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The Role of Green Spaces in High-Rise Environments on human subjective well-being: A Study Using Immersive Virtual Reality

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The Role of Green Spaces in High-Rise Environments on Human Subjective Well-being: A Study Using Immersive Virtual Reality

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Samenvatting

Door de wereldwijde urbanisatie ondergaan steden een ingrijpende transformatie, waarbij het aantal hoogbouwontwikkelingen in dichtbebouwde gebieden toeneemt. Deze verticale uitbreiding biedt een oplossing voor efficiënt ruimtegebruik en woningtekort, maar gaat vaak ten koste van toegankelijke groene gebieden voor inwoners. Deze stedelijke evolutie roept belangrijke vragen op over de invloed van groenvoorziening in hoogstedelijke omgevingen voor het welzijn van mensen. Dit is een aspect dat door stedenbouwkundigen vaak over het hoofd wordt gezien. Deze scriptie speelt in op die tekortkoming door het psychologische en emotionele effect van verschillende groene kenmerken in hoogstedelijke omgevingen te onderzoeken met behulp van immersieve Virtual Reality (iVR).

Het onderzoek is onderdeel van de bredere context van milieupsychologie en studies naar de gebouwde omgeving. Een uitgebreide literatuurstudie laat zien dat groene ruimtes weliswaar goed zijn gedocumenteerd wat betreft ecologische en esthetische functies, maar dat er een duidelijke kenniskloof bestaat met betrekking tot het psychologische effect van groen in hoogbouwomgevingen. Bovendien schieten traditionele evaluatiemethoden, zoals enquêtes en observatiestudies, vaak tekort in het vastleggen van het momentane subjectieve welzijn, vooral bij kortdurende blootstelling aan verschillende omgevingen. Uit de literatuur blijkt dat stedelijk groen stress vermindert en stemming verbetert bij langdurige blootstelling. Recent onderzoek benadrukt ook dat emoties die mensen ervaren in de gebouwde omgeving complex en multidimensionaal zijn, beïnvloed door kenmerken als gebouwhoogte, daglicht en persoonlijke factoren zoals leeftijd, geslacht en woonomgeving. Dit onderzoek vult deze kenniskloof op door deze multidimensionale aspecten mee te nemen en specifiek te focussen op kortdurend, momentaan welzijn, een tot nu toe onderbelicht aspect binnen het groenonderzoek.

De variabelen die in dit onderzoek variëren zijn seizoensverandering (bomen met of zonder bladeren), de hoeveelheid groen en de groepering van bomen. Het effect van deze variabelen op het momentane welzijn van individuen tijdens de simulaties en het post-VR welzijn na elke simulatie wordt onderzocht. Met behulp van iVR zijn acht gecontroleerde scenario's ontwikkeld die alleen in deze genoemde kenmerken van elkaar verschillen. Een interactieve vragenlijst over het momentane subjectieve welzijn van deelnemers is geïntegreerd in elke simulatie, met vaste meetpunten op vijf strategisch gekozen locaties per scenario. Het doel is om bruikbare inzichten te bieden aan stedenbouwkundigen, ontwerpers en beleidsmakers om stedelijk groen in toekomstige hoogbouwontwikkelingen niet alleen op ecologische, maar ook op psychologische en menselijke welzijnsdoelen te optimaliseren.

Het project in dit onderzoek is het KnoopXL-project: een grootschalige herontwikkeling in het centrum van Eindhoven. De gebieden Stationsplein en District E zijn tijdens het experiment gesimuleerd. Omdat dit project zich tijdens het onderzoek nog in de planningsfase bevindt, bood het een unieke kans om verschillende ontwerpscenario's te simuleren vóór fysieke realisatie. De acht scenario's zijn gecreëerd met behulp van de programma's Twinmotion en Unreal Engine: Twinmotion voor de basisstructuur van de modellen, en Unreal Engine voor de interactieve en bewegingsfunctionaliteiten. Deze modellen zijn gebaseerd op de originele plannen van het toekomstige KnoopXL-gebied, inclusief gedetailleerde gebouwen, voetgangerszones en openbare ruimten. Hierdoor kunnen deelnemers het gebied verkennen alsof het al gerealiseerd is.

In totaal namen 40 deelnemers deel aan het iVR-experiment. Elke deelnemer beleefde vier van de acht scenario's, in willekeurige volgorde. Tijdens elke simulatie doorkruist de deelnemer vijf vaste locaties waar door middel van hun locatie in de iVR-omgeving een pop-up vragenlijst wordt geactiveerd. Hiermee wordt het momentane subjectieve welzijn gemeten

op vijf dimensies: veiligheidsgevoel, comfort, opwinding/betrokkenheid, plezier en stress. Deze dimensies zijn gebaseerd op psychologische modellen en eerdere literatuurstudies. De meting gebeurt via een 5-punts Likertschaal, om consistente en betrouwbare feedback te verkrijgen. Na elke simulatie wordt een aanvullende vragenlijst afgenomen over de gehele scenario-ervaring. Tot slot wordt, na afloop van alle vier scenario's, een eindvragenlijst afgenomen om het algemene welzijn en de ervaren realiteit van de simulaties vast te leggen, evenals hypothetische intenties zoals het bezoeken of wonen in het gebied.

Voor de analyse van de dataset zijn statistische technieken gebruikt, waaronder lineaire regressie en fixed-effects panel regressie. De analyse toonde aan dat scenario's met meer bomen en clustering van groen consequent leidden tot hogere welzijnsscores op zowel korte als lange termijn. Daarentegen riep een omgeving met weinig of verspreid groen juist minder positieve reacties op voor het menselijk welzijn. Ook de seizoensverandering had een significante invloed: scenario's waarin bomen bladeren hadden, werden als aanzienlijk positiever ervaren in participanten hun welzijn dan kale wintervarianten.

Het onderzoek hield ook rekening met persoonlijke kenmerken zoals leeftijd, geslacht, bekendheid met stedenbouw en het KnoopXL-project. Hoewel individuele verschillen enig effect hadden op welzijnsscores, bleek niet elk verschil statistisch significant. De huidige woonomgeving bleek echter wél significant: deelnemers die in een stedelijke omgeving woonden, scoorden gemiddeld hoger op alle welzijnsmetingen dan deelnemers uit minder stedelijke gebieden. Na afloop gaven veel deelnemers aan dat ze zich sterk aanwezig voelden in de iVR-omgeving, en sommigen vergaten zelfs tijdelijk dat ze zich in een gesimuleerde wereld bevonden. Dit ondersteunt de effectiviteit van immersieve VR in omgevingsonderzoek.

Naast de empirische resultaten levert dit onderzoek ook een bijdrage aan de academische discussie, waarin stedenbouw en psychologisch welzijn steeds vaker worden verbonden via technologische innovaties. Waar traditionele studies vaak werken met reflectieve vragenlijsten achteraf, maakt dit onderzoek gebruik van iVR om momentane welzijnsreacties direct te meten in een realistische maar gecontroleerde setting. Dit zorgt voor een beter begrip van de invloed van groenconfiguraties op kortetermijnwelzijn. De bevindingen onderstrepen dat ontwerpprocessen ook rekening moeten houden met directe ervaringen, aangezien deze kunnen verschillen van de algemene beoordeling achteraf.

De methodologische opzet van deze studie combineert iVR-modellen, geïntegreerde vragenlijsten en gedragsintenties in een traditionele post-experimentenquête. Door de willekeurige toewijzing van scenario's binnen een factorieel design, is een evenwichtige blootstelling aan variërende groenaspecten gegarandeerd. Alle ethische richtlijnen zijn gevolgd, en de data is geanonimiseerd in lijn met de gedragscode wetenschappelijke integriteit.

Voor de praktijk biedt deze thesis concrete aanbevelingen. Ten eerste: ontwerpen met bladerrijke bomen, een hoge boomdichtheid en clustering verhoogt zowel het momentane als het algemene welzijn. Ten tweede: psychologische effecten van groen moeten structureel worden meegenomen in stedenbouwkundige beslissingen, naast esthetische en ecologische doelen. Ten derde: immersieve VR is een krachtig hulpmiddel om stedelijke projecten te testen en participatief te ontwikkelen vóór de bouw begint.

Conclusie: deze thesis levert overtuigend bewijs dat goed ontworpen groen in hoogstedelijke omgevingen het psychologisch welzijn en de tevredenheid van gebruikers verhoogt. De toepassing van immersieve VR verrijkt niet alleen het onderzoeksinstrumentarium van stedenbouwkundigen, maar biedt ook praktische handvatten voor het creëren van mensgerichte, leefbare en toekomstbestendige stedelijke omgevingen. Naarmate de wereldwijde urbanisatie toeneemt, wordt het belang van groen voor psychologisch gezonde steden steeds urgenter.

Summary

Due to worldwide global urbanization, cities are undergoing a significant transformation by increasing high-rise dense developments. These vertical expansions provide a solution to

efficient land use and housing shortage, but this often comes at the cost of accessible green areas. This urban evolution raises important questions about the effect of greenery in high-rise environments to human well-being, a feature that is often overlooked by urban planners. This thesis addresses this gap by exploring the psychological and emotional impact of different greenery attributes in high-rise environments using immersive Virtual Reality (iVR).

The research is framed within the broader context of environmental psychology and built environment studies. An extensive literature review revealed that green spaces are already well-documented on ecological and aesthetic use, but a gap exists in the psychological effect of greenery in high-rise-built environments. Moreover, traditional evaluation methods with surveys and observational studies that are performed often fail to capture the momentary subjective well-being. This is especially difficult in short-term exposures to different environments. The literature supports that urban green spaces reduce stress and enhance mood in the long-term exposure. Furthermore, recent studies highlight that the well-being experienced by users in built environments is complex and multi-dimensional, influenced by greenery attributes (amount of trees, clustering of trees, and seasonal change) as well as personal characteristics such as age, gender, and current living environment. This research will fill in the existing research gap by taking into account these multi-dimensional attributes and focusing on the momentary subjective well-being, which is a short-term and yet underexplored feature in the influence of greenery on human well-being.

The greenery attributes that vary across this study are the seasonal change (trees having leaves or not), the amount of trees, and the clustering of trees. Their effect on individuals' momentary subjective well-being during the simulations, subjective well-being post-VR scenario (after every simulation), and the overall subjective well-being after the entire experiment is explored. With the help of immersive VR, eight controlled scenarios are created that vary just in the mentioned greenery attributes. An immersive questionnaire about participants' momentary subjective well-being is integrated to capture their short-term responses on five strategically chosen fixed locations in every scenario. The aim is to provide actionable insights for urban designers, planners, and policymakers to optimize greenery in future urban high-rise developments, not focusing on just the ecological goals, but additionally on the psychological and human well-being influence of greenery too.

