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Virtual reality: Applications and implications for tourism

Daniel A. Guttentag*

Department of Geography and Environmental Management, MES Candidate in Tourism Policy and Planning, University of Waterloo, Waterloo, ON, Canada N2L 3G1

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ABSTRACT

Virtual reality (VR) offers tourism many useful applications that deserve greater attention from tourism researchers and professionals. As VR technology continues to evolve, the number and significance of such applications undoubtedly will increase. Planning and management, marketing, entertainment, education, accessibility, and heritage preservation are six areas of tourism in which VR may prove particularly valuable. Part of VR's possible utility as a preservation tool derives from its potential to create virtual experiences that tourists may accept as substitutes for real visitation to threatened sites. However, the acceptance of such substitutes will be determined by a tourist's attitudes toward authenticity and his or her motivations and constraints. As VR is further integrated into the tourism sector new questions and challenges clearly will emerge. The sector will benefit from future research into the topics that are discussed and numerous suggestions for future research are presented.

1. Introduction

Advances in technology, in all of its many forms, frequently have direct and lasting impacts on tourism. Recently, developments in information and communication technologies (ICTs) have been transforming tourism in myriad ways, with impacts on areas ranging from consumer demand to site management (Buhalis, 2003; Buhalis & Law, 2008). For example, many tourists have adopted the Internet as a tool for seeking travel information (Buhalis & Law, 2008; Grønflaten, 2009) and countless tourism businesses and organizations have established themselves online (Buhalis & Law, 2008). Research into ICTs and tourism – the union of which can be referred to as 'eTourism' (Buhalis & Deimezi, 2004; Buhalis & Law, 2008) – has yielded many important insights into how ICTs are changing the tourism sector and how the sector can best adapt to these new technologies (Buhalis & Law, 2008). Nevertheless, eTourism is evolving so quickly that the tourism sector is "constantly redefining itself and requires continual reorientation in marketing and management along the way" (Egger & Buhalis, 2008, p. 1). Moreover, many relevant ICT developments are not made directly for the sake of tourism, so tourism researchers and professionals may not be fully aware of the developments and, therefore, are unprepared to adopt and adapt to the new technologies.

One important area of ICT is virtual reality (VR), which already is used commonly in diverse areas including entertainment, design, and simulation training. In fact, VR already has various uses within the tourism sector. As VR technology continues to evolve, there is little reason to doubt that it will become more prevalent throughout society, in general, and the tourism sector in particular. VR's applications for the tourism sector are numerous and its implications for the sector are significant, so tourism researchers and professionals should gain a greater understanding of VR to best prepare themselves to face the challenges and take advantage of the opportunities that VR presents.

This paper explores the primary uses for VR within tourism, examines the possibility of using VR to provide substitute tourism experiences, analyzes some of the chief questions and challenges associated with VR's integration into tourism, and suggests numerous ideas for future research related to VR's uses within tourism. The numerous tourism-related uses for VR are illustrated through a description of current and future VR technologies and a subsequent analysis of applications for these technologies within six principal areas of tourism: planning and management, marketing, entertainment, education, accessibility, and heritage preservation. VR almost certainly will influence additional areas of tourism, but the chosen areas were selected because they appear particularly suited to benefit from VR. The possibility of using VR experiences to serve as substitute tourism experiences is analyzed by examining several factors that will influence tourists' perceptions of potential VR tourism substitutes, thereby demonstrating that the acceptability of a VR tourism substitute will be determined subjectively by different users. The analysis of key questions and

* 201 Erb Street West, Apt. A5, Waterloo, ON, Canada N2L 1V6. Tel.: +1 519 954 1598.
E-mail address: dguttent@uwaterloo.ca

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challenges relating to VR and tourism focuses on issues associated with the future state of VR technology, the re-creation of real world sites in VR, and the potential consequences of VR tourism substitutes. Finally, numerous ideas for future research are presented, corresponding with the various topics that are covered throughout the paper.

2. What is virtual reality?

Notable discrepancy exists regarding the definition of VR, as proposed definitions vary when describing the different features considered necessary to constitute an experience as VR (Burdea & Coiffet, 2003; Vince, 2004). This paper uses a definition of VR that borrows from definitions used in books dedicated to the topic written by Burdea and Coiffet (2003), Vince (2004), and Gutiérrez, Vexo, and Thalmann (2008). For this paper, VR is defined as the use of a computer-generated 3D environment – called a 'virtual environment' (VE) – that one can navigate and possibly interact with, resulting in real-time simulation of one or more of the user's five senses. 'Navigate' refers to the ability to move around and explore the VE, and 'interact' refers to the ability to select and move objects within the VE (Gutiérrez et al., 2008; Vince, 2004). Vince (2004) and Gutiérrez et al. (2008) actually posed interactivity as a necessary component of VR, but this paper's definition poses it as optional, as this more flexible definition permits the discussion of a wider array of technologies that are relevant to tourism and still are very closely related. For the same reason, this paper accepts augmented reality (AR) – the projection of computer-generated images onto a real world view (Burdea & Coiffet, 2003; Vince, 2004) – as a type of VR. Although Burdea and Coiffet (2003) claimed AR is not "VR in its strictest sense" (p. 1), Vince (2004) described AR as a type of VR system and Milgram, Takemura, Utsumi, and Kishino (1994) argued, "AR and VR are related and … it is quite valid to consider the two concepts together" (p. 283). Even though this paper embraces a somewhat broad definition of VR, the definition still clearly differentiates VR from other types of similar technologies. For example, neither film special effects nor virtual roller coaster rides would qualify as VR because they do not allow for any form of user-controlled navigation (Vince, 2004).

A VR experience can be described by its capacity to provide physical immersion and psychological presence (Gutiérrez et al., 2008). 'Immersion' refers to the extent to which a user is isolated from the real world. In a 'fully immersive system' the user is completely encompassed by the VE and has no interaction with the real world, while in a 'semi-immersive' or 'nonimmsersive system' (the latter includes contemporary 3D video games) the user retains some contact with the real world (Gutiérrez et al., 2008). The level of immersion offered by a VR system is one factor that may influence a user's feelings of 'presence' (Baños et al., 2004). Much like VR itself, presence also has been defined in various ways (Lombard & Ditton, 1997), but, "The common view is that presence is the sense of being in a VE rather than the place in which the participant's body is actually located" (Sanchez-Vives & Slater, 2005, p. 333). Consequently, "A sign of presence is when people behave in a VE in a way that is close to the way they would behave in a similar real-life situation" (Gutiérrez et al., 2008, p. 3). Feelings of 'presence' are naturally subjective, being associated with a user's psychology, but they undoubtedly are influenced by a VR system's ability to provide high quality data to the user's senses (Dinh, Walker, Song, Kobayashi, & Hodges, 1999; Gutiérrez et al., 2008). Not surprisingly, VR systems' capacity to provide such high quality, sensory data has improved dramatically since the emergence of VR-type technologies in the 1960s (Burdea & Coiffet, 2003; Gutiérrez et al., 2008), and modern VR systems are already quite sophisticated.

3. Modern virtual reality technology

Every VR system requires some sort of input device so that the user's actions can be interpreted and the VE can respond accordingly. VR systems generally track the motion of hand-held objects or a user's head or limbs, and the received data is used to determine the user's view, navigation, interaction with objects, and possible movement of a virtual body, known as an 'avatar' (Burdea & Coiffet, 2003; Foxlin, 2002). The types of input devices that VR systems utilize are quite varied, but can be as simple as a mouse, joystick, or fixed, mechanical arm with a visual display at one end. Nevertheless, far more sophisticated devices are also used, such as interactive gloves, voice recognition software, and wands, such as those used with Nintendo's popular Wii video game console. Also, the movement of a user's body can be tracked using body suits with angle measurement devices placed on various joints, or noncontact tracking devices, which may involve the use of optical sensors, ultrasonic sound, infrared emitters, or electromagnetic fields. These noncontact devices may use only a single tracker point that is located in a specific location, such as on top of the user's head, or they may involve numerous tracker points located on primary joints or throughout the body. (Burdea & Coiffet, 2003; Foxlin, 2002; Gutiérrez et al., 2008; Vince, 2004).

In response to a user's input data, a VR system will present an appropriate view of the VE. This visual element of a VE is generally the most important, so logically it is the element that has received the most research attention and, in turn, has advanced the most rapidly (Gutiérrez et al., 2008). By definition, a VE must render an image in 3D and allow it to be seen from any point of view, as determined by the user's perspective. Nevertheless, current technologies go much further. For example, some VR systems replicate the experience of normal vision by offering a separate view for each eye, which provides depth perception known as 'stereoscopic vision' (Vince, 2004). Moreover, to create realistic and dynamic VEs, VR systems account for the 'collision' between objects, so that objects do not blend together when they collide, and the systems also use a process known as '3D clipping' to display only objects within the user's field of view (Vince, 2004). Additionally, the quality of rendered images has improved considerably over the years as improvements have been made in replicating visual cues such as textures, shadows, and transparency. Nevertheless, the need in VR to update the 3D imagery in real-time presents obvious challenges that have limited the ability to reproduce complex phenomena such as light refraction (Gutiérrez et al., 2008; Vince, 2004). Even though image quality is important, it is generally superseded by the need to avoid 'latency', which is a delay between the user's movements and the corresponding update in the rendered point of view. High degrees of latency can reduce feelings of presence and possibly induce motion sickness, and eliminating latency requires a VE to respond to the user's movements in milliseconds (Burdea & Coiffet, 2003; Meehan, Razzaque, Whitton, & Brooks, 2003; Pose & Regan, 1994; Vince, 2004).

