IV International Conference on Civil Engineering Education
EUCEET 2018
J. Turmo, & J.A. Lozano (Eds)

THE AUGMENTED REALITY SANDBOX AS A TOOL FOR THE EDUCATION OF HYDROLOGY TO CIVIL ENGINEERING STUDENTS

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Key words: Augmented Reality, Sandbox, Education, Civil Engineering, Hydrology.

ABSTRACT

The introduction of new technological tools in higher education seems to be of outmost importance since it enhances the ability of students to understand the function of natural phenomena or technical structures. Augmented reality tools offer the advantage of actual – or rather virtual - participation increasing the interest of participants and thus, their level of understanding. In this paper, an advanced application of the Augmented Reality Sandbox is presented.

The original A.R. Sandbox was the result of an NSF-funded project on informal science education for freshwater lake and watershed science developed by the UC Davis' W.M. Keck Center for Active Visualization in the Earth Sciences (KeckCAVES), together with the UC Davis Tahoe Environmental Research Center, Lawrence Hall of Science, and ECHO Lake Aquarium and Science Center.

The application developed by the authors is adjusted to the educational needs of teaching hydrology to Civil Engineering students. Several improvements of the A. R. Sandbox have been developed by the authors, in order to provide to Civil Engineering students, the ability to better understand the concept of a watershed, of surface flow, of flooding and of the impact of constructions in the flow regime of rainwater.

The improvements made on the A. R. Sandbox developed at the Division of Hydraulics and Environmental Engineering, of the Department of Civil Engineering at the Aristotle University of Thessaloniki, refer to the introduction of simplified and user-friendly ways to change the scale of the map, the water level, and the intensity and duration of rainfall, the evapotranspiration etc.

Another significant improvement is the introduction of an automated procedure for the development of a 3-dimensional model and its direct transformation in order to be seen through Virtual reality (VR) glasses.

1 INTRODUCTION

The introduction of new technologies is very important nowadays in all levels of education, from kinder-garden to university. Children of all ages are so acquainted with computers that they are more acceptive and adaptive to educational procedures based on new technologies.

Augmented Reality (AR) devices have already infiltrated and altered traditional educational practices and appear to have a vast field of applications in several sectors. According to Milgram et al [1] the virtuality continuum is a continuous scale ranging between the completely virtual and the completely real. The reality–virtuality continuum therefore encompasses all possible variations and compositions of real and virtual objects. The area between the two extremes, where both the real and the virtual are mixed, is called mixed reality. This in turn is said to consist of both augmented reality, where the virtual augments the real, and augmented virtuality, where the real augments the virtual.

Figure 1: The Reality–virtuality continuum [1]

The field of education of engineers, and more specifically Civil Engineers, provides a very good field of application of this reality-virtuality continuum. The object of studies of Civil Engineers lies between the analysis of natural phenomena and the development of technical structures, with both lying on the real environment edge of the reality-virtuality continuum. At the same time, the development of computers during the past decades shifted the object of studies to computer-based simulation models, reaching the other end of the continuum, that of the virtual environment.

The representation of natural phenomena and technical structures with computer-based simulation models extends to all; fields of study of Civil Engineers. The field of Hydrology is simulated for example with the Hydrologic Engineering Center - HEC series of models [2]. One of the most wide-spread model for the simulation of groundwater aquifers is MODFLOW [3]. A series of Civil Engineering constructions are simulated with the finite-element software ANSYS [4]. And this is just an indicative, and of course non-exhaustive, list of simulation software used in the education and professional practice of Civil Engineers.

This approach, leaves a significant field of development for applications within the so-called Mixed Reality space in the Reality-Virtuality continuum. As very emphatically stated by Bower et al. [5], "Augmented Reality is poised to profoundly transform education as we know it. The capacity to overlay rich media onto the real world for viewing through web-enabled devices such as phones and tablet devices means that information can be made available to students at the exact time and place of need. This has the potential to reduce cognitive overload by providing students with "perfectly situated scaffolding", as well as enable learning in a range of other ways."

One of these Augmented Reality applications attracting the interest of Engineers, is the A.R Sandbox. More details about the A.R Sandbox will be presented in the following paragraphs.

2 DESCRIPTION OF THE A.R. SANDBOX

The augmented reality (AR) Sandbox combines 3-dimensional visualization applications with a hands-on sandbox to teach earth science concepts [6]. The AR sandbox allows users to create topography models by shaping real sand, which is then augmented in real time by an elevation color map, topographic contour lines, and simulated water flow. The system teaches geographic, geologic, and hydrologic concepts such as how to read a topography map, the meaning of contour lines, watersheds, catchment areas, levees, etc.