The case study that is used during this research is the KnoopXL project, a large-scale redevelopment project in the heart of Eindhoven. The areas of the Stationsplein and District E are simulated during the experiment. This project is during the execution of this experiment still in the planning phase, which offers a unique opportunity to simulate different design scenarios before they are physically implemented. The eight scenarios were created using the programs Twinmotion and Unreal Engine, with Twinmotion for the outlines of the models and Unreal Engine for the immersive features and movement build-ins. These models are made according to the original plans of the future KnoopXL area, including detailed building structures, pedestrian zones, and public spaces. This allows the participants to explore and evaluate them as though they were physically present.

In total 40 participants took part in the immersive VR (iVR) experiment. Each participant explores four out of the eight different scenarios in a random order. During each simulation, the participants crosses five predefined locations where a pop-up questionnaire is triggered in the iVR environment by the location of the participant in the simulation. With the help of this questionnaire the momentary subjective well-being is captured across five dimensions: sense of safety, comfort, excitement/engagement, pleasure, and stress. These five well-being categories are established by psychological frameworks and literature study. The questionnaire is measured using a 5-point Likert Scale to create constant and reliable feedback for further analysis. After each scenario a post-VR scenario questionnaire is provided to measure the well-being of the entire scenario that was just experienced, before

entering the next one. The overall experience is captured after all four scenarios are visited with a final questionnaire, all again on the same 5-point Likert Scale to compare the outcomes. Their hypothetical intentions like visits to the area or making this area their living environment are measured here too together with the perceived realism of the iVR scenarios experienced.

To analyze this dataset, statical techniques including linear regression and fixed-effects panel regression are used. The analysis confirmed that scenarios with more trees and clustering of trees consistently led to higher perceived short- and long-term well-being. In contrast, environments with less trees and a non-clustered distribution elicited less positive responses to human well-being. The seasonal variation (having leaves or not) also proved to have a significant influence on human well-being after the scenario (subjective post-VR well-being). Scenarios where trees had leaves were associated with significantly more positive experiences to well-being compared to scenarios of trees without leaves.

The study also includes the role of personal characteristics like age, gender, familiarity with urban design, and the KnoopXL project for instance. While individual differences did effect the different well-being scores to some extent, not all outcomes turned out to be statical significant. The factor that was constantly significant in generating a more positive well-being was living in an urban environment as current living situation. People that were living in outer urban environments scored less positive on all well-being used during the experiment (momentary-, post-VR scenario, overall well-being) compared to people living in urban environments. Furthermore, the feedback of the participants after the experiment confirmed a strong sense of presence in the iVR scenarios, with the majority of the sample even indicating that they temporarily forgot the world they were in was created at some point. This supports the effectiveness of immersive VR in environmental research.

Beyond the empirical results, this research contributes to a growing academic purpose that combines urban planning with psychology effects using immersive technology. Unlike the traditional survey-based studies that make use of evaluations after the experiment, this thesis uses iVR to measure momentary subjective well-being responses in a controlled and engaging manner. This allows for a better understanding of the influence of urban greenery configurations on well-being in a short-term basis. The outcomes demonstrate that urban design decisions should include these momentary experiences too, since they can differ from someone's overall feeling after the experience.

The methodological framework that is used during this study is a combination of iVR modeling for controlled scenario design, integrated questionnaires, and behavioral intention measures in a traditional post-experiment survey. The random order of visits to four of the eight models according to a factorial design, ensures a balanced exposure to different greenery attributes. Ethical considerations were strictly adhered and data was anonymized in accordance with scientific integrity standards.

For practical relevance, this thesis provides conclusions and recommendations for further usage. Firstly, designing with trees having leaves, large amount of trees, and clustering can significantly enhance subjective post-VR scenario well-being. For the subjective momentary well-being, the amount of trees turns out as only significant effect on the participants' perceived well-being. With a richer amount of trees, the subjective momentary well-being was positively affected. Secondly, these urban green designs in evolutionary high-rise environments need to include psychological effects too as an addition to aesthetical and ecological improvements. Lastly, the immersive VR can serve as a powerful tool in future built environment projects, helping urban planners and residents visualize and experience different compositions and their effect on well-being included before they are even built.

In conclusion, this thesis provides evidence that thoughtfully designed greenery in high-rise environments improves psychological well-being. The immersive VR technology not only

expands the methodological boundaries of urban design, but also offers practical guidance in shaping more positive urban environments, resulting in better human subjective well-being. As urbanization worldwide continues to grow, the use of greenery in providing livable and psychologically healthy cities is becoming more important too.

Abstract

As cities continue to expand vertically due to worldwide urbanization, accessible green spaces become more scares. This can potentially impact residents' well-being, even more if greenery is not planned in the right way. This thesis investigates how the amount of trees, clustering, and seasonal appearance (having leaves or not) in high-rise-built environment affect human well-being using immersive Virtual Reality (iVR) as an experimental tool. The experiment consists of eight controlled iVR scenarios based on the future areas Stationsplein and District

E of the KnoopXL development in Eindhoven. The thesis captures participants' momentary subjective well-being, post-VR scenario well-being, and overall well-being across five psychological dimensions: safety, comfort, excitement/engagement, pleasure, and stress. The momentary subjective well-being is measured at five strategically chosen locations within each scenario using an immersive pop-up questionnaire during the simulation. A total of 40 participants entered the experiment and filled in all questionnaires. Statistical analyses, including linear regression and fixed-effects panel regression are used to create insights into effect of changing greenery attributes on all well-being measurements. The analysis revealed that a higher amount of trees, clustered, and with trees having leaves significantly generates more positive well-being scores. Also, the personal characteristics of the participants are taken into account, since literature study reveals that these influence perceived well-being too. The participants with a current living environment in an urban setting resulted in a general more positive well-being output, compared to participants currently living in outer urban areas. This research emphasizes the importance of integrating psychological effects of greenery in planning high-rise environments. Also, the value of iVR as a tool in evaluating short-term momentary subjective well-being is highlighted. With the outcomes of this research, urban planners can take the psychological effect of greenery in high-rise urban spaces into account besides the ecological and aesthetical contribution.

Keywords

Urban green spaces, High-rise environments, Human well-being, Immersive Virtual Reality (iVR), Momentary subjective well-being.

AI Statement

It is important to acknowledge the use of Artificial Intelligence in this Master's thesis. The Artificial Intelligence (AI) tool ChatGPT is merely used for brainstorming and structuring purposes in this study. AI techniques produced none of the research's findings. The researcher collected all of the information and concluded himself. Prompts such as "What do you think about *concept*" and "What are the key elements of this article" were used to understand the literature regarding this topic. Prompts like "What would be the best outline for a chapter about *topic*" are used for structuring purposes. Also, for improving sentences without changing the

input AI is used. Prompts like “Improve this sentence without changing the provided information” were used to clear some of the sentences in the report. Again, the researcher collected all of the input himself, and the tools were only utilized to generate some ideas during brainstorming sessions and help him understand difficult literature. The researcher did not blindly adopt the tools’ output, nor did they write any section.

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1. Introduction

The rapid urbanization of modern cities has led to the rise of densely populated high-rise-built environments (UN-Habitat, 2020; Angel et al., 2011). Forecasts predict that two-thirds of the entire world's population will live in a city by 2050 (Bele & Wasade, 2016). These urban development's aim to address the space constraints and support the growing population effectively, but they also reshape the natural landscape often at the expense of greenery (Darkwah & Cobbinah, 2014; Rehman et al., 2023). The resulting urban areas are often characterized by limited vegetation and expansive solid material usage, which entails significant challenges to environmental sustainability, public health, and overall livability (Gill et al., 2007; Maas et al., 2009; Jennings & Bamkole, 2019). This thesis investigates the effect of varying degrees of greenery in areas dominated by high-rise developments on human well-being, taking into account the role of the quantity, clustering, and seasonal changes of vegetation. The research gap is about the emotional response to these variations, especially

if they are experienced in a controlled context. This research uses immersive Virtual Reality (iVR) to simulate these different greenery configurations.

Greenery within high-rise urban settings plays a crucial role in moderating the adverse effects of urbanization (Chan, 2005; Jaafar, Said, & Rasidi, 2011). For example, Cameron (2016) notes the restorative benefits that greenery brings and states that there is a direct connection with peoples' psychological recovery, even in short-term exposures. The amount and clustering of greenery in these areas can significantly influence air quality, urban heat island (UHI) effects, and biodiversity. Dense clusters of trees and plants can create microclimates that help to regulate temperature, mitigate heat absorption by concrete surfaces, and reduce energy consumption for cooling (Zheng et al., 2022). Such green areas act as ecological buffering zones by absorbing pollution and capturing carbon dioxide. This results in improvements of the environmental quality in high-density neighborhoods. Besides individual patches of greenery, the spatial arrangement and connectivity between green spaces contribute to broader ecological networks that enhance urban resilience (Zhou et al., 2023).

The presence and concentration of greenery also have big implications for human well-being. In areas where high-rise buildings are dominating, the clustering of vegetation offers residents accessible spaces for recreation, relaxation, and social interaction. Green spaces in urban environments are proven to reduce stress, foster a sense of community, and improve overall mental health (Fonseca et al., 2023; Fukano & Soga, 2024). Daily interactions with trees and green spaces are connected to better physical health outcomes and increased stress control capacity and well-being among humans (Jiang et al., 2020). Another important aspect is the clustering of greenery which ensures that these benefits are experienced collectively, creating communal havens within the overwhelming density of urban life. For residents of high-rise developments, who often face limited access to private outdoor areas, the availability of nearby green clusters becomes a vital element in enhancing the quality of life (Chan, 2005).

Furthermore, the spatial configuration of greenery affects the aesthetic and experiential dimensions of urban areas significantly. Neighborhoods dominated by high-rise buildings need a strategically distributed and visually abundant greenery deviation that provides a stark, but yet harmonious contrast to the rigidity of concrete and steel. According to Eizenberg et al. (2019), clusters of vegetation in any form, like small urban parks, landscaped courtyards, or tree-lined pathways, contribute to a more inviting and visually appealing environment. This perception of vegetation as an asset in neighborhoods for social as well as cultural value in these spaces encourages integration into future city planning (Eizenberg et al., 2019).

Despite these advantages, the presence of greenery in high-rise areas is often uneven (Bäcklin et al., 2024). Vegetation is constrained by space, competing land uses, and insufficient urban planning by policymakers who do not consider the potential of trees on streets beside the building-integrated appliance. Inequality in the amount and clustering of greenery can tighten this uneven distribution between greenery and buildings. Some communities will enjoy lush environments while others remain deprived of these benefits (Zhang et al., 2020a). Addressing such issues requires a deeper understanding of how people interact with greenery within high-rise urban environments and how strategic interventions can enhance the effectiveness of greenery.

