Visualizing and Exploring Barley Grain Models in VR with the Elbe Dom Immersive Laser Projection System

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ABSTRACT

This paper reports on an ongoing project's research on the utilization of virtual reality (VR) technologies in a fully immersive 360° laser projection system, the Elbe Dom, to support the analysis of barley grain development. Three-dimensional barley grain models transferred into a virtual environment enable technical staff to collaboratively explore biological datasets and thus obtain accurate analysis results and uncover information hidden in data. An overlay channel allows embedding additional conventional 2-D information on the fly.

Keywords

model exploration, grain analysis, plant visualization, immersive VR

1. INTRODUCTION

The use of three-dimensional contents is opening completely new possibilities to explore, extract and present information in virtual environments. Three-dimensional and interactive representations of virtual prototypes are widespread in various industrial domains such as engineering and design. The added value of 3-D information can for instance dramatically increase the effectiveness of work in the prototype design phase. Its use for crop plant research constitutes a relative novelty.

The use of interactive 3-D models to visualize and explore data in virtual environments will continue to gain importance for crop plant research, which searches for answers to major questions that are hidden in the 3-D structures or architecture of plants.

Figure 1 presents an example of virtual reality in an immersive CAVE environment at the Fraunhofer IFF.

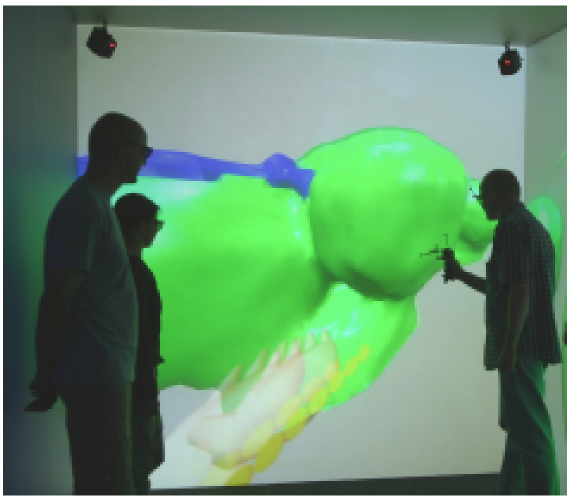


Figure 1: Interactive visualization of a 3-D biological model in a CAVE environment.

The tight space, limited multiuser interaction, low contrast values and shallow depth of field necessitated finding new concepts that better meet technical staff's requirements. This paper outlines new possibilities for crop plant researchers to analyze research data in immersive environments.
New results from research on barley development will help optimize plant cultivation and yield, which in turn will benefit agricultural engineering.

2. RELATED WORK

The following presents a brief overview of existing VR technologies and their features followed by examples of related research projects applying VR to plants or plant parts.

VR Display Systems

The modes of presentation are as varied and diverse as the fields of application for data exploration and visualization in virtual interactive environments. Adapting the classification used by [BL95] and following [Ber04], three basic modes of visual presentation in VR can be differentiated:

– *Immersive VR*: The user is fully or nearly fully integrated in the virtual environment, e.g. in a CAVE [CSD+93] or wearing a head-mounted display [Sut68]. The technology's high acquisition costs and siting constraints have limited its commercial use. Were this technology offered to small and medium-sized enterprises as a service, they would likely find immersive VR solutions financially more attractive.

– *Semi-immersive VR*: Output devices such as vision stations, (stereoscopic) wall screens with up to 220 mega pixels, e.g. HIPerSpace (www.ucsd.edu), or single chip stereo projectors [HHF07] fill most of the field of vision, thus providing users a high level of immersion. Falling hardware prices will likely increase its use in the near future.

– *Desktop VR*: A presentation only takes up a certain area (and typically less than half) of the field of vision. 3-D displays such as Free2c (www.hhi.fraunhofer.de) can also be used.
For more on VR display technologies, the authors refer readers to [Hof05].

Plants, Crops, Grains and the VR Universe

Plant and crop research employs a small number of VR applications but these technologies have differing approaches and foci. The authors were unable to find any clear classification of all existing applications in the literature. VR technologies applied to plant visualization may be subdivided into the following categories:

– *3-D model creation* of plants or plant parts [DHL+98] and [LD98] aims at rendering realistic looking plants (see Figure 2 a and b).

a) b)

Figure 2: Realistic 3-D modeling and rendering of plants [DHL+98].