Many VEs duplicate real world sites or objects, and such VEs probably will be particularly prevalent among those used in tourism. Two primary methods can be used to create a 3D digital model of an existing object: laser scanning and photogrammetry. Laser scanners record data sets defining an object's geometric shape and sometimes color, while photogrammetry involves the acquisition of such data from photographs (Addison, 2000; Blais et al., 2005; Chalmers & Debattista, 2005; El-Hakim, Beraldin, Picard, & Vettore, 2003; El-Hakim, MacDonald, Lapointe, Gonzo, & Jemtrud, 2006). These two techniques have facilitated the efficient and accurate collection of data (Addison, 2000; Powell, 2009), and the techniques are sometimes used in conjunction with one another (e.g. Beraldin et al., 2002; El-Hakim et al., 2003). Although laser scanners, in particular, remain quite expensive (Cignoni & Scopigno, 2008), on the Internet one can freely access some relatively sophisticated 3D imaging tools. For instance, Microsoft recently launched a free online service called Photosynth (http://photosynth.net) that stitches together a collection of images to create a navigable 3D environment (Kemp, 2008; Lowensohn, 2008; Naaman, 2006).

Online, one also can find a variety of large, interactive VEs, one of the most prominent of which is Second Life (SL). In SL, users represented as avatars can explore the application's VE, which has been created by the users and is undergoing constant development and expansion (Mennecke, Terando, Janvrin, & Dilla, 2007; Stangl & Weismayer, 2008). Notably, in virtual worlds like SL, "Vacation/holiday themes are so abundant even the most casual visitor is sure to notice the preponderance of travel-related imagery." (Book, 2003, p. 4). In SL, for instance, one can dance in a virtual Ibiza, visit a virtual Washington Monument, or explore a virtual rainforest (Book, 2003; Gross, 2007). In fact, Dresden's Old Masters Picture Gallery even introduced a virtual re-creation of itself in SL, thereby becoming the first museum to fully duplicate itself in the virtual world (Curry, 2007b; Dresden Gallery, 2009). Also, for assistance locating the best SL destinations, one can use the services of virtual travel agents who provide guided and automated tours (Gross, 2007).

The SL experience involves social interaction, entertainment, and commerce (Mennecke et al., 2007), but not all VEs are designed for such purposes. For example, Rome Reborn is a 3D virtual model of ancient Rome that includes thousands of buildings and dozens of building interiors. This ongoing project, which was made available to the public through Google Earth in 2008, began in 1997 and has involved an international team of subject experts including architects, archaeologists, classicists, and engineers. Aside from serving as an educational representation of ancient Rome, the model also can be used to run experiments on ventilation, illumination, the circulation of people, and other areas of interest. In fact, tests have already helped improve estimates regarding the carrying capacity of the Coliseum (British Broadcasting Corporation News, 2007; Curry, 2007a; Microsoft/National Broadcasting Company, 2007; Rome Reborn, 2009). Moreover, Rome Reborn has been used for two tourism applications: TimeMachine and Rewind Rome (Rome Reborn Brochure, 2008). TimeMachine is a hand-held audiovisual guide that one can point at the remains of certain sites, such as the Coliseum, and see a virtual reconstruction of the site superimposed onto the display of the existing remains (Barras, 2008; Rome Reborn Brochure, 2008). Rewind Rome, located across the street from the Coliseum, is a 30 min, 3D 'edutainment' show in which visitors are guided by an avatar through re-created scenes involving various areas of the ancient city (3D Rewind Rome, 2009; Brown, 2008; Owen, 2008; Rewind Rome, 2009; Rome Reborn Brochure, 2008).

VEs, including Rome Reborn and SL, are displayed to their users through visual output devices, which are quite varied and can be as simple as a computer or television screen. Perhaps the quintessential VR output device is the head-mounted display (HMD), which may come in the form of a helmet, goggles, or glasses, and displays virtual imagery just in front of the user's eyes. Quite similar to HMDs are hand-supported displays (HSDs), which are held to the user's eyes like binoculars. A floor-supported display (FSD) – sometimes referred to as a BOOM after a popular group of models – is a box-like device that is reminiscent of an HMD but is attached to a moveable arm resting on the floor. FSDs, HSDs, and HMDs are all designed for use by a single user, but other output devices allow several users to experience a VE simultaneously. For example, large panoramic projection screens can be arranged to produce a visual experience that numerous users can share. Also, special glasses can be used to observe 3D images displayed by a virtual table or a CAVE, which projects 3D images onto all sides of an enclosed room. When virtual images are superimposed onto the real world, via AR, users also may have a shared experience. In AR, images are viewed through special glasses or other devices that may or may not be fixed to the ground (Burdea & Coiffet, 2003; Gutiérrez et al., 2008; Vince, 2004).

Although the visual aspects of VR often attract the most attention, an audio element also can be very important for the creation of realistic VEs (Gutiérrez et al., 2008; Tsingos, Gallo, & Drettakis, 2004). In VR systems, audio generally is communicated through headphones or specially located speakers. High quality audio is naturally desirable, yet giving 'spatial' qualities to the sound is also important because it allows the user to perceive an external 'sound stage' from which the sounds are emitted. Giving sound spatial qualities involves giving it directionality and accounting for the acoustic properties of the rendered VE. Directionality is important to consider because sounds must be perceived as coming from appropriate features of the VE. The acoustic properties of the VE are important to consider because sound is heard quite differently in different environments (e.g. a bedroom versus a cave), which may generate sound cues like echoes or reverberations. Moreover, sounds originating in different locations will be heard differently by an individual's right and left ears, and how a sound is heard also is influenced by the unique anatomical shape of the individual's body, head, and ears. Accounting for these influences, known as 'head-related transfer functions' (HRTFs), in combination with the real-time positioning of the user's head, is possible but it requires very sophisticated equipment. Consequently, current VR systems accounting for HRTFs often use a generic set of HRTFs rather than those based on a specific user's anatomy (Burdea & Coiffet, 2003; Gutiérrez et al., 2008; Vince, 2004).

Tactile sensations are far more complicated than audio to replicate in VR because the sense of touch involves complex mechanisms of the nervous system. Nevertheless, researchers have made significant progress in re-creating certain tactile sensations. Vibrations, for example, now can be generated successfully in a variety of ways and are already widely used in many video games. Also, researchers have developed 'haptic devices', generally coming in the form of gloves but sometimes covering a user's entire arm or body, which provide the user with 'force feedback' (Gutiérrez et al., 2008, Vince, 2004). Force feedback is felt as a very general tactile sensation, and Vince (2004) compared the experience of touching an apple using a haptic device to touching an apple with a stick, as opposed to one's hand (p. 80). Recent research also has made progress in the simulation of thermal cues and pressure that imitates an object's weight (Gutiérrez et al., 2008). Nevertheless, the difficulties of reproducing tactile sensations will be challenging to overcome and they highlight an obvious limitation of many VR systems.

Smell and taste often are regarded as the least important senses for VR, but noteworthy advances have been made in these two areas nonetheless. Olfactory stimulation, which can increase a user's sense of presence (Dinh et al., 1999), typically is achieved with 'olfactory displays' that spray certain smells or smell combinations at a particular target or area (Gutiérrez et al., 2008; Washburn & Jones, 2004). Some challenges that olfactory displays must overcome include creating realistic scents, ensuring that one scent is removed before another scent is introduced, and accounting for the varying olfactory capabilities of different individuals (Washburn & Jones, 2004). Nevertheless, researchers have developed olfactory displays that can record and reproduce a wide variety of odors, such as citrus smells, by mixing up to 96 different odor components (Boyd, 2008; Greimel, 2006; Kageyama, 2006; Somboon, Wyszynski, & Nakamoto, 2007a, 2007b; Wyszynski, Yamanaka, & Nakamoto, 2005). As an example of the use of an olfactory display in VR, American military doctors, experimenting with VR to treat post-traumatic stress disorder in troops, utilized an olfactory display capable of releasing eight different scents associated with the Iraq War (Brewin, 2007; Pair et al., 2006). Although research into VR and smell is somewhat limited (Washburn & Jones, 2004), research into VR and taste is even sparser (Gutiérrez et al., 2008). Nevertheless, several years ago a team of researchers developed a relatively successful 'Food Simulator' that simulated the chemical sensation of taste by injecting a small amount of liquid into the user's mouth. This liquid was synthesized from the major classes of taste to represent either crackers or an apple-flavored gummy candy (Iwata, Yano, Uemura, & Moriya, 2004).

