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TOWARDS AUGMENTED REALITY EDUCATIONAL AUTHORING

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Abstract: *Nowadays, there is a growing interest in Augmented reality (AR) as a field of research, as well as a domain for developing a broad variety of applications. Since the coining of the phrase "Augmented reality" in 1990, the technology has come a long way from research laboratories and big international companies to suit the pockets of millions of users all over the world. AR's popularity among younger generations has inspired an effort to utilize AR as a tool for education. For teachers, starting with AR educational authoring, we selected some important milestones of the history of the field with the focus on the specific domain of educational applications. We comment on Videoplace and Construct3D projects in more detail. Finally, we draw a few implications from the available literature for educational authoring.*

Keywords: Augmented reality, taxonomy, authoring, digital cultural heritage.

INTRODUCTION

Augmented reality as an extension to GeoGebra (Brzezinski, 2018) presented an important milestone. We survey AR ideas in the context of the related field of virtual reality (VR) systems, which serve to enhance imagination, interaction and immersion. Our focus is educational authoring devices that exploit ideas from digital cultural heritage.

Myron Krueger named the new technology Artificial reality in the mid 70s, but Jaron Lanier's name Virtual reality won. In the year 2016, Dieter Schmalstieg and Tobias Holerer predicted that immersion would would not only be an important quality measure in VR systems, but in AR systems as well. Krueger*'s* Videoplace (1975) artistic goal was to establish a novel art of interaction. It projected silhouettes of users on the wall in real-time, where they interacted and despite the 2D nature of the simple virtual world they had a strong experience of "being there". The breathtaking educational goal of Videoplace was never reached. Myron Krueger presented fantastic 2D creatures to groups of children. They were expected to observe the artificial reality, name the unnamed objects, self-organize seminars to plan their further research, subdivide the workload and, eventually, discover for adults the new methods of research. The author assumed, that there are research methods which were not noticed by "adult science" and he relied on creativity of children… Videoplace visual artists had to create visible objects and their behaviours to be different from anything known. The Artificial reality mixed real and virtual to challenge imaginative, interactive and immersive discovery.

VR and AR are very close research fields and in spite of the clear delineation of the terms, it is sometimes hard for the public to distinguish between them. In the reality-virtuality continuum, defined by Milgram et al. in (Milgram et al., 1995) we can see that AR is a form of a broader mixed reality, which lies between entirely real and completely virtual environments. Azuma in his seminal paper (Azuma, 1997) defines AR as systems that have the following three characteristics:

1. they combine real and virtual,
2. they are interactive in real time,
3. they are registered in 3D.

In other words, this new medium uses real world surfaces for immediate projections, which are put into the same coordinate system. While Videoplace registered real user silhouette in the 2D virtual world of fantasy, AR computer vision subsystem registers the augmenting images into the 3D real world, and the user into 3D virtual one, which provides immediate imagination and immersion. We explain the difference in a more structured way in two AR classifications below.

When defining virtual reality, we have to enclose the 3rd and the 2nd point from the AR definition. Another important aspect of virtual reality is immersion in the virtual environment, but when defining the AR, we should use the term ultimate immersion because there is nothing more immersive than the reality itself.

Despite the differences, these two fields have a connected history. For example, Sutherland's Ultimate display (Sutherland, 1965) or head-mounted display (Sutherland, 1968) are important milestones in both AR and VR history. The term virtual reality has been used to describe different things, for example a theatre, but in the '80s, the term virtual reality was coined and popularized by Jaron Lanier (as referring to immersive environments created by applications with visual and 3D effects, Lanier, 2010) and the boom started at the beginning of the '90s. Not long after, the phrase augmented reality was coined by Tom Caudell in 1990 (Caudell and Mizell, 1992) and the boom started with the beginning of the new century. We describe a chronologic selection of 20 VR/AR milestones (ideas, papers, projects, books) in Part 1 and AR systems in general in Part 2. Part 3 compares two classifications to cover the AR field more generally. Finally, we identify the potential in AR authoring methodology. We discuss the implications and apply our approach to the Construct3D project in Part 4.

