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Article

Appraisal of Architectural Ambiances in a Future District

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Abstract: Auditing future public places that have not yet been constructed can be a laborious, time-consuming, and expensive task. However, the human factor plays a crucial role in successful infrastructure design. By involving users early in the design process, valuable insights can be gained prior to the physical construction, resulting in more appealing spaces for users. In this research, we explore the potential of non-immersive virtual reality to perceive atmospheres in architectural projects. We investigate suitable methodologies for studying this subject and examine its educational implications in architecture. The study focuses on a large-scale neighborhood currently undergoing complete reconstruction. We extract and model four environments in 3D, offering a virtual tour of these spaces and their infrastructures to both expert and non-expert participants. Through a questionnaire, we collect their responses to evaluate the architectural atmospheres of these distinct areas. This article analyzes the expressed feelings and provides projections on the anticipated sensations once the real estate project is completed. Additionally, it compares the expectations of professionals with the impressions of the public based on virtual visits. By emphasizing outdoor architecture and employing a larger city 3D model in the experimentation, this study contributes to the existing literature on participatory studies. The empirical research findings underscore the advantages of involving users early in the design process for buildings and streetscapes, leading to an enhanced user experience before implementing infrastructure renovations.

Keywords: virtual reality; digital twin; city 3D model; architecture; participatory study

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1. Introduction

1.1. Context: From Ephemeral Architecture Spaces to an Urban District

The role of architecture in a scene may serve primarily aesthetic purposes, but it is also reasonable to believe that it has a significant impact on the perceived ambiance of that scene. Ambiance refers to the particular atmosphere of an environment, while mood relates to one's mental or emotional state. More precisely, ambiances can be described as the expressions of micro events that arise from the dynamic interaction between the subject's sensitivity and its context [1].

A study on architectural ambiances can identify the characteristics that evoke specific emotions associated with a particular ambiance. These characteristics can be quantified, allowing for the development of guidelines to create scenes with architectural atmospheres that align with an architect's intended vision. On a social and commercial level, further exploration of these identified characteristics can be beneficial in creating improved working environments and living spaces. In this study, we utilized virtual simulations to investigate these aspects.

The subjective and abstract nature of the term "ambiance" raises questions about how to experiment with the perception of ambiance and test the influence of non-material or intangible factors that contribute to sensory experiences. In this study, we employ virtual reality immersion tools to exert control over light effects and architectural forms using 3D models that simulate outdoor environments.

One perspective of such studies is to leverage human sensations during the design stage to predict the urbanistic interest generated by a built environment. In this paper, we aim to expand upon a study initiated at the University de La Laguna (ULL) [2], focusing on participant responses related to their sensations regarding various dimensions of the virtually constructed space, including scale and size, construction materials, architectural style, usage, related activities, and degree of enclosure. The relevance of sensations such as serenity, warmth, comfort, exposure, nostalgia, elegance, protection, and freedom are then compared to the predominant sensations proposed by the architects.

Figure 1 illustrates the protocol of the study developed at ULL in [3]. In this experiment, we designed a set of six ephemeral architectural spaces featuring diverse materials, textures, colors, and natural lighting. Each participant embarked on a virtual tour of these spaces and subsequently completed a questionnaire. The study encompasses six ephemeral architecture modules of increasing complexity created specifically for this research. We intend to extend this study to encompass a real-world environment, showcasing existing buildings and tours of real estate developments within an urban area.

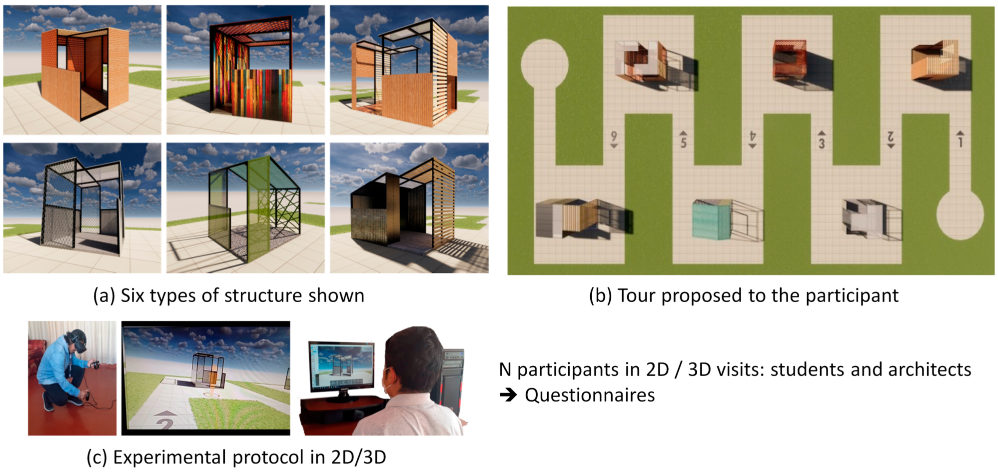

Figure 1. The perception of architectural spaces through immersive virtual reality in a previous study [3]: ephemeral architectural spaces used and journey proposed to the participants.

To accomplish this, we constructed a 3D model of a 20-hectare district known as LaVallée. This eco-district, currently under construction and scheduled for completion in 2027, is situated in the southern suburbs of Paris, France. The district spans an area of 500 m by 400 m, equivalent to 20 hectares or 50 acres. The Architecture, Engineering, and Construction (AEC) professionals involved in this real estate project granted us access to the Building Information Model (BIM) architectural plans for all the district's infrastructures, including buildings, roads, sidewalks, vegetation landscapes, and urban furniture such as benches, poles, and playgrounds. This access enabled us to construct an accurate and enriched 3D model of the neighborhood, incorporating its infrastructures, buildings, and streetscape. Additionally, select AEC experts involved in the development of this future district also participated in evaluating this study.

The territory is undergoing transformation with the introduction of a new tramway line. The site holds a strategic position in terms of accessibility, being serviced by two regional train lines, three bus lines, and the forthcoming tramway T10, which will include a new station in the southern part of the district. It is anticipated that 50% of the trips within the area will be made using sustainable modes of transportation, such as walking, cycling, and public transit. Therefore, ensuring the architectural quality of the spaces is of utmost importance for creating a vibrant city life. LaVallée was conceived as an exceptional eco-district that harmonizes the urban and natural landscapes. Several key objectives need to be addressed, including the integration of multiple urban identities, the seamless incorporation of the new eco-district into the existing green city environment, and the promotion of connections with neighboring areas.

With the arrival of the tram, the site is expected to enhance its status as a city entry point, while preserving important routes and the magnificent landscape. Efforts will be made to establish new ecological connections and create a new urban hub that fosters social interactions and embraces inter-generational diversity. The plateau area boasts exceptional landscape value, characterized by a lively and densely wooded topography. Situated to the east of the district is the renowned Parc de Sceaux, one of the largest parks in Greater Paris, France. This proximity adds to the allure of the area, providing enriching opportunities for residents and visitors alike.

Figure 2 illustrates the map of the future district with its buildings footprint, its road in green lines, and the location of various activities: home, work, education, shopping, leisure, restaurant, kindergarten and the public transportation stops. The figure illustrates the planned urban and landscape framework for LaVallée, a site with abundant potential for exploring a form of urban planning that respects the relationship between nature and the city. The objective is to create an exemplary living environment just a few minutes away from Paris. The district encompasses four distinct urban identities: working in a business office, an outdoor shopping mall with a vibrant and lively atmosphere, living in urban residences with convenient access to stores, and residing in a green environment with ample leisure opportunities. These various urban fabrics contribute to the diverse identities that the neighborhood will embody.

