Interactive thinning in immersive virtual reality

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1. Introduction

Visualization through immersive virtual reality is successfully used in the analyses of complex data and their interpretation in the form of visual perception of users. In the year 1992, the first CAVE Automatic Virtual Environment was developed as a specialized hardware for the visualization of virtual worlds (Cruz-Neira et al. 1993). A specific usage of visualization techniques and systems of virtual reality is in the area of creating and developing trainers. In conjunction with appropriate simulation tools they create complex devices intended for training different fields of human activity (aviation, transport, astronautics, medicine, etc.). Although the development of technologies has also affected the development of forestry, the use of trainers is still a rare phenomenon in this field. Apart from the trainers of harvesting and transport technologies (Ovaskainen 2005), no other trainers are currently used in forestry according to the available literature and internet resources, although this technology could be used with advantage in several areas. One of them is training of thinning methods. This is a practical activity, which is based on the knowledge gained in the educational process and the experience acquired in the field. Moreover, its impact becomes distinct only after a few years or decades. Therefore, training of thinning methods in the field is incomplete. It lacks the immediate feedback that would provide the information about the thinning impact on the forest state, structure and stability. Although these effects can be examined using simulators modelling forest development (Pretzsch 2009, Weiskittel 2011, Burkhart and Tomé 2012, Fabrika and Pretzsch 2013), these tools are not fully-fledged thinning trainers. They lack the dimension of practical performance, i.e. manual selection of trees. In simulators, thinning regimes are designed mostly as algorithms, which replace manual selection of trees with automated selection defined by the thinning type, intensity and interval. Hence, they cannot be considered as fully-fledged simulators. A thinning trainer can be defined as a system composed of a mathematical model of a forest, computer software and hardware used for training tree selection and simulation of immediate impact of thinning on forest condition (production, ecological and economic). A trainer differs from a common simulator in the attempt to mimic reality as well as possible, i.e. it contains elements of advanced virtual reality with a high degree immersivity and interactivity.

The aim of the paper is to present a thinning trainer developed at Technical University in Zvolen, which uses SIBYLA spatially explicit (distance-dependent) empirical tree model as a technological platform and the CAVE system as a platform of a computer aided virtual reality.

2. Technical solution of thinning trainer

2.1 SIBYLA growth simulator

SIBYLA growth simulator (Fabrika 2007) was programmed in the DELPHI environment in Object Pascal language. Input and output information including all data generated during the growth simulation are stored in the MS Access database. The program communicates with the database using ODBC interface and SQL tools. The source code uses modular structure, while individual modules are object-oriented. The basic layout of the modules is shown in Figure 1. The software consists of several application branches: a basic empirical branch, a branch for process-based and structural downscale of the model, a branch of extensions and a branch of supplementary modules from the so-called model chessboard. An educational branch that complements the opportunities of the thinning trainer is also a part of the software. The description of the individual modules is in Table 1. For the thinning trainer, the Caveman module is the key component. This module was created to interlink the growth simulator with the CAVE system.

Table 1: Description of the individual modules of SIBYLA growth simulator (Caveman module was developed for the specific purposes of the forest trainer. It links the growth simulator with the CAVE system).

branch type	branch	module	description of the module
executive	empirical forester	Generator	generating of forest structure
		Medium	card file of simulation plots
		Localizer	specifying and generating of site: i) geocentric, ii) phytocentric
		Cultivator	specifying of management treatments
		Prophet	simulation of forest development
		Calculator	calculation of outputs
		Explorer	exploring of outputs
		Analyst	analysing of outputs: i) descriptive, ii) statistical
		Expert	tree diagnostic card, calibration of empirical model, interface for extensions and for model chessboard
		Lecturer	handbook of the model and of the software
	causal biologist	Astronomer	generator of solar radiation
		Climatologist	weather generator
		Pedologist	generator of soil properties
		Physiologist	modelling of eco-physiological processes
		Alchemist	setting of process model parameters
		Magician	process-based downscale of empirical simulations
	morphological mathematician	Morphologist	description of tree growth grammar
		Painter	definition of visual properties of tree
		Shaman	structural downscale of empirical simulations
	extensions	Agent	data import
		Superman	interface for data from terrestrial laser scanner
		Caveman	interface to CAVE equipment
		Cartographer	management of simulation plots by GIS interface
		Aggressor	risk analysis of disturbances
		Fosterer	analysis of natural regeneration
		Rival	analysis of competition pressure
		Merchant	estimation of ecosystem services
	model chessboard	Gardener	big leaf model
		Emperor	gap model: i) divide, ii) rule
		Separator	frequency model
		Farmer	stand model (yield tables)
		Pharaoh	biome model
education	curious apprentice	Historian	history of forest modelling
		Mentor	ecosystem, eco-physiological and forestry background of forest modelling
		Polyhistor	system and cybernetics background of forest modelling
		Observer	biometrical background of forest modelling
		Developer	classification of forest models
		Genius	functioning of empirical, process-based and structural forest models
		Technologist	application of technologies in forest modelling
		Visionary	visions of forest modelling to the future

Figure 1: Software structure of the modules of SIBYLA growth simulator.