– *3-D model acquisition* through digitization generates digitized models such as the pumpkin in Figure 3 [MBST05]. This technique may be used to store information on a crop phenotype among other things.

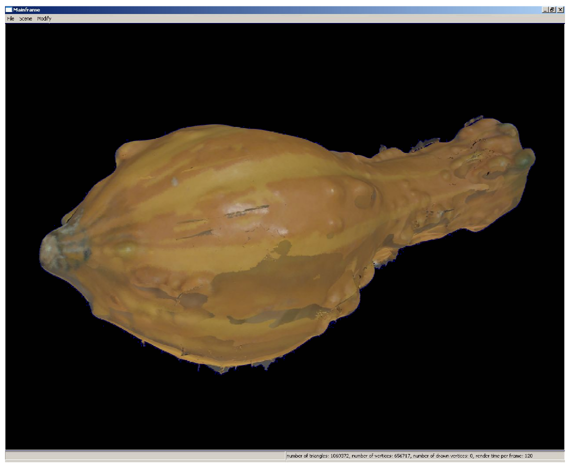


Figure 3: Pumpkin modeled in 3-D with the technique proposed in [MBST05].

– *Simulation of plant or plant part growth* is a well established field of research [XZZ06] and [dVM+03]. Simulated results must be visualized in one form or another. Figure 4 presents one method of visualization. This research aims at optimizing plant growth.

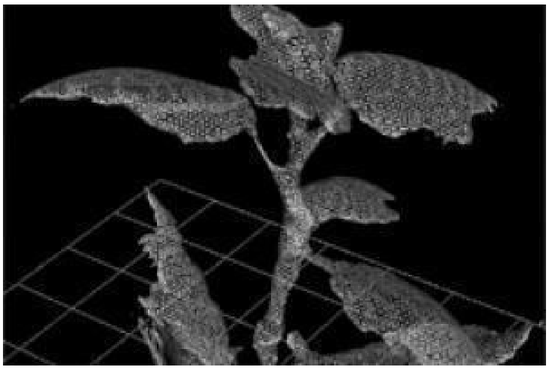


Figure 4: 3-D model of virtual plant growth (www.eureka.be).

– *Analysis of plants or plant parts* is used in particular to identify regions and formations that regulate crop and thus individual plant growth. VR is mainly applied to visualize the results of an analysis, e.g. with the commercial software AMIRA (see Figure 5).

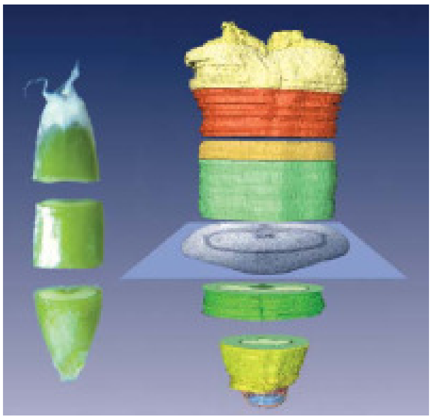


Figure 5: Semi-automatic reconstruction and visualization of plant seeds with AMIRA (www.amira.com).

3. THE INFORMATION DATABASE

IPK Gatersleben generated grain material for visual analysis, which consists of microtome tissue data of different stages (days after blooming), corresponding reconstructed surface models of the main tissues [GDB+07] supported by neuronal networks [BBS+06] and an mRNA dataset.

Each of the datasets segmented consisted of approximately 2000 slices of a barley caryopsis with a height of 3µm. Captured with a color CCD camera (8 bit per color channel), the images originally measured 1600 x 1200 pixels with a pixel size of 1.83 x 1.83µm. Given the very high correlation of the color values, the images were converted to a gray scale with a depth of 8 bits. This reduced the complexity of such a dataset to 3.5 GB.

Semi-automatic segmentation methods can accelerate the process of creating a 3-D model of a caryopsis [SBH+08]. One 3-D dataset with the segmented five main tissues initially consists of approximately 8 GB of data as a VRML model. Datasets can be remeshed down to 2 GB without any significant sacrifice of accuracy.

In-situ mRNA datasets consist of microtome sections stained with gene-specific probes in complex chemical procedures that only allow one section per grain.

In the future, it will be possible to integrate other datasets (NMR data, macro array filter data, etc.) into the database to obtain better synergy and make it easier to infer analysis results.

