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# On the Validity of Immersive Virtual Reality as tool for multisensory evaluation of urban spaces

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**Abstract**

The Europe2020 document indicates a new strategy to turn EU into a smart, sustainable and inclusive economy. At local level urban planning policies may help to reach these aims. Several research works proposed the Immersive Virtual Reality as tool to evaluate the effectiveness of these interventions. Nevertheless people's perception within virtual environments still needs to be verified. In this study, two groups of participants had to provide subjective measures related to the global, acoustic and visual quality of a real environment or of a multisensory reproduced version in Immersive Virtual Reality. Outcomes highlight the ecological effectiveness of this multisensory tool.



*Keywords:* Immersive Virtual Reality, Ecological Validity, Soundscape, Urban design, Multisensory Perception;

## 1. Introduction

Since the early years of this age, the economic crisis has lead to a strong worsening of the economic and social conditions in several world regions. As a consequence new and different, political and economic strategies were developed worldwide. In EU a new strategy to come out from the crisis was proposed with the Europe2020 [1]. This strategy is focused on priorities aimed at turning the EU into a smart, sustainable and inclusive economy. At local level to reach these aims, innovative and comprehensive urban planning policies

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are fundamental for the optimization of resources, preservation of the environment, social inclusion, community cohesion, health and well-being. In this perspective, a key role is played by the urban spaces. They should guarantee the users acceptance,[2] that is affected by design, environmental quality, traffic conditions and other components of the built environment, that support the preference of people to do some outdoor activities such as: chat with friends, walking, relax and other forms of interaction. Errors during the design phase may result in an unused and its rejection by the population, with a consequent waste of energy and economic resources.

One of the aspects of the perceived quality of urban spaces is to understand the right balance between sound and visual components [3,4]. Numerous studies have been conducted to detect the factors that influence the perception of urban spaces. Some of them evaluated the acoustic-visual conditions in parks and squares [5-6]; others proposed methodologies for the characterization of urban spaces by evaluating their effectiveness in places with potential restorative features such as the waterfronts [7]. From the literature on the environmental quality perception, there are two aspects that should be considered. The first one is the need of a holistic approach due to the multisensory nature of human perception [8,9]. The second one is the involvement of the local population during the design assessment phase of the urban spaces [10,11]. The efficient improvement of the computing power and the tools for the virtual simulation, as well as their availability to the mass-market, are leading to the integration of models and methodologies relative to specific aspects (e.g. lighting, acoustic) and to the development of new and more efficient devices for the human computer interaction. The Immersive Virtual Reality (IVR) represents a tool designed to stimulate the different human senses (e.g. sight, hearing, touch) and create the experience of the sense of "being there" [12]. Several studies have demonstrated the high potentiality of this tool, focusing the attention on the influence and the interaction of the audio and visual stimuli on the overall subjective perception [13,14,15,16]. The integration of this technology into assessment procedures of new project for urban spaces, so called e-planning [17], makes the process much more powerful as it involves a large number of heterogeneous actors, experts and non-experts, promoting the active participation of citizens [18,19]. As a consequence of the potentiality of this tool, its increasing use in several application fields makes even more important the necessity to verify the coherence of the multisensory perceived quality of virtual experience versus the real one.

The aim of the present study was to verify the ecological validity of the immersive virtual reality as a tool for multisensory evaluation applied to the e-planning. Here, a subjective measure (questionnaire) was administrated to a group recruited in a real outdoor space sited in Naples and to another group selected to explore the corresponding virtual reality reproduction.

## 2. Methodology

### *2.1. Sample, Setting and Procedure*

A total number of 40 participants took part at the experiment (see Table 1 for characteristics of the sample). In situ, 20 participants (i.e. Field Session Group) were recruited in the target-area. Further 20 participants (i.e. Laboratory Session Group), matched for age, gender, residence zone and familiarity with the site, were recruited for the laboratory session.

Table I. Main characteristics of the sample.

| *Group* | *Gender* | *Age (years)* | | | | *Residence Zone (n.)* | | | | *Familiarity (rating:1-7)* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *15-19* | *20-24* | *25-29* | *30-39* | *City* | *Suburbs* | *Inner city* | *Rural* | |
| Real | Male | 3 | 4 | 1 | 2 | 4 | 4 | 1 | 1 | 4.85 (SD=1.78) |
| | Female | 6 | 3 | 1 | 0 | 6 | 3 | 0 | 1 | |
| Simulated | Male | 3 | 4 | 1 | 2 | 5 | 3 | 1 | 1 | 4.9 (SD=1.12) |
| | Female | 5 | 3 | 2 | 0 | 5 | 4 | 1 | 0 | |

The selected target-area consisted of a part of Partenope Street sited on the waterfront of Naples. The street is one of the most attractive places of the city for tourists and citizens' leisure. It is flanked by the *Castel dell'Ovo* and measures about 420m of length and about 25m of width (Fig. 1). Currently the street it part of a LTZ (Limited Traffic Zone). To prepare the laboratory test, the target-area was graphically modelled and surrounding sound field was reproduced.