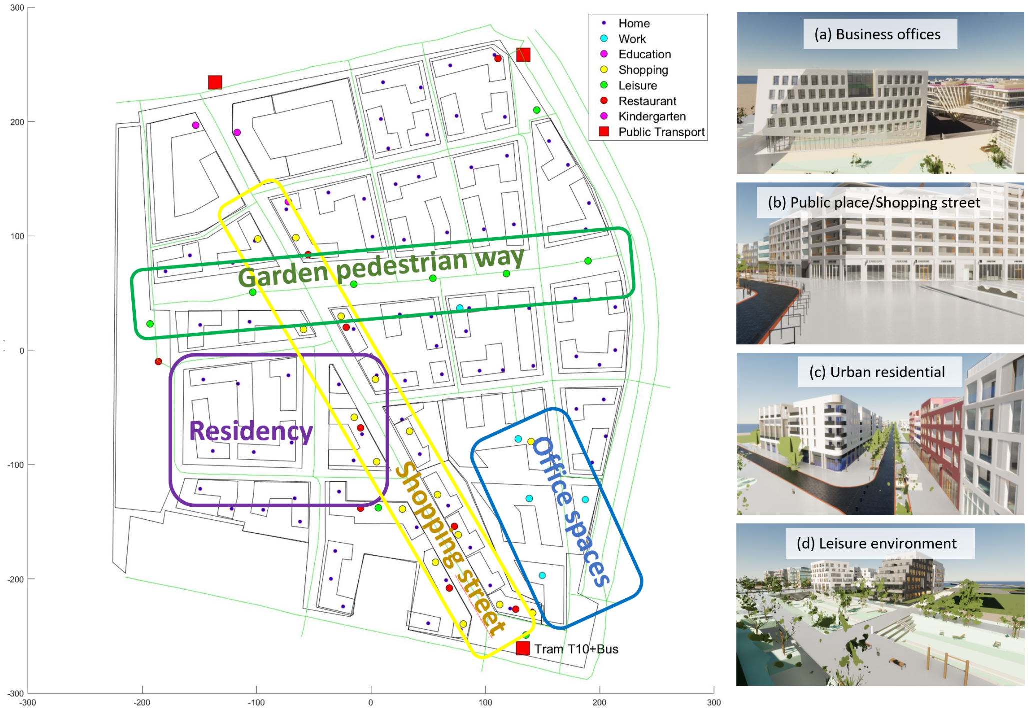

Figure 2. Three−dimensional city model of LaVallée district: Architectural spaces used in [3] were replaced by environments representative of urban vibes modeled in 3D. The four main activities are: work with business offices, a shopping mall, leisure in a green environment and home in urban residential units.

Consequently, the district serves as a remarkable showcase for the city. Beyond its focus on sustainability and housing, it must provide public spaces capable of establishing the site as the new entrance to the city. Alongside the commercial and activity planning, the creation of public spaces and their relationship with private spaces will be a crucial element of the real estate project. Special attention will be given to the ground floors to ensure the district is vibrant and animated.

There are four offices buildings located with the blue circles, one of them being the french headquarter of a major grocery store in Europe (Lidl), appearing in Figure 2a. In yellow circles are the shopping stores mainly placed along the main road positioned from north to south of the district. There is a shopping street starting in the south near a public space as illustrated in Figure 2b: this location provides the main access to the district as it holds a transportation hub with a tram and bus stop which provides access to other cities. This will constitute the structure of the public space of the eco-district along which accessible shopping businesses will develop less than 3 min on foot or by bike from the whole neighborhood.

Throughout the district, small violet dots represent residential homes. Once the real estate project is completed, it is expected to house 6200 inhabitants. Figure 2c exemplifies a particular section of the district, showcasing a typical urban architectural style. Running perpendicular to the shopping street is a pedestrian pathway known as LaVallée's Garden. This space predominantly serves as a public area for leisure activities, symbolized by green circles. It features abundant vegetation and children's playgrounds, as depicted in Figure 2d. The pathway acts as a link between Parc de Sceaux and the city, enhancing the district's green character. The planted promenade serves as a vital green lung and a favored location for leisurely strolls within the district.

1.2. Architectural Ambiances: Theoretical Elements

Although an atmosphere is intangible, there are various physical aspects that contribute to its description. The perception of an atmosphere is shaped by static or dynamic sensory experiences. This implies that factors such as lighting, acoustics, temperature, humidity, the presence of wind, and the presence of movement play a role in what is known as the physical aspect of ambiances. Additionally, symbolic stimuli such as music or literature can also influence the perception of an atmosphere.

In the study of atmospheric perception, it becomes intriguing to employ quantifiable and specific criteria in designing atmospheres to enhance daily life experiences. By design, we refer to computer simulations that incorporate thermal, acoustic, lighting, and other relevant data to create a desired atmosphere. Research on architectural atmospheres holds potential applications in fields such as gaming, cinema, and real estate agencies. These studies aim to create atmospheres that accurately reflect architects' ideas, promoting immersion and potentially influencing purchasing decisions. Furthermore, the study of atmospheres can have implications in cognitive sciences, enabling the assessment of how urban transformations impact individuals' well-being. This aspect also brings sociological and anthropological interests, as the increasing variety of atmospheres in urban environments (especially regarding lighting, sounds, and smells) reflects our evolving world.

When conducting a study on architectural atmospheres, there are four main areas of inquiry that can guide our theoretical and practical analysis [1]:

- How does a combination of signals, symbols, and collective representations create an atmosphere? What bridges the gap between the "objective" and the "subjective" aspects? What observational methods should be employed?
- How are the different sensory components of a place's atmosphere interconnected? Should we consider a singular atmosphere or multiple atmospheres? Are there universal criteria that apply to understanding all types of atmospheres? What form do these universals take? Theoretical concepts, categories, paradigms, or operational concepts?
- From the perspectives of experts and laypersons, what contributes to an architectural atmosphere? How should we balance the active and perceptual aspects? What similarities exist between technical actions and user experiences?

- How can we navigate between normative imperatives, technical constraints, and creative inspiration to control the atmosphere? Does the analysis of ambiance provide new insights into the interdependence of the three key relationships in architectural production: comfort/beauty, function/symbolism, and norm/anomaly?

Regarding experimentation, it is crucial to distinguish between the atmosphere itself and the experience of it. An atmosphere is shaped by the environment and our perception of it. During experiments, it is important to ensure that there are minimal discrepancies between the stimuli generated and those perceived by participants. Specifically, in virtual reality (VR) experiments, high-quality sensory production (e.g., good images and audio) is essential to avoid creating bias in the results and to enhance participants' immersion in the VR environment. Regarding methods and protocols, it is beneficial to first explore existing studies, such as those mentioned in the subsequent subsection.

1.3. Related Works

In the literature, there are not many scientific papers on the subject of architectural ambiances. Nevertheless, analysis of the selected few can provide valuable insight into the current research topic. A recent survey can be found in [4] on the more general but related topic of aesthetic emotions.

Existing tools for auditing public spaces often require time-consuming onsite fieldwork, surveys [5], focus groups, and document analysis [6], which can be labor-intensive. Utilizing images has become a common and cost-effective method for assessing the aesthetic qualities of built environments [7].

Exploiting street view imagery is an example of an easy-to-use and time-saving approach to evaluating the quality of streetscapes. Street-level imagery serves as a vital data source for urban analytics, as evidenced by a comprehensive review of its current applications in studies related to the built environment [8]. This review highlights the prevalence of Google Street View data in urban analytics research across various domains, ranging from analyzing vegetation and transportation to health and socio-economic studies. Both machine learning algorithms [9–12] and human participants [13] can process still images derived from street view imagery.

For instance, in [14], Tang et al. explored the willingness to stay in a space and the results were evaluated by urban designers and compared with a computer vision algorithm. The algorithm assessed the visual quality of street space using Tencent Street View images, considering factors such as greenery, openness, enclosures, street wall continuity, and cross-sectional proportion. Human operators measured subjective criteria including enclosure, human-scale, transparency, tidiness, and imageability. This approach is valuable for existing infrastructure in post-occupancy scenarios, but it is less suited for predicting the ambiance of future built environments. In such cases, a digital twin, preferably in the form of a 3D city model [15,16], needs to be designed.

Volunteered geographic information platforms such as OpenStreetMap contain numerous 3D models of buildings, albeit with varying quality. These models, coupled with descriptive data, provide valuable resources for a wide range of studies, from urban planning and life cycle assessment to energy and microclimate research [17]. While some buildings' 3D models may be of lower quality, with basic footprint and altitude information (2.5D models), others exhibit high completeness, offering potential benefits for various application domains. However, similar to street view imagery, these data can only be used for existing infrastructures. Assessing the urban vibes and streetscape of a real estate project under construction requires a digital twin that facilitates virtual visits.

Our approach is based on real professional Building Information Modeling (BIM) data. Studies have shown that incorporating BIM into basic construction courses enhances students' understanding of building system principles [18]. While efforts have been made to improve BIM learning and explore its potential in architectural education [19], the use of BIM-based city models for studying urban ambiances is an area yet to be fully developed. BIM-based digital twins offer superior data precision, to the millimeter, compared to traditional Geographic Information System (GIS)-based models. From architectural data, only minor adjustments are needed to create a virtual reality model of a city.

