

VISUAL SIMULATION ON ACCUMULATION OF THE DIFFERENTIATING SECONDARY WALL LAYERS

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ABSTRACT

This study describes the accumulation of secondary wall layers of the fast-growing *Populus×euramericana* cv. '74 /76' during the active phase by the methods of polarized light microscopy analysis and computer simulation technology. The results showed that the secondary wall layers of *Populus×euramericana* cv.'74/76' appeared light and shade stratification during the differentiating phase, and the wall layers corresponded to S₁, S₂ and S₃ layer from outside to inside respectively. The S₁ and S₂ layer of wood fibers were differentiated in May, and the S₃ layer was appeared until the July. In addition, the thickness of the three layers all showed a gradual increasing trend. The accumulation process of the secondary wall layers was visually displayed by the computational simulation technology during the active period.

KEYWORDS: *Populus×euramericana* cv. '74 /76', secondary wall layer, computer simulation technology.

INTRODUCTION

In the process of simulating plant growth visualization, the first step need to calculate the physiological state and geometry in a plant growth cycle by growth simulation method, and then to draw them through these visualization techniques based on the plant information.

In early period, the visualization technology of plant growth was mainly based on the two-dimensional graphics technology, which cloud not realistic display the plant growth. With the rapid development of technology, 3D (three-dimensional) graphics technology has occupied a very important position. Prusinkiewicz (1990) presented a whole plant drawing method based on turtle geometry. This method has been widely used in visualization system of virtual plants.

Diggle (1988) and Bengough (1992) established the first three-dimensional model to simulate the structure of the root system. In addition, Oppenheimer (1986) used the fractal method to simulate the deciduous leaf veins. Mundermann and MacMurchy (2003) put forward to obtain the leaf skeleton and contour, and then made it vectorization and meshing, to construct the three-dimensional model of the leaf. Prusinkiewicz (1990), in his earlier work, used cylinders to represent the branches of plants, but this method was very low-fidelity and could not clearly see the traces of splicing at the branches. Kawaguchi (1982) proposed the use of circular polyhedrons, which also used the basic geometry to form the branches, but it achieved to make the branches continuous. Max (1990) discovered the Cone-Sphere method, which is geometry, composed of two spheres and a cone. The branches of the plant were described as geometry that composed of multiple Cone-Spheres. Bloomenthal (1985, 1995) pointed out to form the skeleton of a maple tree using the space curve and then formed the whole branch with a cylinder, who also proposed a method of branch modeling based on implicit surface. Tobler and Maierhofer (2002) invented a modeling approach based on subdivision surfaces to make the branches smooth (especially at the branch). For the bark rendering, Wang (2003) adopted the displacement mapping means to enhance the rendering. Federl and Prusinkiewicz (2004) proposed a simulation method based on solid mechanics multi-layer surface, which effectively solved the problem of fracture orientation order. Hammel and Prusinkiewicz (1992) discovered a method for simulating complex vanes with implicit contours. España (1999) simulated a maize leaf using a rectangular, two-dimensional parametric plane approximating the leaf blade. Ijiri (2005, 2006) in the University of Tokyo allowed the user to modify the flower pattern and the inflorescence, and then depicted the lines, after that the lines were transformed into the mesh faces of the leaves, flowers or sticks by the automatically system.

Visualization techniques cannot only promote the development of the computer graphics technology, but also can enhance the visual representation of the plant growth. In this study, the computer graphics was used to simulate the accumulation and thickening process of the secondary wall layer on *Populus×euramericana* cv. '74/76' during the active phase. Finally, the development process was displayed more intuitively.