This thesis explores the effects of greenery in high-rise-built environments, focusing on how its quantity, clustering, and seasonal change impact human subjective well-being. The focus of this study lies in exploring the understudied momentary subjective well-being, which is the well-being measured during the experience instead of after the experiment. Most traditional data and literature study this overall well-being after experiments and simulations, but the

focus of this study lies in exploring the momentary subjective well-being and providing analytical research on similarities and differences compared to this overall well-being. With the help of an immersive Virtual Reality (iVR) experiment about the KnoopXL project in Eindhoven, data on the momentary subjective well-being of participants is collected as well as their answers to the questionnaires provided. iVR is used for the fact that many parts of the Netherlands will urbanize in the coming years, resulting in high-density and vertically expanded areas to deal with the housing shortage. These areas could be experienced already by the future users of the space with the help of iVR. Immersive questionnaires and feedback are used to capture the momentary subjective well-being. The implementation of this immersive questionnaire will be elaborated in Chapter 3.2.3. This data could provide more detailed and realistic input of momentary well-being that could be used in new projects that have not yet been realized, just like the KnoopXL project areas of the case study that will start with the first construction in 2028 at the earliest. In this way, the urban design including greenery can be optimized before the project is finalized. Through the analysis of case studies, quantitative assessments, and different statistical research methods, this research aims to uncover actionable insights that can guide urban planners, architects, and policymakers in creating green areas in future high-rise developments that cater to the needs of potential residents.

1.1 Scope

There has been extensive research conducted on the environmental and social benefits of urban greenery, with a primary focus on the literature about the integration of vegetation into buildings, rooftop gardens, and vertical green walls (Berardi, 2016; Meerow & Newell, 2017). Green spaces and trees are fundamental for the sustainability of cities, but their potential is usually not reached and overlooked by policymakers and managers (Campagnaro et al., 2019). There is limited research that examines the broader spatial distribution, clustering, and quantity of greenery in the surrounding areas of high-rise-built environments. Yet, understanding these aspects is essential to notice not only the aesthetical and ecological function of greenery, but also the psychological, emotional, and physical benefits for humans.

Inhabitants value green spaces in urban places since they contribute to the reduction of stress, improve mood, and create stronger community ties (Ulrich et al., 1991; Kaplan & Kaplan, 1989). These positive green space effects tend to reduce due to the future urbanization and vertical expansion of cities as a result of the current housing shortage. Research by Hartig et al. (2014) confirms that regular exposure to green environments supports cognitive functioning and emotional restoration. Maas et al. (2006) showed that there is a correlation between perceived general health and the proximity to greenery. All these findings show why examining greenery beyond the extensively investigated rooftop gardens and building-integrated forms is necessary. These cases are particularly interesting for dense urban settings where the access and amount of nature are scarce. Furthermore, most studies emphasize greenery's ecological contributions, such as mitigating the urban heat island (UHI) effect or improving air quality, without adequately addressing how its spatial arrangement influences human subjective well-being, and its effect on feeling safe, pleased, and comfortable in the high-rise-built environment taking in account different greenery settings (Önder & Akay, 2015; Shishegar, 2015).

Additionally, the seasonal change affecting human well-being is taken into account in this study by providing summer as well as winter scenes where the trees lose their leaves. These seasonal dynamics can significantly influence the visual, thermal, and psychological experience of green spaces in high-rise areas (Duan et al., 2024). For instance, a tree-lined street that offers shade and a cooling effect in summer may appear stark and offer limited

environmental benefits in winter. Understanding how these changes affect residents' perception of greenery, as well as its functional benefits, remains an underexplored dimension in urban research.

By focusing on the amount, clustering, and spatial arrangement of greenery in high-rise urban areas with the seasonal effect taken into account as well, this research aims to provide a comprehensive understanding of its impact on human subjective well-being, offering actionable insights for the development of future high-rise environments.

1.2 Research question

The problems defined in the previous section led to the following main research question:
"How do the clustering, seasonal changes, and amount of greenery in high-rise-built environments influence human subjective well-being, as measured using an immersive virtual reality setting?"

To be able to answer the main research question, the following sub-questions are formulated:

1. Which well-being states are most relevant when assessing human subjective well-being in relation to greenery in high-rise-built environments?
2. How can iVR technology serve as a tool to measure the effect of greenery on human subjective well-being?
3. To what extent do people's momentary subjective well-being vary based on the changing greenery attributes of greenery in high-rise-built environments?
4. To what extent do people's post-VR scenario well-being vary based on the changing greenery attributes of greenery in high-rise-built environments?
5. To what extent do technological features of iVR (e.g., resolution, mobility, interactivity) affect users' subjective well-being in virtual green environments?
6. What strategic advice can be given to urban planners and policymakers on the use of immersive VR to evaluate and implement greenery in high-rise urban environments affecting human subjective well-being?

These research questions will be answered with the help of a literature study and with the outcomes of the iVR experiment.

1.3 Research Design

To conduct the research and provide answers to the research questions the approach of Figure 1 will be handled.

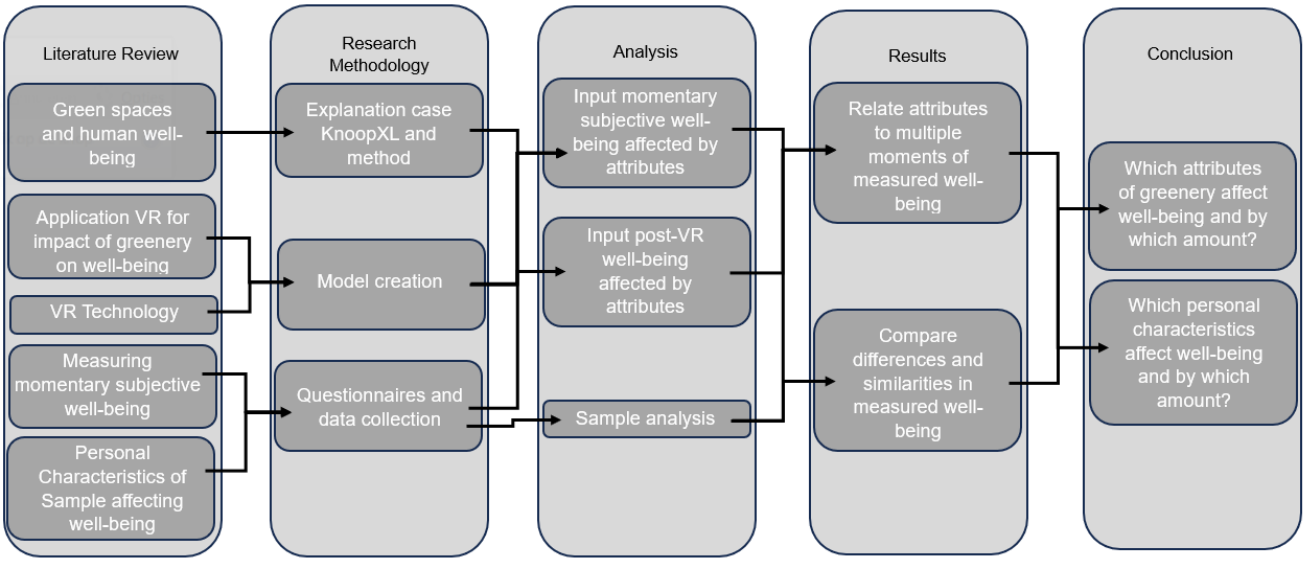

Figure 1 – Visual representation of the research design

Firstly, the literature study in Chapter 2 responds to some of the research sub-questions already. To test the other sub-questions and provide an answer to the main research question, an experiment in the form of an immersive VR model with a momentary subjective well-being feedback integration in the session on multiple spots will be set up. The participants will experience the iVR environment and respond to the given questions on these selected spots. The iVR method is chosen for its affordance of immersion and interactivity. To understand participants' well-being towards varying greenery characteristics during the experiment, pop-up questionnaires are used within the iVR environment. After the immersive VR experiment, the participants' overall experience will be measured with the help of a post-experiment questionnaire.

The research field will have some limits for the iVR simulations in this research. One development area will be chosen for developing different models/simulations. The simulation will make use of immersive questionnaire feedback to measure the momentary experience and feelings on particular spots, considering surrounding and greenery factors at a specific moment. A survey post-experience will be used to provide insights into the overall experience of participants. Furthermore, the Stationsplein Zuid and District E (AM BV, 2023) of the KnoopXL project are considered. These two areas of the project are chosen, since they fulfill all perceived attractiveness factors connected to human well-being in one model and will suit the context scenario about passing time waiting for a friend that you meet at the station area, which will be more elaborated in Chapter 3.1. The outcomes provide insights into the perceived attractiveness of users by greenery, tested by immersive VR with momentary and post-experience feedback and survey applied. The data will be collected from the people who will be asked to participate in the iVR simulation. It consists of answers about personal characteristics surveys beforehand, questions during the experiment about their momentary experience, and post-experience surveys about their overall simulation experience.

The application to design the iVR model is a combination of the programs Twinmotion and Unreal Engine. These platforms were chosen for their free access and user-friendly interface. Unreal Engine is mostly used to make the interactive questionnaire in the immersive VR possible. The 3D modeling input to iVR is done in Twinmotion, due to its plug-and-play interface. To be able to execute this simulation with the participants, the ethics of the data and experiment were checked and approved (ERB-229). After the approval of the board, the data collection phase started. In this part of the experiment, the iVR simulations created were used by as many participants as possible to form the most valid insights.

After a few weeks, all gathered data was collected and analyzed together to provide good insights into perceived attractiveness factors, differences between participants, personal characteristics effects, and patterns. SPSS is the application used to execute this analysis. The relation between greenery attributes (amount, clustering, season) and different well-being inputs is analyzed. The differences and similarities in these multiple well-being scores measured for every participant on a 5-point Likert scale are compared to scenarios, spots in the scenarios, and attached greenery attributes. The outcomes are discussed according to previous data and conclusions are made about the (new) outcomes.

1.4 Relevance of the research

This research contributes to a growing and yet underexplored area within the built environment. While the restorative effects of green environments are explored in research such as Bernardo et al. (2021) and Liu et al. (2021), the focus lies on prolonged and repeated exposure. The short, momentary well-being experiences within an immersive VR simulation are rarely investigated, especially the effects of short exposure to greenery environments on people's subjective well-being in iVR environments. By investigating in what way different greenery attributes affect momentary subjective well-being in short iVR sessions, this study investigates this gap.

Besides this scientific contribution, this research contributes to the decision-making in future urban (re)development projects. This research supports the creation of urban areas that intend to align the design with users' experiences and perceptions of greenery. Understanding how the built environment affects users' well-being under different greenery scenarios will offer insights into their reasoning, decision-making, and social behavior, among other aspects (Daly et al., 2016). The short-term momentary experience of participants could be an addition to the insight into participants' momentary well-being and differences with the long-term overall well-being of a project. This research will equip urban planners and designers with actionable insights to create more sustainable, livable, and visually appealing high-rise urban environments.

