Teaching Topographic Surface Concepts in Augmented Reality and Virtual Reality Web Environments

Paulo Henrique Siqueira
paulohs@ufpr.br
Department of Graphic Expression, Federal University of Paraná,
Curitiba-PR, Brazil

Abstract

This paper shows the use of web resources for the creation of Virtual Reality (VR) and Augmented Reality (AR) environments to teaching of topographic surface concepts. The mockups of the topographic surfaces were built with Sketchup software, include graphical representations of level contours, terrain cuts, topographic profiles and embankments. The terrains textures used are satellite photos available by the Digital Globe platform and contribute to improve the visualization of studied concepts. Developed environments enable students to view surfaces in AR ambient, using their webcam devices, such as smartphones, tablets, or notebooks, from a variety of points of view. Each topographic surface mockup has a link to its respective representation in VR, which allows its manipulation and detailed study of each concept. The environments presented in this work can be used in disciplines of Topography, Geography and Descriptive Geometry.

Keywords: Augmented Reality; Virtual Reality; Topographic surfaces; Virtual Mockups;

1. Introduction

The use of auxiliary resources allows students to better understand subjects in disciplines involving three-dimensional concepts. Object manipulation helps students understand, making it easier to assimilate the theoretical concepts of the subjects. Nowadays, the developing of teaching applications or web environments helps to visualize concepts of Biology [4] and Geometry [5]. The construction of physical mockups can be done using 3D printers for classes in Geography [1], Biology [2], Geometry [3] and other disciplines involving 3D representations.

The use of modeling with virtual technologies is one of the alternatives to help teaching in subjects that involve 3D concepts. Virtual Reality (VR) serves to create an immersive environment with manipulation of objects using controls and immersive goggles [6]. VR environments help the visualization of physical or biological phenomena, training simulations, visualization of planets surfaces, construction simulations, educational games and other education areas.

The Augmented Reality (AR) uses a camera device to insert objects together with the camera image environment, creating virtual layers of 3D objects and text on the camera image in real time [7]. Recent works shows interesting applications of AR to aid in teaching of various areas, such as Geometry [8], Engineering [9], Chemistry [10], Architecture [11] and others [12], [13]. The contributions of the use of AR in education demonstrate that it is a powerful tool for classroom use, as it allows for various forms of visual interactions in learning various disciplines [14].

This paper presents the necessary elements for the construction of a web environment that uses VR and AR technologies to represent virtual models for the teaching of topographic surfaces. The models are create in Sketchup software with the texture and modeling features available from the Digital Globe platform. The drawings of terrain sections, platforms, embankments and level contours are create in Sketchup, with the insertion in the programmed environments in AR and RV, allowing a deep study of the features of the terrain and the main relief forms: valleys, hills, mountains, lakes, plains and plateaus.

The purpose of this paper is show the main elements to create an HTML page in AR, with links to pages developed in RV. On the AR page, students view mockups from various points of view and access the VR sites to manipulate topographic surface representations with mobile devices, computers, or even immerse themselves in the scene with VR goggles.The commands used to create the proposed environments in AR and VR are intuitive, and only require basic knowledge of HTML. It is a didactic resource of simple programming, which enables classroom applications without difficulties pointed out in the use of some AR technologies, as shown in [15].

The present paper is divided into 6 sections, including this introduction. Section 2 present a state-of-art of teaching topographic surface concepts. Section 3 presents modeling of topographic surface mockups using Sketchup. In sections 4 and 5 are shown the basic HTML commands for creating of Virtual Reality and Augmented Reality environments, respectively. In section 6 the conclusions are made.

2. Topographic surfaces teaching

The study of topographic surfaces can be enhanced with the aid of virtual technologies. The construction of 2D elements of terrain graphics can be complemented by 3D visualizations using various available techniques.

According to [16], Sandbox technology has been widely used in the teaching of relief forms in Geography discipline. The system reads the sand layers, creating the level contours using colors defined by hypsometric and bathymetric techniques, giving students the perception of the shape of each terrain. The work of [17] shows the use of the Sandbox tool for visualization of brazilian regions and slopes studies applications of the Topography discipline for the Civil Engineering course.

The use of Descriptive Geometry concepts to represent a simplified design of voltage line installation is shown in [18]. The initial information of the topographic map are presented to students, and used for the construction of the 3D model, with all the technical norms for the correct installation of each transmission tower.

Physical models are also important for teaching topographic surfaces. Activities to create physical mockups with the students to aid in the teaching of relief concepts and level contours are shown in papers [19], [20] and [21]. The results shown by these authors are excellent, with the interaction between students and teachers, resulting in the students' better understanding of topographic surfaces concepts.

The creation of a map of the campus of an brazilian university with Augmented Reality is shown in [22], using available cartographic information. The model was tested with Cartographic Engineering students, and most consider that the AR model improves visualization compared to traditional maps. The

AR map proposed by the authors considered only the features of the terrain and the shapes of buildings on campus.

The paper presented in [23] uses Augmented Reality for visualization of topographic surfaces using the AR-Media application. Using the printed contours of each terrain, the authors show how the application works with the surfaces that appear over the curves, complementing the teaching of relief shapes.