1 SELECTED MILESTONES (1966-2016)

In view of the possibility that any chronological selection remains arguable, we identified the following "minimal set" of 21 cited findings in the first 50 years of VR/AR. This evolution resulted in a relatively general AR system, which we present in Part 2. Analogously with computer graphics reference model, it can serve to specify the particular architecture and application functionality. The variety of options can be found in two prominent textbooks (Bimber and Raskar, 2005), (Schmalstieg and Höllerer, 2016). To reduce the reductionism risk, we describe the classifications of technical alternatives in Part 3. Besides important landmarks, we included several famous items, which influenced world VR/AR popularity in given time. In Part 5, we will explain data streams in one session with the "classic" educational application, Construct 3D. Adding a new chapter to the three already submitted (Prodromou 2019), we explore AR ideas in the context of the related field of VR systems. They discuss AR mathematics teaching and its qualitative evaluation (Babinska, Dillingerova, and Korenova, 2019), rich hardware options (Bohdal, 2019), and adequate didactic evaluation (Kostrub and Ostradicky, 2019). All these aspects should be taken into account by an author of a novel AR educational project.

1966 Ivan Sutherland presented his concept of the ultimate display. His idea, however, goes beyond the limits of VR and AR that we know today. In his paper (Sutherland, 1965), he remarked that: "The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal". This device is considered the first AR interface. In 1968, Sutherland presented his popular head-mounted display (Sutherland, 1968).

1975 Myron Krueger experimented with computer generated art and interaction. In the Videoplace project, a computer responded to gestures and interpreted them into actions. The audience could interact with their own silhouettes generated from the video camera (Krueger et al., 1985).

1978 Professor Steve Mann is wearing the HMD (or HUD) since 1978. In 2001 Peter Lynch shot about him the film called Cyberman. Much of the film was created by Mann himself with his EyeTap (Mann, 2004). EyeTap is the HUD (heads-up display mounted in glasses), which records the reality with the camera, creates an virtual information and merges the reality seen by the user with a virtual information using a beam splitter. (Again, there are multiple meanings of HMD or HUD.)

1990 Tom Caudell, the researcher who developed the AR system supporting the aircraft manufacturing in the Boeing factory (Caudell and Mizell, 1992), coined the phrase augmented reality.

1991 The concept of "ubiquitous computing" was presented by Weiser (Weiser, 1991) in the beginning of the ’90s. The goal of "ubiquitous computing" is to provide computer interfaces that are natural for the users, to develop the computers which are not visible but "omnipresent" in everyday life. This concept is closely connected to the possibilities and techniques of the AR and the fusion of the fields is known as the ubiquitous AR. (In the year 2016, Schmalstieg and Höllerer proposed Weiser-Milgram spectrum of AR options).

1993 The CAVE: Audio Visual Experience Automatic Virtual Environment was presented to the public. CAVE contributed to public awareness of VR.

1993 Steven Feiner, Blair MacIntyre, et al. published two major AR papers. The first paper (Feiner et al., 1993b) presents the KARMA (knowledge based AR for maintenance assistance) system which uses the optical see through head-mounted display that "explains simple end-user laser printer maintenance". The second paper (Feiner et al., 1993a), presents 2D information windows in the AR, a technique, which is nowadays broadly used in smartphone (pseudo) AR systems.

1997 Ronald T. Azuma published the first survey (Azuma, 1997) on AR. He gave the definition of augmented reality, which is considered the most relevant. Also, he listed the biggest problems of AR as the registration and the sensing errors. The paper presents a broad survey of different applications of AR in medical, manufacturing, visualization, path planning, entertainment and military fields.

1999 ARToolkit was developed by H. Kato in the Nara Institute of Science and Technology. In 1999 Kato and Billinghurst published their paper (Kato and Billinghurst, 1999) about using HMD and markers for the conferencing system, based on the method proposed by Rekimoto (Rekimoto, 1996). ARToolkit is a computer library for the tracking of the visual markers and their registration in the camera space (http://www.hitl.washington.edu/artoolkit/). With the ARToolkit one can easily develop AR applications with virtual models assigned to different markers. For an example see Figure 4.

2000 Hannes Kaufmann, Dieter Schmalstieg and Michael Wagner introduced Construct3D, a three- dimensional geometric construction tool based on the collaborative AR system ‘Studierstube’. The setup uses a stereoscopic head mounted display (HMD) and the Personal Interaction Panel (PIP) - a two-handed 3D interaction tool that simplifies 3D model interaction. Applications in mathematics and geometry education at the high school and university levels were discussed.

2002 Bruce Tomas developed the first AR outdoor game called ARQuake (Thomas et al., 2000). It was an AR version of the computer game Quake. Different versions of the system (2000– 2002) used the optical see through head-mounted display, mobile computer stored in the backpack, haptic gun or handheld device with button, head tracker, digital compass, GPS system and/or markers. It allowed the user to walk around in the real world and shoot virtual enemies from the Quake game.