As Dutch cities continue to densify in response to population growth and urban housing demands, high-rise developments are becoming increasingly prominent in the urban landscape (CBS, 2025). This vertical expansion, while offering spatial efficiency, also poses challenges for maintaining human well-being in denser built environments. Research indicates that urban densification can negatively impact mental health and stress levels if not accompanied by supportive green infrastructure (Maas et al., 2009; van den Bosch & Sang, 2017). Therefore, it is essential to integrate restorative green spaces into these high-rise areas to buffer potential adverse effects and enhance the quality of urban life.

1.5 Reading guide

This research is divided into five chapters. Chapter 1 started with an elaborate introduction. Chapter 2 provides a literature review that explores the amount of greenery, the clustering of greenery, the seasonal effect, factors influencing peoples' well-being, and (immersive) VR methods. Chapter 3 describes the methodology by discussing how and what data will be collected and analyzed, including the expected results. Chapter 4 discusses the results of the immersive virtual reality experiment. Chapter 5 provides a conclusion, discussion, and a future recommendation.

2. Literature review

This chapter summarizes the relevant literature found about green spaces effect on well-being, relevant subjective well-being factors, the built environment attributes presented, (immersive) VR technology usage, and the importance of personal characteristics affecting well-being taken into account. The chapter will end with a general conclusion about all the performed literature studies.

2.1 Green spaces and human well-being

Urban green spaces are broadly studied as essential contributors to both physical and social well-being. The greenery included in the spaces differs from parks, to gardens, to tree-lined streets. The purpose of greenery is to provide recreation opportunities but also serve as stimulation for human well-being by buffering negative impacts of urban living, such as pollution, stress, and social isolation (Jabbar et al., 2021). On physical level, access to greenery has been linked to increased physical activity, reduced stress levels, lower blood pressure, and improved cardiovascular health. Regular interaction with green environments encourages outdoor movement such as walking, cycling, and recreational play. Socially, green spaces serve as inclusive public domains where individuals from diverse backgrounds can meet, interact, and build community ties. These spaces foster a sense of belonging, enhance perceived safety, and can reduce feelings of isolation in dense urban environments. In high-rise urban contexts, where ground-level space is limited, integrating greenery into vertical structures may offer similar benefits if carefully designed with accessibility and user well-being in mind.

Insights from recent systematic reviews show that not all green spaces are equally beneficial in their contribution to human well-being (Reyes-Riveros et al, 2021; Carrus et al., 2015). The configuration and quality of green elements, such as size, density, and biodiversity, play a critical role in their effect on human well-being. Certain attributes, like the scale of a tree canopy, vegetation coverage of a surface, and proximity to residences, have been linked to stimulants of physical and emotional health (Reyes-Riveros et al, 2021). This means that more connected green spaces would increase physical activity and reduce perceived stress more effectively than a sparse green environment would.

Biodiversity within these green environments plays a crucial role too. Studies show that green areas that have a lot of plant species and habitat variety generate more positive well-being and support cognitive recovery, particularly during short visits (Carrus et al., 2015; Meng et al., 2024).

While multiple existing literature confirms the positive connection between green urban space and well-being, there remains a gap in understanding the effects of specific configurations of green environments on well-being during momentary experiences. These studies rely on traditional cross-sectional surveys from a population at a single point in time or use objective spatial data that rarely explores the psychological impact of greenery design attributes like season, amount of trees, and clustering of trees (Kothencz et al., 2017; Delgado-Serrano et al., 2024). This highlights an important direction for further research that evaluates momentary interactions of greenery with different configurations included.

2.2 Measuring Momentary Subjective Well-being

According to Ekman (1999), all momentary subjective well-being is related to a set of basic emotions, namely: anger, joy, fear, disgust, sadness, and surprise. Momentary subjective well-being means the direct experience during the simulations or experiments. This momentary subjective well-being is understudied since most of the current literature focuses on the overall well-being after simulations or experiments. This theory is referred to as the discrete approach. Zeile et al. (2015) used this approach to identify emotional responses to urban environments. Olszewska-Guizzo et al. (2018) studied emotional responses in an EEG experiment and found activity in areas of the brain that related to pleasure, joy, relaxation, fear, and disgust, some of which thus correspond to the earlier identified basic emotions. When looking at studies regarding the user experience and emotions in the built environment, other dimensions of user

experience have been applied as well. Birenboim et al. (2021) used momentary social well-being to describe the individual's emotions at a certain moment in time. According to their research, it could be split into four main emotional states: sense of security, comfort, happiness, and annoyance. These have been applied in other studies regarding user experience in the built environment as well (Liao et al., 2022; Weijs-Perrée et al., 2020; Zhao et al., 2022; Limburg 2024).

In addition to the research of Birenboim et al. (2021), there are other aspects to focus on during this immersive VR simulation. For instance, the stress caused by the environment or simulation will provide insights into the method chosen for this research. Bouchard et al. (2017) demonstrated that iVR environments that simulate social threats or dangerous situations elicit psychological stress responses such as increased anxiety, irritability, and unease. Participants in these environments reported feeling overwhelmed or out of control, which heightened their stress levels. Furthermore, Dubovi (2023) shows that iVR simulations can elicit strong emotional responses, with joy being the predominant emotion expressed by participants in this particular case study. The happiness of an individual during the iVR session is better represented in the excitement and engagement of the simulation. That is why this emotional state is covered in a more specified way.

Additional evidence on the benefits of urban green environments supports the inclusion of momentary well-being measures. For instance, Wang et al. (2024) found that exposure to different types of urban greenery in immersive virtual reality significantly influenced both affective responses and momentary perceived well-being, reinforcing the relevance of emotional and experiential indicators in simulated environments. Similarly, (Dane et al., 2019) showed that users of urban green spaces reported not only long-term well-being benefits but also immediate emotional and social experiences such as relaxation, joy, and social connectedness. These findings strengthen the argument for incorporating momentary affective well-being, including the sense of security, comfort, excitement/engagement, annoyance, and stress into iVR-based assessments of urban design interventions.

To conclude, the reviewed literature shows the relevance of focusing on momentary subjective well-being, especially in immersive VR studies that simulate urban environments. While many studies have concentrated on overall or long-term well-being, recent findings highlight the importance of including direct, momentary subjective responses during the experience. These are derived from both basic emotions such as joy or fear and put to more context-specific states like comfort or annoyance. Building on these insights, this research will focus on five specific momentary subjective well-being indicators: sense of security, comfort, excitement/engagement, annoyance, and stress. These indicators are chosen because they are frequently used in similar studies, are cognitively manageable for participants, and provide relevant insights into the emotional impact of greenery in high-rise settings through immersive VR.

2.3 Impact of Built Environment Attributes on Momentary Subjective Well-being

Multiple environmental attributes contribute to human subjective well-being in both the short- and long-term. Other conducted studies have already explored some of these built environment attributes and their relationships to mental health and perception in urban settings (Ho et al., 2017; van Veghel et al., 2024). The research of Ho et al. (2017) focuses on the relation between the risk of a depressed mental state and different urban densities. In their outcomes, they discussed that a lower average building height and more fluctuation in building

heights in an area contributed to a lower risk of getting depressed. The explanation provided in the article is that high-rise buildings influence people's experience by promoting anonymity. Also, the average crime rate in high-rise areas is higher than in lower-built cities, which decreases the feeling of safety (Evans, 2003; Ho et al., 2017; Olszewska-Guizzo et al., 2018). People often feel more relaxed in environments where a clear sense of scale is maintained, but this sense is often disrupted in high-rise urban settings (Lis & Iwankowski, 2021). Similarly, the study of van Veghel et al. (2024) demonstrates that high-density urban environments can negatively affect perceived well-being if spatial openness and visual continuity are lacking. Their human-centric computational model shows that urban layouts with better visibility, more sky view, and variation in building heights significantly improve residents' perceptions of safety and livability in dense areas.

Other research indicates that street design significantly influences safety perceptions in urban environments. Physical elements, such as proper daylight and overview, are crucial in enhancing feelings of safety (Rashid et al., 2017; Park & García, 2020). The morphological complexity of streets, including diverse business types and pedestrian activities, also contributes to a sense of security (Park & García, 2020). Gender plays a role in safety perception too, with women perceiving their environment differently (Rashid et al., 2017). Age is another factor influencing anxiety levels among pedestrians (Park & García, 2020). These studies emphasize the importance of considering both built environment characteristics and human factors in urban design to create safer, more livable public spaces.

Besides the interest in the importance of built environment attributes and the difference in choice behavior, the influence of personal characteristics on choice behavior and outcomes of well-being is interesting too. For that, the aim is to find relations between personal characteristics and greenery attribute levels. Other studies about well-being that include personal characteristics (Liao et al., 2022; Weijs-Perrée et al., 2020; Zhao et al., 2022; Limburg 2024; Dane et al., 2024) use data about: Gender, age, living environment, frequency of visits, personality, mood, pre-knowledge, study background, income, ethics, dwelling type owned, household composition, and health conditions. To make a relevant comparison to some of the earlier found relationships between personal characteristics and well-being change when exposed to green spaces, a selection of these greenery attributes is implemented into this study.

Green spaces in urban environments significantly contribute to human well-being. Cooper et al. (2008) went through 280 articles to find the impact of nature on human well-being. Increased quantity and quality of residential green space are associated with improved child well-being, with optimal benefits observed at 21-40% green space coverage (Feng & Astell-Burt, 2017). Green spaces enhance physical and psychological health, social factors, and self-fulfillment (Cameron, 2016). The research of Olszewska-Guizzo, et al. (2018) provided information about the brainwave patterns of participants who were shown different views of built environments. The environments with a more natural view (grass, trees, water), provided brainwave activation related to joy and relaxation. Trees also provide a positive relation to perceived safety (Lee et al., 2024; Townsend, 2014; Townsend et al., 2016). However, if the trees are too clustered together, the perceived safety changes to a negative feeling (Rahm et al., 2021). When trees lose their leaves during the winter season, the positive relation is still valid (Lévesque-Vézina & Lapointe 2024). The review of Lévesque-Vézina & Lapointe (2024) indicates positive associations between winter urban forests and mental health, physical activity, and physiological relaxation. These benefits appear similar to those observed in warmer seasons, though more research is needed to draw robust conclusions.

Evers et al. (2023) and Dane et al. (2024) identified key design attributes for healthy public spaces. In their report, 27 attributes were defined and subsequently categorized into six main groups: green, building, land use, pedestrian facilities, leisure, and social and safety. In

addition, Dane et al. (2024) describes the development and evaluation of a participatory co-design framework using immersive VR. This framework builds upon these identified attributes and supports the practical application of these attributes in design processes.

