3D tree architecture modeling from laser scanning for urban microclimate study

T. Landes[1], M. Saudreau[2], G. Najjar[1], P. Kastendeuch[1], S. Guillemin[1], J. Colin[1], R. Luhahe[1]

[1] ICube Laboratory UMR 7357, University of Strasbourg – CNRS – INSA Strasbourg, France (tania.landes, samuel.guillemin)@insa-strasbourg.fr; georges.najjar, kasten, j.colin, raphael.luhahe)@unistra.fr

[2] PIAF Laboratory, UMR547 University Blaise Pascal – INRA Clermont-Ferrand, France marc.saudreau@clermont.inra.f

10 June 2015

1. Introduction

The climatic conditions observed in cities are known to be dependent on the presence of urban vegetation. The evapotranspiration process of the vegetation produces a cooling effect and impacts the water and heat balances of urban areas. The project initiated by the ICube laboratory in collaboration with INSA Strasbourg and INRA Clermont-Ferrand aims to provide a better understanding of the impact of trees on the urban microclimate.

The research conducted by the teams involved in this project, in the field of urban climatology, is based on a coupling of two physical models designed for urban climate studies and called LASER/F and SURFEX/MesoNH. LASER/F (LAtent, SEnsible, Radiation fluxes) is a 3D urban canopy model specially conceived for high resolution modeling, at the level of a street. It is designed to work with the real geometry of the town in 3D. After more than ten years of development, the latest version is now able to simulate most of the physical processes (Kastendeuch and Najjar, 2009). SURFEX/Meso NH is designed for urban climate studies at the level of the city. The LASER/F model is fully developed by the TRIO team, while SURFEX/Meso-NH was developed by Météo-France. The LASER/F model is undergoing a major change, particularly through his recent collaboration with INRA Clermont-Ferrand (UMR PIAF). The UMR PIAF (Physique et Physiologie Intégratives de l'Arbre Fruitier et Forestier) is working on the creation of a highly detailed model of the tree, called RATP model (Radiation Absorption, Photosynthesis and Transpiration). The RATP model aims to simulate the spatial distribution of radiation and leaf gas exchange (photosynthesis and transpiration) in vegetated areas, by taking into account the spatial structure of the canopy, microclimate, as well as physical and physiological properties of the sheets (Sinoquet et al., 2001). The combination of the three models RATP, LASER/F and Meso-NH should enable to model thermo-radiative phenomena from the scale of the tree to that of the city.

2. Test area and datasets

The Strasbourg urban community was chosen as test site due to the fact that an important database of micro-meteorological measurements has been collected since 1999 (Najjar et al., 2004; Neusch et al., 2003). An even more important measurement campaign is being implemented since 2012 for understanding the eco-physiological functioning of a tree in the urban environment. Also its influence in the generation of a specific microclimate is studied. Today, 25 measurement sites are operational in Strasbourg and its surroundings. For every site, temperature and humidity are measured. Additional parameters, like for instance speed and wind direction are observed for some of these sites. Among the 25 sites, a vegetated area (urban park) has been chosen, located in the historical garden of the University of Strasbourg. The historical garden is a park with two avenues of silver linden trees (Figure 1). Six trees are equipped with sap flow measurement sensors (Figure 2).