The use of Augmented Reality can complement the use of traditional teaching materials in the teaching of topographic surface concepts, as students can interact and visualize terrain elements more effectively and meaningfully. Virtual Reality can help students interact with 3D representations of terrain, transforming the teaching of content into a kind of field class on reliefs in various ways.

3. Modeling of Topographic surfaces

The mockups shown in this article were create on Sketchup software [24] using the feature available for Digital Globe platform [25] land surfaces. The mockups are exported to be inserted into A-frame [26] programmed web environments for use in both technologies: Augmented Reality and Virtual Reality. Thus, the static concepts of terrain relief shapes can be viewed as they are, making the contents of these classes more realistic and dynamic.

The first step to create the environment proposed in this article is to choose regions that contain interesting valleys and mountains for use in the classroom. Digital Globe's land insertion tool creates square viewports of limited side equal to 2 km, which are modeled for the land surface only, disregarding heights of buildings and vegetation. The textures used in this tool are satellite photos, ideal for modeling surfaces to be closer to reality in AR and VR.

After choosing the terrain location, the satellite photo of the region is loaded into Sketchup, as shown in Figure 1. This is the top view of the terrain from a region of Kamloops mountains, in Canada.

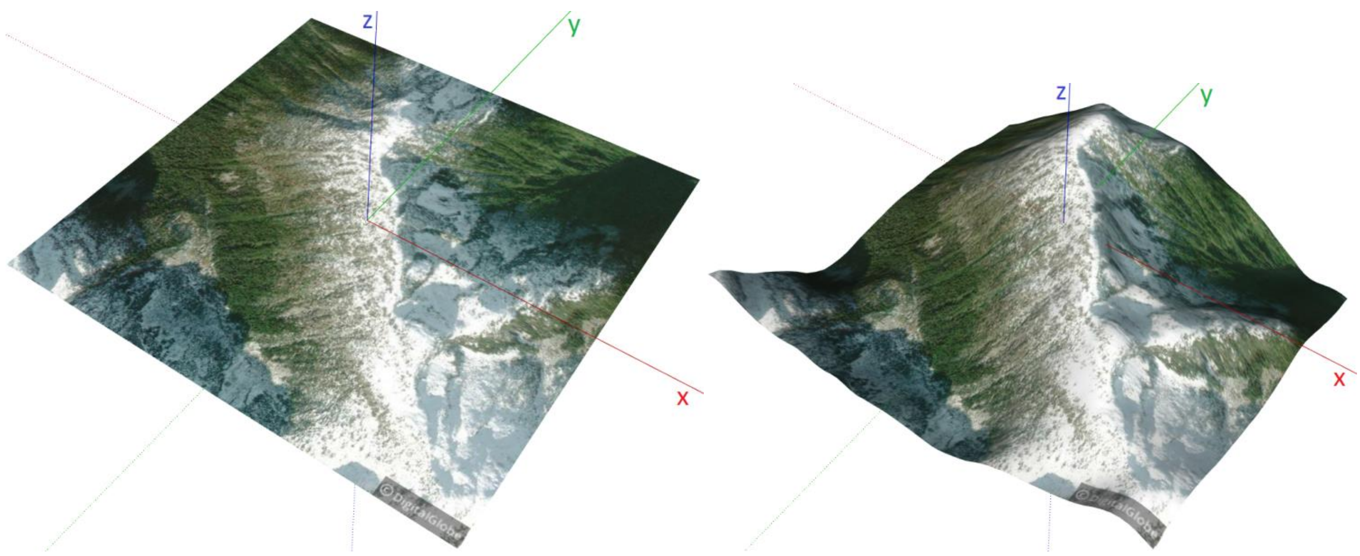

Figure 1. Satellite photo and 3D mockup of the Kamloops mountains region, Canada.

Using Sketchup's option to show terrain, the topographic surface can be modeled with the actual altitudes of the chosen region. Figure 1 shows the modeling of the Kamloops region in 3D with features of the Digital Globe platform.

The creation of the set of level contours of each region can be made by equidistant rectangles with respect to z axis (altitudes), with sides parallel to x and y axes, measured slightly larger than the sides of the surface. These rectangles represent the horizontal sections plans of the surface. The intersections of these equidistant plans with the surface form the set of lines of level contours, as shown in Figure 2. Other important elements that can be defined in Sketchup are elevation dimensions, plans sections, topographic profiles and embankments. The top view of each surface can be used for creating teaching materials on topographic surfaces.

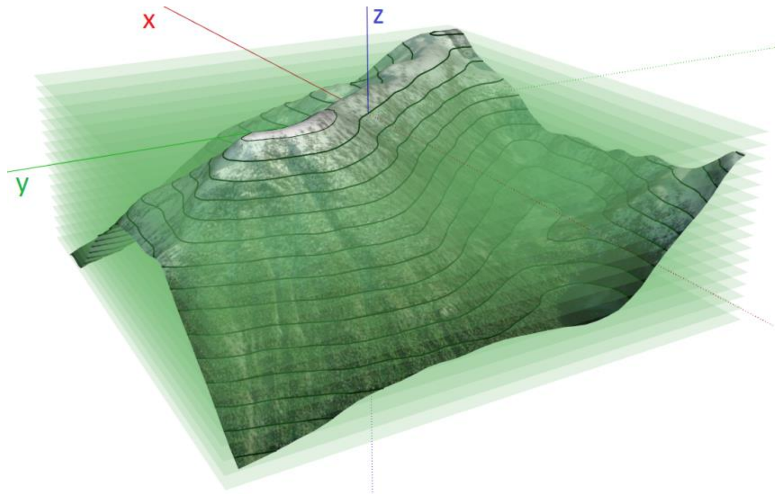

Figure 2. Construction of level contours of the Kamloops region.