Figure 6 presents the database with the different datasets. Its organization is derived from a simple entity-attribute-value (EAV) design as in [Anh03]. This approach can easily be expanded for other sources of data.

For more on data acquisition and handling, the authors refer readers to [SM07].

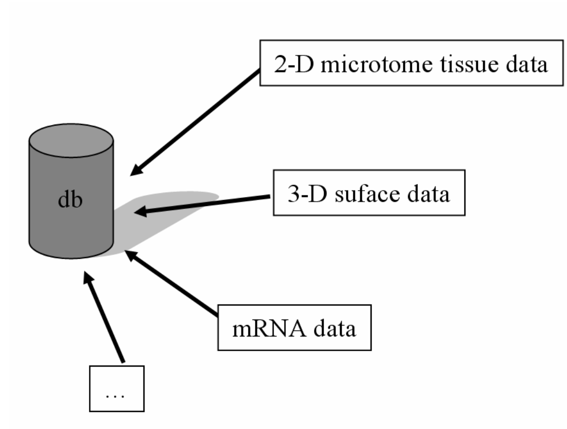
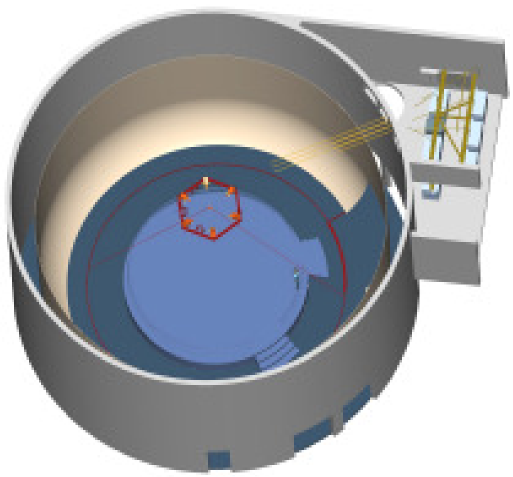


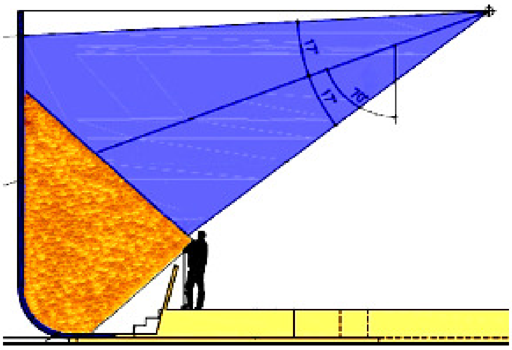
Figure 6: Schematic view of the existing database.

4. IMMERSIVE VR FOR PLANT VISUALIZATION

Increasing demand for interactive, fully immersive virtual environments for multiple active users was the impetus behind the development of the Elbe Dom. Originally mainly intended for factory engineering and product development, the Elbe Dom has evolved into a tool for virtual research studies. The Elbe Dom's physical dimensions and construction enable users to experience an impressively high degree of immersion. The projection surface, specially fabricated by the planetarium dome manufacturer Astrotec Inc. (www.astro-tec.com), is a perforated aluminum cylinder, with a diameter of 16 meters, a height of 6.5 meters and a total surface area of approximately 330 m^2 (see Figure 7 a). The projection surface is not perfectly cylindrical however. Since users view the screen from a circular platform centered in the cylinder, the lower portion is concave to create the illusion of ground projection (see Figure 7 b). Standing in the projection area itself is prohibited since the laser beams (laser class 4) are hazardous to eyes and skin.



a)



b)

Figure 7: The Elbe Dom in a) overhead view and b) sectional detail.

A cluster of seven high-end PCs generates the images. Each of the six PCs and one Nvidia Tesla S870 GPU computing server (www.nvidia.com) are responsible for generating the images for the projectors. The seventh PC supplies and synchronizes the geometry and kinematics data for the other nodes. The software running on each computer must either support synchronization with the other nodes by itself or with appropriate libraries, e.g. CAVELib (www.vrco.com). Other computers in the system preprocess the tracking data delivered by the tracking system (www.vicon.com) or control the lasers and security systems.
The projection system consists of six G2 laser projectors developed and manufactured by Jenoptik LDT GmbH (www.jenoptik.de). Each laser projector utilizes its own laser generator unit to generate one 55 W UV laser beam and convert it with complex optics into three laser beams of different wavelengths (red, green, blue) and intensities. The three base colors of red, green and blue have an intensity output of approximately 1.5, 1.5 and 1.0 watts respectively and cover two thirds of human vision color space. The sRGB color space specification only covers one third (see Figure 8).