When considering the current state of VR technology, it should be recognized that a VR system's ability to stimulate different senses effectively will have varying importance depending on how the system is being used. For example, high quality tactile feedback would be most important for a VR system that simulates surgery for doctors in training, while high quality audio would be most important for a VR system simulating an orchestra in a concert hall (Gutiérrez et al., 2008). With regards to tourism, the visual and auditory aspects of VR likely will often be the most important, yet one still must consider each system's particular use. For instance, a VR re-creation of an Egyptian pyramid that is featured on a museum's website should strive primarily for detailed imagery, a VR re-creation of a Maori haka dance and its accompanying shouts should strive for relatively better audio quality, and a VR re-creation of the gardens of Versailles should strive to include appropriate olfactory stimulation. Similarly, different input and output devices will be best suited for different purposes. For example, a London-based travel agency marketing an Amazonian ecotourism riverboat trip may want to promote the trip using a fully immersive HMD that allows potential customers to enjoy a virtual simulation of the tour. On the other hand, if the operator of this same trip is marketing it to tourists already situated by the river, then it may be most effective to use an AR device that permits the potential customers to see virtual wildlife superimposed over the river, just as the tourists would see it during the actual tour.

4. Future virtual reality technology

As VR technology continues to evolve, there is no question that VR systems will improve in their ability to stimulate each of the five senses. Also, the ways in which users interact with VR systems likely will progress far beyond the currently used input and output devices. Even though it is impossible to know exactly what the future of VR will look like, by examining some examples of ongoing VR research and development one can obtain a general idea of what VR's future may entail. For example, an international design collective named NAU is developing an 'Immersive Cocoon'– a human-sized dome that will display images on its fully enveloping screen, provide audio in surround sound, and use motion-sensing software for data input (Immersive Cocoon, 2009; Tutton, 2008). As another example, a team of British academics is developing a 'Virtual Cocoon'– a fully immersive headset capable of stimulating each of the senses with a combination of high-definition graphics, surround sound, heat and humidity controllers, an olfactory display, a device that can spray flavors into the mouth and provide texture sensation, and a separate glove that provides tactile feedback (Derbyshire, 2009; Engineering and Physical Sciences Research Council, 2009; Madrigal, 2009; towards Real Virtuality, 2009). Additionally, research is being conducted on the use of one's eye (Bates, Istance, & Vickers, 2008; Kageyama, 2008) or tongue (Huo, Wang, & Ghovanloo, 2008) movements to provide signals that could be used to control different devices, including possibly VR systems.

Research on brain-computer interfaces (BCIs), in which the brain directly communicates with a computer through invasive or non-invasive technologies, also appears quite relevant to the future of VR. BCI research "has moved at a stunning pace since the first experimental demonstration in 1999" (Lebedev & Nicolelis, 2006, p. 536) and, while invasive techniques almost certainly will be used only for medical purposes (e.g. Lozano, Dostrovsky, Chen, & Ashby, 2002; Mayberg et al., 2005; Schiff et al., 2007; Weaver et al., 2009), researchers have made significant progress with non-invasive BCIs. For instance, a paralyzed man working with researchers is reported to have successfully controlled an SL avatar using only his thoughts, which were interpreted by special headgear that included three electrodes measuring his brain waves (Agence France-Presse, 2008). In a similar experiment, three able-bodied students used their brain signals to navigate a virtual street (Pfurtscheller et al., 2006), and in another experiment two subjects used their brain signals to compete in a Pong-style game (Peplow, 2004). In fact, the video game industry already is involved in the development of neural headsets that use electrical signals from players' brains to control video game characters. For example, OCZ Technology already is selling its 'Neural Impulse Actuator' (OCZ Technology, 2009) and Emotiv is in the final stages of development for its 'EPOC Neuroheadset' (Emotiv, 2009; Paulson, 2008). In addition to functioning as input devices, such technologies eventually may be capable of serving as output devices too. For example, Sony has patented a theoretical device (not an invention) that would create sensory experiences by transmitting data via fired pulses of ultrasound targeting neurons in specific regions of the brain (Hogan & Fox, 2005; Horsnell, 2005). However, such output devices certainly remain in the distant future and may very well prove unrealistic.

5. Applications for virtual reality within the tourism sector

As VR technologies continue to advance, the possibilities for using VR within the tourism sector will grow. Nevertheless, regardless of how VR technology evolves, there are already many immediate applications for VR within the tourism sector. By analyzing some of these applications within several primary areas of tourism, it quickly is made apparent that VR may have significant impacts on tourism and VR offers myriad opportunities to both tourism researchers and professionals.

5.1. Planning and management

VR's attributes render it uniquely suitable for the visualization of spatial environments (Vince, 2004), which is why VR is commonly exploited for the purposes of urban, environmental, and architectural planning (Heldal, 2007; Vince, 2004). In fact, over one decade ago Cheong (1995) recognized, "VR has the potential to serve as an invaluable tool in the formulation of tourism policy and in the planning process as well" (p. 419). Most obviously, VR permits the creation of realistic, navigable VEs that tourism planners can analyze when considering possible developments. When compared with rudimentary, two-dimensional blueprints or fixed, 3D models, VR models offer numerous advantages. For instance, VR models allow planners to observe an environment from an unlimited number of perspectives instead of just a bird's-eye view, and they permit the rapid visualization of potential changes that subsequently can be assessed (Cheong, 1995; Sussmann & Vanhegan, 2000).

VR also can serve as a useful tool for communicating tourism plans to members of an appropriate group or community, and possibly receiving input from such individuals. This capability is significant, as it has long been recognized that the involvement of local communities in the tourism planning process can be integral to the success of a destination (e.g. Haywood, 1988; Simmons, 1994). One advantage of using VR for participatory planning is that it "offers a way for individuals from diverse backgrounds to communicate through a visual language that mimics the way people interact with the environment in the real world" (Al-Kodmany, 2002, p. 199). Using VR to communicate tourism plans can be done in a variety of ways. For instance, tourism plans can be presented at community meetings in which relevant authorities, professionals, or experts are on hand to discuss the plans, answer questions, and obtain input from the community. In fact, such an approach was used successfully in Sweden during the planning of two roads that passed through cultural heritage areas (Heldal, 2007). Another possible strategy is to create a VE illustrating certain tourism plans and make it freely available to the public via the Internet. This approach was used successfully in Italy where plans for a transportation hub were communicated to the public online with an SL-type VE of the planned hub that users could explore as avatars while interacting with other users and accessing information about the project (Caneparo, 2001). An additional potential strategy would be for tourism planners to use AR systems to superimpose planned developments onto the existing landscape, thereby permitting community members to observe the planned changes almost exactly how they would really appear.

VR also can benefit tourism planning and management through the unique testing capabilities that the technology offers (Cheong, 1995; Sussmann & Vanhegan, 2000). As an example of such capabilities, Bishop, Wherrett, and Miller (2001) conducted an experiment in which subjects navigated a VE simulating a Scottish landscape and chose different paths based on the landscape characteristics of the different options. The researchers found that subjects demonstrated preferences in the VE that often imitated their real life preferences for certain landscapes, as determined in a subsequent questionnaire. In another example, Gimblett, Richards, and Itami (2001) used surveys and interviews to research the behaviors of hikers, mountain bikers, and jeep tour passengers in an Arizona recreation area, and then used the data to program virtual 'agents' representing members of the different user groups in a VE re-creation of the site. The researchers used this VR program to measure the frequency and location of encounters between the conflicting user groups and to test how effective potential new trails would be at reducing such encounters. VR programs similar to the ones used in these two examples could be used for countless other testing purposes as well. For instance, a museum could test the potential popularity of a special exhibit being considered, a tour company could test the preferences for certain attractions as exhibited by members of a target demographic, or site managers could test different pricing and scheduling strategies to reduce congestion at overcrowded sites. Moreover, while Gimblett et al. (2001) and Bishop et al. (2001) used VR to simulate and test user behaviors, VR also can be exploited to simulate users' environmental impacts, like soil erosion, in order to improve land use planning in tourism destinations (Bishop & Gimblett, 2000).