The reviewed literature highlights the importance of greenery in promoting human subjective well-being across various urban contexts. However, the specific characteristics of greenery determine how these benefits are perceived and experienced. In order to maintain focus and avoid strong correlations between variables, this study includes a deliberate selection of three greenery attributes: amount of trees, clustering of trees, and the seasonal effect (having leaves or not). The amount of trees has been associated with increased naturalness and psychological restoration (Lee et al., 2024; Townsend, 2014; Townsend et al., 2016). Clustering of trees can influence perceived safety, as dense groupings may reduce visibility and create a sense of enclosure, which may lead to discomfort or unease in certain contexts (Rahm et al., 2021). The seasonal aspect allows for an exploration of how changes in foliage affect emotional responses to urban nature, as previous research has shown that positive associations with greenery often persist even in leafless conditions, although their intensity may vary (Lévesque-Vézina & Lapointe, 2024). By selecting these three greenery attributes, the study aims to investigate how subtle but meaningful variations in urban greenery design influence momentary subjective well-being in high-rise environments. These greenery attributes are central to the immersive VR simulations used in this research and form the basis for further analysis in the following chapters.

In addition to greenery attributes, this study also includes a selection of personal characteristics, based on prior research that demonstrated their relevance in explaining individual differences in well-being outcomes (Liao et al., 2022; Weijs-Perrée et al., 2020; Zhao et al., 2022; Limburg, 2024; Dane et al., 2024). These characteristics include gender, age, living environment, frequency of visits to greenery, personal importance of greenery, self-reported impact of greenery on well-being, familiarity with the iVR environment KnoopXL, familiarity with urban design, and previous experience with iVR. Including these variables allows for a more nuanced understanding of how momentary subjective well-being is shaped not only by the design of the environment, but also by individual background and perception.

2.4 Virtual Reality Technology

2.4.1 Use of Virtual Reality Technology

Virtual Reality (VR) is a technology that allows users to immerse themselves in an artificial, computer-generated environment and interact with it in real-time (TeamViewer, 2024). The technology can be used for different types of experiences ranging from simulations to fully immersed environments. Virtual reality is by no means limited to a single space.

The history of VR dates back to the 1960s, when computer scientist Ivan Sutherland created the first prototype of a head-mounted display (HMD). From this time forward, VR technology advanced at a rapid pace, with the development of motion tracking, sophisticated HMDs, and other feedback systems. This results in different terms referring to the creation of digital realities that are used nowadays: Augmented reality (AR), virtual reality (VR), and mixed reality (MR). The most important difference between the different digital realities is the function and industry in which this function is useful.

AR adds digital elements to the real world. This technique uses images from the real world and shows the addition into this real world for the user. This technique is mostly used in advertising, retail, and gaming. An example is the retail option of buying a couch for instance and enabling a user to see how the couch would be in the room before purchasing.

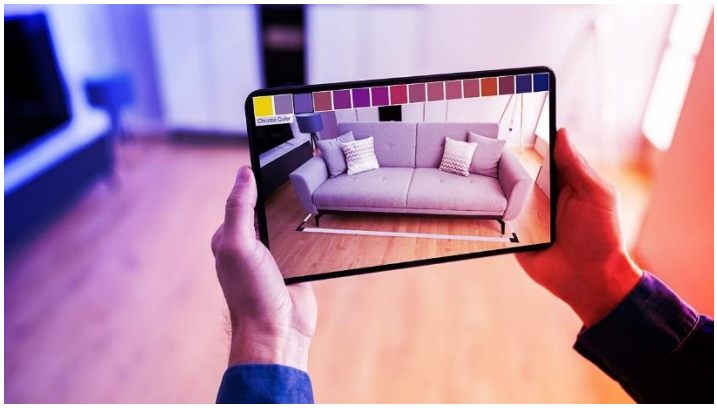

Figure 2 – Example AR (DMEXCO, 2023)

VR does the exact opposite of AR, by leaving the real world and using virtual reality glasses to immerse oneself into an entirely created new world. The better developed this VR world the more immersed a user feels when entering the world. With immersed is meant that a user feels himself/herself present in the newly developed world almost forgetting it isn't real. VR is more commonly used in industries such as healthcare, architecture, and education. An example is the use of VR to train surgeons for operations by simulating them as if they were real.

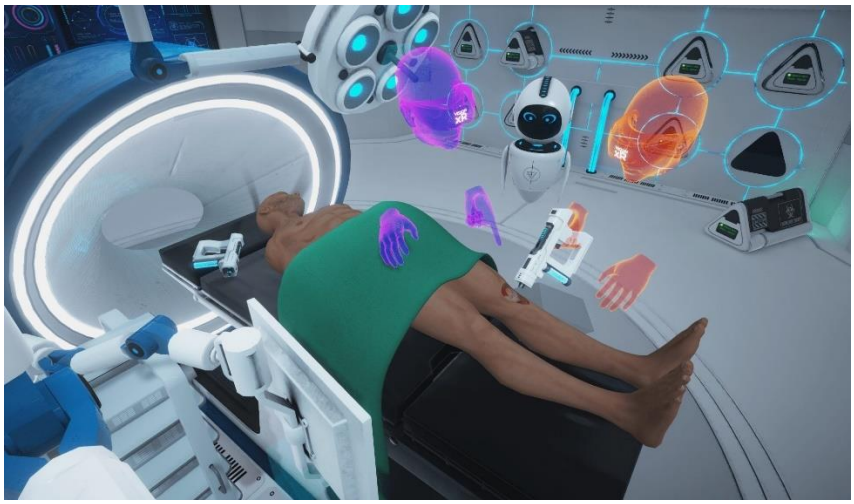

Figure 3 – Example VR (Young, S., 2023)

MR combines elements of both AR and VR together. This technique overlays digital objects in the real world while also allowing users to interact with virtual elements. The overlay of digital objects in the real world is very similar to AR, but MR makes it possible to make changes and interactions with these objects compared to just experiencing the additions. MR has applications in both entertainment and professional settings, such as virtual product demonstrations or training simulations.

Figure 4 – Example MR (Sahota, N., 2023)

Now that the other, sometimes mistaken, concepts are clear and the immersive advantage of the chosen VR application in this research is explained, it is useful to elaborate on the different VR types that are developed before choosing the best option for this thesis. The different types can be categorized by their degree of immersion:

- None-immersive virtual reality: Allows a minimum of interaction with the digital environment. A classic example is the driving simulator used in a driving school for instance. This type of technology feels a bit like a game and the equipment needed is not a headset or joysticks, but a pc screen with any type of controller is enough.
- Semi-immersive virtual reality: Allows digital components to overlay real objects. This means that the virtual elements can be used in a similar way to real objects. An example of this type of VR technology is a flight simulator in a real cockpit. The user becomes partly but not fully immersed in this environment.
- Immersive virtual reality: In this type of virtual reality, users perceive only the VR environment without a fixed point of reference to the real world during the simulation. All gear is needed to get fully immersed in this VR environment.

The big challenge in this thesis lies in the creation of a realistic environment that allows the user to get immersed as fully as possible to test newly built projects or let them experience environments without traveling all the way to see them in the real world. To address this challenge, immersive virtual reality offers a unique solution by simulating urban environments in a way that feels both realistic and immersive, allowing for in-the-moment feedback from participants in a controlled environment (Haydarian, 2022). Unlike traditional survey methods, which rely on reflective evaluations after exposure, immersive VR provides the opportunity to measure momentary well-being due to the changes in greenery directly, as participants move through various urban scenes. This ability to immerse individuals in virtual environments and assess their immediate perceptions presents a significant advancement in urban design research, enabling a more nuanced understanding of how greenery in high-rise-built environments affects the subjective experience of participants.

In recent years, immersive VR has emerged as a powerful and transformative technology with applications in different sectors as stated before, including entertainment, education, and healthcare. Here, iVR is used as a tool to engage the public in new ways by offering experiences beyond the static nature of traditional displays or installations (Yasar & Sheldon, 2024). Users are enabled to explore interactive, three-dimensional environments creating opportunities for deeper engagement and better understanding (Slater & Sanchez-Vives, 2016). In the built environment, these immersive VR simulations create the opportunity to immerse users momentarily in alternative realities that transform how they experience and

perceive the surrounding environment (Zhang et al., 2020b). These immersive capabilities of VR can be recognized in various applications like museums, where iVR enhances historical exhibits by reconstruction of ancient sites. This allows users to walk through these spaces as if they were present. Another example is the retail and shopping environment, where iVR is used to simulate store layouts allowing customers to preview spaces or products into spaces before they are constructed or physically installed. Through these kinds of applications, iVR becomes an extension that is not only visually and spatially immersive but also emotionally linked, giving users a sense of presence and interaction with these presented environments that were otherwise inaccessible.

One thing to take into account when working with iVR is cybersickness. This form of motion sickness experienced in iVR is a significant concern in immersive environments. Studies have shown that higher levels of immersion correlate with increased cybersickness symptoms, particularly nausea and oculomotor disturbances (Martirosov et al., 2021). The underlying cause may be attributed to sensory conflicts between visual, vestibular, and proprioceptive inputs (Gallagher & Ferré, 2018). For immersive virtual reality, these preventions are about the time of being immersed in the environment. If this time is kept relatively short, the participants will have less advanced symptoms in most of the cases. Staying hydrated is also a prevention that will make the risk of getting cybersick smaller. Another prevention is to let participants get used to the immersive VR technology and provide them with sufficient information about what to expect, as well as providing them the option to quit the experiment at any given time. At last, by eliminating the real walking option in this case study and using teleportation to go through the model the risk of losing balance (Clifton & Palmisano, 2019). This will be included in this study to prevent cybersickness from occurring among participants.

2.5 Application of iVR for Evaluating the Impact of Green Spaces on Human Well-being

Nowadays, immersive virtual reality (iVR) is increasingly used in environmental and health research for assessing the impact of green spaces on human well-being. The benefit of iVR use is the ability to create immersive, multisensory simulations of natural environments under controlled conditions. In this way, a subject can be investigated without other changing factors interrupting the outcome.

The study of Hedblom et al. (2019) used 360° VR image environments combined with audio and smell stimuli to investigate the physiological stress responses of 154 humans exposed to an urban street, a park, or a forest. The stress was measured by skin conductance levels (SCL), which is a reliable indicator of autonomic nervous system activity (Andreassi, 2010). During the experiment participants were first exposed to mild stress with the help of electric shocks and then underwent a recovery phase in one of the green iVR environments.

The outcome of the study showed a significant reduction in psychological stress due to park and forest environments compared to the urban environment. This result highlighted the positive impact of green spaces on human well-being. The smell of grass and fir trees had a strong relation with stress reduction. The finding of this strong link between smell and psychological well-being with stress processing is not new. Other literature found already a unique neural pathway between the amygdala and hypothalamus (which is the brain region that activates perceived stress) and the smelling system of humans (Plailly et al., 2008).