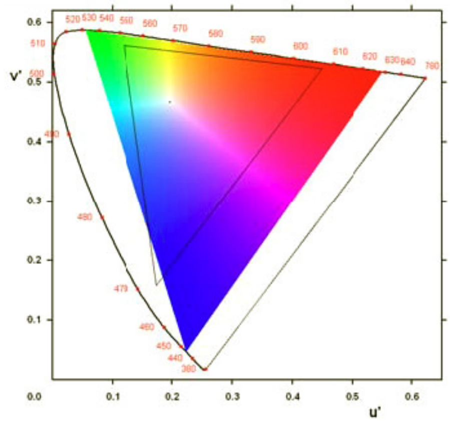


Figure 8: CIE color space gamut (based on human visual perception). The color-filled triangle encloses the laser color space, the black outlined triangle the sRGB specification [Det06].

The projectors' maximum resolution is UXGA with 1600x1200 pixels at a refresh rate of 60 Hz. Since the laser beams write an image line by line, a special feature of the laser projectors is their extremely deep depth of field. Thus, the projected image is always perfectly sharp regardless of the shape of the screen and the distance to it. This is a tremendous advantage of this setup since the unusual shape of the screen and the position of the projectors means the distances between different points on the screen and the projector vary. Each projector handles approximately 68° of the 360° projection. Overlapping sections of the images are utilized for soft edge blending. The construction of the cylindrical aluminum projection plane distorts the rendered VR objects. Therefore, three eyevis openWARP combiner boxes regulate blending and distortion correction. Another advantage of this setup is its capability to insert additional information into a VR scenario by means of a "picture-in-picture" functionality. A netpix box from eyevis netpix distributes incoming signals to the appropriate combiner box. Acoustic signals are delivered by a Dolby Surround 5.1 interface.
For a more detailed survey of this technology, the authors refer readers to [SMH+07].

5. IMPLEMENTATION

The Elbe Dom's physical setup served as the basis for designing and implementing an interface that meets user requirements for the analysis of plants or plant parts. The resultant graphic representation is pictured in Figure 10 a.

The Logitech Cordless RumblePad 2 gamepad (www.logitech.com), the 3Dconnexion Space-Navigator (www.3dconnexion.com), laptops and UMPC, infrared pointers and standard mice were tested as input devices (see Figure 10 a bottom). Intuitive user input devices are the basis for efficient working in the Elbe Dom environment. Laser safety regulations requiring users to remain in the safe area quite a distance from the projection surface limit interaction. This may interfere with a user's sense of immersion.

The grain database consists of the aforementioned types of datasets and is extensible to new types of datasets (see Figure 10 a, left). Additional documents such as graphs or charts of already evaluated experiments can be stored in a separate database or the file system. Needed information can be extracted and stored directly in the grain database or as references.

The VR application visualizes the 3-D information. Therefore, the corresponding cluster node has to render the position, orientation and the field of view of the preliminary image output of a 3-D scene relative to the respective camera (Figure 10 a, center). Figure 10 b presents a 3-D a scene rendered by two adjacent cluster nodes.

Taking the 2-D information from the net pix box, the combiner box blends adjacent rendered edges and computes the distortion correction necessary to convert planar image output to fit the curved screen (Figure 10 a top).

Finally, the combiner boxes' output signal is used to control the laser projector (Figure 10 a, top left).

The visualization of a test scenario combining a 3-D dataset and corresponding 2-D microtome tissues and enriched with 2-D mRNA images is pictured in Figure 9.

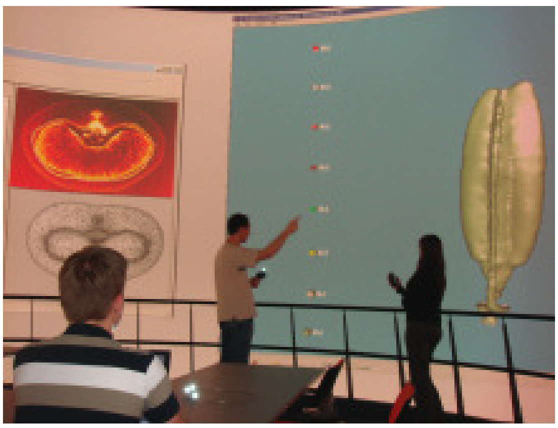


Figure 9: Test scenario in a 360 degree projection with an overlay channel to the left.