If the chosen region is larger than the 2km limitation of the Digital Globe viewport, multiple windows can be created with the sub regions that cover the chosen area, and each image fits the neighboring image as a species of patchwork.

To make the use of the technologies proposed in this paper even more interesting, the region chosen for a particular activity may be tourism, such as Mount Fuji in Japan, Grand Canyon in United States, or Chapada Diamantina in Brazil. To represent a mockup of a region of the Grand Canyon in Arizona, you need 40 viewports, which are illustrated in Figure 3 in 2D and Figure 4 in 3D. In the virtual mockup, a large region of the Colorado River is represented, allowing the exploration of various forms of relief in classroom.

4. Virtual Reality

The topographic surfaces mockups shown in section 3 were inserted into Virtual Reality and Augmented Reality environments using the A-frame libraries. This is an environment developed by the Mozilla VR team [27] that uses the functions of the Java Three.js library with pure HTML tags, allowing all VR or AR programming to be done on one page of the web, which follows the composition of tags with inheritance and hierarchy principles [26].

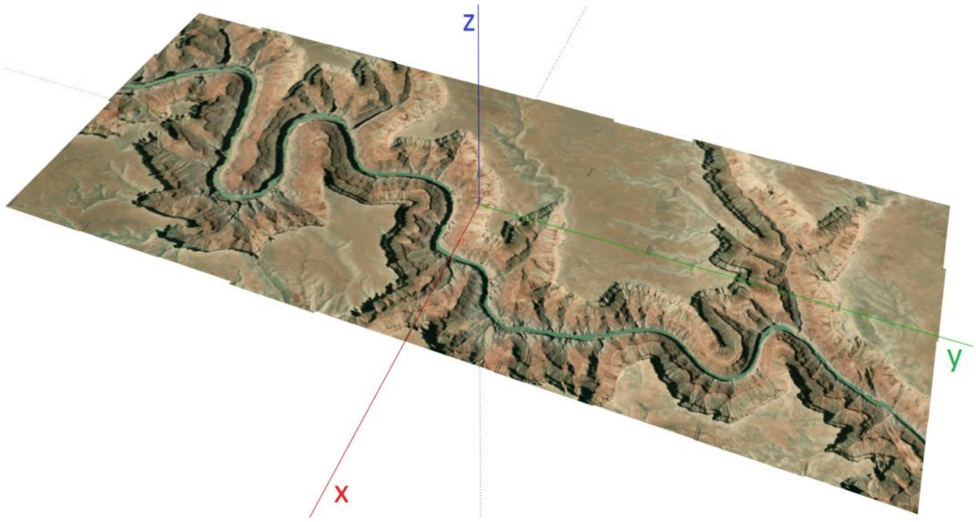

Figure 3. Grand Canyon mockup 2D view blocks.

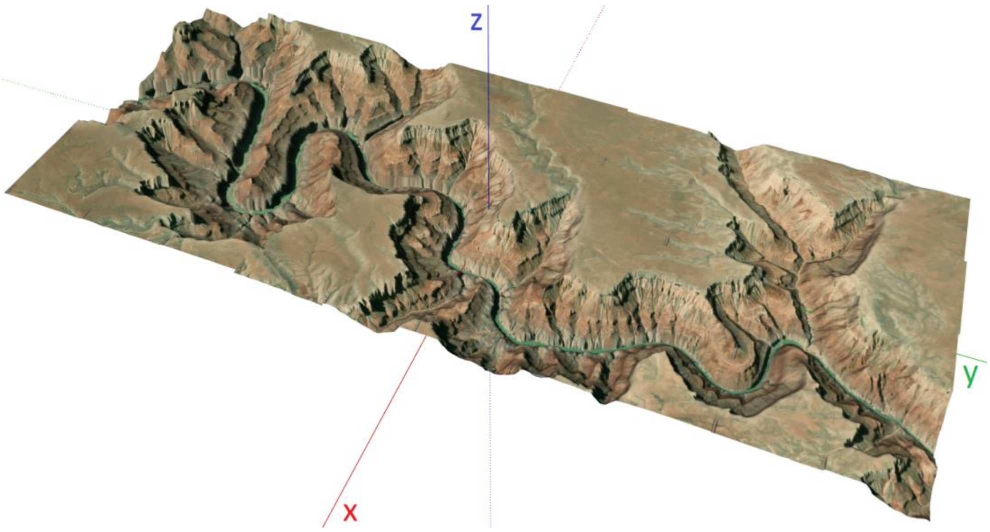

Figure 4. 3D representation of Grand Canyon mockup.