Prior research has also shown that sounds of nature, such as birdsong, can enhance the perceived comfort and psychological recovery quality of environments (Alvarsson et al., 2010; Ratcliffe et al., 2013). Other studies show that the combination of all sensory inputs (visual,

auditory, and olfactory) appears to have a conjugating effect on well-being (Franco et al., 2017; Ohla et al., 2018). These studies suggest that future urban green space designers should keep all sensory aspects into account to provide the maximum stimulation of well-being benefits.

Besides the audio and smelling stimuli, the visual impact is found a significant attribute to improve mood, reduce stress, and stimulate psychological well-being benefits (Browning et al., 2020). During these simulations, iVR enables the manipulation of specific environmental features allowing for a more precise and controlled understanding of the impact of every element to the human well-being. The study suggests that simulated iVR nature can be an effective tool when physical access to nature is limited to enhance psychological well-being.

2.6 Conclusion

This literature review has provided a comprehensive overview of the interdisciplinary knowledge about green spaces, human subjective well-being, physically built environment attributes, personal characteristics effect, and the use of immersive virtual reality (iVR) as an evaluative tool to measure this momentary human well-being.

Out of the literature came forward that green areas can enhance people's physical and psychological well-being, but not all green spaces provide the same benefits and influences. Greenery attributes such as tree clustering, amount of trees, biodiversity, spatial configuration, and seasonal variation all affect humans. At the same time, the literature reveals a growing awareness of the complex and context-specific emotional responses of humans to the built environment that they experience. Emotional states like stress, comfort, and safety are not only shaped by the environment but also affected by personal characteristics such as age, gender, and current living environment.

Well-being is measured in multiple ways. This chapter highlights the basic and context-specific states that are most relevant to the built environment and iVR simulations out of previous literature. In all literature, well-being experiences are multi-dimensional and can be influenced by small environmental changes. The literature review finds a gap in the momentarily measured emotional states of humans in these subtle environmental changes. Previous literature measures the well-being states before and after different experiments performed but lacks the input of momentary subjective well-being.

Different environmental attributes are reviewed in the literature study about their effect on human well-being such as building height, natural views, daylight, and pedestrian areas. The incorporated personal characteristics help to understand differences among population groups in their experiences of the environment. These personal characteristics considered are case/experiment specific and used to explain possible causes for emotional states caused by physical environment changes.

Immersive VR emerges is a powerful tool that could be very helpful in the evaluation of human responses to environmental stimuli in a controllable and repeatable manner, without any other

factors changing. iVR offers unique opportunities to implement tools that could help to measure momentary subjective well-being changes to designed urban green spaces before these spaces are even realized. Currently, this iVR technology is already used in healthcare and for training purposes to simulate case-specific environments in a controlled way. In a simulation of the built environment, iVR allows researchers to manipulate specific variables, like greenery types or building heights for instance, in an isolated way to measure the momentary effects on human well-being.

All reviewed studies together point to promising and valuable new research that combines immersive VR techniques with psychological and environmental science to help in understanding the importance of green urban spaces in high-rise environments. Besides this, the research could help in optimizing the design in the best way possible for users of the built environment before those tested projects are even realized. Currently, gaps remain in the understanding of momentary emotional states to greenery changes. This thesis will build on the previous literature knowledge as a foundation, adding how momentary subjective well-being is affected by the physical built environment with the help of immersive VR.

2.7 Conceptual model

Based on the literature review, a conceptual model can be created including all personal- and environmental attributes included in this study that influence human subjective well-being in a high-density urban environment. The momentary subjective well-being states used in this thesis, as discussed in the literature study, will focus on the sense of security, comfort, excitement/engagement, annoyance, and stress.

The built environment attributes that have a significant impact on well-being in the different literature studies will be combined and a selection will be made to fill in the existing research gap and provide valuable and contributing research. The current research gap exists due to the limited insights into how specific design features of greenery, such as seasonal appearance, tree amount, and clustering, affect momentary subjective well-being in real-time experiences. Numerous studies affirm the positive link between green urban spaces and human well-being, but use traditional cross-sectional surveys or objective spatial analyses which often overlook the immediate psychological responses triggered by these particular environmental configurations (Kothencz et al., 2017; Delgado-Serrano et al., 2024).

To fill in this gap the greenery attributes of this research are narrowed down to analyze the effect on momentary subjective well-being as specific as possible. First of all, the smell and sound attributes will be left out of this research to put the focus on the visual appearance of greenery only. In this way, the contribution of the presence of greenery could be measured more precisely.

The reviewed literature confirms that greenery plays an important role in supporting human subjective well-being in various urban settings. However, the way this greenery is experienced strongly depends on its specific characteristics. To keep the research focused and avoid strong correlations between variables, this study includes a clear selection of three greenery attributes: the amount of trees, the clustering of trees, and the seasonal effect, referring to whether trees have leaves or not. The amount of trees has been shown to increase perceived naturalness and contribute to psychological restoration (Lee et al., 2024; Townsend, 2014; Townsend et al., 2016). The spatial configuration, or clustering of trees, can influence how safe an environment feels. When trees are densely grouped, visibility may be reduced, which in some contexts can create a sense of enclosure and discomfort (Rahm et al., 2021). The seasonal state of the trees allows for a deeper understanding of how visual change, such as the presence or absence of leaves, impacts emotional responses to urban nature. Earlier

studies have shown that even without leaves, positive associations with trees can remain, although sometimes with reduced intensity (Lévesque-Vézina & Lapointe, 2024). These three selected greenery attributes are implemented into the immersive VR simulations of this study and serve as the foundation for the analysis of their influence on momentary subjective well-being in high-rise environments.

Lastly, the personal characteristics that affected human well-being in greenspaces out of previous literature need to be considered too. These are specified to the relevant personal characteristics for this research. Since this experiment uses iVR, which is available at the TUe campus, most of the sample will be students from the university. Therefore, personal characteristic attributes like household composition, dwelling type, and income are less relevant for this study since most of the participants who are still studying at the university will have similar attributes to these characteristics, which are not reliable for an entire population. The final personal characteristics taken into account based on the literature study and specified to relevance in this research are:

- Gender
- Age
- Current living environment
- High-density city visits
- High-density city visits with noticeable greenery
- Greenery importance to enjoyment of area
- Greenery importance for your own well-being
- Familiarity with urban design studies
- Knowledge about the project area KnoopXL
- Previous experience with iVR

The city visits are specified to high-density cities, since the iVR experiment will be about the KnoopXL project as mentioned in Chapter 1.3. The selected areas will consist of high-density new construction, which makes the previous experience with such high-density environments interesting to analyze with the well-being analysis of the area.

This conceptual model is schematized in Figure 5.

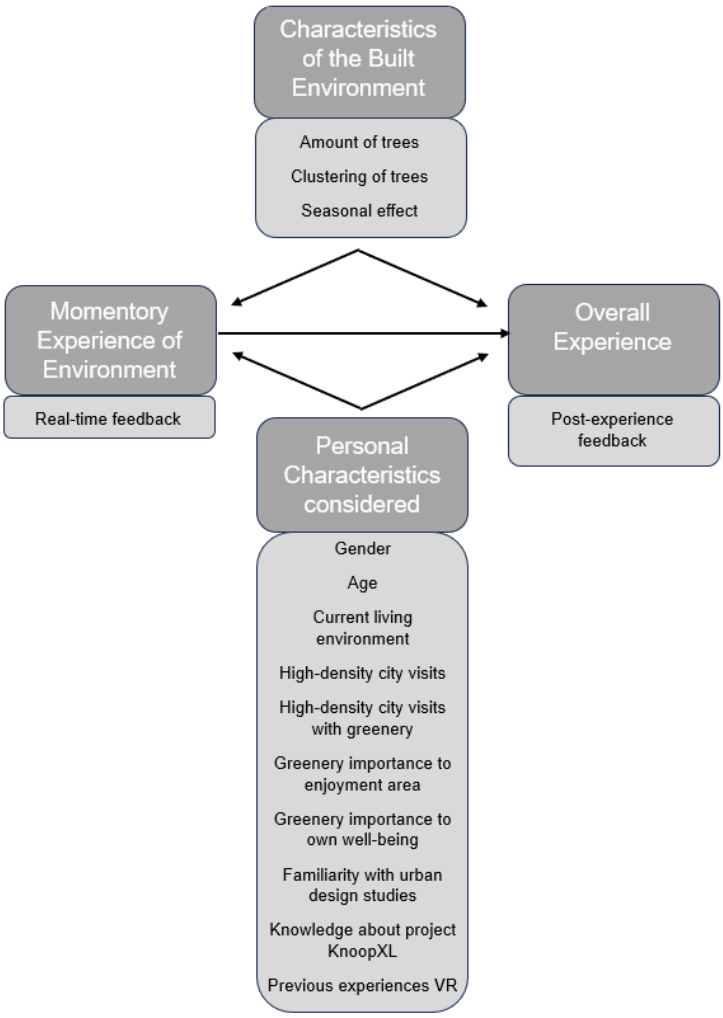

Figure 5 – Schematic conceptual model of the experiment

With these personal- and environmental attributes considered, the existing research gap about momentary experience using iVR will be filled in as completely as possible.

3 Research Methodology

This methodology is an elaboration on the research design outlined in Chapter 1.3 with the literature review included. The case area of KnoopXL is explained, even as the context and the measured spots where the momentary subjective well-being questions are integrated into the immersive scenarios. Also, hardware and software details, the build-up of the models, and different questionnaires of the experiment are discussed. The chapter is structured in chronological steps taken by a participant from the beginning of the experiment till the end of the experiment with all materials and methods described. This is schematically visualized in Figure 6 to make this flow more understandable. During this chapter, all stages are elaborated and explained.