2.2 CAVE System

The developed CAVE system is used to visualize natural and technological objects in the form immersive and interactive virtual reality. It has a cubic shape without one wall, where the entrance is situated, i.e. overall it consists of five walls - a front, a right, a left, a top and a bottom wall. The dimensions of the side walls are 3 x 2.25 meters, and the dimensions of the top and bottom walls are 3 x 3 meters. The walls are projection panels, on which the stereoscopic image is displayed with the back-projection of the pairs of the projectors. INFITEC stereoscopic system (Infitec 2014) is used. The top and the bottom walls of the CAVE system have a square shape. The discrepancy in the shape of the projected image with the shape of the bottom and top walls is solved by their coverage with the doubled number of projectors. The use of the surrounding space of the system is optimized using projection mirrors. The projection system projects onto five walls, while two of them are divided into halves. Hence, 14 projectors are necessary. The bottom wall is reinforced with the safety glass to allow motion inside the cube. The whole construction of the cube is raised, and therefore, the stairs are used to access its space. The design of the system is presented in Figure 2. An observer uses 3D glasses which enable him to see the image in 3D. They are equipped with a device for detecting the position in the space of Polhemus type (Polhemus 2014). Monitoring the position of observer´s head in the space and the direction of its view is used to recalculate and correct the projected images and the stereoscopic perspective of the observer. The movement in the virtual world is mediated either by a Joystick or a Space Mouse in observer´s hands. The interaction with the objects from the virtual world is allowed using another control by activating a fictional laser beam. The movement of the beam in virtual reality is mediated by moving a control; therefore it is also a part of the system used for detecting the position in the space. In the space of the cube, a system of speakers 5+1 is placed to achieve spatial perception of sound. Projectors are connected to a cluster of computers with visualization software. The cluster is located in the adjacent room and is composed of eight computers, seven of which render the image for the projection on the individual projection panels in the stereoscopic mode, and one is a process control computer. The computers contain powerful graphics cards that ensure smooth rendering. The console computer mounted on the construction of the CAVE, which communicates with the control computer of the cluster, is used for the management of the visualization system and for receiving the input from the user. SuperEngine

Control Console software is installed on the console computer for the complex control of the computers in the cluster. It activates the whole hardware via the network, and controls all necessary visualization applications. The tool is versatile, able to visualize different formats of virtual worlds. However, it was designed with regard to the visualization options of a virtual forest produced by SIBYLA growth simulator. Thus, the tool that was created enables the mediation of user´s interventions into a virtual forest visualized with a sophisticated equipment, which enhances the experience from in-this-manner presented reality. Nevertheless, the feedback based on the prognosis of further forest development is essential. For prediction purposes, the growth simulator needs not only the complex data on a forest at a simulation plot, but also the information on performed interventions (marked trees). To ensure this functionality, mutual integration of the growth simulator (SIBYLA), the virtual reality (VR) produced by the simulator, and the visualization system (CAVE) with an adequate software solution is required.