MATERIAL AND METHODS

Healthy plants of fast-growing three year-old *Populus×euramericana* cv. '74/76' grown in a plantation in Beijing (40°17'N, 116°39'E; Beijing, China) with the same diameter at breast height were chosen and marked. Plant material were collected 1.3 m above the trunk and sampled monthly from May to October. On each occasion, blocks of about 10 mm³ including phloem, cambium and xylem cells were immediately immersed in fixative formalin–acetic acid–alcohol. Upon returning to the laboratory, they were placed in the same fresh fixative under a slight vacuum for 30 minutes. Following vacuum, these pieces were fixed in fresh fixative and preserved at 4°C. Cross slices with a thickness of 10 μm including phloem, cambium, and xylem were cut on a sliding microtome, observed with a polarization microscope. Meanwhile, the pictures and the thickness of cell wall layers in all phases were collected using a microscopic image analyzer.

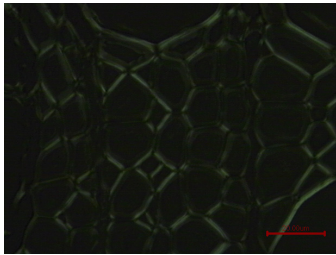
The image processing software Photoshop and Flash animation software were used combining with the photos and experimental data collected to draw the images of cell wall layers changes in different growth period, and then the elements were imported to the Flash documents, the whole development process of cell wall layers was created and made it into visualization.

RESULTS AND DISCUSSION

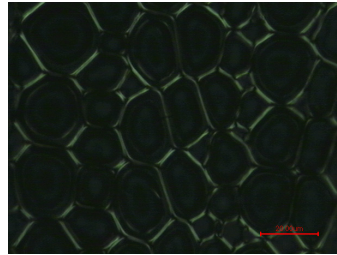
The accumulation of xylem cell wall layers during the differentiation process

Due to the anisotropy of secondary wall layers of wood, cell wall layers under polarizing microscope appear light and shade image. The S_1 layer and S_3 layer show the bright region, while S_2 layer appears dark area, so the polarized images of the cell wall layers from outside to inside, is bright, dark and bright layer corresponds to the S_1 , S_2 and S_3 layer. Fig. 1 shows the polarizing microscope pictures of xylem cell walls' accumulation during the differentiating periods of the *Populus euramericana* cv. '74/76'.

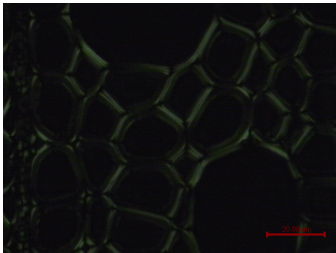
According to Fig. 1a, only two layers of secondary wall were discovered in May, which related to the layer S_1 and S_2 , and the thickness of them were quite thin, when there was no layer S_3 . It can be seen from the Fig. 1b, the S_1 and S_2 layer had different degree of thickening compared with in May, and the walls began to appear the S_3 layer, which were showed by arrows. Thickening of the secondary wall layers of S_1 , S_2 , and S_3 were obvious in October (Fig. 1c). In contrast, on either side of the growth-ring boundary line, it can be clearly seen that the cell wall layer thickness of late wood are obviously greater than that of early wood. Relative to the early wood, the late wood cell shape were more regular (Fig. 1d).



a. The S_1 and S_2 layer appeared in May.



b. The S_3 layer appeared in July.



c. The thickening of S_1 , S_2 , and S_3 layer in October.



d. The layers of early wood and late wood.

Fig. 1: Polarization microscope pictures of cell wall layers in different stages.

The thickness of secondary wall layers were measured during the differentiating phase. The data of cell wall thickness, standard deviation and the percentage of the whole wall layer were showed in Tab. 1. In the active phase (from May to October), The thickness of layer S_1 increased gradually from 0.18 μm to 0.58 μm (Fig. 2), the layer S_2 from 1.28 μm to 3.61 μm (Fig. 3), and the layer S_3 increased monthly from 0.17 μm to 0.35 μm (Fig. 4).