2005 Oliver Bimber and Ramesh Raskar published the first book on Spatial Augmented Reality (Bimber and Raskar, 2005). They describe and categorize AR systems into 3 categories: head-mounted, handheld, and spatial, and then focus on the spatial systems. The main difference between spatial AR and other categories is that in SAR the display is separated from the users of the system and so is suitable for bigger groups of users. SAR systems usually consist of digital projectors, which display graphical information directly onto physical objects. Bimber and Raskar describe the technique of calibration of several projectors, which compensate the inequality and the colour of the surface.

2007 Klein and Murray in their paper (Klein and Murray, 2007) proposed a method for a markerless tracking for small-workspace AR applications. They track a calibrated handheld camera in a previously unknown scene without any known objects or initialization target, while building a map of this environment.

2009 Although the spatial AR (and the projection mapping techniques) was introduced several years before, the biggest boom in the urban projection mapping was in 2009-2010. As the most famous examples we have to mention the projection mapping during the 600th anniversary of Orloj — the astronomical tower clock situated at Old Town Square in Prague — in 2010 (the macula, 2010), or 2009–2011 NuFormer Projections in the Netherlands (NuFormer, 2011).

2010 When Microsoft released Kinect, the motion sensing input device for the Xbox 360 console, it was expected to be "the birth of the next generation of home entertainment" (Takahashi, 2009) but not a milestone in the AR history. The Kinect sensor developed by PrimeSense company became a really cheap ($150) source for the depth information for AR applications, i.e. how far is the real object in the scene. The sensor itself consists of the rgb camera, the infrared projector which projects a pattern of dots and the detector which establishes the parallax shift of the dot pattern for each pixel. Instead of (x,y) we have (x,y,z) measurement of scene geometry. Kinect holds the Guinness World Record of being the "fastest selling consumer electronics device" (8 million units in its first 60 days). When the first hackers broke into the device and found the way how to control the sensors it took only 2 months and hundreds of AR application using Kinect sensor appeared on the Internet. For the top examples see 12 best Kinect hacks (Vsauce, 2010).

2011 Qualcomm presented Vuforia — the software development platform for AR. Vuforia enables the usage of real-world image markers and development of native applications with support for iOS, Android, and Unity 3D (Qualcomm, 2013).

2016 Pokemon GO, an AR game developed by Niantic for iOS and Android devices, was released in summer 2016. The game became massively popular and had been downloaded more than 500 million times worldwide by the end of the year 2016.

2016 Microsoft Hololens headset launched for developers. In was the first AR head mounted display to hit the market in 2016.

2016 Dieter Schmalstieg and Tobias Höllerer published the important textbook *Augmented reality: Principles and practice* (Schmalstieg and Höllerer, 2016). The detailed presentations are available for free download and correct academic use from http://www.augmentedrealitybook.org.

2. ARSYSTEMS

There is a discussion in the AR community whether the definition created in the 90s still suffices the requirements of the users. Especially in the commercial sphere there exist many applications which are categorized as AR applications, but do not fulfil the second or third of Azuma's rules. These applications usually lie within the reality-virtuality continuum, but cannot be considered AR. This lack of true commercial AR leads to misclassification also in some scientific publications.

For example, in the extensive survey (Olsson and Salo, 2011) published in the proceedings of ISMAR authors decided to include 2 kinds of applications: AR browsers which they defined as: "...usually includes the delivery of points of interest (POI), user-created annotations, or graphics based on the GPS location of the device and orientation of the built-in magnetometer" and image-recognition-based AR which was defined as: "based on connecting surrounding objects, products, and other physical targets with digital information with the help of visual recognition. By identifying quick response (QR) codes, bar-codes, other graphic markers, or the objects themselves..." Here, we strictly follow Azuma's definition and we decided to call the systems not fulfilling these rules the pseudo-AR ones.