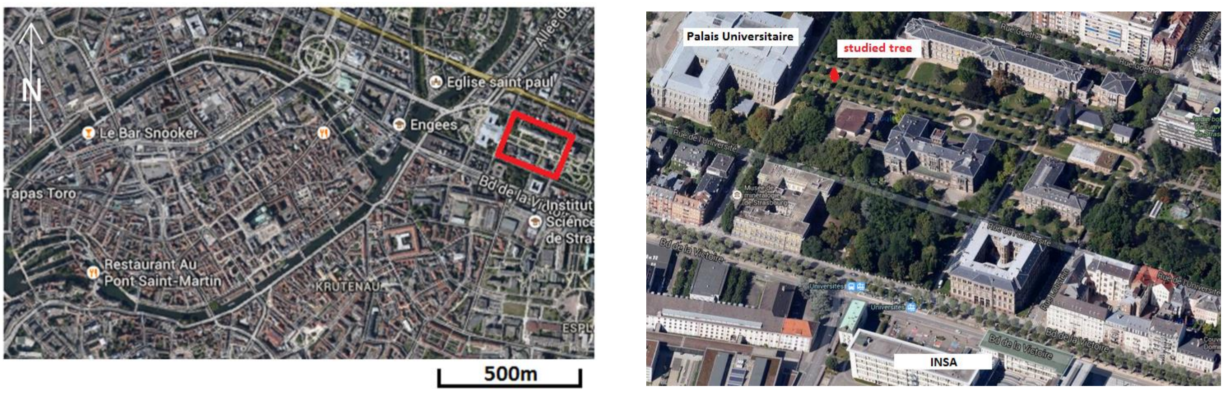


Fig. 1. Vegetated test area of the historical garden of the Palais Universitaire of Strasbourg (Google Maps)

(a) (b)

Fig. 2. Urban park under study, a) with equipped silver linden trees and a 20 m mast; b) The silver linden tree equipped with the most sensors.

The project is unique in France. The type of measurements which are performed are, for instance the study of tree's evapotranspiration, the measurement of sweating of the lawn and soil, the measurement of PAR (Photosynthetic Active Radiation - wavelength 400 to 700 nm), the measurement of moisture and temperature of different levels within the tree's crown, the measurement of climatic parameters at 20 meters above the ground, the measurement of brightness temperature of the tree, grass, and the road, and the measurement of precipitations, temperature and water content of the soil on several levels, from the surface to more than a meter deep. This experimental campaign is currently in progress (Landes et al., 2014).

A crucial information required as input to microclimate models is the geometry of objects composing the study area. The buildings surrounding the measurement site, as well as the trees planted in this area must therefore be modeled in 3D. Very specific parameters characterizing a tree, like the thickness, length, position and volume of the trunk as well as branches, shoots and leaf distribution should be determined, depending on the spatial resolution needed. This requirement resulted in collaboration between climatologists and surveyors.

3. State of the art about 3D modeling of trees

Although the automatic modeling of buildings is a topic which is largely developed in the literature, the issue of automatic 3D reconstruction of individual trees remains rarely mentioned. More papers deal with the extraction of vegetated areas or sometimes individual trees within a forest by remote sensing data classification (satellite images with very high spatial resolution, or airborne lidar and aerial photographs). Three approaches focusing on reconstruction of the geometry of individual trees from the ground can be mentioned: manual and descriptive approaches, approaches based on photographs and those based on laserscanning techniques.

Among manual approaches, many works focus on the representation of the architecture of the tree and its description in terms of topology and/or geometry (Barthélémy et al., 1995). The main method used is the three-dimensional digitizing of tree parts (Sinoquet et al., 1997). This method provides accurate information about plant geometry, but the acquisition stage is very time consuming, especially for trees with complex structures in terms of topology and number of elements (leaves and shoots). It is simply unthinkable for large trees.

Approaches using terrestrial photographs rely either on point clouds generated by dense correlation (Santos et al, 2013) or on image processing in 2D (e.g. Shlyakhter et al., 2001; Delagrange and Rochon, 2011). These approaches have the drawback of requiring a dense photographic coverage of the object, which becomes not practical when several trees must be modeled.