5.2. Marketing

Just as VR can be used to plan and manage a destination, it also can be used to market a destination. Various authors have acknowledged VR's possible contributions to tourism marketing (e.g. Cheong, 1995; Prideaux, 2002; Sussmann & Vanhegan, 2000), and Williams and Hobson (1995) even stated, "From a marketing perspective, VR has the potential to revolutionize the promotion and selling of tourism" (p. 425). VR's tourism marketing potential lies primarily in its ability to provide extensive sensory information to prospective tourists. Such a capability is especially suitable for the tourism sector because many tourism products are 'confidence goods' that consumers are unable to test in advance and must decide whether or not to purchase based simply on available descriptive information (Gratzer, Werthner, & Winiwarter, 2004; Liu, 2005). Internet marketing is, therefore, very important for the tourism sector (Buhalis & Law, 2008; Doolin, Burgess, & Cooper, 2002; Gratzer et al., 2004), and the experiential nature of VR makes it an optimal tool for providing rich data to potential tourists seeking destination information. For example, Cheong envisioned (1995), "A person interested in exploring an island destination would be able to enter virtual island destinations such as Hawaii, the Virgin Islands, the Seychelles, the Maldives, Jamaica, and others" (p. 419). Using such a device, a tourist could make better informed decisions and have more realistic expectations, which may lead to a more satisfactory vacation (Cheong, 1995; Hobson & Williams, 1995).

Many tourism products do, in fact, already use VR or VR-type technologies to attract tourists. For instance, on the Internet one can find many hotels (e.g. www.showhotel.com) and destinations (e.g. www.virtualgettysburg.com) offering 'virtual tours' (Cho, Wang, & Fesenmaier, 2002; Gilbert & Powell-Perry, 2002; Wan, Tsaur, Chiu, & Chiou, 2007). These 'virtual tours' often are simply panoramic photographs that do not permit any free navigation, meaning they are not genuine VR, but they importantly still reveal an interest in VR-type technologies. Also, numerous researchers have advocated the incorporation of such interactive features into tourism websites (e.g. Cho et al., 2002; Doolin et al., 2002; Fotakis & Economides, 2008) and these recommendations are supported by evidence from various studies. For example, Wan et al. (2007) found that virtual experiences provided more effective advertising than brochures for both theme parks and natural parks. Also, Lee and Oh (2007) found that a 'virtual tour' of panoramic photos on a hotel website may offer psychological relief to individuals feeling travel anxiety. Moreover, findings that sites featured in movies experience increased tourism (Riley & Van Doren, 1992; Tooke & Baker, 1996), and visiting a museum's website can increase one's interest in visiting the real museum (Thomas & Carey, 2005), serve as indirect evidence that visiting tourism destinations in VR may encourage real visitation.

VR also offers a unique platform for the communication of information between tourists. As Buhalis and Law (2008) stated, online travel communities, in which tourists exchange information through forums, chat services, or other tools, "are gradually becoming incredibly influential in tourism as consumers increasingly trust better their peers, rather than marketing messages" (p. 612). Therefore, tourism providers will benefit from establishing brand awareness within such communities and analyzing and responding to the opinions of their products voiced within the communities (Buhalis & Law, 2008). Additionally, tourism businesses may benefit from establishing their own online travel communities, like Lonely Planet has done with its Thorn Tree Travel Forum (http://www.lonelyplanet.com/thorntree) (Kim, Lee, & Hiemstra, 2004; Wang, Yu, & Fesenmaier, 2002). Although most online travel communities currently do not seem to use VR, the increasing popularity of virtual worlds like SL (Bates et al., 2008) quite possibly foreshadows the adoption of such technologies by online travel communities, meaning such virtual worlds may become an important element in tourism marketing. In fact, one VR travel community named 'Itchy Feet' (http://www.itchy-feet.org) already is being developed as an SL-type virtual world in which tourists can seek out travel information, communicate with other tourists, and make travel purchases (Berger et al., 2007; Gärtner, Seidel, & Berger, 2008; Seidel & Berger, 2007).

5.3. Entertainment

In addition to serving as a tourism marketing tool, VR systems also can function directly as marketable, entertaining tourist attractions. In fact, the history of VR began with the 1962 patent of a device called the 'Sensorama Simulator' that offered entertaining, simulated motorcycle rides through New York City, providing 3D images, sound, wind, aromas, and seat vibrations (Burdea & Coiffet, 2003; Dinh et al., 1999; Gutiérrez et al., 2008). As VR technology has subsequently evolved, the entertainment industry – and the video game industry in particular – has continued to play a large role in this evolution (Gutiérrez et al., 2008, Vince, 2004; Williams & Hobson, 1994). Although many VR entertainment applications are designed for home use, others, like the Rewind Rome 3D 'edutainment' show, already have been established or will be established as attractions in tourism destinations. Another example of such an attraction is the Cyber Speedway in Las Vegas, in which the user maneuvers around a virtual speedway or roadway while sitting in a replica racecar with a 20-foot wraparound screen (Sahara Hotel & Casino, 2009).

Theme parks are especially logical places to offer VR entertainment, and one already can find VR entertainment in various theme parks around the world. For example, the Dreamworld theme park in Australia offers a 'V8 Supercars RedLine' attraction that is similar to the Cyber Speedway in Las Vegas (Dreamworld, 2009). Also, the Futuroscope theme park in France offers an attraction named 'The Future Is Wild' in which AR technology projects futuristic animals onto a real environment (Futuroscope, 2009). Furthermore, Disney established a VR development studio in 1992 that has produced a variety of attractions featured at the DisneyQuest Indoor Interactive Theme Park in Orlando. For example, on 'Aladdin's Magic Carpet Ride' users wearing an HMD use a motorcycle-type apparatus to race through a VE on a virtual magic carpet. In 'Pirates of the Caribbean: Battle for Buccaneer Gold', a four-person crew wearing special glasses stands on a ship-themed platform surrounded by four screens projecting 3D images. One of the players guides the ship through the VE while the other three players fire imitation cannons at virtual enemy pirates (DisneyQuest, 2009; Mine, 2003). One obvious advantage of such VR attractions over typical theme park attractions is that VR attractions are quite small, thereby potentially permitting VR theme parks to be located in urban areas (Hobson & Williams, 1995; Williams & Hobson, 1995).

5.4. Education

Aside from simply being entertaining, VR also offers tremendous potential as an educational tool. The teaching potential of VR has been recognized by educators for many years (Jacobson, Kelley, Ellis, & Seethaller, 2005) and research already has found VR to be useful for educating students of different ages in a variety of subjects, including history (Mikropoulos, 2006), science (Bowman, Hodges, Allison, & Wineman, 1999; Kerawalla, Luckin, Seljeflot, & Woolard, 2006; Minogue, Jones, Broadwell, & Oppewall, 2006; Salzman, Dede, Loftin, & Chen, 1999; Shelton & Hedley, 2002; Trindade, Fiolhais, & Almeida, 2002), and mathematics (Song & Lee, 2002). This capacity appears to derive from several VR attributes that are particularly suited for education. For example, "A VR model can be an efficient means of communicating a large amount of information because it leverages the user's natural spatial perception abilities" (Jacobson & Holden, 2005, p. 2). Also, Mikropoulos (2006) found that the feelings of presence that VR may induce can assist the learning process. Additionally, "There is general agreement among many educational technologists about the need for interactivity in learning" (Roussou, 2004, p. 3), and VR allows great potential for interaction, such as through games or challenges (Roussou, 2004; Roussou, Oliver, & Slater, 2006). Furthermore, diverse multimedia information can be embedded into a VE, thereby permitting access to a variety of useful information through a single application (e.g. Bowman et al., 1999). Moreover, the entertaining qualities of VR, which have been noted in some studies of VR and learning (e.g. Allison, Wills, Bowman, Wineman, & Hodges, 1997; Roussou et al., 2006), are important to recognize because they may encourage users to remain engaged.

VR's educational potential can be exploited in museums, heritage areas, and other tourist sites. For example, the Foundation of the Hellenic World, a Greek cultural heritage institution, established a VR department in 1998 and has offered a variety of educational VR exhibits in its Cultural Center (Gaitatzes, Christopoulos, & Roussou, 2001) that have proven to be some of the Center's most popular attractions (Roussou, 2004). These exhibits have allowed users to journey through the ancient city of Miletus, become archaeologists who reassemble ancient vases from virtual shards of ceramic, conduct virtual experiments related to some of Archimedes' discoveries, select garb from different time periods that transports the users to VEs representing the relevant eras, and assist an ancient sculptor in creating a statue of Zeus (Gaitatzes et al., 2001; Roussou, 2004). Also the Center recently unveiled 'Tholos', a 130-person VR theater (Gaitatzes, Papaioannou, & Christopoulos, 2006; Tholos, 2009) in which the first productions have featured interactive tours of ancient Athens' agora (Tholos, 2009). In another example of VR's educational potential, Zoo Atlanta at one time offered a 'Virtual Reality Gorilla Exhibit' in which users assumed the character of a young gorilla to explore a virtual gorilla habitat embedded with various educational multimedia information (Allison et al., 1997; Bowman et al., 1999). Bowman et al. (1999) evaluated the educational efficacy of this exhibit with a group of university students and found trends indicating that the VE benefitted students' learning and served as a useful complement to a subsequent lecture on the information covered within the VE.