A literature review conducted in [20] examined VR applications in the built environment. The review identified design maquette development, construction planning, engineering education, construction equipment, and construction safety as the most trending topics for 3D virtual reality simulation. Human behavior was also explored in three main categories: wayfinding behavior and spatial perception, emergency behavior, and energy-consumption-related behavior. Common architecture design features investigated include natural daylight levels, visual cues, surface colors, and spatial openness. Empirical research, such as [21], has already demonstrated the impact of these factors on human experience and behavior, contributing to a deeper understanding of spatial materialization and experience.

Previous studies, such as [22,23], have used recorded virtual environments in the form of 360-degree panoramic videos. Participants were guided through virtual tours using Head-Mounted Devices (HMDs). The advantage of VR audits increases with the size of the study area. However, conducting research with HMDs can be challenging when dealing with a large number of participants. For instance, [22] involved a 10-person expert panel, while [23] included 28 students who audited four streets and four public places. Although the findings of Mouratidis [23] on perceptions of architectural styles are relatively straightforward, findings on perceptions of public space design, overall perceptions of public space, and affective appraisals of public space suggest that these depend on a variety of factors rather than just the specific design. The study does not provide concrete data but the pairwise comparisons and qualitative evaluations suggest that elements such as architecture, vegetation, upkeep, car restrictions, public seating places, and urban fountains may contribute to positive perceptions and affective appraisals of urban spaces. This is a starting point for research on affective appraisals of public spaces.

Less immersive virtual environments, such as those employed in [24], utilized desktop screens to navigate virtual models. Participants engaged in guided walks through buildings, primarily focusing on indoor spaces. The virtual presentations featured predefined routes that covered most of the buildings. Participants evaluated the environment using custom-made questionnaires for environmental appraisal. In our experimental protocol, we also use guided tour videos of the virtual outdoor environment. A similar video-based protocol with guided tours was successfully implemented in [25]. The study proposed architectural solutions to enhance the Canal Port area's continuity with its urban context and improve its perception by tourists and residents. Two VR models were created to assess the quality of the public space in both the current and future conditions following the area's redevelopment.

A recent study in [26] challenges the assumption that more immersive virtual environments, such as HMD-based VR systems, are inherently more immersive. They investigated the relationship between 3D perception and presence in virtual environments using immersive and non-immersive VR apparatus. Surprisingly, people reported a strong sense of presence even in non-immersive environments with two-dimensional images displayed on laptop monitors, contradicting the belief that advanced stereoscopic visualization techniques are necessary for highly immersive experiences.

Existing research on architectural ambiances in virtual environments tends to focus on topics such as the use of VR as a learning tool [27,28], defining ambiance in architectural projects [3,29], and exploring the influence of specific factors on ambiances. For example, the role of vegetation [30] has been investigated, demonstrating that green configurations promote sensorial journeys and create spaces where individuals can rejuvenate. In residential courtyard spaces, green vegetation was found to have more positive emotional impacts compared to fitness facilities [31]. Water's role in ambiance has also been explored, highlighting the connection between place memory, emotion, and architecture [32].

The influence of characters in ambiance was investigated in [33], which revealed that characters assist viewers in projecting lifestyles and identifying potential individuals within future spaces. Other studies examine human-built environment interactions considering multimodal sensory aspects such as visual, auditory, and thermal experiences in semi-outdoor settings [34]. Wearable technology has also been utilized in research, such as in [35], which used physiological signals and eye-tracking data to pre-evaluate the impact of spatial schemes on user experience in a VR environment.

Adopting the methodology detailed in [2], our study was carried out within a virtual environment with a primary emphasis on mineral-related factors. Our investigation revolved around the assessment of different aspects of a forthcoming urban district. This assessment was conducted based on a range of criteria, including dimensions and proportions, building materials, architectural design, spatial confinement, adaptability to various activities, and how public they are. In order to discern any disparities, we contrasted the feedback provided by the general public with the anticipations of professionals in the fields of Architecture, Engineering, and Construction (AEC). These experts played an active role in the ongoing real estate project.

Research findings indicate that architects, as a collective, struggle to accurately predict the aesthetic judgments made by the general public regarding architecture. For example, in the study [36], a comparison was drawn between the preferences for roof silhouettes among laypeople and architects. The findings revealed that laypeople tend to exhibit a more conventional taste compared to architects. Similarly, based on pictures of facades the authors of [37] observed that architects in their research demonstrated a tendency to critique images depicting architecture deemed "inferior", in accordance with established and acquired professional preferences.

In the work of Brown and Gifford [38], a group of practicing architects (totaling eight participants) attempted to foresee how ordinary individuals would react to large contemporary buildings. However, the architects' predictions displayed weak correlations with the actual ratings provided by laypersons. Participants were shown images of real buildings and were required to rate them on a scale ranging from "terrible architecture" to "excellent architecture". Simultaneously, the architects were tasked with projecting the overall impression that an average non-architect individual would have about each building. The key takeaway from this investigation is that architects aiming to comprehend the preferences and evaluative criteria of laypersons should consider delving into the conceptual attributes as perceived by the general public.

The term "conceptual properties" encompasses a collection of notions that represent cognitive constructs derived from the inherent physical attributes of buildings. These notions encompass qualities such as clarity, complexity, originality, and meaningfulness. Consequently, there arises a need to explicitly outline conceptual properties within the framework of physical criteria. Such clarification would facilitate the establishment of an objective design framework, consequently resulting in the creation of buildings that manage to captivate the appreciation of both architects and the public alike. Our study selected a set of physical criteria and assessed how objective they were.

Indeed there are various ways of assessing the architectural aesthetic of a building. In a picture-based study, Akalin et al. [39] chose three adjectives: preference (beautiful–ugly, warm–cold, pleasant–unpleasant), complexity and impressiveness. Building facades representing an intermediate level of complexity were favored over less and more complex ones. In this study, architecture students were more critical than the engineering students as they criticized what they perceived as negative design decisions. Hashemi Kasnani et al. [40] analyze the preference and perceived visual complexity which were evaluated over 36 pairs of images based on physical attributes of building facades such as material, color, ornament, vegetation, windows and architectural style (modern, classic, traditional). Cheuk Fan [41], perform an evaluation of old-style buildings and modern-style buildings on three dimensions: aesthetic evaluation, organization, and friendliness. The experiment was based on pictures of buildings, also on a university student population. The modern buildings were deemed more aesthetically appealing and perceived as less organized than the old-style buildings. Yet the authors conclude that detailed studies about the specific features of buildings would help understand which physical features affect these evaluations.

The study of Prieto and Oldenhave is aimed at a subset of architects [42]. The authors, through a series of semi-structured interviews, discovered two main categories of relevant factors: intrinsic aspects, encompasses compositional elements, plasticity, detailed design, and the overall character of a facade. These aspects are inherent to the facade itself as an object. The second category, extrinsic aspects, involves human elements, intellectual considerations, and contextual associations. These factors contribute to the perceived aesthetic appeal of a facade by virtue of its interactions with external influences.

More recently, Loodin and Thufvesson [43] proposed to measure the architectural preferences of city centre managers (n = 106). Six pictures of buildings with their streetscape were proposed to the participants. Three type of questions were asked for each scenery: would want to live in them; does the buildings make people feel safe, happy and creative; and do they make a city centre more attractive to visitors. In [44], Zhao et al. assessed visual preferences and emotional responses to nine types of residential entrance space facades. The study is based on computer-generated images with or without traditional architectural patterns. Participants were asked to select their preferred entrance among a choice of nine images, then to scale them for the following adjectives: calm, pleasant, safe, and interesting.

1.4. Contributions of This Research

The research presented in this paper is basically an analytic and experimental one in collaboration with architect partners that work on real estate projects in the final stage of the construction work.

The symbiosis between VR–BIM–architecture is a topic that needs to be worked on through research so that it can be implemented in architecture and engineering studios. The built space for experimentation in the real space does not exist yet, so a virtual world had to be used: a large-scale BIM-based 3D city model was built and utilized.

We decided to conduct a study on the quality of different virtual environments of a future district according to a limited set of criteria in order to find out what type of information can be collected from a virtual setup, and what needs to be improved for a complete characterization of urban ambiances.

