KURASHIKI VIEWER:

Qualitative Evaluations of Architectural Spaces inside Virtual Reality

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Abstract. This paper discusses how virtual reality (VR) environments can be employed as a data collection tool beyond visualization and representation tools through a simple experiment in a VR space and speculates about its potential applications. Using a VR model that runs on a web browser based on an existing historic town in Japan called Kurashiki, the experiment asked 30 recruited participants to freely walk around and leave ratings on a 5-point scale on any buildings or objects appealing to them. The proposed system in this paper can display points of interest of multiple participants using heatmaps superimposed on a map that can help users visually understand statistical preferences among them. The project's goal is to provide a quantitative means for qualitative values of architectural and urban spaces, making such data more shareable. We intended to show that such a platform could help multiple stakeholders reach better consensuses and possibly collect training datasets for machine learning models that could extract features related to the attractiveness in architecture and urban spaces.

Keywords. Virtual Reality; Crowdsourcing; SDG 10; SDG 11.

1. Introduction

In recent years, Virtual Reality (VR) is increasingly more accessible, and its visual quality and experience in virtual 3-D environments have become more realistic with development in technology. As Ivan Sutherland pointed out in his article (1970), the challenge in computer graphics has been to make the virtual world look more real, move, and respond to interaction in real-time, and even feel real.

Since the 1990s, the adaptation of VR technologies has been increased through applications in vehicle simulation, entertainment, architectural design, and spatial arrangement to increase productivity, improve team communication, and reduce costs. For example, NASA has used VR for over 30 years for its astronaut training (McGreevy, 1993), and biomedical engineers have used games in VR for rehabilitations and therapies (Holden, 2005). Over the last 30 years, the graphics rendering system has improved with the innovations in both software and hardware. For example, NVIDIA corporation introduced a real-time ray-tracing SDK in 2019,

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widely applied to VR game engine tools and minimizing visual gaps between real and virtual worlds.

Today, in the architecture and real estate industries, VR technology has been widely applied for communications among designers, various engineers, occupants, and clients. Notably, the use of VR in real estate is primarily employed by buyers and clients making initial qualitative selections and judgments, including some subjective evaluations by them. Some leading real estate companies, such as Redfin (2021) in the U.S. and AtHome (2021) in Japan, have listed some of their properties with 3-D walkthrough home tours that allow potential clients to make initial decisions about their selections without physically being at the properties. Another leading company in the U.S., Zillow (2021), introduced their app for free to sellers, including homeowners, to capture their properties using their mobile phones, enabling sellers to post their properties' 3-D walkthroughs on their portal sites. In architecture, engineering, and construction (AEC) practices, a wide range of applications of VR have been reported (Johansson, M., Roupé, M., 2019), including design review sessions (Zaker and Coloma, 2018; Wolfartsberger, 2019). A recent online conference organized by VR game engine developers, Build Architecture 2021 (Epic Games, Inc. 2021), featured many use cases by major architectural corporations such as HOK and Zaha Hadid Architects. Several research works have focused on the visibility of occupants in architectural spaces, such as (Schwartz, 2021) and their perceptual needs in densified urban environments (Fisher-Gewirtzman and Polak. 2019).

Several previous works have studied subjective evaluations in architecture using 2-D images, such as property images, photos, satellite images, and floor plan images (Wang, et al., 2019, Narahara and Yamasaki, 2019). In terms of urban city-scale applications, there are some standardized quantified measures for urban living conditions, including some qualitative, subjective criteria such as safety and ease of access (Walk Score, Zillow Inc. 2021).

The strength of this paper's proposed approach is to use immersive 3-D environments that allow users to leave their feedback more intuitively through the proposed user interfaces. Moreover, users' feedback is associated with local 3-D locations where they are situated within VR, enabling more three-dimensional spatial characteristics analysis than using 2-D images. In addition, more open 3-D data for cities and buildings have been released, for example, Google Map, OpenStreetMap, and Project PLATEAU by the Ministry of Land, Infrastructure, Transport, and Tourism in Japan (2021).