The latter approach is based on the processing of data acquired by terrestrial laser scanning techniques. Terrestrial laser scanning is an emerging technology which is used to capture information on the geometry of an object in form of point clouds. This technique enables the acquisition of a large amount of accurate data in a very fast way with a high level of details (Landes et al., 2011). This technique is widely used in the field of surveying and more specially for building modeling. In the literature, the papers dealing with tree's modeling often present methods for defining and quantifying the distribution of leaves in the crown. Several authors use voxels based methods (Béland et al., 2011, Wu et al., 2013). Other studies using 3D point clouds aim to obtain a reliable 3D reconstruction of the tree's structure (trunk and branches). For instance, Delagrange et al. (2011) has proved the effectiveness of laserscanning techniques for extracting information such as number of branches, height of branches, lengths of the main branches. Regarding these studies as well as the well-known processes already developed by the partners involved in the project, the acquisition by laserscanning technique has been preferred, since it should allow producing a precise geometric representation of a tree. Therefore this work aims to develop a processing chain to automate the creation of 3D models of trees from point clouds.

4. Tree(s) under study

Figure 2b presents the tree under study, with the sensors it is equipped with, i.e. sap flow sensors, radiation measurement sensors, radio-thermometers. Figure 3 presents the point clouds obtained for several acquisition campaigns of the tree at different developmental stages (April, January, July) using a static 3D laser scanner (FARO Focus 3D). For every campaign, 6 acquisition stations have been considered: 4 at the quadrants and 2 in the crown, using a telescopic tripod. The acquisition parameters set on the ground were a point spacing of 6 mm at 10 m range, with simultaneous acquisition of photographs. If we consider the tree with shoots (Figure 3b), the raw cloud covering the tree had approximately 13 million points. In a first step, the point cloud has been processed to reduce measurement noise (or artefacts) and keep only 500 000 points, i.e. about 1 point every 5 mm.

(a) (b) (c) (d)

Fig. 3. Tree under study; a) point cloud acquired on the pruned tree (April); b) point cloud of the leafless and unpruned tree (January); c) point cloud of the tree with leaves (July); d) photograph of shoots

To start the modeling work, it was decided to focus on the pruned tree. The tree has been captured in April 2013, once the shoots have been pruned and in January 2014 before pruning and without leaves. The shoots are long and slender stems starting from the extremity of each branch (Figure 3d). Every winter the silver linden trees located in the historical garden are pruned respecting a traditional practice well known by the gardeners as “cat’s head” pruning. It is a pruning technique which contains the tree development and guarantees a structured shape. Therefore, we call “cat’s head” the growth at the end of a branch resulting from repeated pruning of shoots at the same place. The rings of scar tissue merge together, enlarging the head and gradually forming a complex ligneous mass.

The shoots are the supports on which the leaves grow and are ephemeral as they are observable only in spring and summer. Based on the shoot length, the INRA partner is able to estimate leaf area (Sonohat et al., 2006). Our main objective is to extract as automatically as possible, a complete skeleton of the tree on which the shoots have reached maturity (before pruning), in order to be able to provide the shoot lengths, using exclusively laser scanning data.

5. Developed skeletonization approach

Some 3D reconstruction approaches of trees from point clouds are proposed in the literature, based on graphs or octrees or on geometric primitives like cylinders (Livny et al., 2010; Bucksch, 2011; Eysn et al, 2013; Hackenberg et al., 2014). The 3D reconstruction algorithm developed in this work is partially inspired from Cao et al. (2010) for the skeletonization step, although the authors did not develop it specifically for the 3D reconstruction of trees. According to Jiang et al. (2013), a skeleton is a compact and efficient representation of a solid, which faithfully combines the geometry and topology of the tree’s shape. The application of the algorithm on the point cloud of the pruned tree produces almost satisfying results (Figure 4a). In contrast, when the input point cloud is the tree with shoots, results are disappointing (Figure 4b). This outcome was foreseeable, given the shoots’ density and the difficulty of distinguishing them from each other (Figure 3d). Therefore prior segmentation of the tree to isolate the shoots and the trunk structure must be considered. As a consequence, the skeletonization step will be performed firstly on the pruned tree and secondly on bunches of shoots (Figure 4c), isolated according to the cat's head to which they belong.

