides*, *Acer pseudoplatanus*, *Betula pendula*, *Carpinus betulus*, *Fraxinus excelsior*, *Fagus sylvatica*, *Juglans regia* Sämlinge, *Laburnum anagyroides*, *Liquidambar styraciflua*, *Liriodendron tulipifera*, *Magnolia soulangeana* (x), *Prunus avium*, *Platanus hispanica* (x), *Populus nigra*, *Populus tremula*, *Prunus yedoensis* (x), *Quercus robur*, *Robinia pseudoacacia*, *Salix alba*, *Sorbus aria*, *Sorbus aucuparia*, *Salix caprea*, *Tilia cordata*, *Tilia europaea* (x) 'Euchlora', *Tilia platyphyllos*, *Abies alba*, *Juniperus communis*, *Larix decidua*, *Picea abies*, *Pinus mugo*, *Pinus nigra* subsp. *Nigra*, *Pinus sylvestris*, *Sequoiadendron giganteum*, *Taxus baccata*.

We selected *Tilia cordata*, a tree with a medium growth rate, as an example to illustrate the results. The shape parameters can be easily estimated from the silhouette picture (Figure 3). The two super-elliptic arcs can be approximated by two splines each with 3 CV (control vertices). The weight of the middle CV is directly related to the shape factor of the super-ellipse.

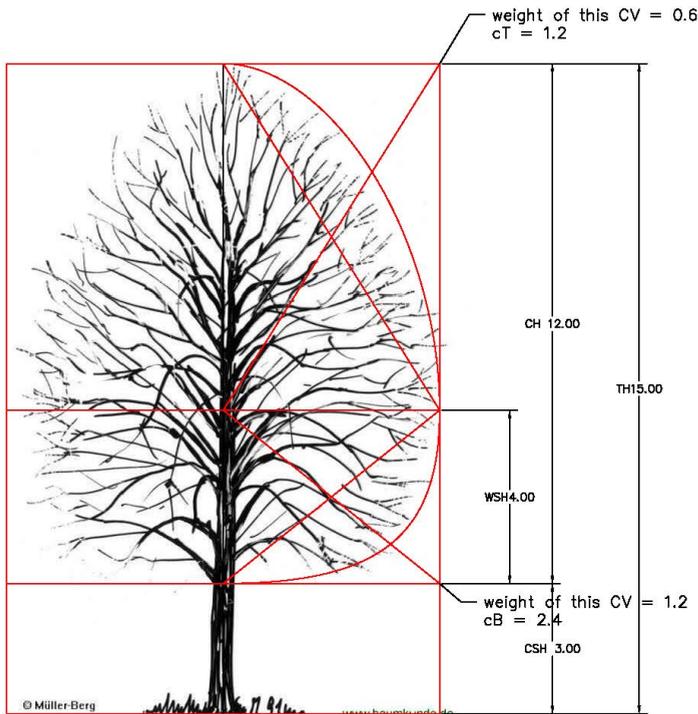


Fig. 3: AutCAD Drawing of the silhouette of *Tilia cordata* Mill

The main sources for obtaining data to estimate the growth function’s parameters are forest inventories, nursery production data, and plant databases. The reference data we are using for the curves were developed from a 2012 Bavaria forest inventory, in addition to standard size data found in literature and plant databases (Jardin Suisse i.e.). The maximum growth rate and the time of maximum growth ($K = 0.6$ m) is well-known from tree nursery production data, as well as the ultimate height (40 m) reduced by the yield factor (0.625) to 25 m. We visually fitted the curve on varying shape parameters ($d = 1.02$) using spreadsheets and line charts. From K_{max} and d we calculated k and p .

We estimated the growth curve for spread and roots based on the relative height growth curve. For the root depth, we know that the maximum root depth is reached very early. For the spread, we adjusted the growth rate and changed the shape to a later inflection point. We visually assessed the resulted shapes with pictures and allometric relationships in charts.