Tab. 1: Thickness of cell wall layers in wood fiber in different stages.

| Sampling time | S ₁ /μm (%) | S ₂ /μm (%) | S ₃ /μm (%) |
|---------------|------------------------|------------------------|------------------------|
| May | 0.18±0.03 (12.3) | 1.28±0.32 (87.8) | — |
| June | 0.22±0.03 (11.8) | 1.64±0.38 (88.2) | — |
| July | 0.31±0.05 (11.8) | 2.14±0.34 (81.7) | 0.17±0.02 (6.5) |
| August | 0.41±0.05 (11.6) | 2.86±0.32 (80.8) | 0.27±0.03 (7.6) |
| September | 0.50±0.07 (12.0) | 3.37±0.51 (80.6) | 0.31±0.03 (7.4) |
| October | 0.58±0.08 (12.8) | 3.61±0.47 (79.5) | 0.35±0.04 (7.7) |

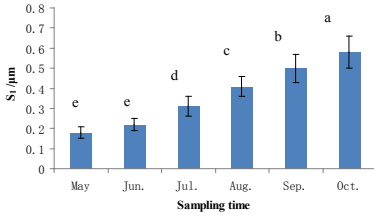


Fig. 2: Changes of cell wall layer S₁ in different stages.

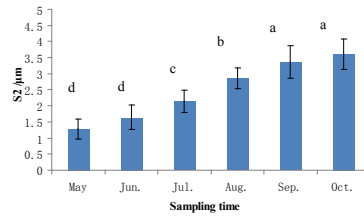


Fig. 3: Changes of cell wall layer S₂ in different stages.

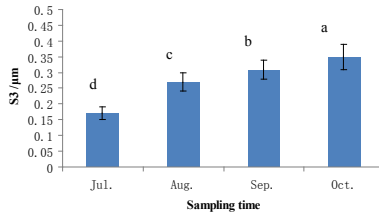
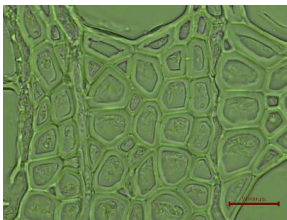
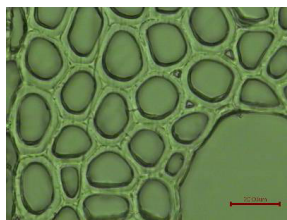


Fig. 4: Changes of cell wall layer S₃ in different stages.

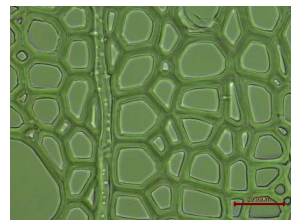
The visualization of cell wall layer accumulation during the differentiating process. In order to show a more intuitive process of the cell wall accumulation and variation in different periods, the visualization of their accumulation process was made combining the picture and the basic data obtained (Tab. 1) with computer simulation software. The Fig. 5 showed the structure pictures of wood fiber cell walls in different phases (from May to October).



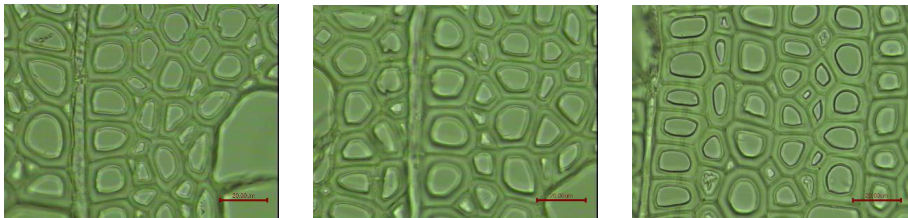
a. Cell wall layers in May



b. Cell wall layers in June



c. Cell wall layers in July



d. Cell wall layers in August e. Cell wall layers in September f. Cell wall layers in October
 Fig. 5: Cell wall structure in different stages

According to the visual simulation, an interactive interface was needed to create, which including the following visual elements: title, data, scaleplate, buttons and three levels of interactive interface. The total size for the interface was 1280×800 cm. First of all, the above elements were designed and typeset in the drawing software Photoshop, then non-text elements were exported from Photoshop to PNG-formatted images, after that a 1280×800 cm canvas was created in CS3 Flash, finally the PNG-formatted element was imported into Flash (Fig. 6).