The contributions of the presented paper are manifold and are centered on a relatively unexplored subject of architectural ambiances in virtual reality. The first contribution can be summarized as follows:

- The adaptation of a methodology conceived for ephemeral architecture to a 3D city model built upon real-world professional BIM data [2,3]. This type of study is usually conducted in an indoor environment, for the study of future offices, for instance, or on simulated isolated buildings, and has never been conducted at the scale of a district with real future buildings.

The first research question can be stated as follows:

What benefits can a methodology for characterizing the ambiances of ephemeral architecture bring to the appraisal of a future large-scale district?

Indeed, as stated in the related work section, there are many ways to characterize an urban space, including simple adjectives such as terrible architecture/excellent architecture, spatial quality factors such as enclosure/human-scale/transparency/tidiness/imageability, a scale for attributes such as preference/complexity/impressiveness, or material/color/ornament/vegetation/windows, others like the architectural style aesthetic/organization/friendliness, and the characterization of intrinsic aspects/extrinsic aspects or choosing between calm/pleasant/safe/interesting. Therefore, we need to investigate a methodology (adapted from Gomez-Tone’s protocol) at the large scale of a district, and then answer its questions from the point of view of laypersons and experts. Since the real estate of interest is under construction, we proposed to use a 3D city model and four types of neighborhood to investigate variety in the responses.

Based on the adaptation of the methodology developed in previous works for the analysis of ephemeral architecture elements, and applied in this case to a 3D city model, we pose the other following research question:

To what extent does the comparison between the answers of experts and laypeople lead to different opinions of those who experience or design buildings?

One of the differences with previous studies in the divergence between experts and laypersons is that our experts are actively participating in the real estate project. This type of comparison is usually performed on post-occupancy scenarios, with an existing environment, and by experts who have not contributed to the design of the buildings.

It is our hope that this investigation will reveal the following:

- What information can be forecast from non-immersive VR visits?
  With this limited experimental setup, helpful information can be collected about the appraisal of architecture and explicitly outline conceptual properties within the framework of physical criteria, to apply them to our case study and evaluate the disparity of responses between individuals.
- The appraisal of architectural ambiances for a future district, on four different types of environment: business, commercial, urban and green residential, with their site-specific constituents. The comparison of the feelings brought by the four locations gives prospective insights of the future atmosphere that can be expected once the real estate project is built.

2. Materials and Methods

2.1. Virtual Tours of the Urban Area

The study takes place in an urban area of the south of Paris: a district under construction called LaVallée. The real estate project started in 2021 and the completion of the construction is due in 2027. Figure 3 illustrates the mass plan of the future district with its infrastructure and its buildings. Flavor and nuance vary street-by-street, sometimes building-by-building. The city 3D models of LaVallée are first extracted as IFC extension files from the collaborative BIM360 platform collecting the architectural data of the AEC partners involved in the real estate project. The models provide all the necessary architectural information, and can be used in compatible 3D modeling software such as Revit 2020, which then allows the use of TwinMotion software 2020.2 in which it is easy to add basic objects (trees, stones, characters, etc.) and animations: we used Revit 2020 and TwinMotion 2020.2, see [45] for the technical details about the design of the 3D city model. The relevant characteristics of our 3D model are:

- The extent of the district is 500 m $\times$ 400 m, and four tours of 100 m to 140 m length were selected as potential visits.
- The sensations stimulated with the software we use can be visual and auditory, yet the experiments we developed only stimulate the participant's vision.
- The software used to create the virtual tour is Twinmotion that gives acceptable visual quality in terms of functionalism [45].

LaVallée will be an eco-district: sustainability is first and foremost about well-being, the comfort of the neighborhood and thus the pleasure felt to live there or to stroll there. Elsewhere, sustainability is also measured in the ability of a neighborhood to be appropriated by its inhabitants as well as to renew without incurring additional costs for the community. The original design of the eco-district must therefore meet all these requirements by integrating a necessary dose of flexibility. The neighborhood aims to look outward and to offer through these shared places of articulation new landmarks in the city.

Figure 3 illustrates the map of the future district with its buildings footprint and its road network. This figure shows the urban and landscape framework planned for LaVallée; four urban identities were selected in the district: working in a business office, the shopping mall with more intense and active life, living in an urban residency with easy access to shops and living in a green environment with more access to leisure. These four urban identities were acquired in videos of four guided virtual tour of the future district. The itineraries of the guided tours are drawn with red and yellow lines on the map of Figure 3. The first tour revolves around the business part of the district with extravagant modern looking buildings: it is a pedestrian way only accessible by foot. The second tour starts at the public Place LaVallée where the tram will stop and moves on along shopping ventures of the commercial street. The last two tours show more residential areas with home places under two types of environment, a traditional mineral urban area surrounded by a road and a greener area with half of it being a pedestrian-only sidewalk.

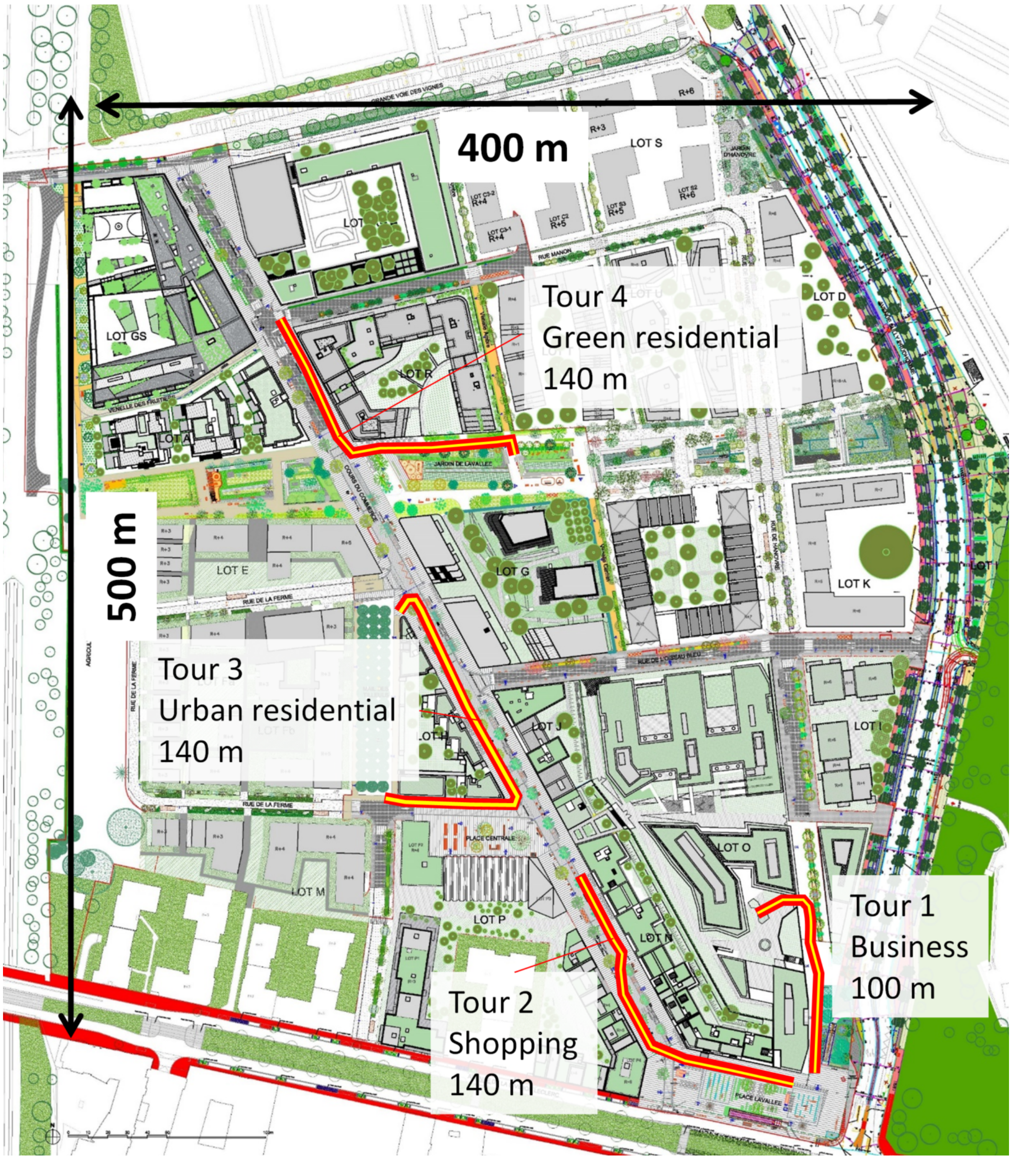

Figure 3. Blueprint of the future district LaVallée. Four tours were selected with various styles of buildings and infrastructure: their paths are drawn with red and yellow lines.