The AR Sandbox comprises the following hardware components:

- A computer with a high-end graphics card, running Linux.
- A Microsoft Kinect 3D camera.
- A digital video short-throw projector with a digital video interface, such as HDMI or DVI.
- A sandbox with a way to mount the Kinect camera and the projector above the sandbox.
- Sand.

A typical arrangement of the projector and the Kinect 3D camera above an AR Sandbox is shown in Figure 2. The short-throw projector is mounted at the same height as the Kinect camera, but above to the rear long edge of the sandbox to account for its above-axis projection [6].

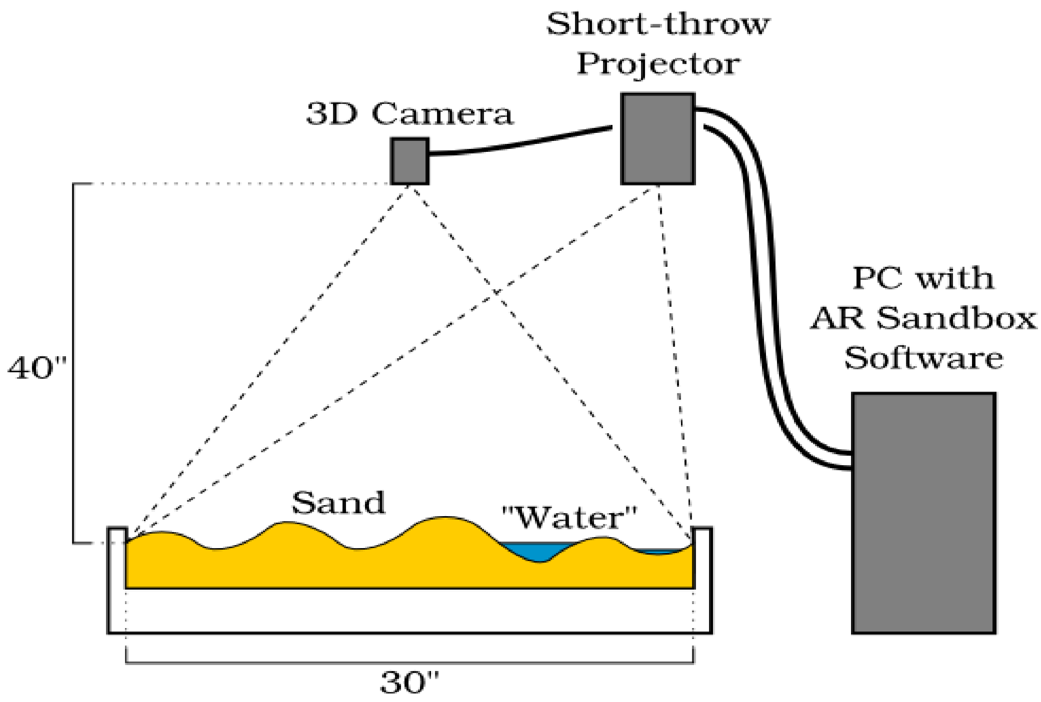

Figure 2: Typical arrangement of an AR Sandbox [2]

Raw depth frames arrive from the Kinect camera at 30 frames per second and are fed into a statistical evaluation filter with a fixed configurable per-pixel buffer size. The resulting topographic surface is then rendered from the point of view of the data projector suspended above the sandbox, with the effect that the projected topography exactly matches the real sand topography. The software uses a combination of several GLSL shaders to color the surface by elevation using customizable color maps, and to add real-time topographic contour lines [7].

At the same time, a water flow simulation based on the Saint-Venant set of shallow water equations, which are a depth-integrated version of the set of Navier-Stokes equations governing fluid flow, is run in the background using another set of GLSL shaders. The simulation is an explicit second-order accurate time evolution of the hyperbolic system of partial differential equations, using the virtual sand surface as boundary conditions. The simulation is run such that the water flows exactly at real speed assuming a pre-defined 1:100 scale factor [7].

The software that performs all these tasks is available for free download from the developers at UC Davis [8].

3 IMPROVEMENTS AND ADJUSTMENTS OF THE A.R. SANDBOX

The AR Sandbox of the Aristotle University of Thessaloniki was developed with co-funding by the Erasmus+ Program of the European Union, «Educational Lab – Big Machine – ElBigMAC» [9]. It was originally developed following the detailed instructions provided by the UC Davis [6, 7, 8]. A series of changes and improvements were then developed by the authors in order to adjust the AR Sandbox to the needs of Hydrology courses for Civil Engineers. These adjustments are described in the following paragraphs.