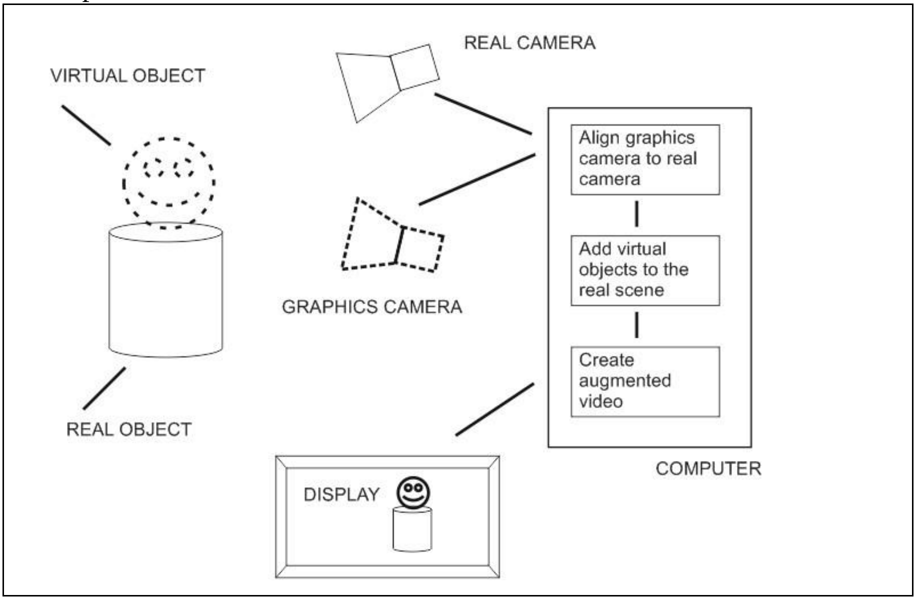

Figure 1. A scheme of AR system
Source: Own work

AR systems can consist of many different elements, depending on the type of the application. We can divide these elements into four categories: *inputs (sensors)*, *outputs (projectors, displays)*, *computers* and *accessories*. It is necessary for every AR system to have at least one sensor for the estimation of the user's position (camera, GPS receiver), one device to display the AR or to add virtual objects into user's view frustum (display, projector) and some device capable of processing data (computer). All the different components, elements, subsystems, necessary for the AR system can be incorporated in one device, for example a smartphone, tablet or notebook with a built-in webcamera. Many types are explained in (Bimber and Raskar, 2005), (Schmalstieg and Höllerer, 2016).

In Figure 1, we can see the scheme of the common AR system equipped with a camera, a computer and a display. As the first step, the position of the real camera in space has to be estimated and the alignment (registration) of the real camera to the graphics camera has to be done. Visual (or other types of) markers, pattern matching or local features matching are usually used for the estimation of the rotation and translation of the camera to the object to be augmented (we will focus on the registration of the virtual and real camera in the next section). The virtual objects are then merged with the real scene and the augmented video is created and displayed.

3. TWO CLASSIFICATIONS OF AR APPROACHES

The AR systems can be categorized by different factors, including the application area, the possibility of more people collaborating or the size of the full system. In the following section we present two different classification schemes of the AR applications. The first one was developed by Bimber and Raskar in (Bimber and Raskar, 2005) and it presents a device-based categorization (3.1). The second scheme is our own classification based on the way of augmentation of virtual and real world. The user's immersion is the key aspect of the AR systems. Our classification (3.2) is inspired by the survey from Azuma (Azuma, 1997) and it can be helpful in taking project decisions.

3.1 Device based classification

The categories proposed in (Bimber and Raskar, 2005) are based on how the output device is connected with the user. If the user wears the device on his head, we talk about head-mounted devices. The systems designed to be carried in hand belong to the handheld category and stationary systems not carried by the user are the spatial category.

3.1.1 Head-mounted devices

The head-mounted category consists of five main types of devices: Optical see-through HMD, Video see-through HMD, HMProjectors, HMProjective display and retinal displays. For more information about HMDs see (Cakmakci and Rolland, 2006).

Optical see-through head-mounted display Azuma (1997) states that: "Optical see-through HMDs work by placing optical combiners in front of the user's eyes. These combiners are partially transmissive, so that the user can look directly through them to see the real world. The combiners are also partially reflective, so that the user sees virtual images bounced off the combiners from head-mounted monitors. The optical combiners usually reduce the amount of light that the user sees from the real world. Since the combiners act like half-silvered mirrors, they only let in some of the light from the real world, so that they can reflect some of the light from the monitors into the user's eyes."

Video see-through head-mounted display. This type of HMD was defined (Azuma, 1997) as: "Video see-through HMDs work by combining a closed-view HMD with one or two head-mounted video cameras. The video cameras provide the user's view of the real world. Video from these cameras is combined with the graphic images created by the scene generator, blending the real and virtual. The result is sent to the monitors in front of the user's eyes in the closed-view HMD."

Head-mounted projectors beam the generated images onto the ceiling and use two half-silvered mirrors to integrate the projected stereo image in front of the user.

Head-mounted projective displays redirect the image created by miniature projectors with mirror beam combiners so the images are beamed onto retro-reflective surfaces in front of the users eyes.

Retinal displays use low-power semiconductor lasers to project modulated light directly onto the retina of human eye. The main disadvantage of this technique is that it provides only a non-stereoscopic monochromatic image (Bimber and Raskar, 2005).