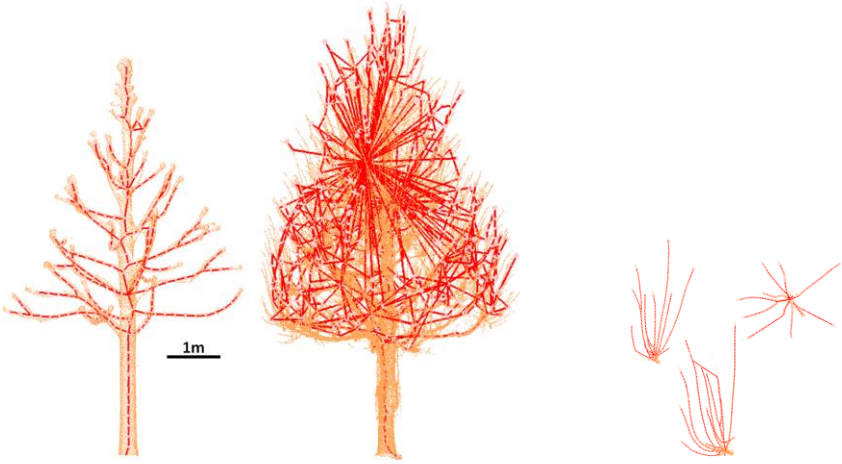


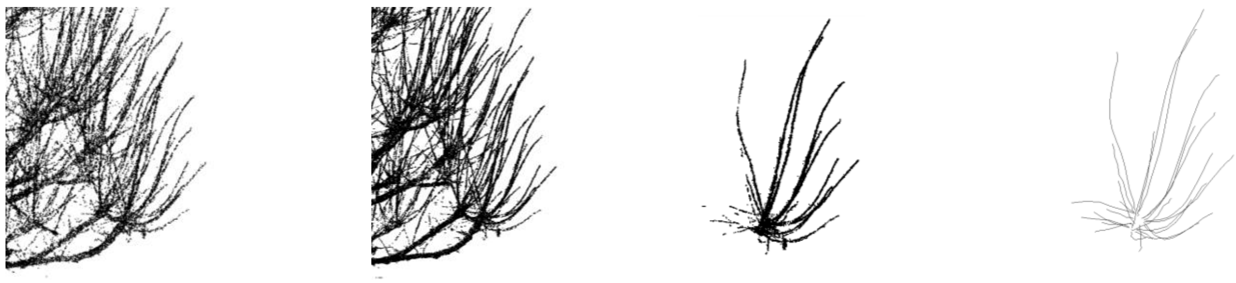
Fig. 4. Skeletonization results for the 3D reconstruction of a silver linden tree; a) for the pruned tree; b) for tree with leafless shoots; c) for 3 individual cat's heads.

After registration of the 6 point clouds per campaign, a georeferencing process, based on conventional surveying techniques, allows to orient the surveying in a local repository. The advantage of georeferenced data is the possibility to superimpose the scanned data on the 3D database of the Strasbourg city. An additional advantage is that every measurement campaign will be projected in the same local cartographic coordinate system; this is interesting for further monitoring. For isolating the cat's heads of shoots, the point cloud of the tree with shoots is subtracted from the point cloud of the tree without shoots (Figure 5) in CloudCompare (EDF R & D software).The segmentation of the point cloud covering the shoots (Figure 5c) into individual cat's heads remains currently a manual process and requires a previous noise reduction process (Figure 6b).

A first improvement of Cao et al. (2010) was necessary in order to connect the nodes composing a shoot in the growth order of the shoot (Landes et al., 2014). At this stage of 3D reconstruction of shoots, a major problem arises. The connection between the shoots and their base, i.e. the cat's head is not trivial. The problem comes on the one side from the fact that a cat's head is not adjustable by a point; it is rather a complex ligneous mass. On the other side, shoots intertwine and become difficult to distinguish from each other near to the cat's head. Moreover, the lack of points does not facilitate the connection assumption. The best way to join the shoots and the branches is under study.