2.1.1. Tour 1: The Business District

The office buildings are situated in the southeastern part of the district, facing Parc de Sceaux. This area encompasses approximately 36,500 square meters of office space, seamlessly integrated into the neighborhood, ensuring a vibrant atmosphere throughout the day. Notably, one of the buildings will house the French headquarters of a major European grocery store, Lidl, as depicted in Figure 4, featuring a canopy roof. The buildings boast a modern, state-of-the-art appearance with monochrome facades and contemporary materials such as wood and metal.

To prevent an enclave effect, specific recommendations are necessary for the installation of business buildings. The integration of these buildings within the district is achieved by their active participation in the daily life of the neighborhood, which includes accommodating 2000 employees and offering a diverse program mix. Furthermore, along the route, a carefully planned right-of-way with coordinated fencing by various architects is proposed.

Access to this part of the district is limited to pedestrians and commences from the tram stop. The video of the virtual visit tour is one minute long and is available at youtu.be/YW9rH46Fg-U, accessed on 11 July 2023.

Figure 4. Guided tour 1: modern buildings of the business district.

2.1.2. Tour 2: The Shopping Strip

In addition to the business district, a crucial aspect of the real estate project lies in the creation of public spaces and their relationship with private spaces. Giving careful attention to the ground floors is essential in establishing an animated and lively district. The "living in the course of stores" identity, characterized by mixed programming within individual parcels, contributes to a dynamic urban environment and serves as a new entrance to the city. This identity fosters a connection with the city center through its commercial offerings.

A one-minute guided tour, available at youtu.be/pkWtZFwvBjk (accessed on 11 July 2023), takes participants on a journey through the district, starting from a public plaza where the tram arrives and continuing along the main strip featuring various shops. The facades of the buildings are aligned, smooth, and regular, adorned with recessed balconies. The use of modest materials and colors lends an elegant character to the shopping street, as illustrated in Figure 5. The ground floor houses the shops, while residential units are located on the upper floors.

Figure 5. Guided tour 2: the main public place and the shopping street.

2.1.3. Tour 3: The Urban Residential Area

The urban residential area within the district follows a more traditional design found in urban areas, featuring a continuous row of residential buildings amidst a mineral environment with roads. The facades maintain a sense of sobriety by employing a maximum of two tones and two materials. The facades are treated in a contemporary and unpretentious manner, tailored to their specific orientations.

The ground floors of the residential buildings prioritize transparency toward the interior courtyards from the public space. Angled and intersecting halls serve as meeting spaces between residents and provide access to communal amenities such as mailboxes, bicycle storage, and stroller areas. Setbacks are observed to ensure visibility of the facades and adequate sunlight for the accommodations. A one-minute video showcasing this area is available at youtu.be/7yVzSWGaXUA (accessed on 11 July 2023), with selected scenes presented in Figure 6.

Figure 6. Guided tour 3: the urban residencies with linear facades.

2.1.4. Tour 4: The Green Residential Area

The green residential area, known as *living on the planted promenade*, constitutes an identity within the district, organized around a green axis that connects to the vast Parc de Sceaux. This promenade serves as an urban park, offering residents a peaceful retreat.

The urban planning aims to create a neighborhood with densities that deviate from traditional urban morphologies. It seeks to rediscover the qualities of a city garden, where the exterior spaces of the accommodations are intricately connected with their interiors. Openings and passages are incorporated to break the linear facade design, resulting in a stepped architectural approach.

In terms of programming, the ground floors of the green residential area primarily feature housing, as depicted in the virtual tour video. Additionally, a kindergarten and a transparent commercial space are present at the beginning of the tour. The video, available at youtu.be/yalKWzBo9NM (accessed on 11 July 2023), showcases a journey that begins on the road and continues along the sidewalk until reaching the pedestrian way known as the Garden of LaVallée. The parcel typology is designed to ensure permeability and transparency from the public space. The planting promenade, secondary roads, and outdoor spaces aim to reflect the essence of the public spaces, evoking a bocage atmosphere and a close connection to nature. The visuals for this tour are illustrated in Figure 7.

Figure 7. Guided tour 4: the green residencies with its planted promenade.

2.2. *Experimental Protocol*

The voluntary participants consist of adults from both the University Gustave Eiffel (France) and the University of La Laguna (Spain), as well as some AEC experts who are involved in the LaVallée real estate project. Each participant receives a link to an online questionnaire, which they can access from their computer, laptop, or handheld devices as long as they have an internet connection.

The experiment begins with the following simple explanations and instructions:

> "In this study we are focused on the feeling brought by selected point of views of an urban district. The participation is anonymous. The whole survey will take you about 8 min.
>
> You will be shown four videos of the some specific part of a district. You are asked to watch each video for 1 min. You will be then asked question about the sensation that the scene make you feel. The last part of the study regards the technology used to build the immersive visits. This opinion survey may be published in a research paper: by completing it you voluntarily consent to the processing and publication of your data".

We have chosen to follow the protocol proposed in [2,3] without providing specific definitions of architectural ambiance to the participants. They have not been trained in the various subjective characterizations of urban spaces presented in the questionnaire, to avoid biasing their judgments.

The questionnaire consists of four identical parts, each featuring a 1-min video of a virtual tour. Participants are asked to imagine visiting the depicted space and respond to a set of seven questions. These questions were adapted from Questionnaire 1 of the protocol proposed by [2], which focuses on the perception of spaces based on 2D sketches. In our study, these questions were applied to a 3D city model created from professional BIM data. Participants are encouraged to reflect on their feelings and evaluate the public nature of the urban space, the intended usage of the public space, and their impressions of size, materials, enclosure, and architectural style during the virtual tour.

After experiencing the four video tours, the fifth part of the questionnaire collects responses to Questionnaire 3 of the protocol proposed by [2], which relates to the immersive visit in 2D. Participants are asked to rank certain features of the virtual visits based on their perceived realism. These features include the materials of the 3D models, the panoramic view, the scale, the environment, and the lighting. Participants also have the opportunity to rate the realism of the virtual tours in terms of photorealism, size, materials, lighting, and urban details of the infrastructure.

3. Experimental Results

3.1. Participants Corpus

Participants to this study were recruited online and are from various backgrounds: mostly students, researchers and professors from the University Gustave Eiffel in France and University de La Laguna in Spain, and some AEC professionals that have worked on the LaVallée real estate project.

Among the university communities, a quarter of the respondents are in the area of expertise related to this study: students and teachers in architecture, urbanism or civil engineering. The remaining 75% of the participants have a more general background and no particular expertise in the area of architectural ambiance.

A total of n = 118 non-expert participants were included in this study with the only inclusion criteria being of adult age. The participants are equally balanced in terms of gender, half male, half female. Of the participants, 50% are under 26 and can be considered as the students corpus, 30% are aged between 26 and 50 years old, and 20% are more than 50 years old. Six AEC experts that have worked for the construction project and the architectural design of parcels of the district responded to the same questionnaire, half male and half female, aged between 32 and 45 years-old.

All the participants were shown a one-minute video of each tour; a total of 40 questions were asked about the quality of the 3D visit, how private the scenes were, the type of usage of these public spaces and the feeling inspired by the virtual tours in term of size, material, enclosure and style. Personal questions were limited to age, gender and occupation as the questionnaire was anonymous.

3.2. Realism of the Virtual Visits

The realism of the virtual scenes depicted in the four videos were assessed by the participants of the study. They were asked five questions about the naturalism of the shown visits, the credibility in terms of spatial extent and used materials for roofs and walls, the importance of the details of the infrastructure such as pavements and urban furniture, as well as the lighting and shadows displayed.

A scale of answers was set from 1 for *not at all* to 5 for *much*, response 3 being judged as *neutral*. Inspired by the proposed protocol in [2], the following questions were asked:

- How realistic do you judge the shown spaces?
- Do you find that the size of the buildings is close to real ones?
- How much realism do the materials used give the space?
- How much realism do the light and shadows give the space?
- How much realism do the urban details give the space?