Programmed environments in A-frame support four mockup file formats. The first is obj (object file), a widely used format that can be opened in any 3D software, whose files include coordinate information, texture maps, and polygonal faces. The second format used by A-frame is collada (collaborative design activity), which is supported by many 3D software and uses the xml standard to load texture, animation and lighting information. The third format that can be used is gltf (graphic library transmission format), which has the same information as obj in a more compact way, getting faster loading in web applications. The binary version of gltf, called glb, is the fourth file type supported by A-frame.

The only format that exports lines is collada. As the visualization of lines is essential for the study of level contours and terrain sections, the environments were built with mockup of terrain in glb, gltf or obj format combined with lines of collada files.

Eight models were used in didactic materials to classes of basic Topography to study following topics: level contour lines, topographic profiles, roads, embankments, platforms and terrain sections. According to Table 1, it can be seen that the best combination of files is glb for polygons and textures and collada for lines, with 6,702 kB, which represents 28.56% of the total file size when used with collada extension. With this combination of files, sites load on average 3.5 times faster compared to configuring collada format models only.

Table 1. Comparisons between sizes (using kB units) of files used to make mockups.

description	collada	obj and collada	gltf and collada	glb and collada
1. topographic profile	3.760	1.824	1.394	852
2. platform	3.082	1.363	1.173	909
3. road	1.929	875	992	768
4. level contours	2.232	1.125	1.030	657
5. terrain section	5.502	2.521	1.761	1.053
6. level contours	1.372	667	765	585
7. topographic profile	3.425	1.529	1.171	708
8. road with curve	2.160	1.495	1.330	1.170
total	**23.462**	**11.399**	**9.616**	**6.702**

The main tags of the modeling of one of the topographic surfaces are illustrated in Figure 5. In the header tag of the HTML page is inserted the reference to the A-frame main library between lines 3 and 5. All library references can be inserted in this header tag.

The body of the HTML page contains the programming of the other page elements. In lines 7 and 8 of Figure 5 are the definitions for user interaction with the mouse or VR control and the camera of the scene with starting position at coordinates x (right / left), y (height) and z (depth). The initial values are: x = 0 and y = 0, which center the camera on screen; and z = 6 m to distance the observer from the origin of the system.

```
1 <!DOCTYPE html>
2 <html>
3  <head>
4   <script src="https://aframe.io/releases/0.8.2/aframe.min.js"></script>
5  </head>
6  <body>
7  <a-scene cursor="rayOrigin:mouse">
8  <a-entity camera look-controls position="0,0,6"></a-entity>
9  <a-assets>
10   <a-asset-item id="estrada" src="imagens/curva16.dae"></a-asset-item>
11   <a-asset-item id="estrada1" src="imagens/curva16.glb"></a-asset-item>
12   <img id="ceu" src="imagens/ceu1.jpg">
13 </a-assets>
14 <a-sky src="#ceu"></a-sky>
15 <a-entity scale="0.003,0.003,0.003" position="0,0,0">
16  <a-entity collada-model="#estrada"></a-entity>
17  <a-entity gltf-model="#estrada1"></a-entity>
18 </a-entity>
19 </a-scene>
20 </body>
21 </html>
```

Figure 5. A-frame HTML code for VR presentation of a Sketchup mockup.

The tags that define the texture and loading of the mockup are placed between lines 9 and 13. The model is defined on lines 10 and 11, where you must enter the folder path of collada and gltf files. The blue gradient background image is set to line 12 and referenced as the 360º background image of the scene in the <a-sky> tag of line 14.

Between lines 15 and 18 are the tags that define the position and scale of the model. To properly load it, the scale used is 0.003 in all three dimensions and the position at the origin of the system. Figure 6 shows the model programmed in VR with the tags shown in Figure 5. It is the graphical representation used for road construction study, with embankment slopes and level contours. With this VR representation, students can view constructions that are made with terrain contours to define sections and embankments positions in 2D.

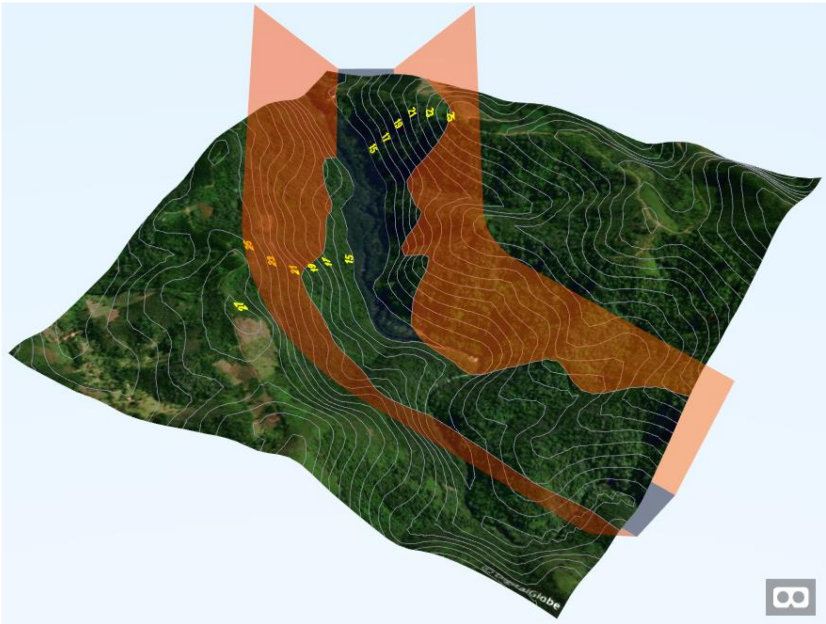

Figure 6. VR representation of model with terrain sections for road construction.