3.1.2 Handheld devices

Handheld devices are nowadays the most popular platforms for the AR applications. These devices usually incorporate all the necessary sensors, computer and display (or projector) in one portable gadget. Common handheld devices are smartphones, tablets, palmtops or notebooks. Although most of the published papers in the area of mobile AR focus on these particular devices, there were also some efforts to build special handheld devices, for example iLamps (Raskar et al., 2005). In iLamps Raskar et al. presented object augmentation with a handheld projector utilizing a new technique for adaptive projection on non-planar surfaces using conformal texture mapping.

3.1.3 Spatial devices

The spatial category encloses different solutions designed to be fixed within the environment (not to be worn in the hand or on the head). An example of spatial solutions are: PC stations with a webcamera, the CAVE (cave automatic virtual environment) (Cruz-Neira et al., 1993), Projection mappings (the macula, 2010; NuFormer, 2011), Virtual showcase (Bimber et al., 2001). The Fish tank is the title of a system consisting of a computer station equipped with a webcamera and a monitor which are used for AR at home. The CAVE is an immersive virtual reality/scientific visualization system, which lies between VR and AR. The CAVE is a room-sized cube where three to six of the walls are used as projection screens.

The Virtual Showcase developed by Bimber et al. (Bimber et al., 2001) presents a projection-based multiviewer AR display device which consists of half silvered mirrors and the graphical display. In this device the user can see real objects inside the showcase (through the half-silvered mirrors) merged with virtual objects or layers displayed on the projection screen under the showcase. This technique makes use of the concept of Pepper’s ghost developed in 1862 (Burns, 2010).

3.2 Perception-of-reality-based classification

In our classification we start from Azuma’s work (Azuma, 1997) and we divide AR systems based on the way they create the augmented experience. The first category includes applications which create AR by adding the virtual information (3D models, images, text) to the record of reality. The second category includes systems which create AR by displaying/projecting virtual information directly in front of our vision of reality. Table 1 relates the device-based classification and perception-of-reality-based classification.

3.2.1 The record of reality mixed with virtual information (added to record)

All of the video see-through approaches belong to this category. The video see-through device basically consists of the camera which records the reality and the display (or a projector with a projection screen) which provides the user with the reality mixed with the virtual information (the augmented experience). This category includes video see-through head-mounted displays, most existing handheld devices (smartphones, tablets, palmtops, netbooks) and the Fish tank solutions.

3.2.2 Reality mixed with virtual information (added to reality)

This category includes all the applications in which the virtual information is projected directly on the real world objects, or onto the optical see-through device. The typical representatives of these approaches are the projection mapping applications, for example, the projection on the astronomical tower clock Orloj situated in the centre of Prague (the macula, 2010). Other systems which belong to this category are optical see-through head-mounted displays, retinal displays, head-mounted projectors, head-mounted projective displays, CAVE (Cruz-Neira et al., 1993), Virtual showcase (Bimber et al., 2001), and also some handheld solutions (for example, iLamps (Raskar et al., 2005), as described in the section 4.1.2).

The morphological Table 1 offers for AR systems a two-dimensional orientation, which can be helpful both for study and authoring. In fact, any AR system was built following such a project decision. The classification is open. We can add a next row for retinal display, for example.

Figure 2 illustrates some general AR building blocks (Bimber and Raskar, 2005) in 3 layers. We added selected user responses above. Tracking and registration, display technology and rendering represent fundamental components (subsystems). "On top of this base level, three more advanced modules can be found: interaction devices and techniques, presentation, and authoring... Ideas and early implementations of presentation techniques, authoring tools, and interaction devices/techniques for AR applications are just emerging", wrote the authors in 2005. "Some of them are derived from the existing counterparts in related areas such as VR, multimedia, or digital storytelling. Others are new and adapted more to the problem domain of AR. However, it is yet too early to spot matured concepts and philosophies at this level". "The third layer, the application, is finally the interface to the user. Using AR, our overall goal is to implement applications that are tools, which allow us to solve problems more effectively. Consequently, AR is no more than a human-computer interface which has the potential to be more efficient for some applications than others." In other words, there are 2 phases of communication: authoring and presentation.