AR systems' capacity to superimpose educational information over real world views also can be useful for educational purposes. For instance, several Portuguese heritage sites, including the Lisbon National Pantheon and the 12th century Pinhel Castle, have introduced fixed AR devices that are reminiscent of traditional tourist binoculars but display images on a single, larger screen. Through these devices one can access a variety of multimedia explanatory information superimposed over the locations being viewed (The Economist, 2007; Thomasson, 2006; YDreams, 2009). In a similar application, researchers with the PRISMA project developed and tested a comparable device that was situated on a hill overlooking the Spanish city of Donostia-San Sebastian. Using the device one could view and select cultural tourist attractions within the city and access a variety of relevant information, including historical information about the sites and practical information about how to visit them (Linaza, García, Torre, & Torres, 2008). AR's educational potential was further demonstrated in research on the ARCHEOGUIDE project, which was developed and tested in the archaeological site of ancient Olympia. The ARCHEOGUIDE system allowed users wearing HMDs or carrying small, non-immersive screens to explore the Olympia site and view virtual reconstructions of buildings superimposed over their existing ruins, or view avatar athletes competing within the Olympic stadium. Also, prior to touring the site, users could input their interests and allotted time, which the system then could interpret to generate a recommended itinerary and personalize the accompanying informative audio commentary (Stricker, Karigiannis, Christou, Gleue, & Ioannidis, 2001; Vlahakis, Ioannidis, Karigiannis, Tsotros, & Gounaris, 2002; Vlahakis, Ioannidis, Karigiannis, Tsotros, Gounaris, Stricker, et al., 2002; Vlahakis, Karigiannis, et al., 2002; Vlahakis et al., 2001).

Besides being used in such ways to educate tourists, VR also can function as a unique and valuable investigative tool permitting researchers to gain greater knowledge about the sites and objects that tourists visit. VR provides numerous advantages for researchers, such as the ability to test theories or evaluate virtual restorations without disturbing actual objects (e.g. Chalmers & Debattista, 2005; Rizvić, Sadžak, Buza, & Chalmers, 2008), the ability to observe objects from otherwise impossible viewpoints (e.g. Bernardini, Rushmeier, Martin, Mittleman, & Taubin, 2002), and the ability to re-create environments and lighting to observe how a site or object would have appeared in the past (e.g. Sundstedt, Chalmers, & Martinez, 2004). Such special capabilities were highlighted by Frischer (2003), the Project Director of Rome Reborn (Rome Reborn, 2009), in his description of projects undertaken by the UCLA Cultural Virtual Reality Laboratory, which he also heads (Cultural VR Lab, 2009). Frischer (2003) explained, "We can, for example, gauge the carrying capacity of a structure such as the Colosseum, study the circulation of people through the Roman Forum, [or] analyze the statics of a building like the Basilica of Santa Maria Maggiore, whose original apse was replaced for unknown reasons centuries after it was built" (p. 9). In an example of such research, Chalmers and Debattista (2005) investigated whether prehistoric Maltese temples, of which only roofless ruins remain, were originally covered by roofs. Chalmers and Debattista tested two theories involving possible forms for stone roof architecture and the researchers determined that neither of the proposed roof structures would have been stable. In another example, Sundstedt et al. (2004) demonstrated that the flame light and sunlight that originally illuminated hieroglyphic carvings on the walls of the ancient Egyptian temple of Kalabsha would have enhanced the carvings' three-dimensional nature, which is less perceptible under modern lighting.

5.5. *Accessibility*

The opportunity for researchers like Sundstedt et al. (2004) to investigate virtual re-creations of different sites demonstrates the general increase in "accessibility" that VR provides to both researchers and the general tourist public. By definition, such access is limited to a virtual world, yet it certainly is preferable to any alternative apart from actual visitation, which in many cases may be impossible. For instance, a tourist site may be too remote, too expensive, too inhospitable, too dangerous, too fragile, or simply no longer exist. In addition to providing a best possible alternative in such scenarios, virtual models also can permit unique interaction with historical objects or other fragile items that cannot be handled in the real world (Paquet & Viktor, 2005).

One example of the increased access offered by VR is provided by an exhibit once developed for China's Dunhuang Caves. Beginning in the fourth century, Buddhist monks dug and decorated these caves with thousands of statues and 45 000 square meters of painted murals, but the site mostly had been closed to tourists because the tourists' presence, along with other factors, was damaging parts of the site. The VR exhibit developed was a CAVE system in which visitors could navigate a re-creation of two caves using a virtual flashlight to illuminate the murals while a virtual voice provided background information (Lutz & Weintke, 1999). Although this exhibit no longer appears to be offered at the site, a more substantial VR tour of the caves is being developed in order to further reduce the amount of time tourists spend within the real caves (Tang, 2007). In another example of the unique access offered by VR, audiences of over 600 in a VR theater were able to tour a VE representing the ancient city of Seorabol, located in modern-day Korea. Navigation in this VE was controlled by an individual acting as both an actor and a guide (Park, Koa, & Kim, 2003). In addition to offering virtual access to otherwise inaccessible sites like the Dunhuang Caves or ancient Seorabol, VR also can provide widespread access to a virtual site when the VR application is made accessible over the Internet. For instance, Carrozzino, Brogi, Tecchia, and Bergamasco (2005) developed a virtual replica of Pisa's Piazza dei Miracoli that is freely accessible online (http://piazza.opapisa.it/3D/index.html). In this VE, one can navigate the Piazza and view it from numerous perspectives; switch between different time periods to see the site's transformation through various centuries; and click on certain relevant points to access related historical, artistic, and architectural information.

VR's capacity to facilitate access to sites can benefit everyone, yet this capacity is particularly beneficial for disabled individuals. Disabled people who travel, or would like to travel, comprise a large yet often overlooked market segment (Huh & Singh, 2007). Unfortunately, they face a range of sometimes insurmountable barriers, including unaccommodating architecture or landscape, transportation difficulties, and negative attitudes (Goodall, Pottinger, Dixon, & Russell, 2004; Smith, 1987). Physical access barriers sometimes may be easily eliminated with cooperation from tourism providers, but in some sites, such as historical heritage sites, altering physical features to accommodate disabled visitors may be impossible due to conservation requirements or prohibitively large costs (Goodall et al., 2004). In such situations, VR can provide disabled visitors with alternative forms of access (Cheong, 1995; Ford, 2001; Goodall et al., 2004; Hobson & Williams, 1995). For instance, disabled visitors to Shakespeare's Birthplace in Stratford-upon-Avon may be physically unable to access the house's second floor, so the site has installed a VR exhibit on the first floor that offers a VR re-creation of the floor above (Goodall et al., 2004; Shakespeare Birthplace Trust, 2009; The Virtual Experience Company, 2009). Additionally, online virtual worlds like SL can provide outlets where disabled individuals can bypass traditional barriers and enjoy dynamic and interactive virtual travel experiences (Ford, 2001). For instance, one woman who suffered from a chronic pain disorder and had used SL to skydive, ice-skate, and interact with distant friends and family was quoted in a *Newsweek* article on SL claiming the program had "opened up another world" for her (Bennett & Beith, 2007).

5.6. *Heritage preservation*

The list of heritage sites and objects that can be accessed virtually is constantly expanding and countless heritage sites and objects from around the world already have been digitized as 3D virtual models, although many are not available to the public. Besides those that already have been discussed, some of the other countless examples of heritage sites and objects that have been rendered as 3D models include Michelangelo's statues of David (Callieri et al., 2004) and the Florentine Pietà (Bernardini et al., 2002), over 150 sculptures from the Parthenon (Stumpfel et al., 2003), the Great Buddha carving from Afghanistan (Grün, Remondino, & Zhang, 2004), assorted Angkor temples in Cambodia (Kenderdine, 2004), numerous Terra Cotta Warrior statues from China (Zheng & Zhang, 1999), various castles in Northern Italy (El-Hakim et al., 2007), a Byzantine crypt in Italy (Beraldin et al., 2002), frescoes from the House of the Vettii in Pompeii (Devlin & Chalmers, 2001), the Hawara pyramid complex from ancient Egypt (Shiode & Grajetzki, 2000), the Hagia Sophia Mosque of Istanbul (Foni, Papagiannakis, & Magnenat-Thalmann, 2002), the Dutch castle of Huys Hengelo (Reidsma, Kragtwijk, & Nijholt, 2001), a 19th century aboriginal chief house in Canada, a chapel in Ottawa (El-Hakim et al., 2006), a 14th century Bosnian king's monumental gravestone, and the Sarajevo City Hall (Rizvić et al., 2008).

