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New Trends in Sound Planning Using Immersive Virtual Reality Technology

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ABSTRACT

Sustainable sound planning has been drawing more attention as citizens are demanding higher levels of comfort and livable environment while keeping the convenient access to transportation and neighborhood in urban settings. Particularly in Hong Kong, we see a lot of innovative building designs, such as smart facades, are there improving the overall indoor sonic environment of the premises. Apparently, different situations and designs can result in varying levels of costs and benefits. How to balance these becomes a challenge for the acoustical designers and sound planners. This paper presents a case study revealing how virtual reality technology can be applied to let the relevant stakeholders "experience" the noise benefits that a particular smart facade design can bring by "perceiving" the sonic environment and having it associated with different design options and costs.

Keywords: Sound planning, Virtual reality, Smart facades, Hong Kong

1. INTRODUCTION

Urbanization has been an outgoing trend in developed and developing countries for centuries. According to the United Nations (1), the world's population living in urban areas increased from 0.75 billion in 1950 (i.e. 30 percent of the world's population at that time) to 4.2 billion in 2018 (i.e. 55 percent). The figure was projected to about 6.7 billion in 2050 (i.e. 68 percent). Among the world's largest cities, Tokyo was ranked the first with 37 million inhabitants, followed by Delhi with 29 million in 2018. In China, Shanghai had about 26 million inhabitants and Beijing had about 20 million inhabitants (1). In South China, the Greater Bay Area had a total population of 70 million with Guangzhou having the largest number of inhabitants at 14.5 million, followed by Shenzhen at 12.5 million, Dongguan at 8 million, and Hong Kong at 7.4 million (2). Additionally, most people have busy and hectic schedules in cities (3). Thus, it is not unusual that people like to live in apartments which are located in the vicinity of shopping malls, metro stations, public transport interchanges, major roads, and even roundabouts. The easy access to shopping, food and drinks, and transport has come with costs tied to it. Unavoidably, people are exposed to high levels of traffic noise, noise from dining places including pubs and bars, and oily cooking fume (3-6).

The Hong Kong Government has advocated the development of smart city for a number of years. However, the definitions of a smart city and its components such as smart transportation, smart buildings, smart utilities, smart healthcare, and smart services have yet to be officially established and thoroughly validated. For example, To et al. (7,8) reviewed the meanings of smart buildings and found that the definition of smart buildings has evolved from those of smart buildings' predecessors such as intelligent buildings. To et al. (7,8) reported that Hong Kong's building designers and users indicated an intelligent security system to be the most important feature, followed by an intelligent and responsive fresh air supply in commercial buildings. On the other hand, building designers and users generally considered the systems that monitor people's movement to be the least important feature. Building users also considered features of smart facade i.e. building envelope to be a group of

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secondary features when comparing with features that have direct impact on indoor environment (8). However, To et al. (7,8) focused on commercial buildings and did not explore smart designs for residential buildings. In a residential development, a building facade does not only determine the appearance of the building, it also determines the thermal load transmitted through it and the sound (or noise) transmitted through it. Hence, different facade designs can be considered to optimize the thermal and sound insulation/reduction properties. Specifically, the size, geometry, orientation, and materials of an opening such as a window can significantly influence the transmission of thermal and sound energies through a building facade. Thus, a smart facade must consider both thermal and sound insulation that can be adaptive to changes in both outdoor and indoor environment. This paper describes such a smart facade and its perceived effectiveness – focusing on its sound reduction property using virtual reality technology.