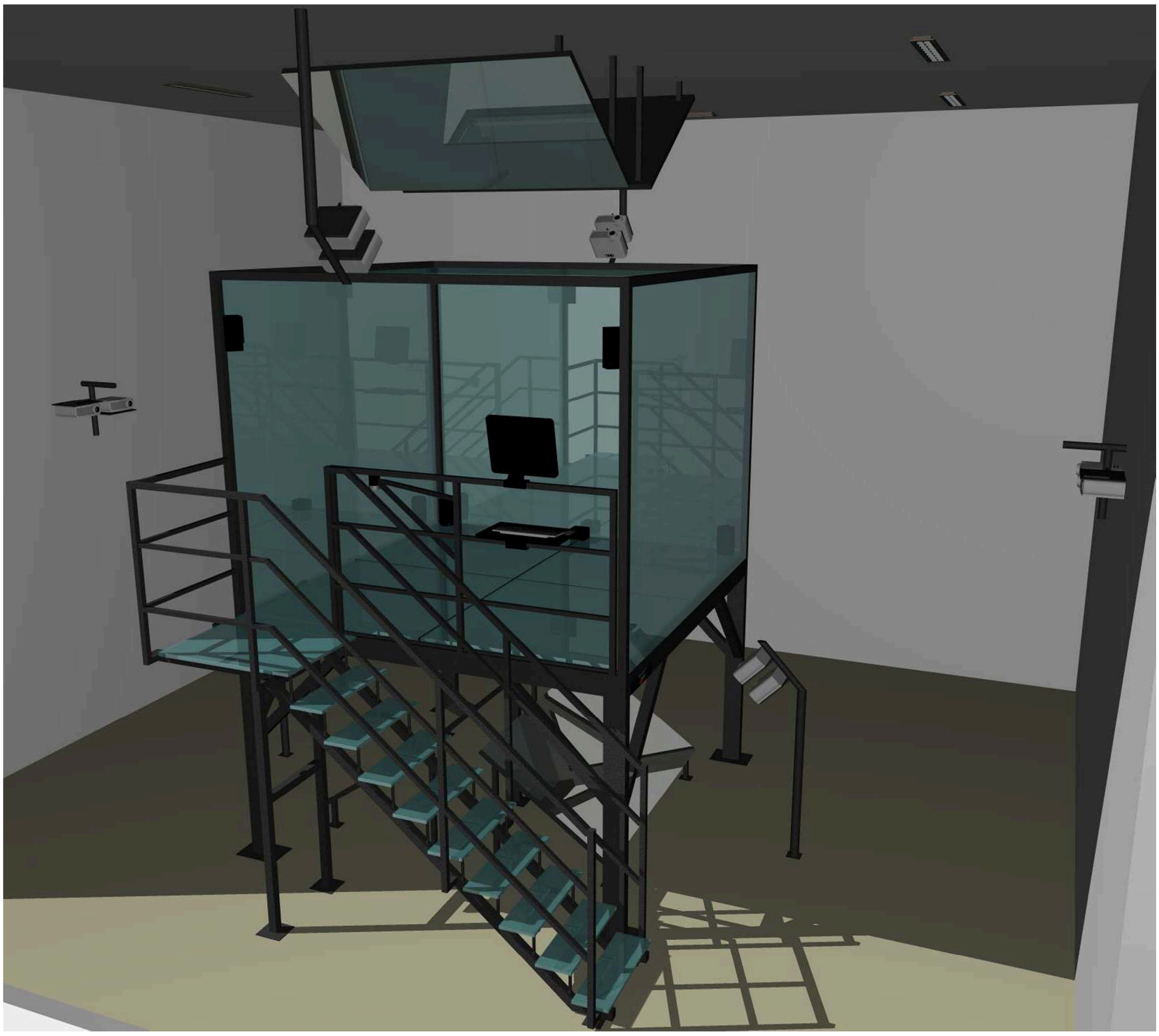

Figure 2: Drawing of the CAVE system developed at Technical University Zvolen (drawn by Búryová 2014).

2.3 Thinning trainer (system of SIBYLA - VR - CAVE)

The sophisticated approach of forest visualization in the CAVE system tries to create virtual representation that is sufficiently credible to arouse a feeling in an observer that he really occurs in the visualized environment. In such a stereoscopic and immersive form of a virtual forest, users can obtain a perfect image of the whole forest structure and its condition. Inside the simulation plot they can move without any restrictions, they can obtain detailed information about individual trees and look into their crowns, and thus, they can assess their mutual competition in the canopy. In this way, forest visualization in the CAVE system wants to provide a user with the complex information on the forest and its individual trees through intensive and interactive visual perception. All of the above mentioned features provide a user, who performs the intervention in the virtual forest, with all the necessary information that is also available in the real forest. The information is necessary when making decisions which trees are to be left in the forest and which are to be removed with regard to the type of the thinning intervention and its objectives. In the environment of a virtual forest, a user can freely move using the assistance control devices (joystick or space mouse). The controller for the implementation of interactions can be used to obtain the information on individual trees by pointing a virtual laser beam at a tree, after which the data is displayed at the front wall of the CAVE system (Figure 3a). Interventions in a forest are performed by marking individual trees (Figure 3b) using the controller for the implementation of interactions. With this device the user activates a laser beam. He points the beam at a desired tree at a height of 1.3 m. A spray icon occurs. The user marks the tree either as a target (green) or to be removed (red), or leaves the tree unmarked by repeated pressing of the button. It is also possible to cut the tree in the actual time. If the laser beam points at a tree foot, a symbolic icon of a chain saw is displayed. By pressing the button, the tree is cut (Figure 3c). If the removed tree was not the correct one, it can be returned to its original state in the same way as it was removed.