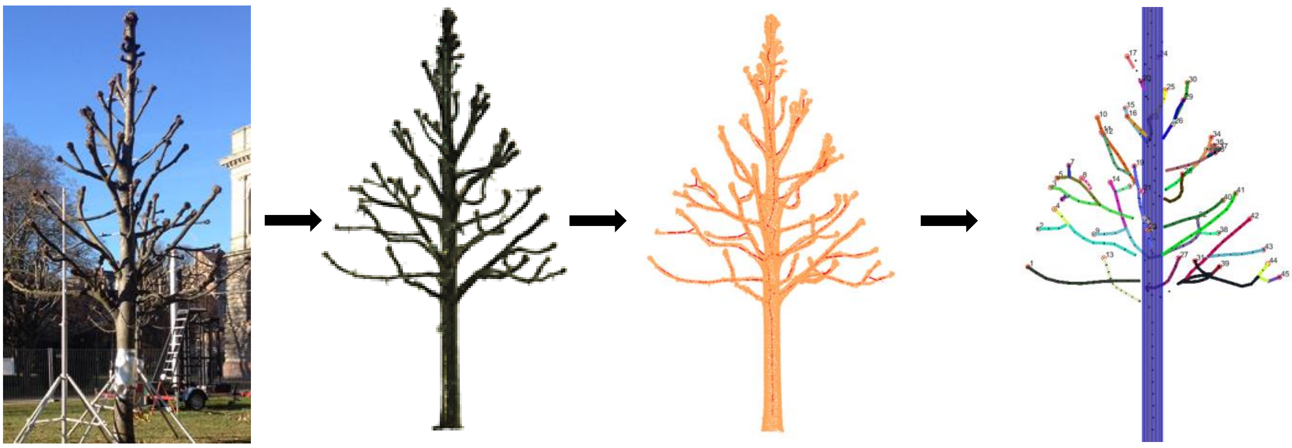
At this stage, the skeleton of the silver linden tree is first produced for the pruned tree (Figure 7c) and then completed with the skeletons of the cat's heads and shoots (Figure 8). The skeleton of the shoots is calculated for every cat's head. Since the point cloud is georeferenced, the algorithm provides the nodes composing every shoot of every cat's head in the same coordinate system. As a consequence, several products can be delivered as output of the developed algorithm and transmitted to the INRA partner, like the curvilinear length (and rectilinear length) of the branches or shoots, the coordinates of every node of the skeleton, i.e. the position, orientation and length of the branches and shoots.

Fig. 5. Subtraction of two point clouds ; a) point cloud with leafless shoots, b) point cloud of the pruned tree ; c) point cloud with shoots only



(a) (b) (c) (d)

Fig. 6. Point cloud of shoots; a) before noise removal; b) after noise removal; c) segmentation of cat's head; d) digitizing of the reference shoots.



(a) (b) (c) (d)

Fig. 7. Result of the processing chain of tree's skeletonization from terrestrial laser scanning; a) photograph; b) point cloud of a pruned tree; c) skeleton of the tree; d) skeleton of trunk as a cylinder and branches

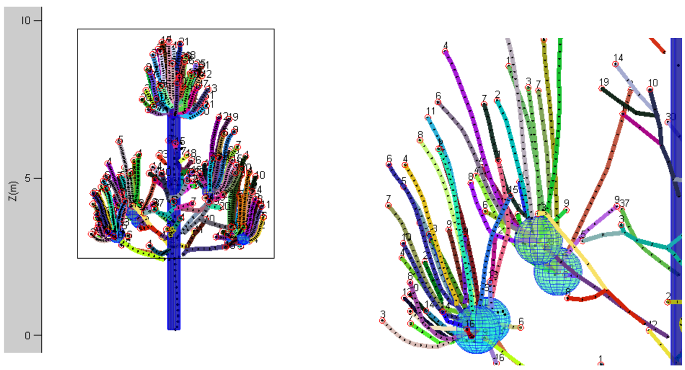


Fig. 8. Skeleton of tree and shoots composing the previously segmented cat's heads