Table 1

Relating the device based classification and perception of the reality based classification.

	added to record	added to reality
head-mounted	video see-through HMD (Museum wearable (Sparacino, 2002))	optical see-through HMD (Sutherland's HMD (Sutherland, 1968))
handheld	mobile/tablet AR (e.g. museum guides (Bruns et al., 2007; Miyashita et al., 2008), (Kusunoki et al., 2002; Bay et al., 2006; Föckler *et al.*, 2005))	optical see-through handheld displays handheld projections (iLamps (Raskar et al., 2005))
spatial	fish tank mirror projections (Kalman, 1960).	Pepper's ghost (Adrien and Claire, 2013) projection mappings (the macula, 2010) holographic displays (Bimber et al., 2006)

Source: Own work

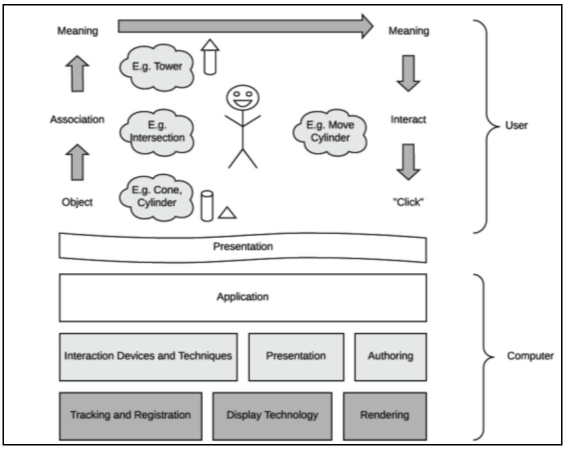

Figure 2. The AR building blocks and an example of user responses, recognizing objects, generating associations, fixing meaning, and interacting eventually.

Source: Own work based on Bimber and Raskar, 2005

About a decade later, there is a brief Chapter 10 Authoring in (Schmalstieg and Höllerer, 2016, pp. 329-344): "Based on a definition of setup for input and output, the authoring defines a story (application logic), driven by interaction and influencing actors arranged on stages". Multimedia objects are named actors here, the story can be described as a state machine, and game is not taken into account. The shift from single word authoring in the first AR book to a separate chapter in the second prominent AR textbook can be extrapolated to a vision of an universal AR authoring tool and workflow, like PowerPoint for a wide public, Movio for a virtual heritage community... Moreover, "AR has the potential to become the leading user interface metaphor for situated computing... The world becomes the user interface... (Schmalstieg and Höllerer, 2016)" The authoring, teaching, and learning can be everywhere, any time. How to solve the authoring problem more effectively? The AR literature does not offer either an universal authoring tool, or the methodology. Therefore we propose to apply the novel theoretical framework introduced in *Theorizing digital cultural heritage* (Cameron and Kenderdine, 2010). In other words, VR evaluation is more matured than AR one. We are going to explain this with the Construct3D example.

4. AUTHORINGIMPLICATIONS

Combining parts of real and virtual worlds, human communication organizes the content using stories and games (monologue, dialogue). A "Virtual Museum" can be defined as a multimedia semiotic system, which offers a set of microstories or game moves to communicate the given message, main story, part of metastory. Virtual museums present multimedia collections for visualization, activization, and even hermeneutics (presenting invisible). A recent prognosis is given in (Papagiannakis, 2018) "Storytelling, presence, and gamification are three basic fields that need to be taken into account when developing novel mixed reality applications for cultural heritage...".

How should one measure virtual museum quality? The key human experience with stories and games is a depth of immersion, which has five levels: curiosity, sympathy, identification, empathy, transportation (Glassner, 2009). The strongest form of gameplay immersion is flow experience (Csikszentmihalyi), “the sense that the outer world has fallen away” (Glassner, 2009). The question is how to measure a quality of story/game immersion. The general answer lies in the level of interestingness. In particular, the quality measurement can be obtained using quantitative, qualitative, and virtual museum engagement factor (Sherwood) measurements (Visits/visitors*duration) after (Cameron and Kenderdine, 2010). The time of engagement is proportional to the level of interestingness. E.g. the winning MOOC seems to be the world-famous Coursera hit Learning How To Learn, with over 3 million subjects, who were engaged for 12 recommended hours (https://www.coursera.org/learn/learning-how-to-learn).

The specific quality measure for education with AR is proposed by (Kostrub and Ostradicky, 2018). According to SAMR (Puentadura, 2018), there are four levels of technology contribution in the classroom: Substitution, Augmentation, Modification, and Redefinition. These SAMR model levels proposed by Puentadura can be compared against classical Bloom's taxonomy of educational goals. For example, "redefinition" (Computer technology allows new tasks that were previously inconceivable) can be seen as Evaluating and/or Creating level as defined by Bloom.