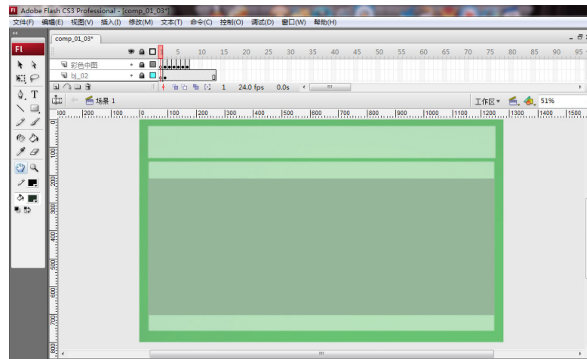


Fig. 6: Import the PNG-formatted element into Flash.

According to the layout design in Photoshop, the text and data were edited in the Flash screen editor (Fig. 7).

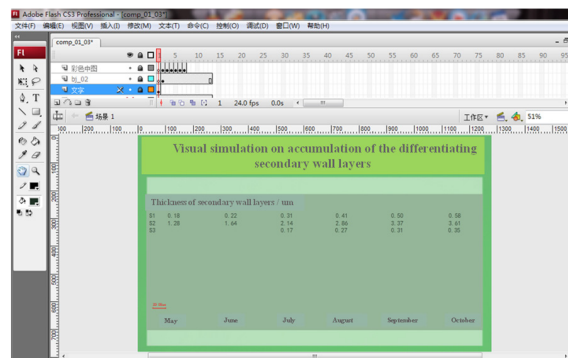


Fig. 7: Edit text in Flash.

According to the structures of cell wall layers collected from May to October in Fig. 5, and the pictures were arranged in chronological order, and then made it into a continuous development of cell wall layers (Fig. 8). The simulation of cell wall layers was painted in Fig. 9. When drawing, the wood cell wall was divided into the Middle lamular layer, S_1 layer, S_2 layer and S_3 layer with the thickness showed in Tab. 1 and marked them with different colour (Fig. 10). The simulation map was converted from the Photoshop into the ready-made interactive interface in Flash (Fig. 11).

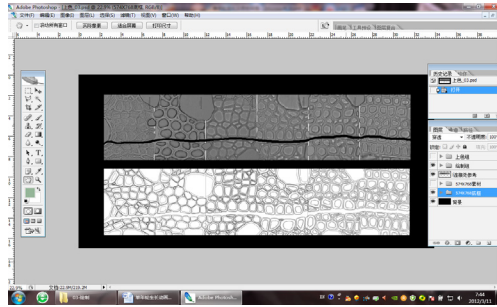


Fig. 8: The continuous development process of cell wall layers.

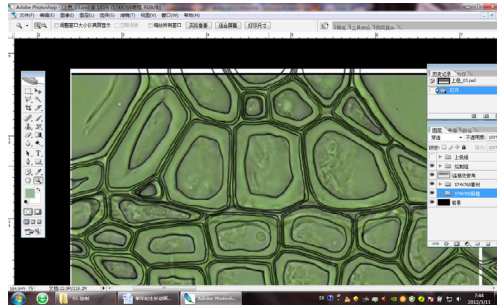


Fig. 9: The simulation of cell wall layers with the Photoshop.

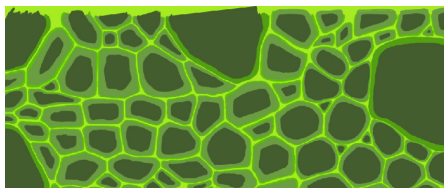


Fig. 10: Cell wall layers coloring.

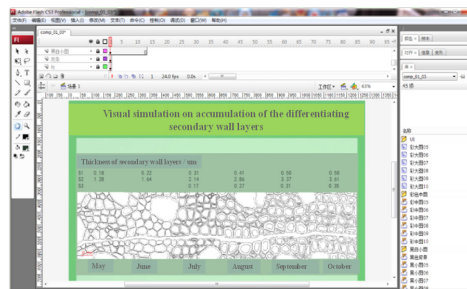


Fig. 11: Convert the pictures into Flash.