To exploit these results we regrouped responses with scale 1 and 2 as answers reflecting a *not realistic* interpretation, and responses 4 or 5 as a *realistic* evaluation of an aspect of the virtual scenes.

The first question is the most general: 85% of the participants deemed the virtual scenes realistic or very realistic or were neutral while only 15% found them not so realistic. It was a good enough characterization of the virtual environment displayed in videos: 18% only of the participants were neutral. This validates the proposition of a study using virtual tours in videos, although one can expect a much higher feeling of realism using immersive virtual reality that the use of a head-mounted display for example. Additionally, it is a validation of the TwinMotion software used for the 3D environment rendering, although a better degree of photorealism can be achieved if one uses a 3D engine such as Unreal Engine or Unity, but at the cost of much more technical development, as is described in [45].

The spatial extent of the built environment and buildings was found to be reasonably convincing, with 82% finding their size close to real ones, the remaining participants were mostly neutral regarding this aspect of the virtual visits and only 3% of the participants were less convinced by the simulation.

As reported in [2], materials, lighting and environment detail are usually the most severely criticized aspects. The materials used give the space realism for 47% of the corpus, 34% were neutral and 19% found it not realistic. The light and shadow convinced 51% of the respondents, 30% were neutral and 19% judged that they do not bring much realism to the spaces.

The urban details provide realism for 41% of the respondents, while 29% did not agree with this statement. It has to be said that at this stage of the BIM development, the vegetation elements proposed in the scenes were somewhat basic and foliage replacement would have been required. At this stage, these operations can be performed manually under TwinMotion to enhance the prototype, in order to place a more realistic vegetation display, and it is the one of the main limitations of this work.

However, even if material, light and details were less contributing to the realism of the virtual visits compared to the size of the buildings and the infrastructure, the proportion of contented participants can be judged as reasonably high. Indeed, in the study of Gomez-Tone et al. [2], the participants reported less value to the shadows (which were faint), the materials (which were not realistic due to the tool, see Figure 1) and to the environment details (somewhat gray and darkened), all of which were less helpful to experience the environment as reality.

After watching the four visit tours, the participants were also asked to order the following characteristics according to the realism they considered appropriate for the visited spaces: the materials of the 3D models, the panoramic view, the scale, the environment and the lighting. Figure 8 reports the answers collected with a scale from 1 for the most important feature to 5 for the least significant. There is no clear first attribute that contributes to the realism of the scene. The environment was the second- or third-ranked characteristic that contributed to the realism. Light and shadows were ranked mostly third or fourth attributes, as were the wall and roof materials. The scale was the fourth-ranked attribute by most of the participants, while the possibility of looking everywhere was ranked as the fourth or fifth element.

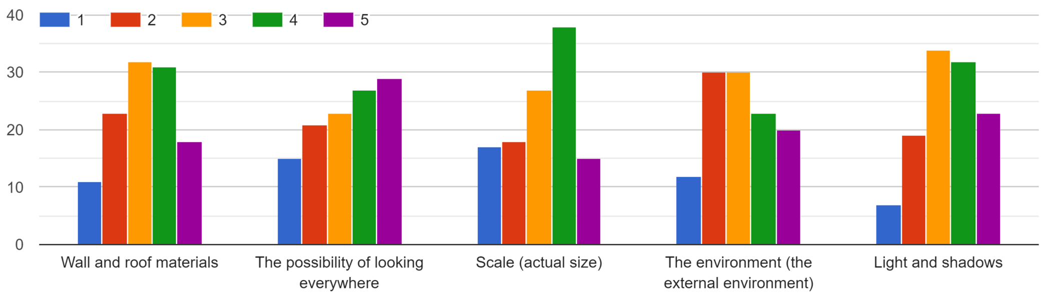

Figure 8. Order of characteristics according to the realism the participants gave the four virtual visits.

So, the order of importance with regards to realism are: the environment first, wall/roof materials and lighting as equally second characteristics, the scale is only third. The possibility of looking everywhere is the last which was to be expected since the virtual tours are guided: the point-of-view of visitors is fixed in advance.

Since this study, a more photorealistic version of the 3D city model of LaVallée was built in Unreal Engine [45], and it will be used in our future works that plan to use a head-mounted device. However, the video-making tools available in TwinMotion were more appropriate to select the points-of-view developed along each of the virtual visit, and the results of the previous opinion pool related to the realism of the constructed scenes are deemed satisfactory for the evaluation of ambiance aspects of the built environment of the future district.

3.3. Auditing of Architectural Ambiances

3.3.1. How Private/Public Is the Space Considered?

Participants were asked to evaluate the space on a scale from 1 to 5, from totally private (1) to totally public (5). The first two tours were mostly perceived as public spaces by 50% and 63% of the participants for the business district and the shops avenue, respectively, which conforms to intuition and to the opinion of the experts. The two guided tours of residential areas were perceived almost equally as private as public or neutral, showing indecision in the general group for this type of sensation space. The experts considered all the virtual tours as mostly public spaces or at least neutral, and not particularly private.

3.3.2. Activity in the Places

Participants were asked to select one or several choices of activity the shown place is good for, among the following choices: watch, play, read, rest, contemplate, move. The four scenes were unanimously judged as good for moving, especially the shopping strip. In guided tours 1 to 3, the other actions were equally selected, although less frequently than “to move”.

Scene 4 shows more differences: Figure 9 displays the answers from both participants and experts in the green residential area virtual tour. The experts expected this residential/garden environment to be more of a contemplation place or a place to move, but this scenery inspired the participants to respond with more of the other actions such as to read, to rest or to play.

The four types of urban identities were qualified by all participants as suitable places to move, probably a cognitive bias nudge by the dynamic effect of the video tours where the people are placed in a perspective where they are in motion. We can note that AEC experts sometimes see their construction work as artwork to contemplate when a public audience is more pragmatic and see the utilitarian aspects of places for activities such as reading, playing or simply resting.

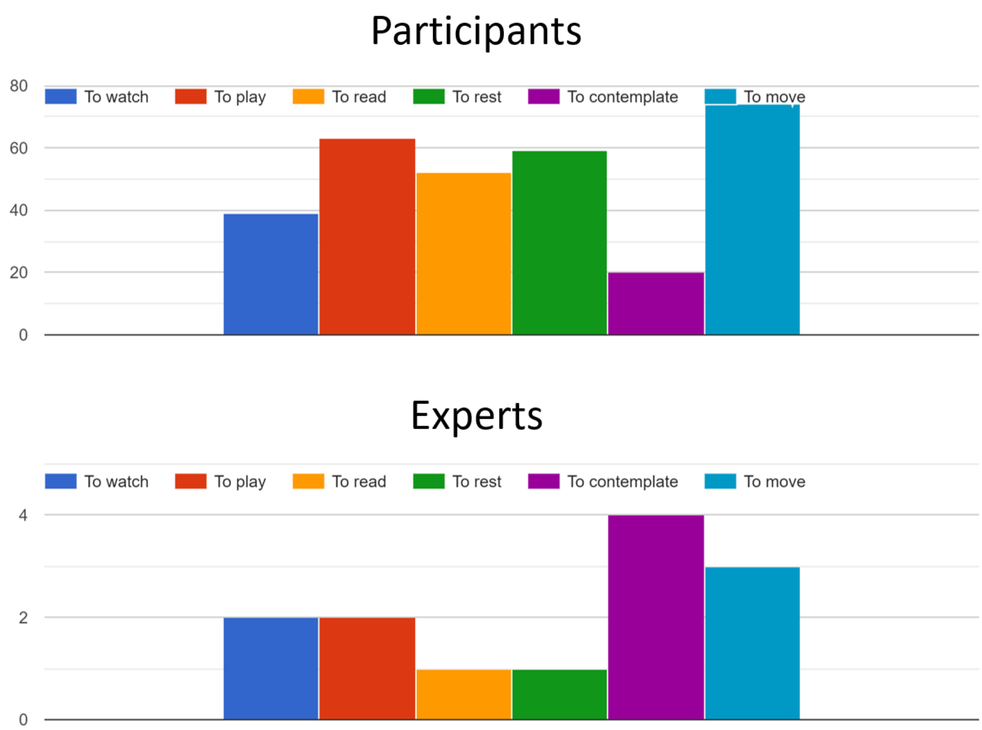

Figure 9. Possible actions in the green residential area (virtual tour 4).