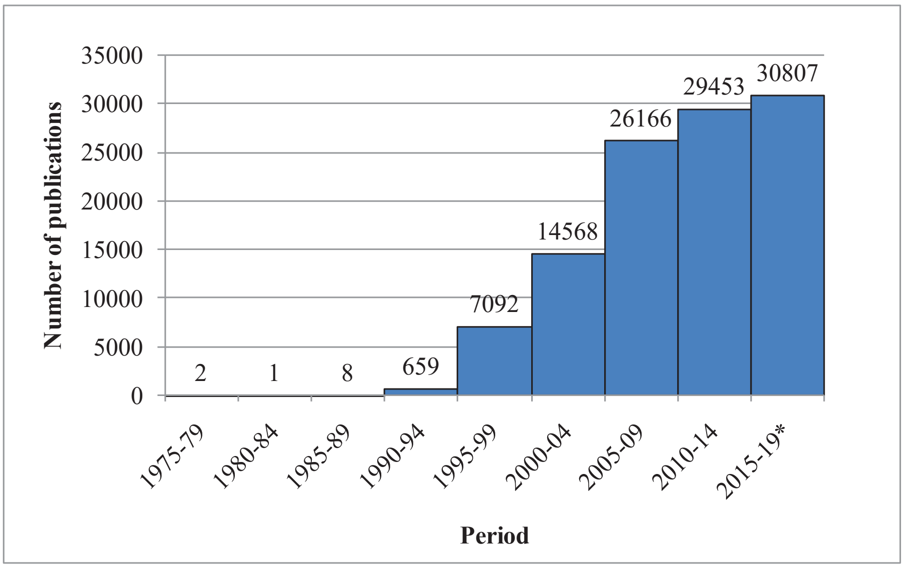
2. VIRTUAL REALITY

Virtual reality means different things to different people at different times. In motion pictures and the entertainment industry, stereoscopic techniques have been used as a way for creating the illusion of depth of moving images and objects, giving audiences a sense of virtual presence in different environments. Charles Wheatstone, James Elliott, and David Brewster were credited to invent and develop different types of stereoscopes independently back to the 1830s (9). However, the world's first stereoscopic (or 3D) commercial firm "The Power of Love" was shown in the Ambassador Hotel Theater, Los Angeles on September 1922 (10).

Similarly, the predecessors of stereophonic sound can be dated back to the 1880s in France where Clememt Ader invented theatrophone – a system of telephonic transmission through which listeners received two separate channels (left and right) for their ears (left and right), enabling an illusion of the depth of auditory perspective (11). In the 1930s, Alan Blumlein of the Columbia Garphophone Company (later known as EMI) invented and filed a patent on binaural (now known as stereo) sound recording, transmission, and reproduction using two-channel system, as well as stereo films (12). At about the same time, Harvey Fletcher of Bell Laboratories investigated techniques for stereophonic recording and reproduction using multi-channel (three to eight channels) systems. Yet, two-channel stereophonic reproduction (or 2-0, meaning two channels and no surround channel) has been widely used in the music industry for decades. Indeed, by having more than two channels or introducing additional phase shifts between two or more channels, stereo sound can become surround sound or the so-called 3D sound (13).

The arts and sciences of realism or virtual reality migrated from theatrical reproduction or movie production to personal experiences. In the 1950s, Morton Heilig developed the Sensorama – a semi-enclosed chamber in which different stereoscopic images, stereo sounds, odors, air movements, and motions can be experienced by a person. In 1984, Jaron Lanier founded VPL Research and developed products such as data glove, audio sphere, virtual reality head-mounted display unit (known as VR goggles), etc. Since then, virtual reality gain momentum across a wide range of industries and different academic disciplines. On 20 February 2019, we performed a literature search using Scopus – one of the largest academic databases, with search terms "virtual reality" in "Article title, Abstract, Keywords". We identified 108756 documents in which 63036 of them were conference papers, 36547 journal articles, and 9172 others. Figure 1 shows that the number of publications about "virtual reality" increased rapidly in the past three decades.

As for the terminology of virtual reality, Steuer (14) defines "a virtual reality" as "a real or simulated environment in which a perceiver experiences telepresence". Others such as Bisson et al. (15) suggested that virtual reality as a computer-simulated environment allows users to interact with virtual objects and images that appear in the virtual environment in real time. Since the late 1990s, virtual reality technologies including VR head-mounted displays have been used as training and practical tools in landscape designs, architectural designs, and interior designs (16-19). Virtual reality has also been adopted in education (20), medical training (21), rehabilitation (22,23), etc.



Note: *This period only covered January 2015 to February 2019.

Figure 1 – The number of publications on "virtual reality" during the period of 1975-2019.

2.1 Virtual Reality for Soundscape and/or Sound Planning

On 20 February 2019, we also performed a literature search using Scopus with search terms "virtual reality" in "Article title, Abstract, Keywords" and "soundscape" in "Article title, Abstract, Keywords". The search results showed that there were 120 documents, including 86 conference papers, 27 journal papers, and 7 others. After entering "head mounted" to a special function "search within results…", we identified 7 documents including 6 conference papers and 1 journal article on "virtual reality", "soundscape", and "head mounted…". All these 7 documents were written by European research groups which primarily focused on the realism of virtual walks based on the visual and audio effects from different VR head-mounted displays.

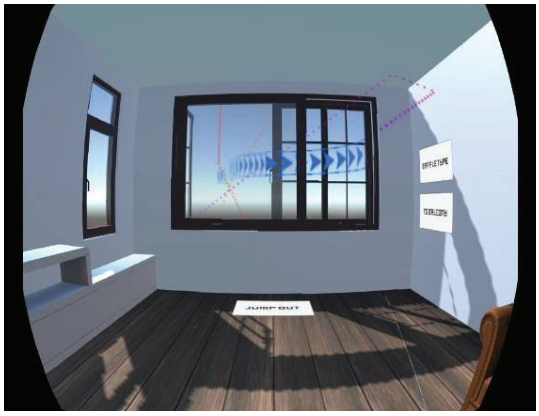
3. A CASE IN HONG KONG

In Hong Kong, almost a million people have been affected by high road traffic noise, exceeding L_{10} 70dBA (4,27,28). The latest 3D noise mapping supported these observations and findings (29). Direct mitigation measures at sources have been implemented for the past three decades including road side noise barriers, low noise road surfaces, etc (30). Nevertheless, there are still significant residual traffic noise impacts on people after the direct technical remedies are exhausted. Previously, efforts have been devoted to explore upgrading windows such as double-glazed windows (30). However, due to regulatory requirements of the Building Authority to maintain natural ventilation and provisions of some prescribed windows, the protection of people from road traffic noise was remained a big challenge.