In the interactive interface of Flash files, the AS3.0 scripting language was used writing interaction design in different frames. It mainly included the following three kinds of interaction effects: (1) Click on the black-and white figure of each month in the first level of the interface can jump into the second one (Fig. 12a), in which displayed the colored picture continuously

corresponding with a progressive relationship (Fig. 12b). (2) Click on the colored picture can jump into the third level and display the larger colored image (Fig. 12c). (3) Click on the black background of third level can return to the first one (Fig. 12d).

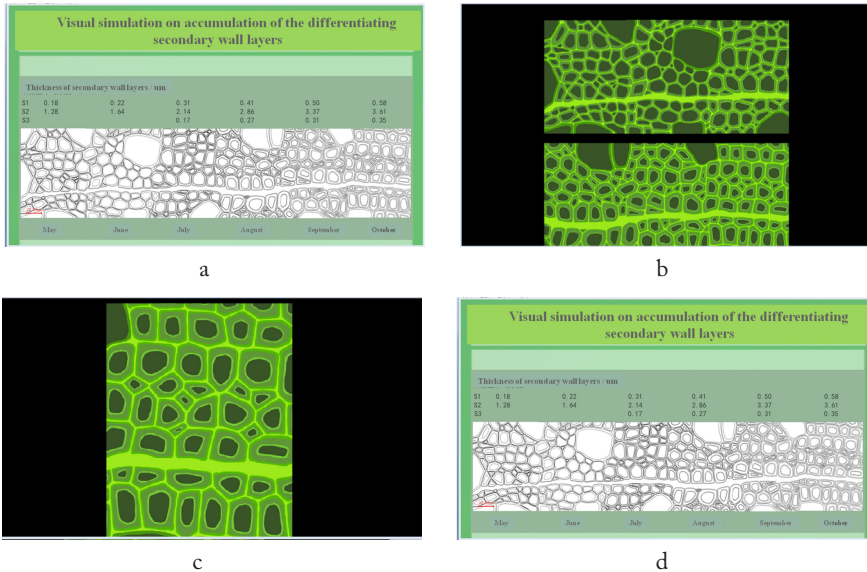


Fig. 12: Write the Script in the interactive interface.

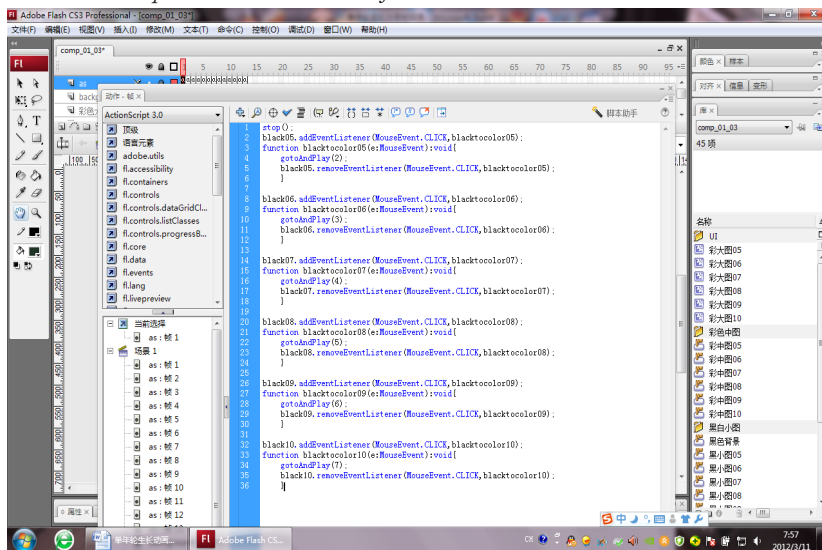


Fig. 13: Write the Script in the interactive interface.