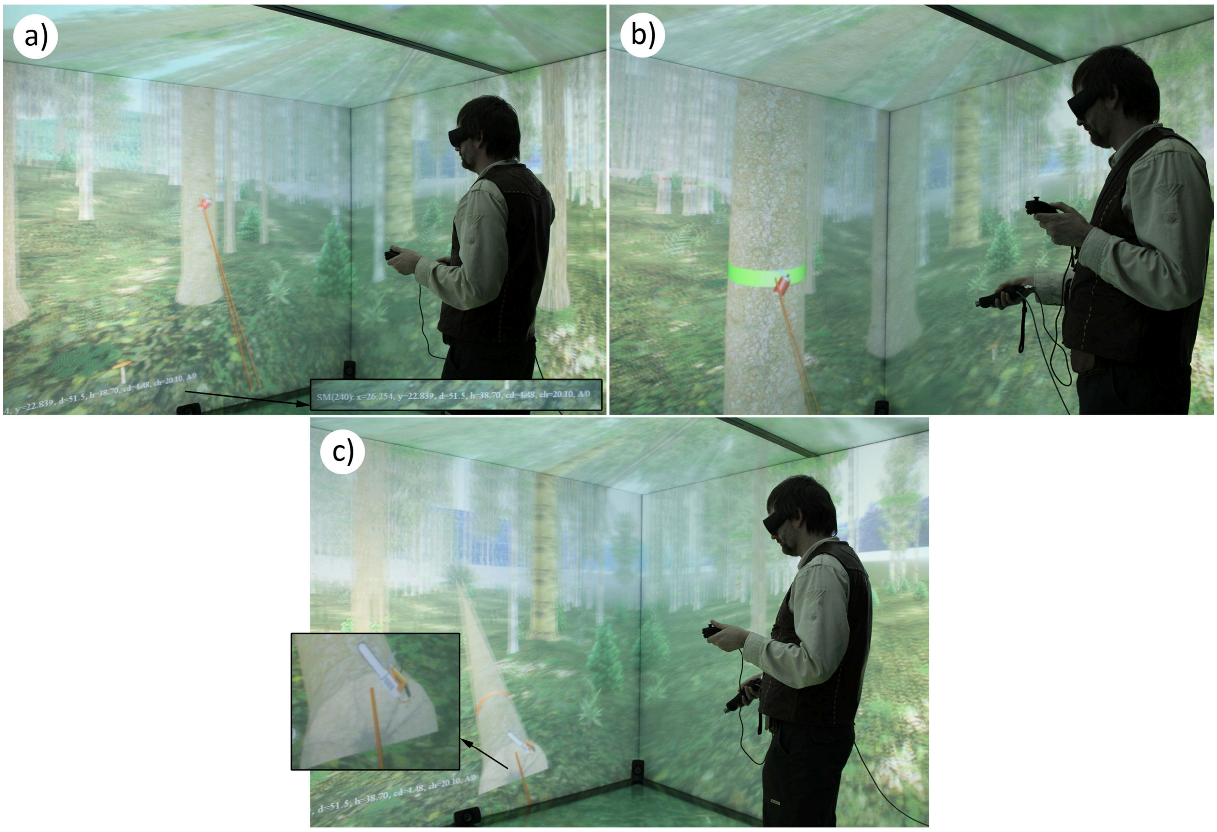

Figure 3: Interaction with trees in the environment of a virtual forest: (a) information about the selected tree, (b) marking the tree, (c) cutting the tree.

After the implementation of the intervention in a virtual forest, the prognosis of its future development with regard to the performed selection starts. For these purposes, the growth simulator needs the following input data:

- parameters and positions of individual trees, their dimensions and terrain configuration of the simulation plot,
- climatic and soil characteristics of the site,
- specification of the categories for each tree at the simulation plot (target, to be removed, unmarked).

The acquisition and the transfer of these data are the tasks of the Caveman module, which ensures the communication link between SIBYLA model and the CAVE hardware tool. The Caveman is a part of the modular structure of the growth simulator and is activated in the menu of the main control software of the CAVE system called SuperEngine control console. The module includes a set of operations that are necessary for starting forest growth prognosis and for the calculation of the results. The principle of module operation is clarified in Figure 4.