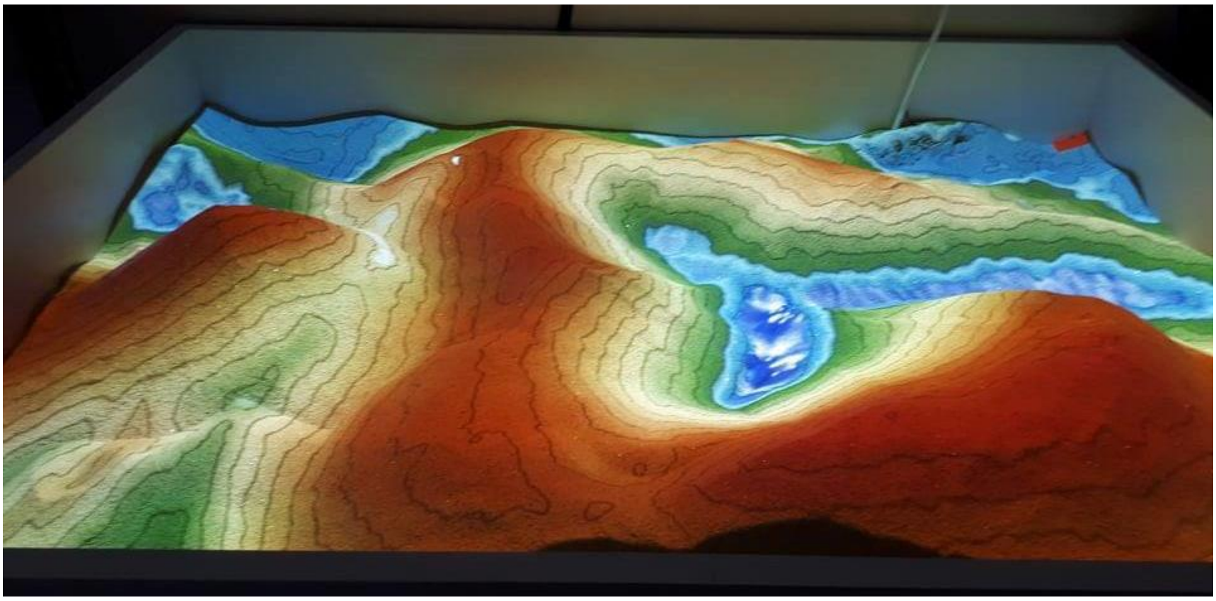

Figure 3: The A.R. Sandbox of the Aristotle University of Thessaloniki

3.1 Scale of the map

The AR Sandbox has a pre-defined scale factor of 1:100. The scale factor does not affect the topographic representation, but it affects the water flow. This relatively small scale, provides an impressive, but not very realistic, representation of the water flow. The authors added am external button to the device through which the user can adjust the scale factor to a level more suitable to the map of the area under investigation.

3.2 Water level

The water level is a contour that separates areas of the map covered by water, from dry ones. Depending on the level of water, more or less areas of the map are presented to be below or above water. This level can be adjusted by changing the respective values within the code of the software. This is not very easy to do and thus we decided to add another external button through which the user can adjust the water level. Thus, be turning left or right the button, the user sees the water rising or dropping.

3.3 Intensity and duration of rainfall

The ability of the user to define the intensity and duration of rainfall is very important for a realistic hydraulic simulation. This was accomplished again by introducing buttons that simulate rainfall when pressed. Rainfall "stops" when the button is released. One of the future developments that we plan to introduce, is to connect the AR Sandbox to on-line meteorogical stations and represent actual rainfall phenomena.

3.4 Evapotranspiration

In the same way as above, a button introduces evapotranspiration, reducing the amount of rainfall that actually outflows along the slopes of the watershed.

3.5 Three-dimensional model

Last of the improvements we have introduced to the original AR Sandbox, but definitely not least, is the introduction of an automated procedure for the development of a 3-dimensional model and its direct transformation in order to be seen through Virtual reality (VR) glasses. Through a special software we introduced, the topographic surface is transformed into a 3-D model and adjusted so that it can be viewed through VR glasses. This was tested with a set of HTC VIVE VR glasses (figure 4).

Figure 4: Virtual Reality glasses

4 APPLICATION OF THE A.R. SANDBOX IN HYDROLOGY

The AR Sandbox of the Aristotle University of Thessaloniki was suitably adjusted in order to be used by students following Hydrology classes at the Department of Civil Engineering. The procedure followed is the following:

The map of a watershed with known characteristics is selected and it is projected through the short-throw projector of the device, onto the sand. The students try to replicate, using the sand, the topographic surface of the watershed adding or removing the sand across the sandbox. In order to achieve that, they change the projected image between the map of the watershed and the image recognized by Kinect.