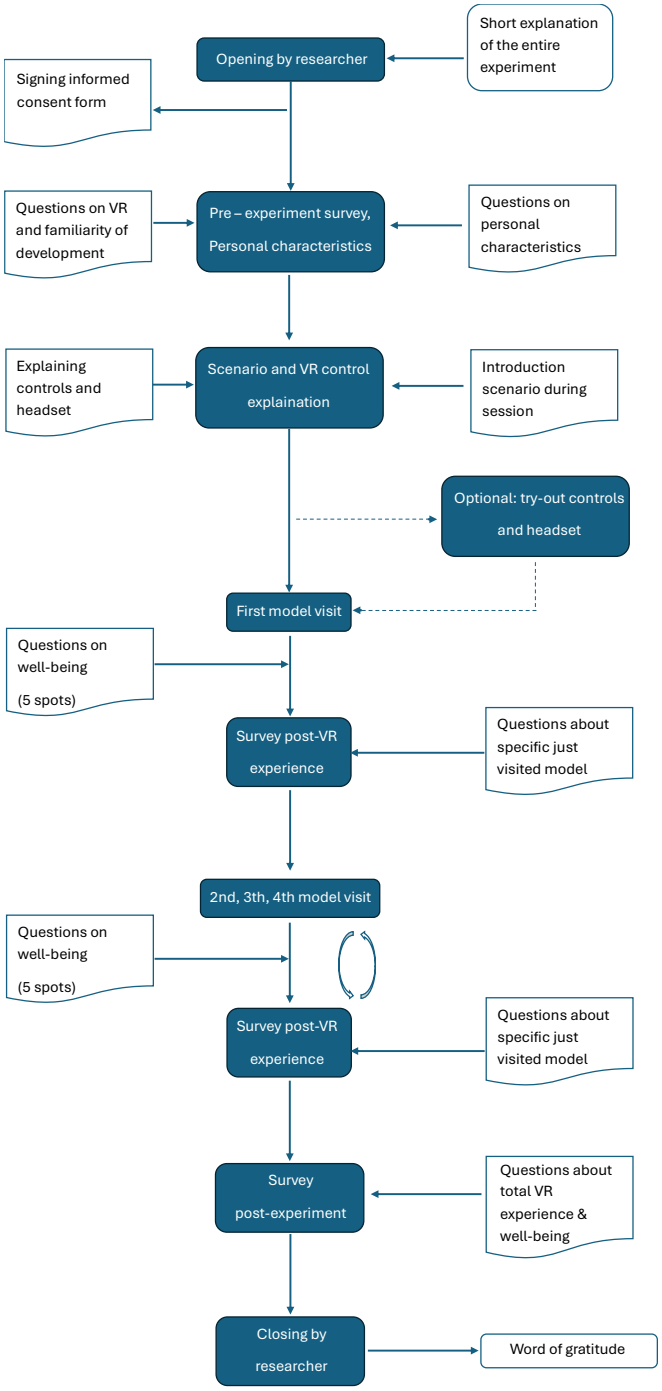

Figure 6 – Process of the experiment

3.1 Case Area KnoopXL and Context of Experiment

As mentioned earlier, the iVR case focuses on a future-built project aimed at generating valuable insights into greenery preferences, without the influence of opinions formed by already existing areas. The iVR technology has the ideal aspects to create such an unbuilt project and show the end result of the area before any physical work is performed. Such a near future project in Eindhoven is KnoopXL, which will be a residential area where living, recreation, and more greenery along the Dommel River for 16,000 new residents will take shape over the next 20 years (OpenEindhoven, 2025). This project is built up out of different areas that are developed in stages.

Before the experiment starts, the participants are briefed about the experiment that they will enter and the data that is collected. This briefing is shown in the introduction of Appendix I. After their approval, the consent form is signed (Appendix I), and the experiment starts with answering the pre-experiment questionnaire. This questionnaire is about their personal characteristics (gender, age, current living environment, etc.), answered in multiple-choice categories. The pre-experiment questionnaire can be found in Appendix II.

After this questionnaire, the participants are introduced to a context scenario about the purpose of their visit to the area of KnoopXL and to provide a reason why they are located at that specific part of the KnoopXL project for an amount of time. The scenario is that the participant arrives by train in Eindhoven and a friend that would be met there is delayed by 15 minutes. That is why there is some time to spend in the area around the station until the friend arrives. The starting position of every iVR scenario is therefore at the exit/entrance of the station on the Stationsplein. The areas that suit the context scenario are the Stationsplein & District E area of the KnoopXL project, because these areas are the link between the inner city of Eindhoven and the Central Station.

Figure 7 – Starting position iVR at the entrance/exit of the station

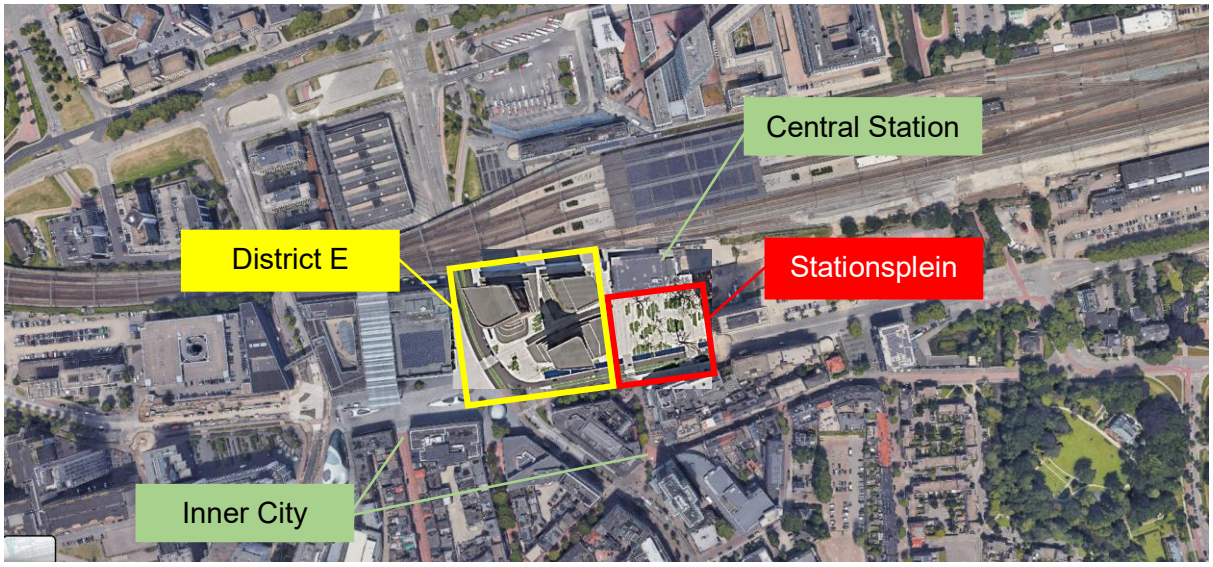

Figure 8 – Location modeled area KnoopXL project

After the experiment is well explained and the context is clearly given, the participant is introduced to the iVR controllers and iVR headset. The researcher explains how to move and interact with the iVR environment, and if requested, a try-out iVR environment is provided to participants to get familiar with the controls. The experiment starts with entering one of the models allocated according to the participant number in the table of Appendix VI.

3.2 The Experiment in iVR Scenarios

3.2.1 Greenery Attributes and Scenarios Consideration

As concluded in Chapter 2, the influence of different greenery compositions is analyzed in high-rise environments with the help of immersive virtual reality. As mentioned in Chapter 1, the questionnaire is interactive and integrated into the iVR simulation to keep the participants as immersed as possible. Because the KnoopXL project has not been realized yet, the outcomes of this study are valuable for the project developers in choosing the best possible greenery composition before any tree is planted.

The greenery attributes that came forward out of the literature study of Chapter 2 are not used entirely, but a selection is made that is most relevant for this research as explained in Chapter 2.7 of the conceptual model already. These greenery attributes about trees having leaves/not (season), amount of trees, and clustering of trees contribute most to the current research gap on momentary subjective well-being changes in high-rise-built environments.

The greenery attributes need to have some different levels to provide insights into changes. The more levels chosen, the more participants and models are needed to keep the research valid. Since the number of aspects is limited to 3 the number of levels can also be kept limited to make a strong and valid research possible with a small selection of different scenarios. A factorial design approach is used to make sure every participant can test the different aspects and provide data on different scenarios. This factorial design is an experimental approach that examines all possible combinations of factor levels in a study (Antony, 2014). For this research, the minimum outcome is 8 models if there are 2 levels for each aspect. To make the experiment exciting and doable in time for the participants, without losing interest or becoming bored due to the time of the experiment, the number of scenarios visited is 4 of the 8. In this way, the well-being outcomes of the participants at the end of the experiment and the beginning are not affected by the experiment time and change in mood. The random distribution of participants among the models is shown in Appendix VI. Table 1 provides an overview of all models with greenery attributes and levels of variation included. Due to the application of the factorial approach, all aspect levels are represented in these 8 models.

Table 1 – Overview of model variation with greenery attributes attached

Model:	*Aspect 1: leaves*	*Aspect 2: amount of trees*	*Aspect 3: clustering*
1	Having leaves	Many trees (30)	Clustered
2	Having leaves	Many trees (30)	Not clustered
3	Having leaves	Low amount trees (15)	Clustered
4	Having leaves	Low amount trees (15)	Not clustered
5	Not having leaves	Many trees (30)	Clustered
6	Not having leaves	Many trees (30)	Not clustered
7	Not having leaves	Low amount trees (15)	Clustered
8	Not having leaves	Low amount trees (15)	Not clustered

3.2.2 Creating the iVR Scenarios

As mentioned in Chapter 2.4, how immersed someone can become depends on the quality and realism of the model (Jung & Lindeman, 2021). That is why the highest possible quality of modeling was aimed to be achieved. Since this thesis is about the KnoopXL project, the development company of this project was contacted. Together with this company, named KCAP, the best base model was composed to modify and detail. As mentioned in Chapter 1.3 before, the selection was made to work out the Stationsplein Zuid and District E (AM BV, 2023) of this project. The context scenario of the project of killing time to wait on a friend when arriving by train made it logical to select the area between the station and the city center as explained at the beginning of this chapter.

The variation of greenery attributes: the amount of trees, seasonal changes, and clustering of trees results in 8 variants of models provided in Table 1. The tree kind and leaf color are kept constant to not interfere with the changing greenery attributes and their effect on the subjective well-being of participants. To provide an impression of the variation used in the models' variants 1 and 8 are shown below on the same spots in the models. These models are created with the program Twinmotion, which was chosen for its straightforward plug-and-play build-up.

Figure 9 – Model 1 position between towers District E

Figure 10 – Model 8 position between towers District E

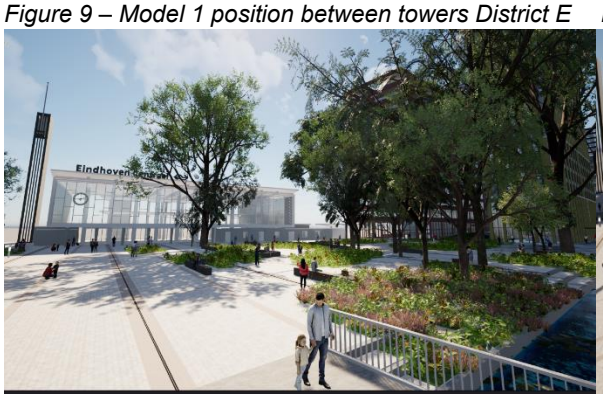

Figure 11 – Model 1 position at Stationsplein

Figure 12 – Model 8 position at Stationsplein

Figure 13 – Model 1 position at District E

Figure 14 – Model 8 position at District E

Model 1 includes the greenery attribute levels of having many trees, clustered together and the trees having leaves. Compared to model 8 with the greenery attribute levels of having fewer trees, not clustered together, and trees having no leaves. The other 6 variants will differ too in these greenery attribute levels as shown in the previous chapter Table 1.