The intersection of a topographic surface with the plan that defines the slope of a section or embankment can be made by matching each level contour with the respective horizontal line of this plan of the same elevation. Students can construct the cut and embankment curves of these slopes in 2D, and the concept can be complemented by 3D visualization of what was built in VR.

One way of interacting with scene elements is using the orbit function [28], which allows the camera to move around the objects in the scene. When using VR goggles, the camera's movement with orbit function is automatic. On computers, tablets, and smartphones, the camera can be moved around objects using the mouse, keyboard, or touch. All models used in this article have this orbit function, so that students can move the scene to find the best viewpoints to observe the constructed elements.

The projects shown in this article are applied in basic Topography disciplines for Civil Engineering, Environmental Engineering and Forestry Engineering projects. Other projects involving topographic surfaces are from topographic profiles, as shown in Figure 7 with a VR representation with level contours of 20-by-20 meters.

Because it is a web page, users have viewing options on tablets, computers, smartphones, as well as Oculus Rift, Oculus Vive, Daydream and gearVR. Mockup interaction commands can be programmed by immersing the VR scene with orbit manipulation [29] or teleporting to scene locations [30]. With the teleport function, students can immerse themselves on each surface with VR goggles, making the use of

VR mockups more interesting: a virtual tour of the terrain depicted.

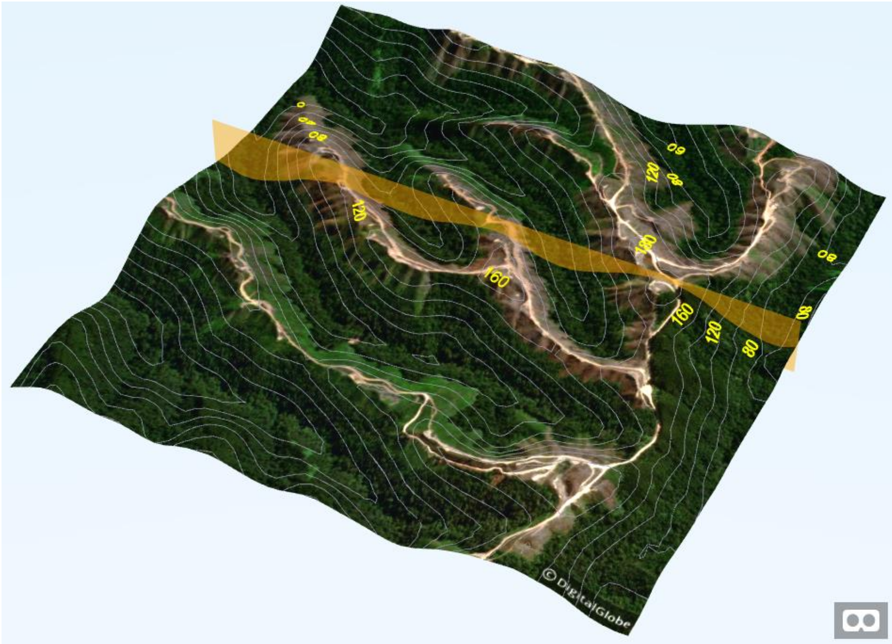

Figure 7. VR representation of a topographic profile mockup.

5. Augmented Reality

In an Augmented Reality programmed environment, elements modeled in Virtual Reality can be mixed with real objects shown using the camera of a device. Programming the AR web page uses the same structural tags shown in section 4, including the AR referential tag developed by Jerome Etienne [31], which should be inserted into the page header together the referential A-frame tag.

When a marker image is recognized in the AR scene, RV-modeled elements are activated. There are more than 80 programmed marker options in the library developed by Jerome Etienne, which are represented by tags that contains the programmed VR elements that are activated. The most common are hiro, kanji and the QR codes, shown in Figure 8.

Figure 8. Markers used by A-frame: hiro, kanji e QR codes #58 e #60.