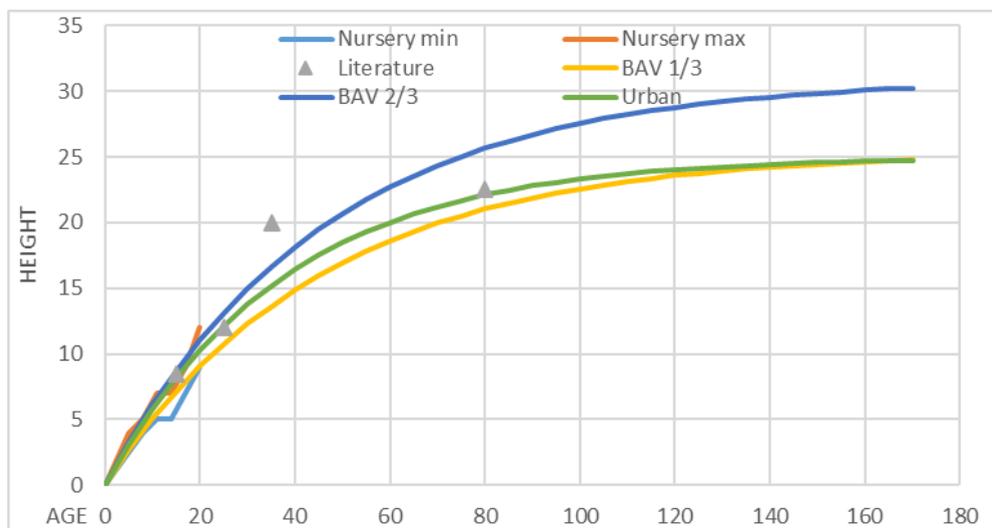


Fig. 4: Growth curve of *Tilia cordata* Mill

Table 2: Parameter for relative growth of *Tilia*

	<u>max</u>	<u>p</u>	<u>k</u>
<u>Height</u>	<u>25.00</u>	<u>1.022</u>	<u>0.027</u>
<u>Spread</u>	<u>10.00</u>	<u>2.000</u>	<u>0.020</u>
<u>Depth</u>	<u>2.00</u>	<u>1.111</u>	<u>0.065</u>

An additional parameter (asset id) estimated the height from the information for asset management in the visualization/rendering pipeline. By linking the asset parameter to the Revit family we can automatically override/replace the BIM trees with high resolution rendering trees inside the rendering environment, without bloating the BIM model (Figure 4).

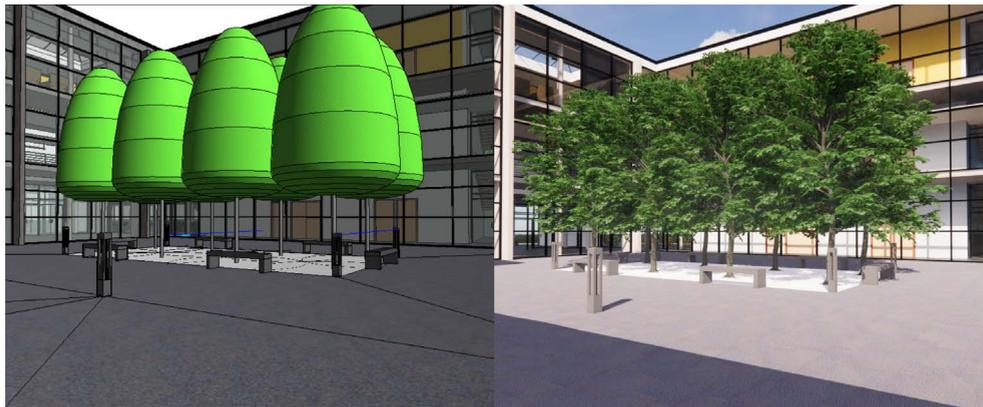


Fig. 5: Family in Revit and rendered in Enscape with the linked assets

The proof-of-concept implementation of an app suite shows that with a consistent parameter set and a unique identifier, it is possible to request and track assets, and give on-site guidance for machine operators. With the main augmented reality app running on a tablet mounted on a machine (i.e. a construction forklift), and connected to a positioning sensor and label reader, the operator can identify an asset by its EAN number, find possible positions for planting, and monitor the machine/asset position. After positioning the tree correctly, the BIM data gets updated by marking the position, and adding values such as planting time. It is also possible use the app to select a specific plant on the plan and send a request to find and identify that plant on another mobile device, and obtain a response from this mobile app.