The script writing (taking the first frame for example) was showed in Fig. 13. After testing, the file was output with the SWF-format and played, which achieved the final interaction results.

CONCLUSIONS

According to the observation using the polarizing microscope, it was found that the secondary wall layers of *Populus×euramericana* cv. '74/76' appeared light and shade stratification during the differentiating process, and the cell wall layers corresponded to S₁, S₂ and S₃ layer from outside to inside respectively. The S₁ and S₂ layer of wood fibers were differentiated in May, and the S₃ layer was appeared until the July. During the active period, the thickness of the three layers presented increasing trends. The computer technology (including Photoshop and Flash) were used to simulate the visualization on the development changes secondary wall layers during the active period. The accumulation process of the secondary wall layers was visually displayed.

ACKNOWLEDGEMENTS

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REFERENCES

1. Bengough, A.G., Mackenzie, C.J., and Diggle, A.J., 1992: Relations between root length densities and root intersections with horizontal and vertical planes using root growth modeling in 3-dimension, *Plant and Soil* 145(2): 245-252.
2. Bloomenthal, J., 1985: Modeling the mighty maple, *ACM Transactions on Graphics (SIGGRAPH 1985 Conference Proceedings)*. Pp 305-311.
3. Bloomenthal, J., 1995: Skeletal design of natural forms. PhD thesis. University of Calgary, 237 pp.
4. Diggle, A.J., 1988: ROOTMAP- a model in three-dimensional coordinates of the growth and structure of fibrous root systems, *Plant and Soil* 105:169-178.
5. España, M.L., Baret, F., Aries, F., Chelle, M., Andrieu, B., Prévot, L., 1999: Modeling maize canopy 3D architecture application to reflectance simulation, *Ecological Modeling* 122: 25-43.
6. Federl, P., Prusinkiewicz, P., 2004: Finite element model of fracture formation on growing surfaces, in *Computational Science - ICCS 2004: 4th International Conference*. Springer Verlag Berlin, Heidelberg. Pp 138-145.
7. Hammel, M.S., Prusinkiewicz, P., Wyvill, B., 1992: Modeling compound leaves using implicit contours. In: *Visual Computing: Integrating computer graphics with computer vision* (ed. T.L. Kunii). Pp 199-212.
8. Ijiri, T., Owada, S., Okabe, M., 2005: Floral diagrams and inflorescences: Interactive flower modeling using botanical structural constraints, *ACM Transactions on Graphics, (SIGGRAPH 2005 Conference Proceedings)*. Pp 720-726.
9. Ijiri, T., Owada, S., Okabe, M., 2006: Seamless integration of initial sketching and subsequent detail editing in flower modeling, *Eurographics* 25(3): 617-624.
10. Kawaguchi, K., 1982: A morphological study of the form of nature, *ACM Transactions on Graphics, (SIGGRAPH 1982 Conference Proceedings)*, Pp 223-232.
11. Max, N., 1990: Cone-sphere. *Computer Graphics* 24: 59-62.

12. Mündermann, L., MacMurchy, P., Pivovarov, J., Prusinkiewicz, P., 2003: Modeling lobed leaves. Proceedings of Computer Graphics International - CGI 2003, Pp 60-65.
13. Oppenheimer, P. E., 1986: Real time design and animation of fractal plants and trees. Computer Graphics 20 (4): 55-64.
14. Prusinkiewicz, P., Lindenmayer, A., 1990: The algorithmic beauty of plants. Springer-Verlag. New York. 240 pp.
15. Tobler, R.F., Maierhofer, S., Wilkie, A., 2002: Mesh-based parametrized l-systems and generalized subdivision for generating complex geometry, International Journal of Shape Modeling 8(2):173-191.
16. Wang, L., Wang, X., Tong, X., 2003: View-dependent displacement mapping, ACM Transactions on Graphics (Siggraph 2003 Conference Proceedings) Pp 334-339.

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