With the recent exponential development in hardware and software for real-time 3-D visualization technologies, it is expected that VR environments will be further used for collecting data through human interactions with their near photo-realistic visual qualities beyond mere representation tasks. Such data can link spatial representations, such as rendered perspective images or spatial geometries, to certain characteristics of spaces quantified based on user feedback. The data could also be used as training datasets for machine learning models to predict these characteristics, including perceptive values found in architecture and urban spaces in VR environments.

Recently, there are some reliable existing network models for tasks, including object detections and Bounding Box Regression, such as Faster R-CNN (Ren et al., 2016) and YOLOX (Ge et al., 2021), that can estimate certain values associated with

Figure 1. A view of Kurashiki viewer app that allows users to post location-based ratings (left); a virtual model of Kurashiki town (middle) and the real-life photo of the town (right). (VR environments produced in VR Design Studio and F8VPS by Forum8 Co. Ltd. (2022))

Figure 2. (a) Participants' paths in red dashed lines; (b) heatmap of cumulative target scores where participants added heart marks and magnitude are normalized from 0 to 1 in scale with red being high and blue being low; (c) participants' positions and directions of views superimposed on b; (d) heatmap of cumulative scores based on where participants situated when they added heart marks.

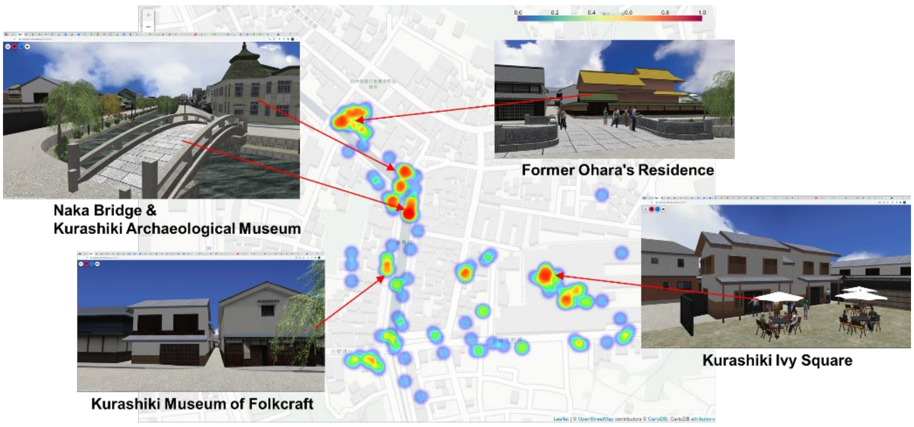

Figure 3. Target locations highlighted red in Figure 2b, where participants added higher scores with more frequencies, coincide with the locations of common tourist destinations in real-life. (VR environments produced in VR Design Studio and F8VPS by Forum8 Co. Ltd. (2022))

objects on images. In future practice, the use of the data retrieved from VR environments for training such models could be considered as a possibility. The paper further discusses how VR environments can be employed as a data collection tool for such applications in Section 3.

2. Methods

The proposed tool was built using an existing 3-dimensional real-time VR software package, VR Design Studio (2022) and its SDK offered by a Japanese software development company, Forum8 Co., Ltd. (2022), who supported and sponsored this project. With the support and help from Forum8's software developers, Forum8 Virtual Platform System (F8VPS, 2022) was also used to run the proposed application (app) on a web browser to record user feedback in addition to VR Design Studio. The software, VR Design Studio provides a series of VR models of existing cities in its library, and we used one of the VR models based on an existing preserved historic town on a canal in Japan called Kurashiki. The 3-D buildings on the site from its library were modeled and textured using street view photos of the real-life buildings to capture characteristics of the original buildings. To balance the speed of performance to run the app on a web browser, the real-time rendering is not at the highest level of photo-realistic quality compared to today's state of the arts for this experiment (Figure 1).

In total, 30 participants were recruited, and the following overall reasonably balanced attributes of participants were obtained. Eighteen participants identified themselves as male and 12 as female. Twenty-three participants are students in their 20s, of which 11 of them are in architecture major, and the others are not. Seven participants are in their 30s or over. In total, 18 participants are in the areas related to architecture, and 12 are in the areas non-related to architecture.