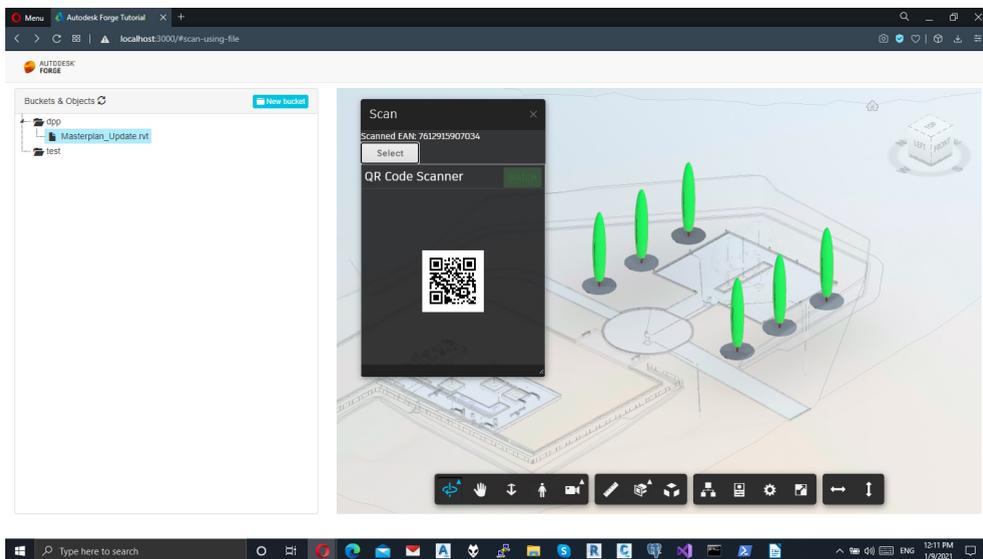


Fig. 6: Forge Application highlighting potential planting positions after scanning and decoding a QR code on the label

The proof-of-concept suggests that it is possible to transfer data from the BIM model into GIS and display it as augmented reality. We show how to extract the necessary information with a manual ELT, and translate it into the correct geographic coordinate system. Inside the GIS software the data are translated into a transparent yet selectable and simple geometry, associated with points from a Lidar based point cloud, and using the data transferred from the BIM system. Thus, data sets include information relevant for maintenance, the metadata of the BIM model, and unique identifiers that allow assets to be found in the BIM model.

We successfully automated this process by creating a cloud service that uses an Autodesk Forge API to query the Revit file and send JSON to the GIS software updating the system. We are also able to use the parametric model to represent existing trees with asymmetric crowns, and simulate their future growth inside the GIS software.

5 Conclusion and Outlook

The parametric tree object is an important element in the development of BIM for landscape architects (or LIM) and contractors. This will ensure that designers, contractors, suppliers, and clients can use the same object across the entire life cycle of the project. Better tree models will make professionals more effective and increase the value of collaboration between architects and engineers. Parametric trees will create a better link between BIM models and the built environment, and give us the possibility to create intelligent facility management models (digital twin).

With the parametric tree model, landscape architects can benefit from BIM capabilities, such as:

- Clash detection with infrastructure and buildings for root and crown space
- Analysing their model by extending the model with performance parameters
- Improving collaboration with other disciplines, throughout the whole life cycle (on-site, FM)
- Reducing duplication of models for different tasks
- Using BIM tools for sequencing and on-site management

The parametric tree can be integrated in the workflow of landscape architecture by connecting the parameter sets to established plant databases, and by using their selection tools as well as connecting the BIM trees with assets for rendering/visualisation.

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