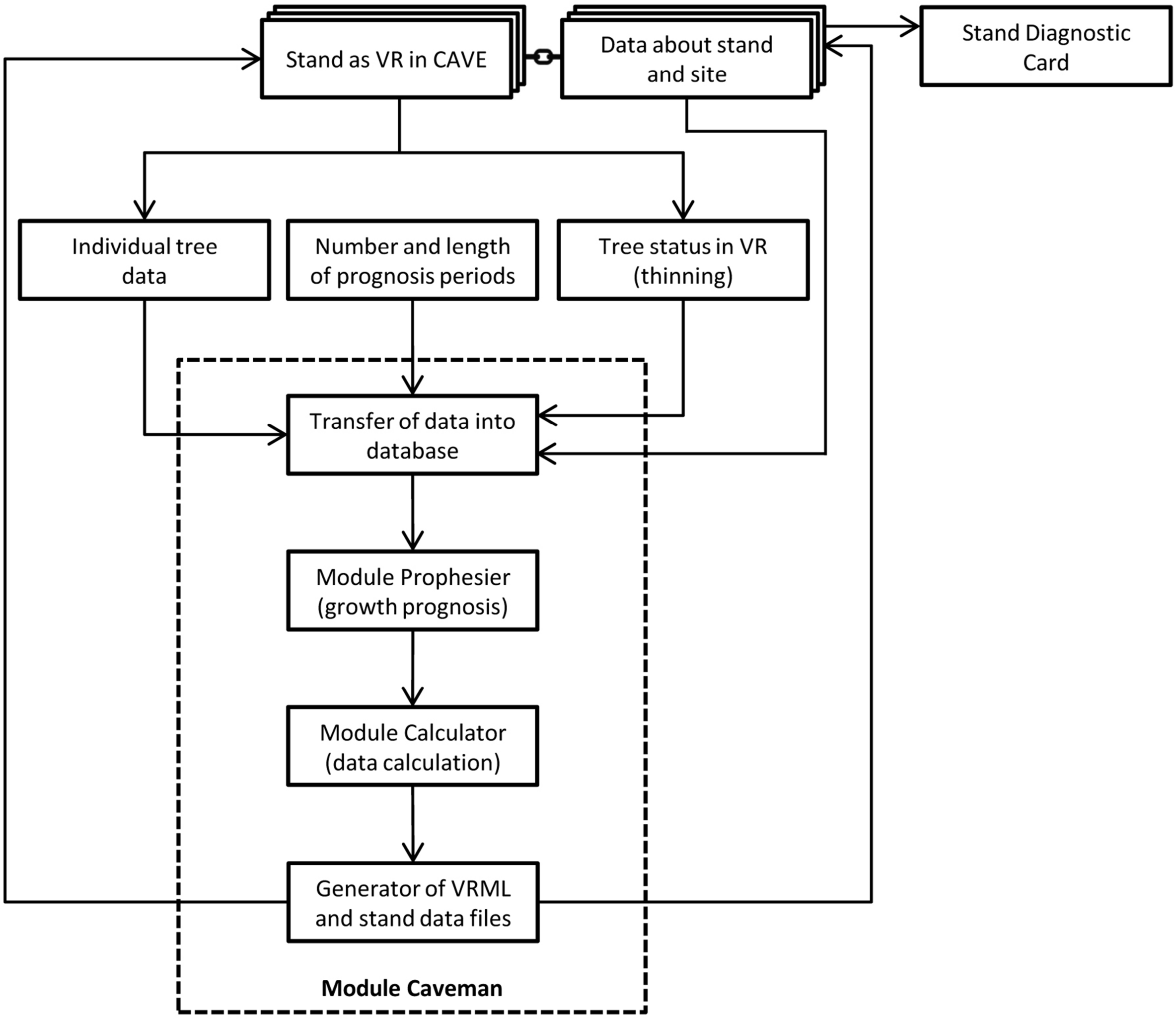

Figure 4: Diagram of the interactions in the system of SIBYLA - VR - CAVE driven by the Caveman module

The virtual reality of the stand in * .wrl format is the initial condition visualized in the CAVE system environment. In this virtual forest, a user performs interventions using the approach presented above. In addition, the information on stand and site of the particular virtual forest is given in a text file. The file contains the data about forest parameters quantified with production, ecological and economic indicators, as well as climatic and soil characteristics of the simulation plot. Both mentioned files are produced simultaneously by the growth simulator since they represent the same simulation plot in the given growth period. Their cross-connection is indicated with the bond in the scheme. From the file about the stand and site, the characteristics representing the active simulation plot can be read and provided to a user at any time using the tool called Stand Diagnostic card. Stand diagnostic card has a form of a dynamic web site, which uses ActiveX component to read and display the content from the text file.