Rendering such sites and objects as virtual 3D models can function as a valuable tool for heritage preservation because such virtual models can contain extremely precise and accurate data sets that theoretically can be stored indefinitely (Cignoni & Scopigno, 2008; Paquet & Viktor, 2005). While a site or object may suffer degradation from impacts like erosion, a VR model can provide precise information on its earlier form that can be used both to monitor degradation and offer a blueprint for restoration (Paquet & Viktor, 2005). VR also can aid restorations by monitoring the restorative actions or visualizing the effects of potential restorative actions (Cignoni & Scopigno, 2008). As an example, Fontana et al. (2002) utilized a virtual model to guide the restoration of the Minerva of Arezzo, a bronze statue from modern-day Italy that dated back to around the third century B.C. and had undergone various previous restorations. The virtual model provided detailed information that could be used to help reassemble parts that would be removed for repair, visualize possible changes that would be made to correct mistakes theorized in the earlier restorations, and maintain a permanent record of the statue prior to the new restorations.

As with the Minerva of Arezzo, heritage preservation and restoration efforts sometimes are needed to account for natural degradation or damages that occurred centuries ago. However, some heritage sites require preservation efforts as a direct result of the sites' current popularity as tourist attractions. For instance, Prideaux (2002) claimed, "A growing number of travellers threaten to overwhelm many of the sites that visitors currently find popular" (p. 320). In fact, some of the world's most treasured sites – those listed as UNESCO World Heritage Sites – may be particularly threatened simply because their World Heritage status can attract increased numbers of visitors to the point of detriment (Drost, 1996; Li, Wu, & Cai, 2008). As Li et al. (2008) stated, "Many researchers believe the very designation of a World Heritage Site is the catalyst to rapid tourism development … [and] the number of visitors is the major threat to the sustainability of the sites" (p. 311). As an example, the rapid growth in tourism at Cambodia's Angkor temples has been reported to be causing a variety of consequences, including the depletion of groundwater, which some fear may result in the sinking of temples; an increase in air pollution to threatening levels; and the erosion of temple stones caused by multitudes of tourists walking through the temples and touching their carvings (Furuuchi et al., 2007; Sharp, 2008; Watson, 2008; Winter, 2007).

Numerous researchers have suggested that VR potentially could function to preserve heritage by providing an alternative form of access to threatened sites. For instance, Hobson and Williams (1995) stated, "With VR offering realistic experiences, it could offer a way of visiting sensitive environments that cannot cope with demand" (p. 133); Cheong (1995) stated, "With more people choosing to partake in vicarious travel experiences via VR, fewer would actually visit a tourist destination," which would "significantly lessen the impacts of visitor encroachment" (p. 421); Addison (2000) stated, "Perhaps with realistic enough virtual visits, we can soon curtail some of the tourism that's threatening to 'love to death' a growing percentage of our heritage" (p. 25); Refsland, Ojika, Addison, and Stone (2000) stated, "To a greater degree, technology is solving one of the largest problematic issues concerning cultural heritage assets—nondestructive public access" (p. 20); Paquet and Viktor (2005) stated that, in order to decrease site degradation, "a virtual copy of the original can replace the latter" (p. 1); and Arnold (2005) stated, "Virtual tours can also be used to help preserve heritage and/or improve opportunity by giving visitors access to a simulation, rather than placing the original at risk of wear and tear" (p. 228).

6. Virtual reality as a tourism substitute

6.1. The prospect of VR tourism substitutes

Although VR substitutes may be ideal for preservation purposes, one naturally must question how receptive tourists would be toward such substitutes. Some tourists may sympathize with the preservation objectives of a VR substitute, but as Paquet and Viktor (2005) noted, "Most people want to see reality and not only virtuality" (p. 1). Moreover, many aspects of a tourist experience may never be fully replicable in VR. "For instance, how is VR able accurately to simulate the smell of ocean spray and the splash of seawater on one's face as one participates in virtual surfing?" (Cheong, 1995, p. 421). In fact, in a 2001 survey involving 31 university students in Australia, the students almost unanimously rejected the prospect of using VR as a substitute for real travel, citing logical limitations such as the lack of spontaneity, the absence of opportunities to relax, and the inability to purchase souvenirs (Prideaux, 2002). Similarly, Sussmann and Vanhegan (2000) investigated this topic by surveying 50 people in Britain who had taken at least one week-long holiday during the previous year, and the researchers concluded, "Our limited empirical study seems to indicate that there is a current consensus among UK tourists that virtual holidays cannot replace the real holiday experience, regardless of apparent inconveniences and environmental dangers to destinations" (p. 6).

Furthermore, it is possible that an attempted VR substitute would have the exact opposite of its desired preservationist impact and actually increase users' desire to visit the real site (Buhalis, 2003; Dewailly, 1999; Refsland et al., 2000). As Dewailly (1999) questioned, "Would an individual believe that he or she has seen enough of a tourist site by 'visiting' it virtually, or does a virtual visit provide further incentive to go to the site in question so as to enjoy fully its richness?" (p. 48). Dewailly then speculated that VR reproductions may actually increase tourism demand, which is an opinion consistent with Refsland et al.'s (2000) claim that "[t]he majority of virtual heritage researchers believe that their work encourages people to actually go see the real site, giving the visitor extra knowledge to enhance the real site visit" (p. 20).

Nevertheless, aside from a VR substitute's general preservation benefits, with which individual tourists may or may not sympathize, VR substitutes also could provide tourists with a variety of direct, personal benefits. For example, VR substitutes could offer lower costs, no lines, no transportation hassles, greater safety, no language issues, no bureaucracy or visas, no weather concerns, and an overall guaranteed experience (Dewailly, 1999; Hobson & Williams, 1995; Prideaux, 2002). Also, VR substitutes would not always involve accessing a virtual site from afar, as VR could be used on a site's premises as a substitute for a particularly vulnerable section of the site. Such implementation may be perceived as a more satisfactory substitute simply because the tourists would still have the experience of visiting the real site. Moreover, it must be recognized that the ability of a VR experience to provide an acceptable tourism substitute will not be contingent on its ability to perfectly mimic the replicated site to the point that the user is unable to distinguish between the virtual and the real. Rather, a VR experience simply must be perceived as a satisfactory substitute in the mind of the user.

In fact, countless existing tourism sites and activities already involve artificial, reproduced environments. For instance, at the World Showcase in Disney World's Epcot one can explore environments representing several different countries, and in Las Vegas hotel casinos like the Luxor and the Venetian one can observe re-created environments from ancient Egypt and Venice, respectively. Williams and Hobson (1995) noted that the popularity of such simulated environments indicates, "VR is then no more than another logical step down a path whereby tourism experiences are manufactured for consumption to the wishes of the consumer" (p. 424). However, the existence and popularity of such attractions in no way indicate that tourists view the attractions as acceptable substitutes, as few tourists probably would accept visiting the Venetian as an acceptable substitute for visiting Venice, for example.

Nevertheless, other replicated environments seem to function better as genuine substitutes. For instance, visitors to the popular Lascaux Cave in France, which contains paintings dating back 17 000 years, cannot even enter the original cave, but rather enter Lascaux II, a replica of some of the most significant portions of the cave that is located just a few hundred yards from the original. The real cave was closed to the public in 1963 after it was discovered that carbon dioxide from tourists' breath was causing the paintings to deteriorate, yet the replicated cave appears to function as a satisfactory substitute for visitors (Périer-D'Ieteren, 1998; Pine & Gilmore, 2007; The Cave of Lascaux, 2009). Although Lascaux II is a tangible substitute, rather than a virtual one, it serves as an important example of tourists' willingness to accept replicas as substitutes.

6.2. The authenticity of VR tourism

A user's perception of the authenticity of a VR experience will be one factor influencing his or her acceptance of it as a VR substitute. Obviously, VR experiences are inherently inauthentic if one evaluates them with an objective, criteria-based evaluation of authenticity, known as 'objective authenticity' (Wang, 1999). However, when a user assesses the authenticity of a potential VR substitute it will be his or her personal perception of the substitute's authenticity that is relevant. This conceptualization of authenticity, known as 'constructive authenticity' (Wang, 1999), was argued by Cohen (1988) and has been demonstrated in a variety of studies (e.g. Budruk, White, Wodrich, & Van Riper, 2008; Chhabra, 2005; Chhabra, Healy, & Sills, 2003; Littrell, Anderson, & Brown, 1993; Revilla & Dodd, 2003; Waitt, 2000; Xie, 2003). Cohen (1988) posited, "'Authenticity' is a socially constructed concept and its social (as against philosophical) connotation is, therefore, not given, but 'negotiable'" (p. 374). In other words, authenticity is not based on certain fixed criteria, but is rather a subjective and negotiable phenomenon that is context-based, relative, evolving, and can be determined by the viewer or participant (Cohen, 1988; Xie, 2003). Even if a tourism product exhibits features that are clearly staged or contrived (as a VR substitute inherently would), tourists may still view it as authentic (Cohen, 1988). For example, Chhabra et al. (2003) found that many tourists at a Scottish Highland Games festival held in North Carolina viewed the event as authentic, and Waitt (2000) found that many visitors to an Australian heritage precinct accepted the site's commodified environment as authentic. Therefore, even though a VR substitute clearly would not be authentic in the strictest sense, it is quite possible that some users would nonetheless perceive it as authentic.