The programmed HTML page structure with tags of two mockups is illustrated in Figure 9. The scene tags in AR include the webcam image embedding properties and mouse interaction capture or rays on linked objects (lines 7 and 8). The scene in AR has markers, which work with bit codes 0 and 1 in matrix form of images that are recognized by the webcam [32]. Markers perform as reference points, where specific positions can be set for the virtual objects that appear in the actual webcam image.

```
1  <head>
2   <script src="https://aframe.io/releases/0.8.2/aframe.min.js"></script>
3   <script src=" https://jeromeetienne.github.io/AR.js/aframe/build/
4      aframe-ar.min.js"></script>
5  </head>
6  <body>
7  <a-scene embedded cursor="rayOrigin:mouse" raycaster="objects:[link];"
8     arjs='sourceType:webcam; detectionMode:mono_and_matrix; matrixCodeType:3x3;'>
9  <a-assets>
10   <a-asset-item id="plataforma" src="imagens/curva13c.dae"></a-asset-item>
11   <a-asset-item id="plataforma1" src="imagens/curva13c.glb"></a-asset-item>
12   <a-asset-item id="splana" src="imagens/curva10.dae"></a-asset-item>
13   <a-asset-item id="splana1" src="imagens/curva10.glb"></a-asset-item>
14 </a-assets>
15 <a-marker type="barcode" value="60">
16   <a-link href="curva13c.html" title="VR"></a-link>
17   <a-entity position="-3.7,0,-5.5" scale="0.0035 0.0035 0.0035">
18    <a-entity collada-model="#plataforma"></a-entity>
19    <a-entity gltf-model="#plataforma1"></a-entity>
20   </a-entity>
21 </a-marker>
22 <a-marker type="barcode" value="58">
23   <a-link href="curva10.html" title="VR"></a-link>
24   <a-entity position="-4.4,0,-3.5" scale="0.0037 0.0037 0.0037">
25    <a-entity collada-model="#splana"></a-entity>
26    <a-entity gltf-model="#splana1"></a-entity>
27   </a-entity>
28 </a-marker>
```

Figure 9. A-frame HTML code for AR presentation of two Sketchup mockups.

With printed markers, students can access the web page using their devices. Thus, they display the programmed markers and the respective objects programmed in VR appear on AR ambient in device screens. The QR codes markers #58 and #60 were used for the AR visualization of mockups of a terrain section and a platform, respectively. The platform tag structure is between lines 15 and 21 of Figure 9. Tag <a-entity> is used to group the programming elements in VR, position them over the marker, and use scales. The coordinates shown on line 17 serve to position the model over the 2D representation of the level contour lines. In this way, students can visualize in 3D the drawing of the terrain sections constructed in 2D that represents the top view of the mockup.

The <a-link> tag, shown on line 16 of Figure 9, creates the interaction for accessing VR programmed pages through blue circles that appear over the markers. Between lines 22 and 28 are terrain section tags using the QR code #58. References for loading models are inserted in the <a-assets> tag, between lines 9 and 14. The other models are programmed in a similar way. Figure 10 shows AR views of the terrain section and the platform constructed by students using geometric concepts of Topography.

With markers printed on didactic materials, students can view 3D constructions that are made in 2D. In this case, the orthogonal projections that represent the top view of the level contours of each terrain are represented in the books, and students can overlay the objects in AR on their drawings to check the results or just view for a better understanding of the concepts studied. Using the technologies presented in this article, students are able to materialize the concepts of projections and topographic map readings more efficiently and dynamically.

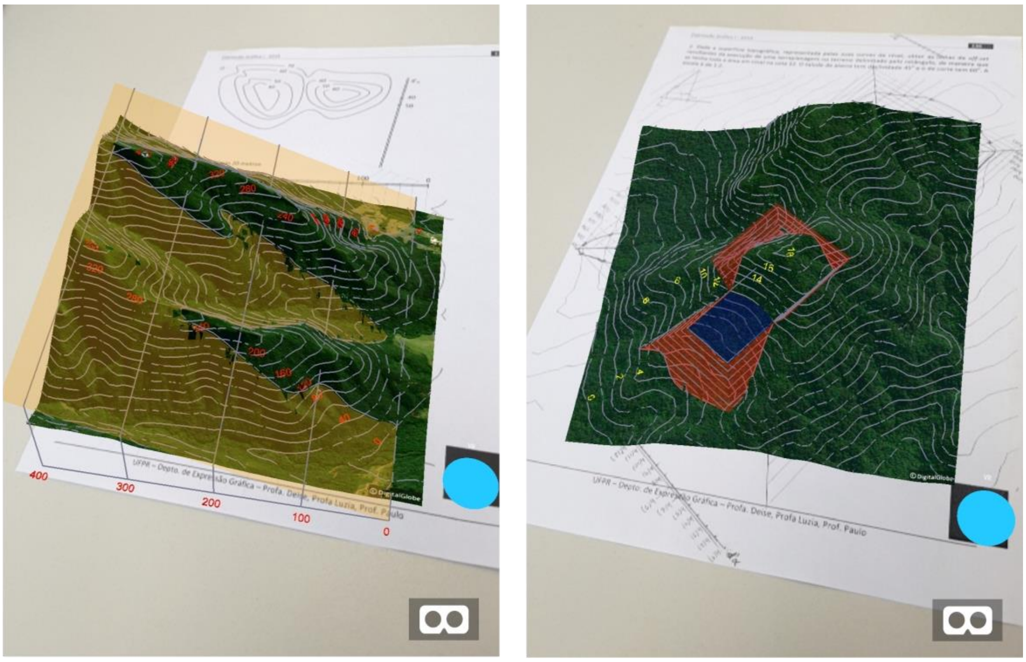

Figure 10. Mockups of the terrain section and the platform with AR.