After completing this task, it is assumed that the distribution of the sand across the sandbox actually represents the topographic map. The scale factor is set according to the one of the topographic map and the water level is suitably adjusted.

The next step is to simulate rainfall using all the additional buttons that were introduced. Thus, the users can change the intensity and duration of rainfall and reduce runoff by increasing evapotranspiration.

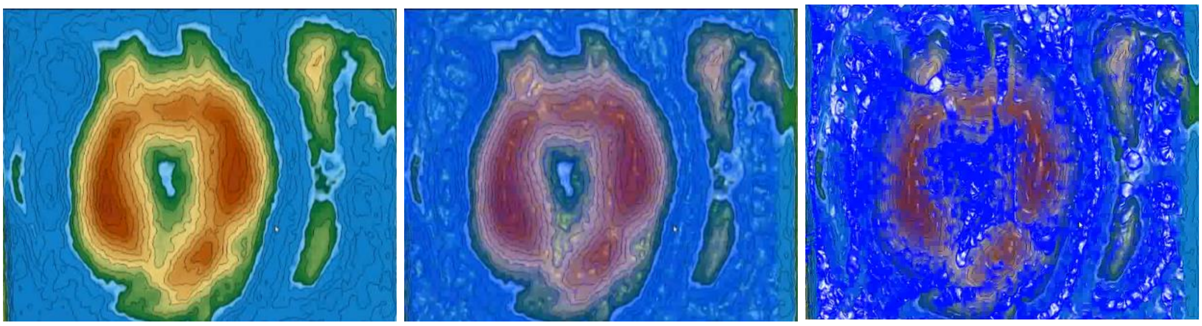

Figure 5. Effect of the variation of rainfall duration

Then the AR Sandbox's software solving the Saint-Venant set of shallow water equations, which are a depth-integrated version of the set of Navier-Stokes equations governing fluid flow, represents the flow of water. The students can actually see water flowing along the slopes of the watershed and across the riverbed. When the amount of water exceeds a certain level, then flooding occurs.

Students can also introduce flood-preventing measures, like small dams, or water deviations, to investigate their impact and usefulness.

By adjusting the water level value, students can also simulate the effects of sea water rise due, for example, to the impacts of climate changes.

Future plans include, the connection of the AR Sandbox to on-line meteorological stations operated and managed by our department, in order to make rainfall simulation more realistic. Also, an even denser discretization of the scanned by Kinect, area will result in more detailed representation of the watershed's characteristics. The only problem with this option is that, denser discretization will result in more complex systems and may cause a delay between changes made in the sand and their projection by the device.

The final intervention made to the Sandbox, is the three-dimensional analysis of the topographic map, its suitable transformation and its projection through the Virtual Reality glasses. The whole procedure is uploaded to a cloud server and it can be downloaded and used simultaneously by students located all over the world. This was already successfully tested with university students located in another country. The only problem is that due to this time-consuming procedure, the response was not immediate, but it took a few minutes from the moment the users of the AR Sandbox made some changes to the moment these changes were viewed by the VR glasses users.

The result was that students located far away from the AR Sandbox could "see" the watershed and virtually move around it viewing all the characteristics of the landscape.

5 CONCLUSIONS

The introduction of new technologies is definitely the future of education. In order to attract the attention of students of all ages, teachers need to improve and modernize their practices taking advantage of the opportunities arising from the development of new technologies. In between the actual experiments, characterized as real environment and their simulation models, characterized as virtual environment, lies the space where actual intervention of users is combined with the virtual environment. This space is known as augmented reality. The profession of Civil Engineering is a typical example of parallel applications of experiments and simulation models. This is why, augmented reality systems have a very wide field of applications in Civil Engineering.

In this paper the Augmented Reality Sandbox developed under the original instructions of UC Davis but improved and extended by members of the Aristotle University of Thessaloniki, is adjusted to the educational and research needs of the scientific field of Hydrology for Civil Engineers. The results, but also the comments and reactions of the students who had the opportunity to use the device during their Hydrology classes, indicate the opportunities that arise from future implementation of augmented reality technologies in higher education study prohrams.

6 AKNOWLEDGMENT

The original A.R. Sandbox was the result of a National Science Foundation funded project under Grant No. DRL 1114663 on informal science education for freshwater lake and watershed science developed by the UC Davis' W.M. Keck Center for Active Visualization in the Earth Sciences (KeckCAVES), together with the UC Davis Tahoe Environmental Research Center, Lawrence Hall of Science, and ECHO Lake Aquarium and Science Center.

The AR Sandbox of the Aristotle University of Thessaloniki was developed with co-funding by the Erasmus+ Program of the European Union, «Educational Lab – Big Machine – ElBigMAC».

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