First, participants were provided with the link to the proposed application that runs on the Chrome browser on Windows 10 computers with a mouse and keyboard as user interfaces. Participants were asked to freely walk around the VR city as if they were visiting the city for sightseeing (None of the participants have ever visited the modeled site of Kurashiki city in their real life.) Then, they were asked to put heart marks on a scale of 1 to 5 on target objects on a screen whenever they found anything they liked, as many times as they preferred. The start position of the trip is fixed in the middle of the environment near the bridge for all participants in the app. There is no time limit for the experiment, they can finish anytime when they feel that they have completed their tour, and all participants finished within 15 minutes.

We added a function to create logs of the user position periodically each time the user has moved after a certain distance (over 1 meter) or the user has put the rating on a certain target position. The log files of the users were saved as JSON files after the users ended their tours and were collected. The logs of the user were recorded in the following format:

- Timestamp (elapsed time in millisecond since the start of the app)
- User position in (x, y, z)
- Target position in (x, y, z)
- Rating (Number of heart marks)

Extracted data from 30 participants were processed using Folium (2022), an open-source library for visualizing geospatial data built on Python and mapping capabilities of leaflet.js (a JavaScript library) and mapped on the OpenStreetMap using the latitude and longitude estimated from the 3-D model. Figure 2a shows 30 participants' paths in red dashed lines superimposed in 50% semi-transparent color cumulatively. The result shows that participants' paths concentrated on the same walkways and bridges along the canal, which indicated that their travel paths overlapped quite a lot and went through similar paths even though they were not instructed to go any specific route. Figure 2b shows the heatmap of cumulative target scores where participants added heart marks and magnitude are normalized from 0 to 1 in scale with red being high and blue being low. Figure 2c shows participants' positions and directions of views when they added heart marks superimposed on 2b. Figure 2d shows the heatmap of normalized cumulative scores based on where participants were situated when they added heart marks.

3. Results and Discussion

Figure 2b shows that certain buildings in target locations selected by participants are more popular than other locations in the VR model as the heatmap shows concentrated areas. We can infer that there are common preferences among participants. In Figure 2b, participants added higher scores with more frequencies for three to four target locations. Those locations coincide with the locations of common tourist destinations in real-life, including Kurashiki Archaeological Museum, Former Ohara's Residence, Kurashiki Ivy Square, and Kurashiki Museum of Folkcraft (Figure 3).

The proposed app runs on any device supporting web browsers. The proposed app was developed using the cloud-based VR software package's platform and its SDK, allowing multiple users to participate and retrieve data automatically (Figure 4). Easy retrieval of big data from multiple locations and users can benefit the communication among different parties through quick derivations of visual results that reflect opinions from multiple users. Therefore, the platform could support consensus building in urban or architectural environments among different stakeholders. Since multiple users can participate online and virtually observe spatial conditions in architectural or urban environments under consideration, the app allows users to communicate their opinions after their tours through the proposed rating system and visualized results that statistically reflect collective opinions.

There are perceptual gaps between VR and real spaces, and the purpose of this experiment is not to validate that the results from VR spaces alone can deliver reliable results in real physical spaces. Further, inspection in the real spaces is required to validate any results based on subjective evaluations inside VR spaces. However, schematic experiments in VR spaces could be used to develop possible hypotheses for further validations in real spaces without constructing and preparing new physical spatial conditions or events, which could save costs for many practitioners. The software platform supports physical-based rendering technology, which could further minimize the gaps by using more sophisticated user interfaces for future experiments.

This time, the experiment used only one 3-D model of a city from Kurashiki and collected data from only 30 participants. However, this platform can be used with multiple city models and can acquire thousands of data into the cloud server with the appropriate consent from users and approval from IRB reviews (we have approval from the author's organization for this experiment on this paper.) The proposed platform can create a dataset that includes images (street views) labelled with