3.3.3. Scale and Size Aspects

Three characterizations were proposed to quantify the scale and size aspects of the virtual tours: grandeur, balance and restlessness. Figure 10 illustrates the results obtained from the participants and from the expert, showing some differences and some similarities. The two virtual tours of residential units (green and urban environment) obtained the same cast of choice from the participants and the experts, respectively, so that the diagrams in the third column of Figure 10 are the same in the case of the visits of the two residential areas.

The experts felt balance and grandeur in all of the virtual scenes, whereas the feelings of the other participants were more subtle with the choice of restlessness in some cases. The business office environment was judged as a grandeur scene by almost two thirds of the participants and judged as balanced by the remaining third. The shopping street stimulate a grandeur-type feeling in 17% of both experts and participants. Experts judged it in majority as a balanced kind of place, while in participants the feeling is balance for 58% and restlessness for 25%. The two virtual tours of residential units were judged as balanced by two thirds of the experts and as a grandeur scene by the remaining third. The feeling of balance is also shared by approximately two thirds of the participants, but the rest of them equally shared the feeling of restlessness and grandeur.

The feelings aroused by scale and size are more contrasted by non-expert participants and more intransigent in the AEC experts' opinions.

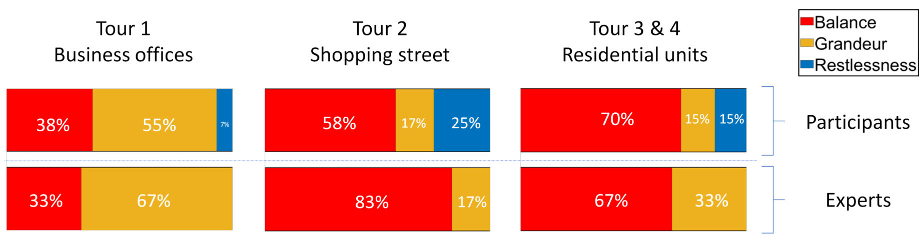

Figure 10. Scale and size: feeling most aroused. Experts are more binary than a public audience.

3.3.4. Feelings Brought by Materials

For each virtual tour, participants were asked about how the materials (walls, floor, furniture, road) used in the scene inspire them. As reported in the legend of Figure 11, four possible answers were proposed: warmth/comfort, fragility/exposure, distance/frigidity and sobriety/coldness. Public participants used the whole range of descriptors in their auditing, while experts did not choose the fragility/exposure descriptors at all, probably due to an occupational hazard as AEC never design such types of urban ambiance. Nevertheless, a sensation of exposure was felt by more than 10% in the two residential areas, by 15% in the shopping street and by a fourth of them in the business offices area.

However, experts largely conceded a sensation of distance/frigidity in the business and the shopping areas, mixed with sobriety/coldness. The feelings of almost a third of public participants in these two areas were warmth/comfort which was surprising at first but can be interpreted as a feeling of increased security in areas where work and shopping activities occur. The two residential areas were also largely described using the warmth and comfortable descriptors by the public, while the experts grade them more using sobriety and coldness.

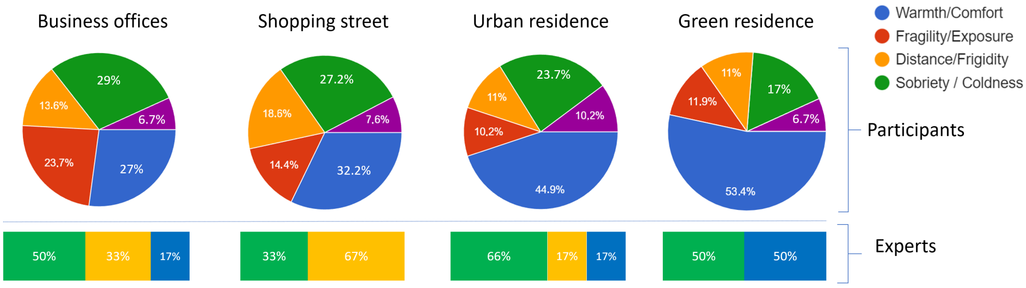

Figure 11. Materials bring sensations from comfort to coldness: public versus experts opinions.

Materials used in the virtual scenes stimulate a large panel of sensations in the public audience, with warmth and comfort largely evoked in residential areas and a noticeable feeling of fragility and exposure in business and shopping areas. Experts are more keen to label this kind of modern-looking area using the distant and fragility or sobriety and coldness descriptors.

3.3.5. Architectural Style

Architectural style can be audited with three criteria: the sensation of elegance bringing satisfaction, a feeling of more simplicity with a concomitant serenity, or more eccentric styles that spark surprise. Public and expert opinions were canvassed based on these three qualifiers, with only one possible choice among them. As illustrated in Figure 12, the four urban identities selected from LaVallée district stimulated two kinds of reaction among the public audience. The virtual tour of the business office area aroused an elegance/satisfaction sensation in a majority of participants, simplicity or eccentricity qualifiers were chosen second. The impression of the AEC experts was different, as 50% of them found this part of the district to be of a more eccentric style, a third of them selected elegance and satisfaction as a good attribute to this modern stylistic set of elements.

The three other virtual tours, either the shopping street or the residential area, sparked a more general feeling of simplicity and serenity in 53% to 60% of the participants, and secondly a feeling of elegance/satisfaction for 25 to 33% of them. The experts mostly agreed on this qualification except on the urban residential area which was found to be a little more eccentric than elegant as a second choice of architectural style, simplicity/serenity being the most tallied qualifier.

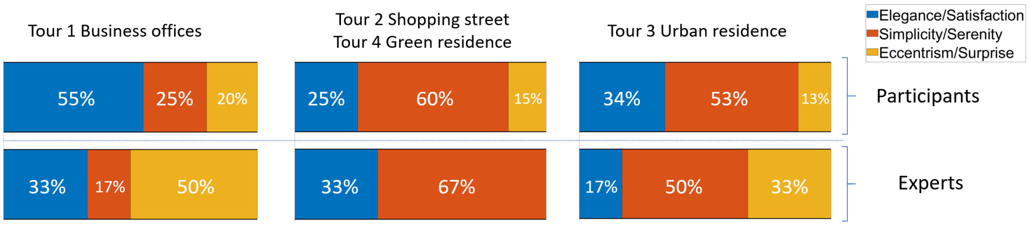

Figure 12. What the buildings inspire in term of architectural style: public and expert opinions.

3.3.6. Degree of Enclosure

Buildings and streetscape elements define a space: the degree of enclosure is important to the character of the space. It capture the sense of pertaining to a predefined space. The height of the vertical plane and its distance from the view are important in establishing the degree of enclosure. The more the sensation of feeling surrounded by the elements, the more the degree of enclosure to it. Instead of being to technical, we proposed to scale this sensation from protection and calmness to freedom and animation: whatever most appropriately describes what would be felt inside the virtual scenes.

When buildings enclose a space, the arrangement, height and proximity determine the sense of enclosure that they impart to the user. Protection and calmness reflects a high degree of enclosure, while freedom or animation are associated with a sense where minimal enclosure is perceived and a more clearly free volume exists. When there are gaps between buildings, plants or garden walls can link the architectural elements to form the spatial volume. It is what happens in the green residential area where the buildings style comprises a stepped floor with vast free space towards the sky, but the vegetation links the various structural elements, so that almost half of the participants considered it as calmness-type environment. The experts are more formal with 83% of them considering this virtual tour appropriately described using the calmness descriptor.

As can be seen in Figure 13, the urban residential area brings more mixed feelings with about 30% of the vote expressed for both protection and calmness. The business district and the shopping street evoked more calmness, freedom and animation, so a less enclosed space with more animation, which opinion the experts agreed with, although not in the same proportion. The AEC experts felt especially the business office location as a more dynamic area with a stronger sensation of freedom and animation.