Recently, there are new developments of mitigation measures at noise sensitive receivers based on advanced technologies such as integrated smart windows that can provide a further noise reduction of 5-10dBA. In essence, a smart window comprises movable window panels with acoustic treatments. The design of such integrated smart windows had undergone laboratory tests. While laboratory tests were very good and provided important data for design purposes, it was important to have the physical presence of future users and stakeholders at the laboratory to collect their feedback. Yet, stakeholders' involvement did not exist because there were situations where such designs were demanded to be more sophisticated, or more iterations were required during the design processes. Besides, the time and costs incurred would increase substantially.

In this connection, the Hong Kong Environmental Protection Department (HKEPD) has decided to adopt a 4D immersive virtual soundscape system - a hybrid 3D space and sound with the additional feature for users to control their own spatial locations and to select different design options. Figure 1 shows the image of this system and how a user would experience in a virtual setting.

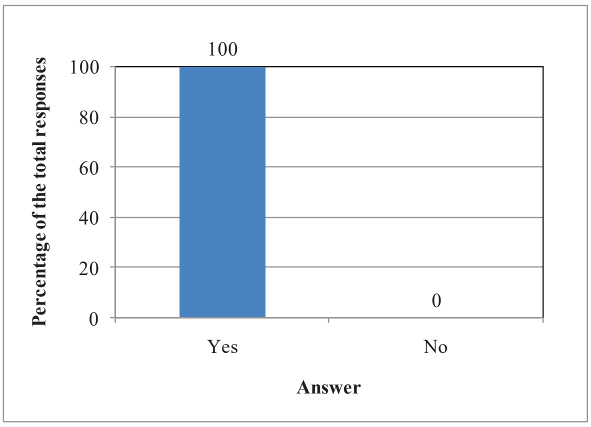
(a) A display about 4Dsound including its hardware



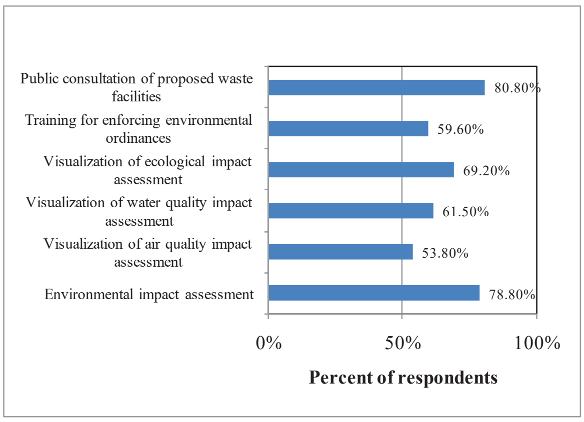
(b) A virtual indoor environment (image provided by HKEPD)

Figure 2 – 4Dsound and a virtual indoor environment (with visual and audio clues).

In April 2019, the HKEPD conducted an in-house training in which over 50 government officials and relevant stakeholders participated and helped to give further suggestions. The training began with an introduction to the system and its functionality. After that, each participant was given chances to experience and query the applications and limitations of the system. Responses from participants were positive. Participants were found that the system was very convenient and easy to use. They mentioned that the system would be helpful to understand the detailed design features of smart facades in noise reduction because they could select and experience i.e. hear the differences in sound levels when different options such as balconies, window types, active components, etc. were utilized. At the end of this training, participants were invited to fill in a short anonymous questionnaire. Figure 3 shows the outcomes of this survey.



(a) Do you consider that the VR technology would facilitate the public engagement process?



(b) Other than visualization and auralization of noise mitigation measure performance, please indicate potential applications of VR.

Figure 3 – The findings of the exit survey.

4. CONCLUDING REMARKS

This paper presents a review of virtual reality and its application to different areas. More specifically, the paper describes a case study about how virtual reality technology has been applied to let the relevant stakeholders including government officials, media reporters, and some councilors to "experience" the noise benefits that a particular smart facade design can bring by "perceiving" the sonic environment and having it associated with different design options and possible costs. By soliciting feedback from participants of an in-house training on the 4D immersive virtual soundscape system, it was found that participants considering the use of virtual reality technology would facilitate public engagement process. Participants suggested that virtual reality could also be applied to other environmental and ecological impact assessments.

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