Fig. 1. (a) A partial view of the real environment; (b) A partial view of the simulated environment in IVR

In both Field and Laboratory sessions, a questionnaire was administrated to the subjects. It was structured on tree parts, for measuring respectively: global, auditory and visual perceived quality of the surrounding environment. Before starting the test, the respondents were asked to read the instructions of a questionnaire and then explore the surrounding environment. While in the Field Session, they were already in the target-area, in the Laboratory Session, they were asked to perform this explorative phase, once they worn a head-mounted display within of the reproduced surrounding soundfield. Then they were free to start answering questions as they saw fit. The scheme of the workflow is shown in Fig. 2.

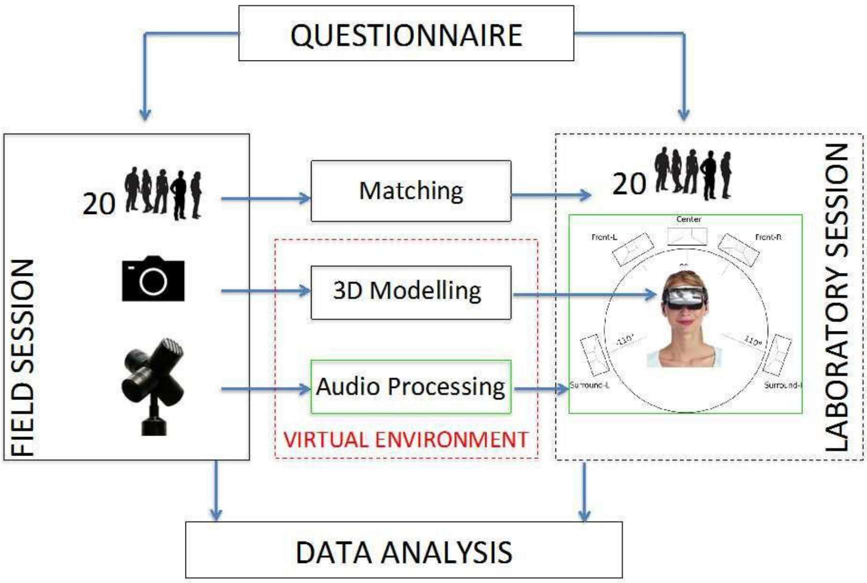


Fig. 2. Scheme of the workflow

## 3. Materials

### *3.1. Subjective measure*

A 12-item questionnaire measuring global, *visual* and *auditory perceived* of the environment was prepared. Each item was rated on a 7-point Likert scale. The questionnaire was structured on three parts.
The first consisted of four items about the global environmental perception:
*(Q1)- How would you rate the environmental quality of this place? Negatively/Positively*
*- How do you rate this site in reference to the following adjectives? (Q2) Not-Pleasant/Pleasant; (Q3) Chaotic/Calm; (Q4) Boring/Vivacious*
The second and the third part investigated the sound and the visual environmental perception. Each part consisted of four items, as the first part:
- *(Q5) How would you rate the sound environment around you? Negatively/Positively*
*- (Q6) How do you rate the sound environment around you in reference to the following adjectives? Not-Pleasant/Pleasant; (Q7) Chaotic/Calm; (Q8) Boring/Vivacious*
*- (Q9) How do you rate the visual environment around you? Negatively/Positively*
*- How do you rate the visual environment around you in reference to the following adjectives? (Q10) Not-Pleasant/Pleasant; (Q11) Chaotic/Calm; (Q12) Boring/Vivacious*

### *3.2. Recording, measurements and audio playback system set-up*

During the administration of the questionnaires in the *field session*, several audio recordings and measurements were made by an ambisonic microphone (Soundfield SPS 200) and a portable recorder (Zoom H6). The microphone was placed at the height of 170 cm. This recording technique (Ambisonic) allows to record the surrounding sound field in any direction by means a special 4-capsules microphone. The recorded signals can be then converted to be replayed by headphones or loudspeakers. At the same time, by a sound level meter with the microphone close to the ambisonic one, the sound pressure levels were measured. For the laboratory test a representative recording of about 7 minutes with a sound equivalent level of 56.3 dB(A) was chosen. The playback system consists of 5 speakers (Dynaudio BM5A MKII) and a woofer (Dynaudio BM9S) arranged in a 5.1 configuration. The system was placed in an anechoic chamber 5x5x5m. A sound card Motu 828 MKII drove the loudspeakers. Within this chamber the arrangement of the loudspeakers was inscribed within a square with the side dimension of 3 m. The B-format recordings were than converted by means of the Surrounding Zone plug-in into a 5.1 format. The set-up of the audio playback system was calibrated in order to reproduce at the centre of the anechoic chamber the same sound equivalent levels of the field survey with a tolerance of $\pm$ 1 dB.