This perception will be influenced partly by the user's personal characteristics. For instance, Bruner (1994) suggested that different individuals will define authenticity differently: it may mean being the original, being an exact replica of the original, resembling the original, or having been created or certified by a certain authority. Moreover, various studies have found that personal characteristics, such as age, gender, nationality, education level, tourism style, and past travel experience, can influence an individual's perceptions of authenticity (Budruk et al., 2008; Littrell et al., 1993; Waitt, 2000). Furthermore, different people will assign different levels of importance to authenticity and "individuals who are less concerned with the authenticity of their touristic experiences, will be more prepared to accept as 'authentic' a cultural product or attraction which more concerned tourists, applying stricter criteria, will reject as 'contrived'" (Cohen, 1988, p. 376). Additionally, in the case of VR, perceptions of authenticity may be influenced by one's general attitudes toward technology, which may vary between cultures (Sensales & Greenfield, 1995). Therefore, two different users of a single VR tourism application may hold entirely opposing views regarding its authenticity, with one user perceiving it as an authentic substitute and the other perceiving it as an inauthentic, virtual replica.

The user's perception of a VR tourism application's authenticity also will be influenced by the nature of the application. For example, the location of the VR system may be significant, as a 'sense of place' may contribute to a reproduction's perceived authenticity (Halewood & Hannam, 2001). Tourists at Machu Picchu, for instance, may accept the authenticity of an on-site VR substitute for a particular structure that is closed for restoration, while these same tourists may reject the authenticity of the same VR application if it is situated in a German museum. Also, as Bruner (1994) suggested, the perceived accuracy or quality of a product (Chhabra, 2005; Waitt, 2000) or the involvement of a relevant authority (Budruk et al., 2008; Revilla & Dodd, 2003) may contribute to its perceived authenticity. In other words, a virtual reproduction of the Venus de Milo should be more likely to be viewed as authentic if it is sanctioned by the Louvre and produced with laser-scanning technology than if it is reproduced quickly by a member of SL. Furthermore, the nature of the VR experience may be significant, as re-creating a site or object to be observed, such as the Egyptian pyramids, is much simpler than re-creating an activity, such as riding a camel around the pyramids.

6.3. Travelers' motivations and constraints

An individual's willingness to accept a VR tourism substitute also will be influenced by the motivations behind his or her desire for the particular experience. Tourists often travel for pleasure, but they may also possess a variety of other, more complex motivations (Wall & Mathieson, 2006). These motivations may include personal push factors, such as the desire to escape one's daily routine, find excitement or novelty, or engage in social interaction. VR applications are capable of satisfying essentially all of one's push factors–yet only to a limited degree. For instance, VR can provide a form of 'escape', but this is a mental rather than physical 'escape'; it can provide novelty and excitement, as user's may view the VR systems themselves as novel (e.g. Kerawalla et al., 2006; Stangl & Weismayer, 2008) or find excitement in virtual rides like the Cyber Speedway in Las Vegas, but such feelings probably will not equal how the replicated experiences, like racecar driving, would be felt outside of VR; and VR can provide an easy and cheap tool to interact with family, friends, or strangers from all around the world, but the nature of this interaction is confined to the available technology. Tourists are also motivated by destination pull factors, such as the desire to go to a certain attraction, visit certain people, or participate in a certain activity (Dann, 1981; Wall & Mathieson, 2006), and VR provides a varied ability to satisfy such motivations. As has been discussed, VR can re-create sites or objects much better than activities, and social interaction can be enjoyed, but only to a limited degree.

Therefore, certain push and pull factors will best lend themselves to the suitability of a VR substitute. For instance, Cheong (1995), Hobson and Williams (1995), and Sussmann and Vanhegan (2000) have all noted that the opportunity to hold long-distance meetings in VR could supplant much business travel. On the other hand, tourists seeking risk and novelty (e.g. Pizam et al., 2004) probably would reject a VR substitute because the desired sensations could not be mimicked fully in such a controlled environment. Consequently, even tourists interested in visiting the same destination may vary in their acceptance of a VR substitute due to their divergent motivations. For instance, Zhang and Lam (1999) investigated the motivations of visitors to Hong Kong from mainland China, and it is reasonable to presume that some correlation would exist between the tourists' potential acceptance of a VR substitute and the five clusters in which Zhang and Lam placed the tourists, based on what they were primarily seeking: knowledge, prestige, social interaction, relaxation, or novelty. Those tourists seeking knowledge about specific Hong Kong attractions, for example, may find that VR applications enhanced with multimedia information could offer satisfactory substitutes, but those tourists seeking several days of relaxation would likely find a VR substitute unappealing.

Motivations are not the sole actors guiding a tourist's decision making process, however, as they rather moderate this process in conjunction with constraints (e.g. Funk, Alexandris, & Ping, 2009; Prentice, Davies, & Beeho, 1997; White, 2008). Possible tourism constraints are quite varied, but common examples include a lack of money, a lack of time, poor health, safety fears, concerns about managing in a foreign environment, perceived lack of skills for an activity, and an absence of desired travel partners (Fleischer & Pizam, 2002; Funk et al., 2009; Gilbert & Hudson, 2000; Nyaupane, Morais, & Graefe, 2004; Pennington-Gray & Kerstetter, 2002; Prentice et al., 1997; White, 2008). Just like constraints influence general tourist decisions, constraints also likely will influence a tourist's potential acceptance of a VR substitute. For example, Funk et al. (2009) researched Australians' and Americans' feelings toward possibly attending the 2008 Beijing Olympics and found that those individuals more accepting of a television substitute perceived greater constraints to attendance, even though these individuals exhibited motivations similar to those exhibited by individuals who indicated a greater likelihood of attending the event in person. Much like television may provide a satisfactory (and sometimes superior) substitute for individuals perceiving significant constraints to attending a sporting event, VR may provide a satisfactory substitute for individuals perceiving constraints to a variety of tourism experiences. For instance, an individual living in Washington, D.C. may see no reason to visit a virtual Lincoln Monument because he or she can easily visit the real one, but an individual living in Bangladesh and confronting constraints such as a lack of money and time may be far more receptive to the same VR substitute.

7. Questions and challenges for the future

7.1. The state of VR technology

Although the opportunities that VR offers the tourism sector are quite significant, many questions and challenges remain regarding VR's future roles in tourism. For instance, even though VR technology will continue to evolve, it is difficult to predict the level of advancement that the future technologies will offer. Existing technologies already permit high quality visual and auditory output, and the accurate re-creation of existing sites. However, even in these areas numerous advances still have yet to be made, such as the real-time rendering of moving, photorealistic avatars and the easy and accurate simulation of an individual's sound stage. Moreover, VR's ability to stimulate the other three senses remains somewhat rudimentary, and it is unclear how much progress will be possible in these areas. A VE in which the user is completely or mostly unable to feel, smell, or taste can still offer myriad uses, but its utility is clearly limited. Such limitations are especially significant when considering the prospect of VR tourism substitutes, but the limitations are also important to remember when considering other, simpler uses for VR. For instance, Bishop et al. (2001), who used VR to test landscape preferences among individuals navigating virtual paths, noted that the lack of haptic feedback could decrease the VE's accuracy, as choosing uphill paths in the VE did not demand the same physical effort that the same choice would have entailed in a real walk. Additionally, it is difficult to predict advances in non-invasive BCI technology or the development of future multi-user output devices, and either of these technologies may prove quite relevant for many tourism applications. Although there is no reason to doubt that future technological advances will permit VR experiences that are far more realistic than those that are currently possible, the available technology will always place limits on what is feasible.

Also, as VR technology advances, these advances themselves may lead to various challenges. For example, Paquet and Viktor (2005), Addison (2007), and Cignoni and Scopigno (2008) have all noted that VR data used for heritage preservation may have a shorter lifespan than tangible records like books or photographs. Although counterintuitive, the problem is that VR data is often stored in formats that quickly can become obsolete, rendering the data inaccessible. Additionally, advanced VR applications may exhibit so much 'novelty' that they fail to perform their functions effectively. In participatory tourism planning, for instance, community members may be persuaded by the novelty of a VR system rather than the merits of the plans it is presenting. In fact, Stangl and Weismayer (2008) re-created an Austrian hotel in SL and found that individuals unfamiliar with SL viewed the SL re-creation more positively than the hotel's website, due to a 'novelty effect', while SL users did not exhibit such an attitudinal distinction. Consequently, VR technology even could be used deliberately to sway community members into accepting a specific plan (Heldal, 2007).