The mockups used in this work with collada and glb formats are loaded quickly on any tested device. The VR and AR pages of the models shown in this paper are available at:

https://paulohscwb.github.io/cotadas/superficies/

The didactic materials shown in this article were used in the classroom with 5 classes of Civil Engineering and Forestry Engineering courses in the first semester of 2019, totaling 220 students. The websites programmed in AR and VR with the mockups were loaded without fail on all tested smartphones. There were no errors in loading websites on notebooks and tablets. The only notable observation is that AR sites tend to take a little longer to fully load because they use the device's webcam features. However, VR programmed sites load almost immediately on all tested devices on any operating system.

The technologies shown in AR and VR mockups for platform and terrain sections construction have helped students understand reading and geometric constructions involving topographic surfaces. Many students are able to create platform and terrain sections automatically and mechanically, without really knowing what shapes was represented in 3D. Using the proposed environments, the reading of the representation of a terrain through level contours was available to all students of the subjects tested in this work.

6. Conclusions

This article shows the steps of building a web-based environment for visualizing topographic surfaces in Virtual Reality and Augmented Reality. Using the visualization of printed markers, students can view AR terrain on any device with webcam and internet access, with links to sites in VR.

Sketchup mockups have topographic surfaces modeled using the Digital Globe platform, enabling the creation of level contours, terrain sections, topographic profiles and embankments. These visualizations improve students' perception of constructions made in disciplines that involve projection concepts, as students can check out constructions made in 2D by overlaying the respective 3D models. Thus, the teaching of basic relief forms becomes more interesting, effective and dynamic, as it includes the simulation of reality in the drawings constructed by the students.

The result shows that developed environments are useful tools for classroom use as they allow students to view and manipulate graphical representations of mockups with their devices or employing Virtual Reality goggles for complete immersion in the scene. All devices tested by students in the basic Topography discipline loaded the sites without error, showing the versatility of the tool that works on any operating system.

The programmed environments shown in this paper can also be explored in Geography classes. All elements can be viewed in AR and VR and students can move the camera around the scene to find the best views of VR mockups with A-frame functions to orbit the camera around objects.

Some advantages of creating AR and VR environments such as classroom web pages are low cost, great performance, simplicity of programming, and operation on all types of smartphones, tablets and notebooks. By accessing the AR and VR sites, students can view virtual mockups anytime and anywhere in a very practical way, overcoming restrictions that students would have if they had only access to physical mockups.

Another advantage of the environments shown in this paper is the almost immediate loading of websites, as they are programmed in HTML with references from VR libraries developed in Java. Students do not need to download applications and multiple markers can be used on the same HTML page to create didactic materials with various topics programmed in AR and VR. Similar environments can be used in other disciplines such as Geometry, Differential and Integral Calculus, Statistics, Biology, Chemistry, Engineering and other areas that use 3D graphical representations.

7. References

[1] S.M. Attardi, and K.A. Rogers, “Design and implementation of an online systemic human anatomy course with laboratory,” Anatomical sciences education, v. 8, n.1, 2015, pp. 53-62.

[2] L.C. Cantos, J.L. Izquierdo, and E.C. Cantos, “Interactive multimedia application for teaching and learning in Analytical Geometry,” IEEE Latin America Transactions, v. 14, n. 7, 2016, pp. 3461-3466.

[3] C.C.R.G. Sena, and W.R. Carmo, “Cartografia Tátil: o papel das tecnologias na Educação Inclusiva,” Boletim Paulista de Geografia, v. 99, 2018, pp. 102-123.

[4] P.G. McMenamin, M.R. Quayle, C.R. McHenry, and J.W. Adams, “The production of anatomical teaching resources using three-dimensional (3D) printing technology,” Anatomical sciences education, v. 7, n. 6, 2014, pp. 479-486.

[5] M. Huleihil, “3D printing technology as innovative tool for math and geometry teaching applications,” IOP Conference Series: Materials Science and Engineering, v. 164, n. 1, 2017, pp. 1-7.

[6] C. Moro, Z. Stromberga, A. Raikos, and A. Stirling, “The effectiveness of virtual and augmented reality in health sciences and medical anatomy,” Anatomical sciences education, v. 10, n. 6, 2017, pp. 549-559.

[7] C. Kirner, and T.G. Kirner, “Development of an interactive artifact for cognitive rehabilitation based on augmented reality,” International Conference on Virtual Rehabilitation (ICVR’11), Zurich, Switzerland, 2011, pp. 1-7.

[8] N.A.A.A. González, “Development of spatial skills with virtual reality and augmented reality,” International Journal on Interactive Design and Manufacturing, v. 12, n. 1, 2017, pp. 133-144.

[9] P.P. Cerra, J.G. Rodríguez, H.F. Álvarez, and B.B. Parra, “Combining multimedia and self-assessment CAD tools in an interactive web environment to learn engineering drawing,” Interactive Learning Environments, v. 27, n. 2, 2018, pp. 1-14.

[10] F.S. Irwansyah, Y.M. Yusuf, I. Farida, and M.A. Ramdhani, “Augmented Reality (AR) Technology on The Android Operating System in Chemistry Learning,” IOP Conference Series: Materials Science and Engineering, v. 288, n. 1, 2018, pp. 233-237.