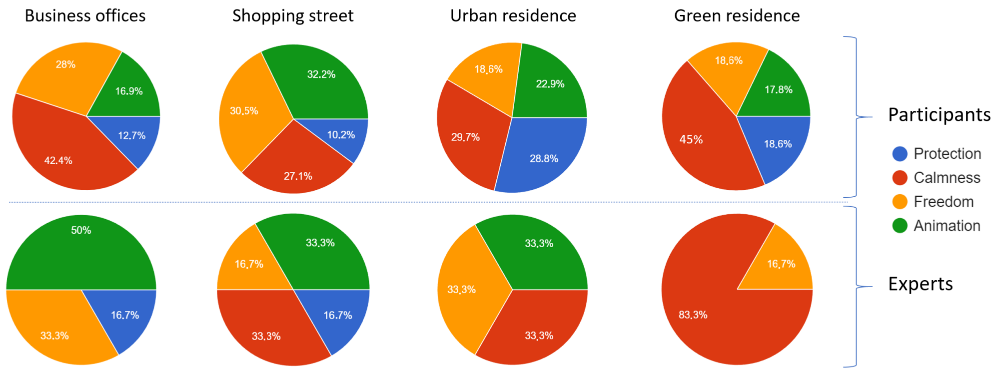

Figure 13. Degree of enclosure: protection, calmness, freedom, animation.

3.3.7. General Scene Sensation

Participants were asked a more general question about the ambiance felt during the virtual tours. The question asked was: "What kind of feeling describe most your sensation inside the scene?" A set of four emotions was proposed: indifference, sadness/nostalgia, emotion/spirituality and joy/theatrically.In green in Figure 14 are the votes tallied for the indifference emotion: in all parts of the district it is the most expressed feeling, especially in the shopping street where this feeling was shared by almost 60% of the participants, and more than 40% in each of the other tours. Emotion/spirituality was the second choice in the business district, while joy/theatrically was chosen second to indifference in the green residence area. Sadness/nostalgia represented a minority of feelings in all the guided tours.

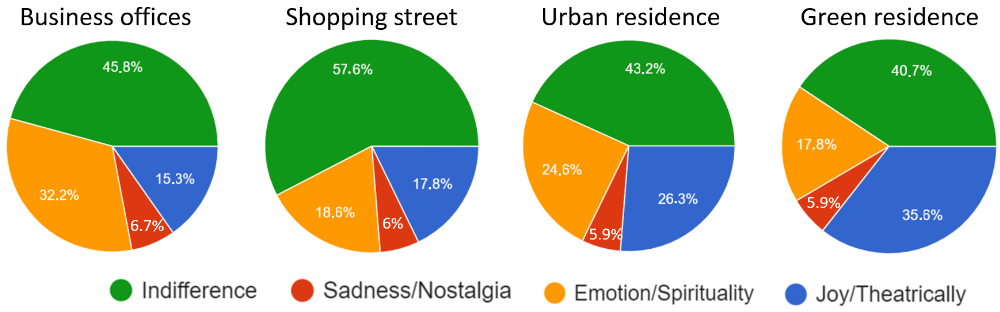

Figure 14. Feeling describing the most the sensation inside the scene for the public audience.

This overwhelming share of the indifference emotion can be explained by a lack of definition of what an architectural ambiance is. The participants have difficulty choosing between the different proposition because they simply might not fit their experience during the guided tour. Sadness, emotion and joy are strong feelings and it is probable that less colorful feelings could be expressed. There is room for improvement in this study, and finding a general emotion more subtle than indifference is still to be found.

One way to improve the public space auditing is to break it down into groups of characterization, instead of a direct question about the architectural ambiance—this was our method during this study, by dividing the various aspects such as scale and size, material, architectural style and enclosure. Table 1 recaps the most expressed feelings during the questionnaire for each of the four guided tours.

Table 1. The sensations felt most often in the guided tours.

Business Offices	Shopping Street	Urban Residential	Green Residential
Grandeur	Balance	Balance	Balance
Comfort/Sobriety	Comfort/Sobriety	Warmth/Comfort	Warmth/Comfort
Elegance/Satisfaction	Simplicity/Serenity	Simplicity/Serenity	Simplicity/Serenity
Calmness	Freedom/Animation	Protection/Calmness	Calmness

4. Discussion and Conclusions

In this research, we attempted to adapt a method used to characterize ephemeral architecture elements for the public assessment of architectural ambiance in a future district. To accomplish this, we utilized professional BIMs to construct a 3D city model of a large district that is still under construction, and we selected four distinct urban identities. We designed pre-defined guided virtual tours of these four locations.

The first tour featured a place of business, consisting of modern office buildings capable of accommodating 2000 employees, accessible only on foot. The second tour showcased a shopping street with stores accessible via a public plaza and a single lane road. The remaining two tours focused on residential areas: one within a traditional urban street context, and the other surrounded by a green environment of a park and pedestrian walkway.

A one-minute virtual tour of each of these spaces was presented to a public audience, followed by a set of 40 questions specifically tailored to the virtual environment and the characterization of urban vibes. The same set of questions was posed to AEC experts currently involved in the real estate construction project, allowing us to compare their expectations with the public's perceptions.

After watching the four tours, participants were asked to rank the following characteristics based on the realism they attributed to the visited spaces: materials of the 3D models, panoramic view, scale, environment, and lighting. The proposed virtual environment for the guided tours was considered sufficiently realistic for our study. The most significant elements contributing to the realism of the virtual experience were the environment, followed by wall/roof materials and lighting.

The study has provided new empirical knowledge about the evaluations of the perception and sensation of the users towards the urban space (prior to its construction). The study findings suggest that users are able to identify personal sensations when experiencing a 3D tour of the designed urban and architectural space.

Participants were asked to evaluate how public or private the spaces were; the business place and the shopping street were mostly perceived as public. The feeling was more undecided in the two residential tours.

The AEC experts considered all the virtual tours as mostly public spaces or at least neutral, and not particularly private which is the first difference of perception in the residential areas. The type of activity a place is good for was also investigated—we noted that AEC experts sometimes see their construction work as artwork to contemplate while a public audience is more pragmatic and see the utilitarian aspects of places for activities such as reading, playing or simply resting.

Scale and size aspects were characterized using adjectives such as grandeur, balance, or restlessness. The experts perceived balance and grandeur in all of the virtual scenes, while the public's feelings were more nuanced, occasionally leaning towards restlessness. However, both groups generally agreed on attributing grandeur to the business district and balance to the other parts of the district.

The materials used in the virtual scenes evoked a wide range of sensations in the public audience, with warmth and comfort being strongly associated with residential areas, and a noticeable feeling of fragility and exposure in business and shopping areas. Experts were more inclined to describe it using descriptors such as distance and fragility or sobriety and coldness, characteristic of modern-looking areas. The public participants used a broader spectrum of associations in their assessments, while the experts did not choose the fragility/exposure sensation at all.

Regarding architectural style, there was a contrast in perception between the public audience and the AEC experts in the business district. The public saw elegance, while the experts identified eccentrism. However, there was general agreement on the other three virtual visits. Overall, in the entire category we proposed, including the degree of enclosure, the opinions of the public audience tended to be more mixed, while the experts' evaluations were often less compromising and more positively inclined.

Future Research

One perspective of this work is to expand the set of questions to allow for a more comprehensive characterization of architectural and urban ambiances. We discovered that directly asking participants about the emotions evoked by an environment was mostly inconclusive. Additionally, other aspects such as tidiness, imageability, and transparency need to be addressed more specifically.

We are also planning to investigate the extension of the protocol to more immersive environments using headsets, allowing participants to freely explore the tours. This would provide an opportunity to compare 2D and 3D setups and evaluate the potential benefits and drawbacks of immersive apparatus. Another potential extension is to incorporate physiological sensors, such as EKG and EEG, as well as emotion-recognition software, to examine the benefits of such apparatus in psychological studies of this nature.

Finally, one of the perspectives of this work is to compare the virtual tours with reality once the district is built by posing the same questions to actual residents [46]. This would enable us to validate or enhance the use of non-immersive environments for public assessments of existing or future built environments.

We must take into account that the possibility of manipulating the elements of an urban space (in a virtual environment) can provide new and different perceptions to those obtained in a non-immersive VR environment. Additionally, carrying out the experience in the built environment will allow comparisons between the virtual and real environments in order to determine the degree to which the studies in virtual environments correspond to perceptions in real life.

In addition, future studies could focus on how residents perceive and experience specific attributes of architecture and urban design. It should be investigated which of these attributes are perceived and experienced positively and negatively by relating them to the characteristics of architecture, e.g., color, light, scale, materiality, shapes, volumetry, etc.

Future virtual reality studies could also use spatial audio to provide a more immersive and realistic experience during experiments.

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