To assess the quality of the developed skeletonization algorithm, a statistical analysis has been carried out. For this purpose, 8 cat's heads of a total of 51 cat's heads composing the tree have been segmented and modeled manually by creating a 3D polyline for each shoot. This work, although tedious, enables the availability of a reference model (Figure 6d). The point clouds corresponding to these 8 cat's heads have been introduced in the developed algorithm, which automatically produces shoots skeletons. The number of shoots automatically detected was faced with the number of shoots digitized manually. It shows that 86% of the shoots were correctly skeletonized. 14% are missing because of shoots which are too small to be detected by the algorithm. In addition, discrepancies were found in the detection of the first centimeters of a shoot (about 7 cm on shoots of 2 m).

It remains to accurately estimate losses in terms of leaf area, relating to the use of the algorithm. Anyway, the time savings and accuracy that our algorithm provides is obvious, because so far, shoots measurements were done manually and in a straight line linking the base and the shoot's extremity. Moreover, the fact of having the position and orientation of each shoot, will allow moving forward on the issue of spatial distribution of leaf.

6. Conclusion

The research project presented here brings together ecophysiologists, climatologists, meteorologists, geographers, computer scientists and surveyors for carrying out several microclimate measurements related to heat fluxes, surface temperatures, and also tree architecture metrics. All of them follow the same objective which is to contribute even a little bit to the understanding of the extreme complexity of the interactions between vegetation and urban climate.

The knowledge of the tree architecture is essential as input to the development of thermal radiative models of urban areas. Regarding automatic techniques, a state of the art enabled to highlight the potentiality of terrestrial laser scanning techniques for 3D modeling of trees.

The processing chain developed in the project provides a skeleton of the tree as well as a skeleton of every segmented set of shoots. Moreover, since the INRA team requires specific shoot's metrics for leaf area reconstruction based on allometric relationships, the developed methodology has been improved to extract not only the skeletons composing the tree but also the shoot lengths and orientations.

Results provided by our approach are better than expected; since skeletons of more than 86% of the segmented shoots are automatically produced. The first results are promising. In the future, the developed approach will be applied on other silver linden tree as well as on other tree species, in order to test the limitations of the 3D reconstruction algorithm.

Acknowledgements

We would like to thank Christelle Hayot and Elena Bournez, Master Students of INSA Strasbourg for their contributions to the project.

References

Barthélémy, D., Blaise, F., Fourcaud, T., Nicolini, E., 1995. Modélisation et simulation de l'architecture des arbres : bilan et perspectives. *Revue Forestière Française*, Vol. 47, pp. 71-96.

Béland, M., Widlowski, JL., Fournier, R., Coté JF., Verstraete M., 2011. Estimating leaf area distribution in savanna trees from terrestrial LiDAR. Agricultural and Forest Meteorology - *Elsevier Journal*, Vol. 151, pp. 1252-1266.

Bucksch*, A.*, 2011. Revealing the skeleton from imperfect point clouds. *PhD Thesis, Delft University of Technology; ISBN: 9783868538779;* 147 pages.

Cao, J., Tagliasacchi, A., Olson, M., Zhang, H., et Su, Z., 2010. Point cloud skeletons via Laplacian based contraction. In *Proc. of IEEE Conference of Shape Modeling and Applications*, pp. 187-197.

Delagrange, S. et Rochon, P., 2011. Reconstruction and analysis of a deciduous sapling using digital photographs or terrestrial-LiDAR technology. In *Oxford University Press*, 10 pages.