[11] F. Abdullah, M.H.B. Kassim, and N.Z. Sanusi, “Go virtual: exploring augmented reality application in representation of steel architectural construction for the enhancement of architecture education,” Advanced Science Letters, v. 23, n. 2, 2017, pp. 804-808.

[12] M.E.C. Santos, A. Chen, T. Taketomi, G. Yamamoto, J. Miyazaki, and H. Kato, “Augmented reality learning experiences: Survey of prototype design and evaluation,” IEEE Transactions on learning technologies, v. 7, n. 1, 2014, pp. 38-56.

[13] P.H. Siqueira, “Augmented Reality and Virtual Reality Web Environment to Visualizing the Planets of The Solar System,” To Physics Journal, v. 3, 2019, pp. 167-185.

[14] M. Akçayır, and G. Akçayır, “Advantages and challenges associated with augmented reality for education: A systematic review of the literature,” Educational Research Review, v. 20, 2017, pp. 1-11.

[15] J.A. Munoz-Cristóbal, V. Gallego-Lema, H.F. Arribas-Cubero, J.I. Asensio-Pérez, and A. Martínez-Monés, “Game of Blazons: Helping Teachers Conduct Learning Situations That Integrate Web Tools and Multiple Types of Augmented Reality,” IEEE Transactions on learning technologies, v. 11, n. 4, 2018, pp. 506-519.

[16] G. Andrade, A.C.C.A. Oliveira, and M.C.A. Diniz, “Geografia e Sandbox: Contribuições da Realidade Aumentada para o Ensino das Formas de Relevo,” 3ºCongresso sobre tecnologias na Educação, Fortaleza, CE, Brasil, 2018, pp. 258-270.

[17] R.S. Santos, R.S. Santos, C.M.S. Alencar, and C.E.S. Macedo, “Realidade Aumentada no Processo de Ensino-Aprendizagem da Topografia em Projeto de Engenharia Civil,” 3ºCongresso sobre tecnologias na Educação, Fortaleza, CE, Brasil, 2018, pp. 582-589.

[18] E.T. Santos, R. Mafalda, A. Kawano, L.Y. Cheng, J.R.D. Petreche, B.C.C. Leite, S.L. Ferreira, and L.R.A. Cardoso, “Da geometria cotada ao modelamento 3D: projeto didático,” Simpósio Nacional de Geometria Descritiva e Desenho Técnico e International Conference on Graphics Engineering for Arts and Design, Santa Cruz do Sul, RS, Brasil, 2003, pp. 1-7.

[19] E.L.S. Becker, and M.P. Nunes, “Relevo do Rio Grande do Sul, Brasil, e sua representação em maquete,” Revista Percurso, v. 4, n. 2, 2012, pp. 113-132.

[20] C.M. Silva, and G.C. Ferreira, “Produção de material didático: jogo das curvas de nível,” Boletim Goiano de Geografia, v. 28, 2008, pp. 157-170.

[21] R.R. Sousa, “Oficina de maquete de relevo: um recurso didático,” Terrae Didatica, v. 10, n.1, 2014, pp. 22-28.

[22] W.O. Souza, G.M. Espíndola, A.R.A. Pereira, and L.A.C.M. Sá, “A realidade aumentada na apresentação de produtos cartográficos,” Boletim de Ciências Geodésicas, v. 22, n. 4, 2016, pp. 790-806.

[23] C.C. Carrera, and L.A.B. Asensio, “Landscape interpretation with augmented reality and maps to improve spatial orientation skill,” Journal of Geography in Higher Education, v. 41, n. 1, 2017, pp. 119-133.

[24] Sketchup, “3D Design Software,” available in: https://www.sketchup.com, access in: 25.09.2019.

[25] Digital Globe, “Explore geospatial data in context,” available in: https://www.digitalglobe.com, access in: 25.09.2019.

[26] A-frame, “A-frame documentation of Virtual Reality,” available in: https://aframe.io/docs/0.8.0/introduction, access in: 25.09.2019.

[27] J.R. Oliveira, “Visualização de conteúdos multimídia num ambiente de realidade virtual,” Masters dissertation: Faculdade de Engenharia da Universidade do Porto, Porto, Portugal, 2018.

[28] T. Hinrichs, “An Orbit Controls Component for A-Frame VR,” available in: https://github.com/tizzle/aframe-orbit-controls-component, access in: 25.09.2019.

[29] W. Murphy, “All-in-one natural hand controller, pointer, and gaze interaction library for A-Frame,” available in: https://github.com/wmurphyrd/aframe-super-hands-component, access in: 25.09.2019.

[30] F. Serrano, “A-Frame teleport controls component,” available in: https://github.com/fernandojsg/aframe-teleport-controls, access in: 25.09.2019.

[31] J. Etienne, “Efficient Augmented Reality for the Web,” available in: https://github.com/jeromeetienne/AR.js, access in: 25.09.2019.

[32] H. Ishii, “Augmented Reality: Fundamentals and Nuclear Related Applications,” International Journal of Nuclear Safety and simulation, v. 1, n. 4, 2010, pp. 316-327.