7.2. Re-creating the world in VR

Although re-creating sites in VR may provide myriad educational opportunities, any possible inaccuracies in these virtual sites may be accepted as fact. As Mosaker (2001) warned, "Abstract ideas made visual are powerful in the sense that they present interpretations in very persuasive ways" (p. 24). Similarly, Refsland et al. (2000) wondered, "How far does artistic interpretation go before it impedes on historical accuracy and convinces a young virtual visitor that history was something that it's actually not?" (p. 20). In fact, this problem is particularly relevant to historical re-creations because such re-creations may simply represent one specific time period or one specific interpretation of the past, so viewers not appreciating such conditions will be misled (Jacobson & Holden, 2005). Moreover, many VR re-creations, such as the sites re-created by members of SL, are not overseen by experts, and even though people presumably will be skeptical about the veracity of such reproductions, viewers still may be misled by inaccuracies.

The opportunity for the public to re-create tourism sites in VR and potentially profit from these re-creations also raises a number of intellectual property issues. "Heritage is part of the fabric of society and is usually considered to be part of the public domain" (Nuryanti, 1996, p. 254). However, in some cases authorities do attempt to control their heritage sites with intellectual property laws, thereby demonstrating possible problems that could arise with the replication of such sites in VR. For instance, some Mediterranean countries have long claimed ownership over images of their nations' monuments (Addison, 2007); the construction of a Taj Mahal replica in Bangladesh triggered threats from the Indian High Commission that it would sue for copyright infringement

(Blakely, 2008; Sky News, 2008); and the City of Chicago prohibited professional photographers without a permit from taking pictures of the city's Millennium Park, claiming that different aspects of the park were protected by copyright law (Joravsky, 2005). Intellectual property laws also are sometimes more reasonably used to protect the production of certain heritage products, such as souvenirs produced by indigenous groups (Guttentag, 2009).

Such intellectual property issues can prove quite complex in the real world, yet they are further complicated in the digital realm in which even fundamental questions, such as "What is real, and what is a copy?" (Jones, 2006, p. 212), become difficult to answer (Jones, 2006). For instance, consider a hypothetical VR programmer who re-created a VE of the entire Louvre Museum and then charged a fee for entering this 'Virtual Louvre'. Should such action be illegal even though much of the art in the Louvre is old enough to be part of the public domain and the museum itself is property of the French government? Should it still be illegal if the programmer altered various features of the museum's architecture, added paintings from other museums, and gave the VE a new name that did not include the word 'Louvre'? Should it be illegal even if there were no charge or, instead of replicating the inside of a building one must pay to enter, the programmer had replicated the Eiffel Tower, which can be seen freely from public places?

If any of these hypothetical actions were deemed illegal, it still would not be clear which jurisdiction's intellectual property laws would render it such (Jones, 2006). For example, although the Virtual Louvre replicated a site located in France, it may have been created by an American citizen and based on a Russian server. Moreover, if the Virtual Louvre was deemed acceptable, it is unclear how the VE itself would then be protected by intellectual property law (Barfield, 2006). Another programmer, for instance, could steal the Virtual Louvre's programming code and offer entrance to the same virtual model, or a slightly altered version, for a reduced fee. In fact, in SL this type of situation has already resulted in a lawsuit in which one member's virtual property, from which he earned real income, was copied and subsequently sold by another member (Davis, 2007; Elliott, 2008).

7.3. VR substitutes

The prospect of VR tourism substitutes raises the question of whether such VR experiences could ever be considered a form of 'tourism'. As Hobson and Williams (1995) questioned, "Is it entertainment when you can experience travelling around the Himalayas from the privacy of your living room – or is it tourism?" (p. 132). Many existing tourism definitions reference some sort of physical movement (e.g. Wall & Mathieson, 2006, p. 1) and the definition of tourism agreed upon in 2000 by numerous international organizations, including the United Nations and the World Tourism Organization, begins, "Tourism comprises the activities of persons traveling to and staying in places outside their usual environment …" (Wall & Mathieson, 2006, p. 14). Based on such definitions, using a VR substitute would only be considered 'tourism' if the user had travelled to use the VR. For example, an Australian resident would be considered a tourist when exploring a VR Petra application situated in a British museum, but if the same Australian explored the same VR application at home then he or she would not be considered a tourist. In other words, the qualification derives from the required travel of the user, as opposed to the application's relevance to tourism. Although this analysis initially may appear as both obvious and inconsequential, it will hold significance in certain instances, such as when researchers are measuring the economic impacts of tourism or governments are devising budgets for their tourist boards. For example, if an official VR Petra program were sold to home users, then it may need to be determined whether the generated revenue should be considered tourism revenue or if the program should fall within the domain of the Jordan Tourism Board.

The potential revenue derived from VR substitutes could provide a unique means of capitalizing on threatened tourist sites while simultaneously decreasing overall visitation to those same sites. However, such a development inevitably would have broad impacts on a destination's tourism economy, as the VR revenue would go directly to the designated coffers while community members involved in tourism, such as tour guides, restaurant owners, hotel employees, and souvenir vendors, would face a dearth of real clients. As Cheong (1995) recognized, "If VR were to emerge as a successful application in tourism, many countries would undoubtedly voice their concerns. These countries, especially in the Third World and other developing nations, rely to a huge extent on revenue generated by their respective tourism industries" (p. 421). Moreover, as was mentioned in the discussion of intellectual property, official VR substitutes potentially could be copied and offered by unauthorized competitors freely or at reduced rates. As a result, VR Petra applications, for example, could theoretically enrich VR programmers living in countries all around the world, but no one in Jordan. Such threats posed by VR tourism substitutes should not be misconstrued as threats to the tourism sector as a whole, but it is nonetheless possible that some sites could face economic challenges in the face of sufficiently sophisticated VR substitutes.

8. Future research

Because the integration of VR into the tourism sector remains in its infancy, only a limited amount of existing research has directly examined VR's applications and implications for the sector. Also, because VR technology is evolving rapidly, and younger generations may prove far more receptive than their predecessors to these technologies, VR tourism research needs to be constantly re-validated through continuous investigation. For instance, research like Sussmann and Vanhegan's (2000) study of attitudes toward VR tourism substitutes would quite possibly receive different results if it were conducted today or another decade from now. Therefore, much more research is needed regarding the topics discussed throughout this paper, and many of these topics easily lend themselves to potential future studies.

For example, previous planning research conducted in places like Sweden (Heldal, 2007) and Italy (Caneparo, 2001) could be expanded to investigate the effectiveness of VR as a participatory tourism planning tool in developing countries, where communities less familiar with VR-type technologies may be more easily influenced by VR's novelty effect. Future research into VR and tourism marketing could investigate the effectiveness of using VR to market tourism destinations to different demographic segments (e.g. by gender, age, or nationality). Similarly, research could build on the work of Wan et al. (2007), who compared virtual experiences with brochures for marketing theme parks and natural parks, to compare VR with other marketing devices (e.g. video) or for other types of attractions (e.g. museums). Moreover, marketing research could investigate the comparative effectiveness of different VR output devices (e.g. HMDs, AR goggles, or CAVEs) for marketing different types of attractions (e.g. historical ruins or beach resorts). Research on VR as tourism entertainment could investigate the viability of establishing entertaining VR attractions at different types of existing sites (e.g. natural attractions like the Grand Canyon or manmade attractions like the Eiffel Tower). Research on VR and tourism education could investigate the educational benefits of VR museum exhibits as compared with more traditional exhibits. Research on accessibility for disabled tourists could investigate which characteristics of a VR application (e.g. providing extensive information or offering realistic graphics) are most strongly desired by disabled visitors unable to access a particular site.

Many opportunities exist to research the possibility of using VR experiences as substitute tourism experiences as well. For example, research could investigate tourists' opinions about the authenticity of tangible simulacra like Lascaux II. Alternatively, research could investigate whether certain characteristics of tourists (e.g. age, nationality, or travel experience) that have been found to influence perceptions of authenticity in other circumstances (Budruk et al., 2008; Littrell et al., 1993; Waitt, 2000) also influence perceptions of authenticity for VR tourism experiences. Moreover, research could investigate what situational factors (e.g. location or approval by a relevant authority) or VR characteristics (e.g. olfactory simulation, full immersion, or sharing the experience with others) increase the perception that a VR substitute experience is authentic. Additionally, research could investigate how different motivations (e.g. seeing a parade, shopping, or meeting locals) and constraints (e.g. lack of funds, poor health, or safety fears) impact tourists' acceptance of a VR substitute.

9. Conclusion

As this paper has demonstrated, VR's applications and implications for the tourism sector are both vast and significant, so the insights gained from future VR tourism research can provide direct, practical value to the tourism sector. This sector is constantly evolving and, just like any other emerging technology, VR will present the sector with both challenges and opportunities. Only with a more widespread and complete understanding of the relationships between VR and tourism will these challenges best be met and the opportunities best exploited. Fortunately, despite its associated challenges, VR offers a variety of promising applications in areas ranging from planning and management to entertainment. Moreover, VR offers the potential to create substitute experiences that may be extremely useful for heritage preservation in certain situations. As new VR technologies are developed, the potential uses for VR within the tourism sector will continue to increase in both number and importance, so it will be the job of tourism researchers and professionals to exploit VR for the unique opportunities it presents.

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