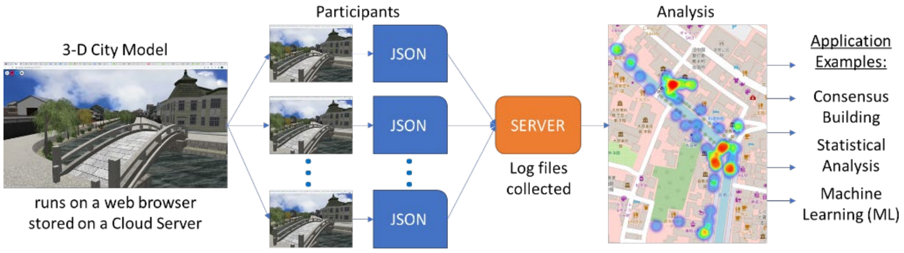

Figure 4. From log files of users and saved camera views with ratings of objects that are appealing to participants, annotated datasets can be created for training networks such as Faster R-CNN to predict estimated popularity from any new images. (VR environments produced in VR Design Studio and F8VPS by Forum8 Co. Ltd. (2022))

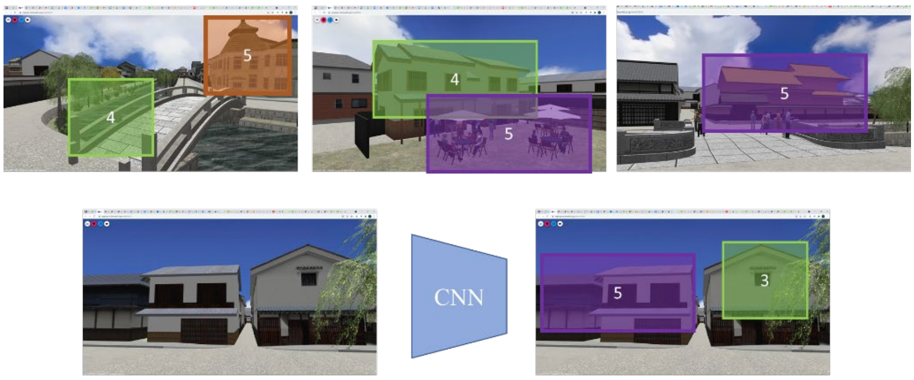

Figure 5. Images representing potential applications: From log files of users and saved camera views with ratings of objects that are appealing to participants, annotated datasets can be created for training networks using Bounding Box Regressors such as Fast R-CNN to predict estimated popularity from any new images. (VR environments produced in VR Design Studio & F8VPS by Forum8 Co. Ltd. (2022))

participants' review scores, which will provide training data for a Bounding Box Regression model using networks, such as Faster R-CNN (Girshick et al., 2014; Ren et al., 2016; Lee et al., 2019) and YOLOX (Ge et al., 2021), to predict estimated scores of objects that are more appealing to people from street views (Figure 5). The images can be retrieved from a recorded user and target positions in (x, y, z) with ratings provided by users. With a sufficient number of variations in users and city models, such datasets can train deep neural networks to predict estimated popularity and values for objects detected inside images for future applications to help planners estimate the values of their proposed spatial conditions yet to be constructed in the real world. With the improvements in real-time photorealistic rendering technology in the future, the gaps between real and virtual worlds are anticipated to be further minimized, contributing to opening new possibilities.

4. Conclusions

This paper discussed how virtual reality environments could be employed as a data collection tool beyond the visualization and representation tools through a simple experiment in a VR space.

The project's goal is to provide a quantitative means for qualitative values of architectural and urban spaces, making such data more transparent and shareable. The app can display and visualize multiple users' statistical preferences to certain locations instantaneously from data collected from the app running on a web browser. We intended to show that such a platform could help multiple stakeholders or people from different backgrounds reach better consensuses.

A platform such as ours could also be used to automatically collect annotated training datasets for machine learning models through interactions from multiple online participants. Understanding relationships between spaces and their implicit qualities in a quantitative data format would be essential to obtain machine learning models that could extract features related to their attractiveness found in architecture and urban spaces. In future studies, I plan to use the dataset to develop prediction tools for qualitative values from given spatial conditions.

Our cities are becoming more efficient using new hardware proposed by engineers, as we can see from recent developments in many proposed Smart Cities. Innovations in new energy harvesting technologies such as highly efficient solar cells and AI-inspired hardware technologies, including autonomous driving and smart home electronics, could make our cities and human settlements more sustainable and efficient.

Beyond simply providing efficiency and functionality, I aim to contribute the proposed methods to serve as the step to provide quantitative measures to assess qualitative values of cities. I hope that such tools can help incorporate more purpose and joy beyond efficiency into our living conditions.

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