The user can recognize visual percepts with growing complexity: single pixel, output primitive, graphical object, semiotic representation, pattern, metaphor and even an enthymeme. Enthymeme experience changes the user into the co-author, the student into an cooperating (self-)teacher. This sharing of untold, "the body of proof", "the strongest of rhetorical proofs..." can be exemplified with classical syllogism "Socrates is mortal because he's human", where one of premises is not stated (All humans are mortal. Socrates is human. Therefore, Socrates is mortal.) In virtual museology (Cameron and Kenderdine, 2010) the enthymeme means a top achievement, presenting unpresented, visualising invisible. These museologic enthymemes are not reduced to rhetoric only, they consist of multimedia objects (actors in AR system).

We learn in three ways only: 1. by pain, via amygdala, no repetitions, 2. by repeating, via thalamus, 3. by discovery, enjoying endorphins, expressing AH, AHA or HAHA (Koestler, 1964). The third way activates multiple brain parts in a symphony of reconnections (Aamodt, 2009), A. Koestler calls this bisociation. These two observations led us to define local interestingness.

Painful learning tradition was stopped by Comenius. Repetitive learning tradition prevails today, motivated not by internal interestingness, but by external needs. The third one, learning by discovery, is interesting itself, pleasant and funny. Using this opinion, we can comment on AR educational authoring, as well.

Arthur Koestler discovered this a posteriori definition of interestingness, which we use as a technique of making any text or image sequence locally interesting. What was interesting, causes the AH, AHA or HAHA reaction in three areas of human creativity Art, Science, and Humour (ASH). We live to escape from the banal associative mental life to maximize our cultural capital with bisociations, the acts of creation at the side of an author and, hopefully, at the side of the reader or virtual museum visitor. If we are not sure with AHA, we are halfway, expressing audible HM... How to reach HM? Ask a question, use rhetoric.

The global interestingness of any story/game is given by its theme (Rizvic, 2013). The local interestingness can be authored or evaluated by the bisociations, causing AHA reactions. The engagement can be improved by a set of rhetorical devices (e.g., pause, question, metaphor, intonation, repetition, and even an entymeme), gamification, funology (from usability to enjoyment) (Blythe, 2004). Good presentation ideas improve local interestingness of given communication. While rhetoric organizes oral presentation, AR application can profit from these well-working attention-getting tricks using sets of mutimedia objects, as well. For example, very inspiring metaphors for explaining algorithms can be found in (Forisek and Steinova, 2013). The HAHA reactions were measured and even classified by Huron (Huron, 2004).

The virtual visitors enrich and train their multiple intelligences (after Gardner) and they are expected to achieve various educational goals (within Bloom's taxonomy) with given level of attention. We understand educational AR authoring as a specific subsystem of virtual museum in a wide sense, e.g. educational content with GeoGebra YouTube Channel is a specific educational virtual museum or exhibition. AR may serve as an ubiquitous or standalone subsystem within any educational unit, story, or serious game. Using this approach, one can author or even evaluate the AR system effects. Let us apply the proposed approach to comment on Construct3D demo.

4.1 Classical project Construct3D on Youtube in 90 seconds overview

The far-reaching educational goal of Videoplace was a sort of visionary dream. The successful practical project appeared decades later, it was Construct3D (Kaufmann et al., 2000), which has been the most cited project in the field of mathematics education using VR. What is the theme of Construct3D?

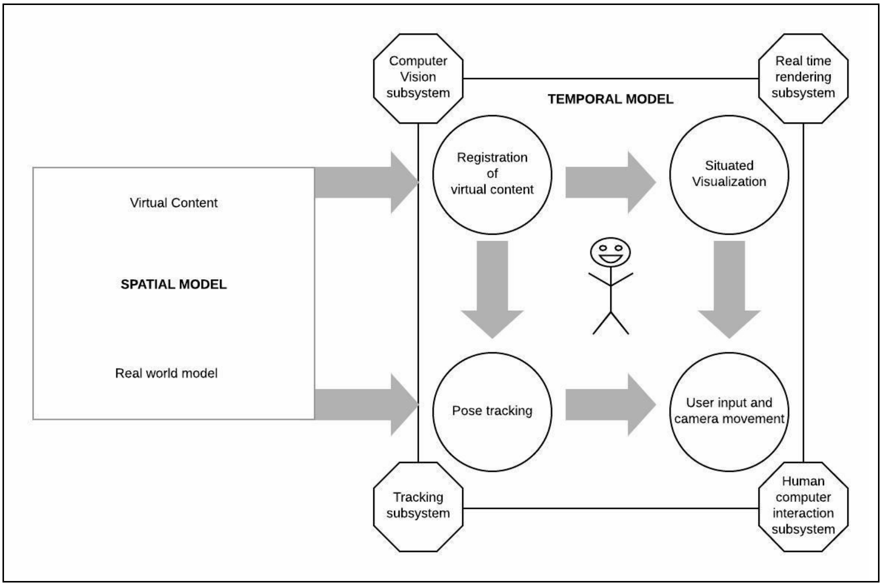

Figure 3. Spatial and temporal modelling of Construct3D session
Source: Own work based on Schmalstieg and Höllerer, 2016