An additional benefit of this approach is that every modification during the exploration process is executed on a consistent database on the basis on the specification (provided references have not been deleted). This makes it possible for modifications or annotations, e.g. in the 2-D dataset, to trigger modifications of the representation of the 3-D model.

6. CONCLUSION AND FUTURE DIRECTIONS

The Elbe Dom's novel 360 degree laser projection system and support of collaborative interaction represents an opportunity to overcome the limitations of conventional VR technologies. Figure 11 a – c presents initial results of studies of this approach's feasibility of are shown. This paper outlines the first steps taken toward visualizing interactive analysis and exploring different types of datasets.

The resemblance of Elbe Dom's construction to a command center is a key advantage of this immersive virtual environment with extremely high visual quality. The enormous potential field of view guarantees easy access to useful information in the data presented. User tests have verified that the level of immersion is outstanding, not least because of the relation established between users and a virtual environment. Moreover, the depth contrast of 50000:1 and the relative resolution of 42 % horizontally and 43 % vertically generate a quasi 3-D sensation among users.[1] Users can interact with a virtual 3-D model while simultaneously accessing additional contents such as analysis charts and graphs with ease.

The application developed is a prototype. A variety of improvements, particularly to generate annotations in 3-D space and store so called meta information, will be necessary before the system can run under real conditions. Furthermore, priority handling of synchronous user input and efficient storage of work sessions has yet to be implemented.

7. ACKNOWLEDGMENTS

This research project is being supported in part by the BMBF grants 0313821B and 0313821A. The authors wish to express their gratitude to the staff of IPK Gatersleben and extend a special thank you to Jenoptik LDT GmbH and Jenoptik AG.

[1] Relative resolution is expressed as a percentage of the maximum resolution of the human eye (1 arc min).

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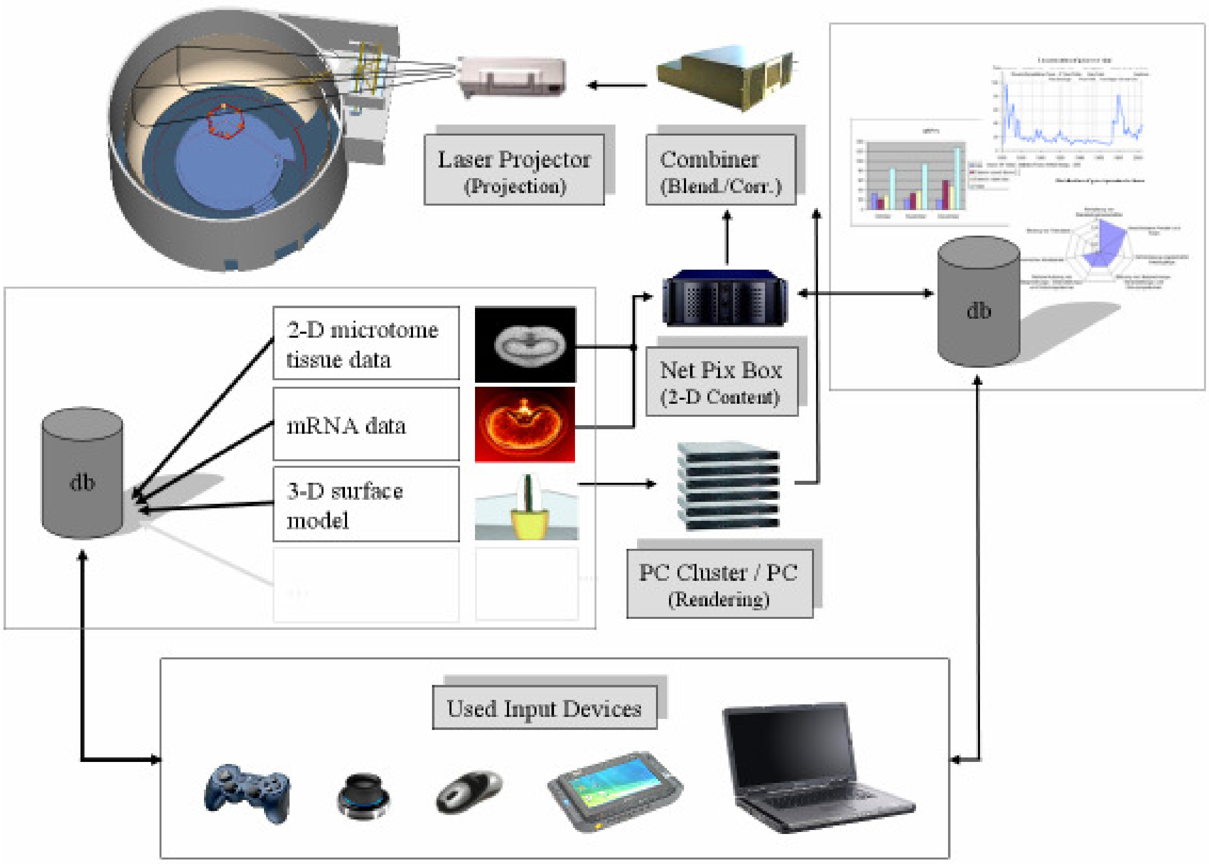