The first phase of the Caveman module activity is the import of necessary data. From the virtual reality file * .wrl of the visualized forest, the module obtains the information on individual trees and the simulation plot. The information includes the data on tree species, sequential tree number, tree position given in coordinates of x, y on the plot, age, diameter, height, crown diameter, height to crown base, assortment class and tree damage, as well as the data on terrain configuration and dimensions of the simulation plot. From the file with stand and site data, the Caveman module obtains the data on climatic and soil conditions of the plot. Tree status after the intervention in the virtual reality is recorded in a file, which is automatically created by control software of the CAVE after the start-up of the Caveman module on the console. The status of the tree corresponding to the performed intervention in the forest will be taken over from this file. The information includes the sequential tree number, and its status (0 - unmarked tree, 1 - target tree, -1 - tree to be removed). At the end of this phase, the user sets the length of the prognosis in a dialogue box of the module.

In the next phase, the data are transferred to a database structure of SIBYLA growth model. When the data import is finished, the Caveman module automatically activates the Prophesier module of SIBYLA growth simulator, which performs the prognosis of the growth of individual trees at the simulation plot. During the prognosis, the initial forest structure, climatic and soil characteristics and performed interventions in the forest are taken into account. After the successful completion of the prognosis, the Prophesier module is terminated.

From the predicted data representing individual trees, production, ecological and economic characteristics of the whole stand have to be calculated. The Caveman module ensures this by running the Calculator module. This module updates all relevant data of the given forest stand.

After the Calculator module is terminated, all necessary data are stored in the database of the growth simulator. The data include the results of the growth prognosis that are linked to the initial forest structure, the calculated stand characteristics, and the data obtained during the data import, which did not change after the simulation. Such data represent the simulation plot and its terrain configuration, climatic and site data, and marking of the target (crop) trees.

At the end, the Caveman module activates the generator of the virtual stand and stand data. The generator creates a new virtual reality in * .wrl format representing the state after the prognosis of forest growth. The links on the crystal balls for time teleport of the user to the past or the future and the link for the Stand Diagnostic card are updated in the file of virtual reality. A new text file with the updated data on stand and site is also created.

In the environment of the CAVE system, the new virtual reality showing the forest condition after the intervention with changed parameters of individual trees and updated stand data in the Stand Diagnostic card is presented to the user. This information is important for the evaluation of the intervention on the basis of the changes of stand characteristics. By clicking on the crystal balls, time teleport between the growth periods at the simulation plot is possible. At the same time, in the new virtual reality a user can again perform interventions in the forest and start the growth prognosis. Thus, the whole cycle of operations of the Caveman module is repeated, as shown in figure 8 by loops and a set of cards of virtual reality and stand and site data.

This results in a fully automated process with minimum need of assistance from a user. It is sufficient when after the implementation of the intervention the user starts the Caveman module on the console of the CAVE system and sets the prognosis length. The module takes care of everything else.

3. Conclusion

Modern methods of simulating developments in the real world and its visualization using immersive systems of virtual reality represent a prospective direction of scientific development and popularization of scientific results to the public. Many scientific and practical disciplines are equipped with trainers for training carried out activities. The realization of thinnings is an area of practical and scientific activities in forestry, which deserves attention in the field of trainers development. Such trainers should be linked to an efficient simulation tool of forest development, they should contain forest visualization using virtual reality, and they should use hardware for immersive visualization of virtual reality. Despite a great number of applications for immersive visualization from different areas of science, research, education and practice, we could not find any references about an existing forest thinning trainer in available publications and internet sources that would meet our requirements. Considering the design solution of our CAVE system, is an innovative device in European conditions regardless of its application designation. From the point of its application as a thinning trainer and the technical link of individual components, the system is unique at a global scale. We proposed a solution that connects a forest growth model with forest visualization solution and modern hardware of the CAVE type. It is a fully automated system with frugal maintenance. In addition, it has an open architecture, which allows to improve individual components (e.g. thoroughness of tree visualization) and to add new functionality (e.g. link to forest landscape or integrating point clouds from a terrestrial laser scanner). It is a practical tool that can support decision-making in forests and landscape, and forestry education. Our solution can become the basis for similar devices applied in forestry and ecology.

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