"Spatial abilities present an important component of human intelligence. The term spatial abilities includes five components, spatial perception, spatial visualization, mental rotations, spatial relations and spatial orientation... Generally, the main goal of geometry education is to enhance special abilities by training spatial skills. As shown in various studies... spatial abilities can be improved by virtual reality (VR) technology." For any given task, it is possible to make the geometric solution visible for the teacher, but not for students. The theme means the global interestingness.

Construct3D offers both visualization and activization of students. This can be demonstrated by a 90-second YouTube video named Construct3D – Overview (Kaufmann, 2009). The real and virtual spaces are merged, augmented with an interactive PIP (Personal Interaction Panel) and 3D geometric objects (cone, cylinder, globe, and annotated coordinate axes). The user experience serves immersing collaborating students to improve their imagination, interaction, and spatial skills. There are local interestingness devices like real-time feedback or indicating the top of cone by a red marker, however, the closing part of the video offers a new level of local interestingness – two views from two viewpoints in a single screen. This trick destroys the illusion of single view and moves us to another virtual space, where we can compare. The comparison leaves the field of associations to bridge over two contexts, to bisociate, and, if one is fortunate enough, this results in an AHA, AH or HAHA moment (Koestler). This possible effect may bring a bit of the personal discovery for an activated student, and even result in seeing the invisible, a percept not directly presented by AR system.

Construct3D is implemented using StudierStube. The data flows are indicated in Figure 3, which we adapted after (Schmalstieg and Höllerer, 2016).

What are the properties of geometric objects in this setup? They are inspired by real world, physical universe, but they have to be modelled in mathematics. This means that they consist from infinite number of points. This number must be reduced for computer representation, typically using textured triangles. In final implementation are these AR actors stored with given precision. The four universes of computational mathematics (world, model, representation, implementation) offer a basis for visualization (pixels, triangles, objects, iconic and symbolic representations, metaphors...). However, some parts of virtual and real scene should serve for augmenting and interaction. Such real-time actions require careful optimizations [Lack19], especially for AR mobile applications, where the computational power is limited.

4.2 AR workshop for kids

The first scientific exhibition for the general public in Slovakia, named Virtual World 2012, took place in a large shopping centre, Avion. We included the AR workshop for school kids there. The aim was to teach creation of an own AR by pupils from elementary and secondary schools, or people with some programming skills. First, we demonstrated tasks manageable for a given age category, like adding virtual objects (virtual information) to the real scene (reality). Further, we explained basic requirements such as registering a 3D object and real time interaction in medicine, advertising, sport news, design, cultural heritage, and entertainment, of course.

Afterwards, the workshop continued with the practical part to familiarize the participants with the selected tool (ZooBurst.com) to create their AR message. The youngest authors prepared their own fairy tales, which appeared in the reality of the image webcam on the computer, using printed black and white images (marks, marker). The secondary school students worked in Flash, using Flartoolkit, which allowed them to combine their own 3D model with their own AR application.

The "adult informatics" authors were challenged with ARtoolkit, multiple markers and 3D objects. They were provided with explanations of algorithms used to detect markers and display 3D models. Our main concern was that each participant, after graduating the workshop, understood the concept of AR and had sufficient mastery to create his/her own AR application. We can conclude that this sort of “novelty” interestingness is positively influenced by their own creativity.

Figure 4. Photo from the workshop for high school students, the AR was created using Artoolkit.
Source: Own work

CONCLUSION

We selected an overview of AR ideas in the context of the related field of VR systems, which serve to support imagination, interaction and immersion. The importance of immersion for AR systems evaluation is expected to grow (Schmalstieg and Höllerer, 2016). Naturally, the quality can be measured either by standard didactic quantitative or qualitative methods, but the research in virtual museology offers more matured authoring and success metrics. The authors (Cameron and Kenderdine, 2010) combine theory of appraisal and ideas from rhetoric into a promising double theoretical framework. However, we propose to think practically, in terms of global and local interestingness as devices to improve engagement, user experience, immersion. Virtual museum authoring and research offer valuable alternatives of educational inspiration. For specific maths-oriented educational purposes, we recommend studying and enriching the Construct3D research line.

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