Donès N, Adam B, Sinoquet H (2006). PiafDigit - software to drive a Polhemus Fastrak 3 SPACE 3D digitiser and for the acquisition of plant architecture. Version 1.0. (UMR PIAF INRA-UBP: Clermont-Ferrand)

Eysn, L., Pfeifer, N., Ressl, C., Hollaus, M., Grafl, A., Morsdorf, F. 2013. A practical approach for extracting tree models in Forest Environments based on equirectangular projections of terrestrial laser scans. *Remote Sensing* 2013, **5(11)**, 5424-5448; doi:10.3390/rs5115424

Hackenberg, J., Morhart, C., Sheppard, J., Spiecker, H., Disney, M., 2014. Highly accurate tree models derived from terrestrial laser scan data: a method description. *Forests* 2014, **5(5)**, 1069-1105; doi: 10.3390/f5051069

Jiang, W., Xu, K., Cheng, Z. Q., Martin, R. R., et Dang, G., 2013. Curve skeleton extraction by coupled graph contraction and surface clustering. *Graphical Models*, Vol. 75(3), pp. 137-148.

Kastendeuch P. P., Najjar G., 2009: Simulation of radiative transfers in urbanised areas. *Solar Energy*, **83**, 333-341

Landes T., Hayot C., Najjar G., Kastendeuch P., Saudreau M., Colin J., Luhahe R., Guillemin S., 2014: Modélisation 3D d'arbre pour comprendre le climat urbain. *Revue XYZ* n°**141**, pp. 55-62.

Landes, T., Grussenmeyer, P., Boulaassal, H., 2011. Les principes fondamentaux de la lasergrammétrie terrestre : acquisition, traitement des données et applications. *Revue XYZ*, n°**129**, ISSN 0290-9057, pp. 25-38.

Livny, Y., Yan, F., Olson, M., Chen, B., Zhang, H, El-Sana, J, 2010. Automatic reconstruction of tree skeletal structures from point clouds. *ACM Trans. Graph*. 2010, **29**, 151:1–151:8

Najjar G., Kastendeuch P.P., Stoll M.P., Colin J.R., Nerry F., Ringenbach N., Bernard J., De Hatten A., Luhahe R., Viville D., 2004: Le projet RECLUS, télédétection, rayonnement et bilan d'énergie en climatologie urbaine à Strasbourg. *La Météorologie*, **46**, 44-50.

Neusch, T., Grussenmeyer, P., Najjar, G., 2003. Télédétection et photogrammétrie, chaînons dans la détermination du climat urbain à Strasbourg. *Revue XYZ* n°**103**, pp. 25-30.

Santos, T. et Ueda, J., 2013. Automatic 3D plant reconstruction from photographies, segmentation and classification of leaves and internodes using clustering. In Proc. of *7th Intern. Conf. on Functional-Structural Plant Models* (FSPM 2013), pp. 95-97.

Sinoquet, H., X. Le Roux, Adam, B., Améglio, T., Daudet, F. A., 2001. RATP: a model for simulating the spatial distribution of radiation absorption, transpiration and photosynthesis within canopies: application to an isolated tree crown. *Plant Cell and Environment* **24(4)**: 395-406.

Sinoquet, H., Rivet, P. et Godin, C., 1997. Assessment of the three-dimensional architecture of walnut trees using digitising. *Silva Fennica*, **Vol. 31(3)**, pp. 265-273.

Shlyakhter, I., Rozenoer, M., Dorsey, J., Teller, S., 2001. Reconstructing 3D tree models from instrumented photographs. *IEEE Computer Graphics and Applications*, Vol. **21(3)**, pp. 53-61.

Sonohat G, Sinoquet H, Kulandaivelu V, Combes D, Lescourret F, 2006. Three-dimensional reconstruction of partially 3D-digitized peach tree canopies. *Tree Physiology,* **26(3)**:337-351.

Wu, B., Yu, B., Yue, W., Shu, S., Tan, W., Huang, Y., Wu, J., Liu, H., 2013. A voxel-based method for automated identification of morphological parameters estimation of individual trees from mobile laser scanning data. *Remote Sensing* 2013, 5(2), 584-611; doi: 10.3390/rs5020584