### *3.3. Graphical modeling*

A 3D reconstruction was built up using Google Sketchup software. Starting from the plans of the place, the elements present (roads, sidewalks, volumes of the buildings) were drawn and implemented into the virtual environment. By using a SLR camera Nikon D a photographic survey was carried out, then an image editing software was used to correct and merge the photos with the elements. The whole model was mapped with textures and other relevant urban elements were added to improve the graphics impression. Thanks to the observation of the events, in situ, and of the listening of the sound tracks in lab, several events (e.g. cars, pedestrians, bicycles) were included into the virtual model. In this way it was possible to recreate, the closest possible, both the audio and visual stimuli as were in situ. The 3d-model and the visual events were implemented into the software Worldviz Vizard v4.0, while a head-mounted display (Z800 3Dvisor) and a tracking orientation sensor (Polhemus Patriot) were used to explore the virtual environment. The audio stimuli and the visual events were synchronized.

## 4. Data Analyses

An ANOVA for mixed design analysis was carried out to evaluate the effects of Real vs. Simulated experience on self-report measures in order to find out possible significant differences between both approaches. The Groups Real-Experience vs. Simulated-Experience were treated as 2-level between-subjects factor and Global Evaluations about the target-environment as a 4-level within-subjects factor (Environmental Quality, Not-Pleasant/Pleasant, Chaotic/Calm, Boring/Vivacious). Then, to better understand the impact of Real- vs. Simulated-Experience on acoustic and visual ratings, two 2×4 ANOVA were performed with Groups (Real- vs. Simulated-Experience) as a 2-level between-subject factor and Acoustic or Visual Evaluations as a 4-level within-subject factor (Environmental Quality, Not-Pleasant/Pleasant, Chaotic/Calm, Boring/Vivacious). The ratings of acoustic/visual features were used as dependent variables. The Bonferroni correction was used to analyze post hoc effects.

### *4.1 Results*

No significant difference between the groups Real vs. Simulated experience emerged ($F<1$). There was a main effect of Global Evaluations, $F(3, 114)= 8.879$, $p < .001$, due to the pleasantness that showed higher ratings as compared to all other evaluations. These two factors significantly interacted, $F(3, 114)= 4.007$, $p < .01$, by revealing that, within the Real-Experience group, the ratings of pleasantness (M= 6.0) were higher than those for chaotic/calm (M= 4.25) and environmental quality (M=4.7) evaluations. No differences emerged within the Simulated group. Across groups, instead, a mirror-like trend appeared: the ratings of the pleasantness of the real-experience were also higher than that of boring/vivacious (M=4.6) of group with simulated-experience; whereas, the ratings related to pleasantness of the simulated experience (M= 5.4) were higher than those of the chaotic/calm (M= 4.25) of the Real-Experience group.

### *4.2 Analyses on acoustic ratings*

No significant difference between the groups Real vs. Simulated experience was found ($F<1$), whereas a significant main effect of Acoustic aspects was reported, $F(3, 114)=7.540$, $p < .001$. The post-hoc analyses highlighted that the ratings for the pleasantness (M= 5.2) and acoustic environmental quality (M=5.1) were generally higher than those assigned to chaotic/calm (M= 4.3) and boring/vivacious (M= 4.6) evaluations.
A significant interaction between two factors emerged, $F(3, 114)=4.530$, $p < .005$, with the acoustic environmental quality of the Simulated-Experience being positively more rated than the ratings of the chaotic/calm and boring/vivacious evaluations of the same Simulated-Experience. By comparing both groups, the acoustic environmental quality (M= 5.7) of the Simulated-Experience was more appreciated than the chaotic/calm of the real context.

### *4.3 Analyses on Visual ratings*

As regards analyses on visual evaluations, neither a main effect of Groups, $F (1, 38)=1.998$, $p > .05$, nor an interaction Groups x Visual Features, $F < 1$, were found. Only a significant main effect of Visual Features appeared, $F (3, 114)=9.903$, $p < .001$, with visual pleasantness (M= 5.8) and visual environmental quality (M= 5.5) being more rated than the both chaotic/calm (M= 4.5) and boring/vivacious (M= 4.9) evaluations.

## 5. Conclusions

The aim of this research was to verify the ecological validity of the Immersive Virtual Reality by comparing the subjective evaluations of two groups about acoustic and visual features of a real target-environment vs. its simulated reproduction. The results showed that both groups did not differ in the way they perceive the visual features of the target-area. With all cautions, this result may be attributed to the goodness and high realism of the simulated scenario that made the evaluations strongly overlapping. Interestingly, the global evaluations along with the acoustic evaluations showed generally a mirror-like trend. In the first case, both groups with real and simulated experience appreciated sensitively and in a converging way the pleasantness of the place over the other connotations. Similarly, the analyses of the acoustic features showed that the good environmental quality of the simulated-experience was better than the average of chaotic/calm description in both real and simulated experiences. To sum up, all data revealed a converging appreciation of both simulated and real contexts. Overall, the subjective evaluations of both groups appeared strongly coherent and highlighted the emergence of subtle quantitative but not qualitative differences. Besides, our data support the idea that the effect of visual/acoustic stimuli on subjective sensitivity may mutate if considered separately. Indeed, when considered together, as it is in our natural multisensory perception, the evaluations overall appear even more homogeneous. In conclusion, the findings presented here are encouraging and sustain the multisensory study of target-environments with IVR devices.

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