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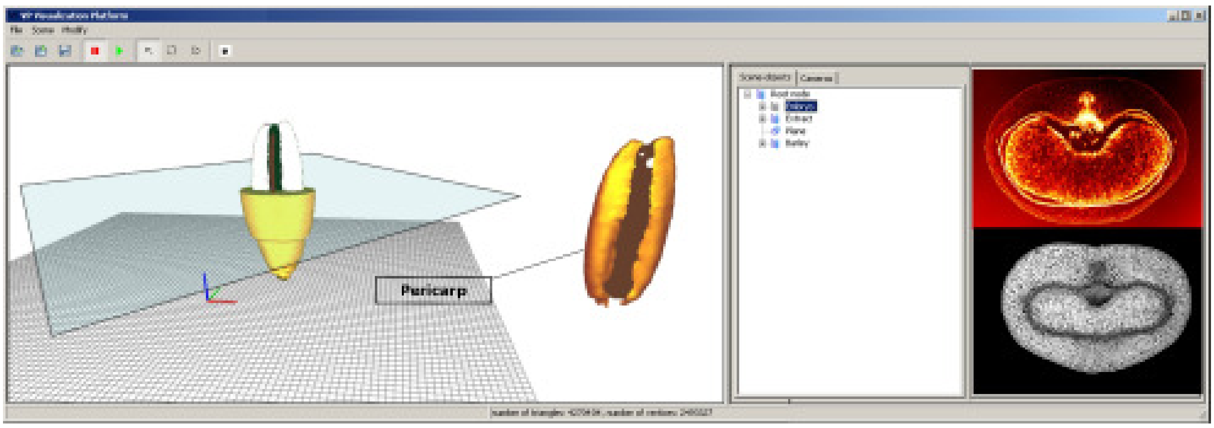
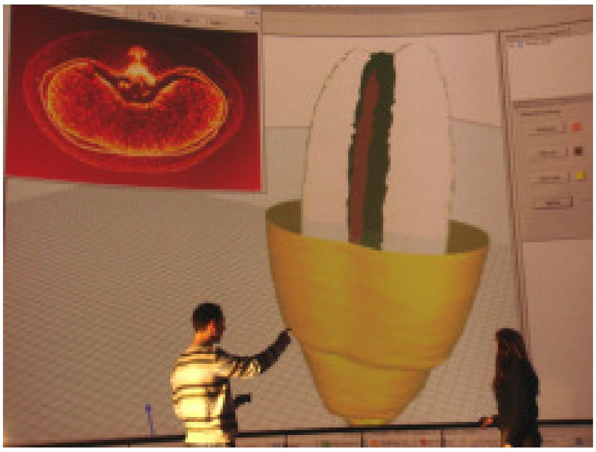


b)

Figure 10: a) Schematic overview of the implemented interface and b) screenshot of the application before mapping (corresponding to approximately 120° of the Elbe Dom's projection surface).



a) b)

c)

Figure 11: Visualization and exploration of a 3-D model of a barley grain: a) Using the gamepad to interactively adjust the cutting plane. b) Preselecting datasets on a laptop while the 3-D shape is projected in the Elbe Dom. c) Comparing interactively selected regions of interest with the underlying data distribution and marking correct regions in the model with annotations.