Not only the trees will differ in every scenario, but the low greenery (bushes and grass) will too. This low greenery is changing, just for the scenarios of having leaves or not, and remains the same for the clustering and amount of tree variants. This means that scenarios 1 to 4 contain a constant low greenery as shown in Figure 15, and scenarios 5 to 8 contain a constant low greenery shown in Figure 16.

Figure 15 – Greenery for scenarios 1 to 4

Figure 16 – Greenery for scenarios 5 to 8

3.2.3 Integrating Momentary Subjective Well-being Questionnaires into iVR

The questionnaire about the participants' momentary subjective well-being in different variations of the Stationsplein and District E is integrated into the iVR model with the help of the program Unreal Engine. The program Twinmotion did not have the option to create specialized interactions, like the questionnaire that pops up, so this file is converted into the gaming platform program Unreal Engine to add these interactions. On 5 spots in each model, the questionnaire is built in, and answers are captured to analyze differences in participants' momentary subjective well-being that could be connected to the changes in greenery attributes discussed before. To keep the participants as immersed as possible the questionnaire needs to be built in the simulation to stay connected to the session. If the questionnaire about their momentary subjective well-being at certain spots was on paper or static displayed at the location in the simulation, it would result in a non-immersive moment where the participants would be disconnected from the world displayed to answer the questions. This interactive questionnaire, with buttons to click on and the ability to provide answers with the help of X-ray communication to the Vive HTC controllers of the participants, is the ideal solution to keep the participants immersed during the entire scenario.

Unreal Engine includes a coding interface with blueprints that make interactions and menu building in the simulation possible. That is why the Twinmotion model was transferred to Unreal Engine where the questionnaires are designed, coded, and placed. Also, different iVR features are added such as movement in the leaves of the trees, teleportation movement of the participant connected with the plugin of XR presets, nanite surface addition to not fall through the surface beneath, transportation area addition to move around in the area, and XR Origin with hands is designed to make it able to spawn a participant in the iVR simulation and looking at realistic hands to move instead of controllers during the simulation.

Figure 17 – Hands designed to project on the controllers in the simulation

The questionnaire is designed with blueprints as shown in Appendix VII. The questionnaire is activated by the participant, if being located close enough to the position code of the questionnaire in the model. To clarify these spots during the simulation, a pink notable tile is placed on the surface at these spots. This serves as a marker of the spots for the participants.

Figure 18 – Pink tile located on the questionnaire spots

The questionnaire that is used during the scenarios is triggered by the participant's position in the area. As soon as the participant is near one of the 5 locations, the questionnaire that measures their momentary subjective well-being (safety, stress, excitement, pleasance, comfort) appears. The participant is then able to read the questions and click with the Vive HTC controllers on the buttons of the questionnaire to provide an answer with a slide menu of options. This is repeated on 5 different spots in the model, which are strategically chosen close to the greenery surroundings that will change in the different models. In this way data is gathered about the participants' changes in momentary subjective well-being at these spots and a correlation with the varying greenery attributes could be researched. The interactive questionnaire used during the experiment is shown in Table 2.

Table 2 – Questionnaire of momentary subjective well-being interactive shown in the iVR model on 5 strategic spots

	1	*2*	*3*	*4*	*5*
How safe do you feel right now?	Very unsafe	Unsafe	Neither unsafe nor safe	Safe	Very safe
How comfortable do you feel right now?	Very uncomfortable	Uncomfortable	Neither uncomfortable nor comfortable	Comfortable	Very Comfortable

How annoyed do you feel right now?	Very annoyed	Annoyed	Neither pleased nor annoyed	Pleased	Very pleased
How stressed do you feel right now?	Overwhelmed, unable to cope with current demands	Moderate stress, mildly struggling with demands	Neutral, manageable level of stress	Calm, with few stressors	Completely relaxed, free from stress, mentally at peace
How excited / engaged do you feel right now?	Bored, disinterested or apathetic	Mild disinterest, not engaged	Neither bored nor excited	Engaged, curious, and interested	Highly excited, deeply immersed in and enjoying current activities

The 5 answering options shown in Table 2, are the ones to select in the grey sliding bars of the interactive version used in the iVR model and shown in Figure 19. If the participant clicks with the controllers on this bar the 5 options will appear for the question selected. Then the corresponding option to their momentary subjective well-being could be selected, which will be saved in an Excel file for the researcher to use in the analysis.

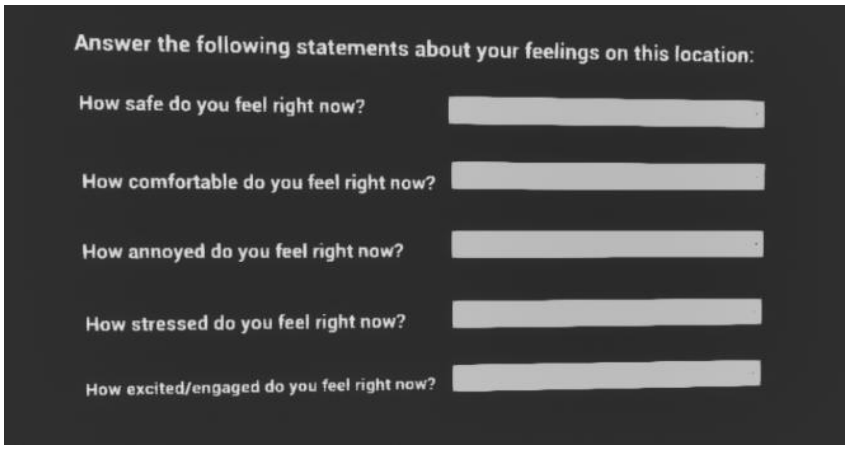

Figure 19 - Blueprint outcome of the questionnaire used in the models

Figure 20 – Perspective view of the final modeled area in Unreal Engine

3.2.4 Hardware & Software Used

The equipment used during the iVR experiment included the HTC Vive Pro VR glasses together with the motion controllers of HTC Vive. This is a wired VR headset that is connected to one of the PCs in the Digital Twin Lab on the TUe campus. The space is limited to 2 meters by 1 meter behind the desk where the base stations are installed and calibrated to notice the movement of the headset and register the motions in the right way. For usage of the headset, the participant needs to be positioned between the base stations during the experiment. The headset, controllers, and base stations used are shown in Figure 21.

Figure 21 – HTC VIVE Pro iVR full system

Table 3 – Specifications of the Hardware & Software used

Item		***Specification***
Headset	Screen	Dual AMOLED 3.5″ diagonal
	Resolution	1440 x 1600 pixels per eye (2880 x 1600 pixels combined)
	Refresh rate	90 Hz
	Field of view	110 degrees
	Connection	USB-C
	Sensors	SteamVR Tracking
Controllers	Input	Multifunction trackpad, Grip buttons, dual-stage trigger, System button, Menu button
	Use per charge	6 hours
	Sensors	SteamVR Tracking
Software	Twinmotion	Version 2025.1
	Unreal Engine	Version 5.5
PC	CPU	Core i9
	Memory	64GB RAM
	Graphic	nvidia geforce rtx 3060
	OS	Windows 11

Figure 22 – Interaction with the iVR setup

Figure 22 left shows how the researcher answers the momentary subjective well-being questionnaire inside an iVR scenario. The red lines are connected to the controllers in the

simulation to make participants able to see where the X-ray is pointing. On the right of Figure 22, the iVR movement by teleportation is shown in the scenario visible on the screen with the blue circle where the participant teleport will go if the button is triggered by the participant. In Figure 23 below the head movement up is indicated with the adjusted PC visual that the participant will see through the VR headset at that moment.

Figure 23 – Head movement of the VR headset

3.2.5 Selection of 5 Locations to Measure Momentary Subjective Well-being in the Scenarios

During the walk around in the surrounding area the experience of the participants is about the momentary subjective well-being in the explored area. Their feelings about their safety, stress, excitement, pleasance, and comfort are captured with the help of an interactive questionnaire on five different locations in every scenario. These five locations are selected based on the amount of greenery in the area. Additionally, care is taken to ensure that the locations are not too close to each other and that they are evenly distributed across the entire area, in order to capture variation in different places. The following five locations are selected based on these criteria.

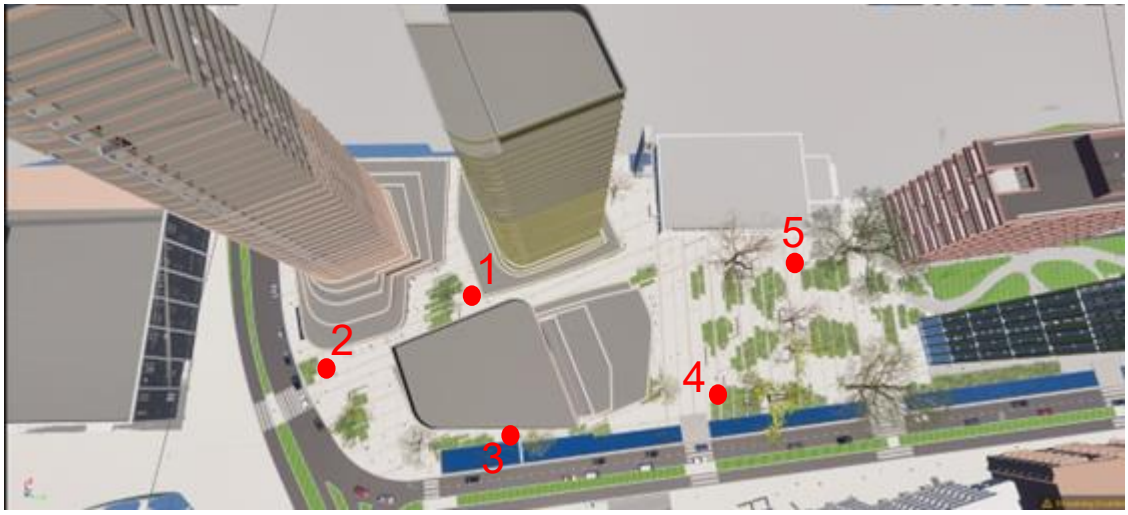

Figure 24 – Overview of 5 locations in each model provided with the momentary well-being questionnaire

Location 1: This location is located in between the 3 high-rise buildings. According to the plans of KnoopXL, a small green park is located at this spot, differing from a few trees to many trees and bushes depending on the scenario the participant is experiencing.

Figure 25 – Model 1 location of momentary subjective well-being questionnaire 1

Location 2: This spot is located near a road. The greenery differs by the scenario experienced. A lot of low greenery is placed, just as in the original plans of KnoopXL. This makes the spot different from the others where the trees are more dominant. Therefore, an interesting connection could be found connected to the road or low greenery influence.

Figure 26 – Model 1 location of momentary subjective well-being questionnaire 2

Location 3: This spot is located next to one of the high-rise buildings and the small water stream that are created according to the KnoopXL plans. The water got, just like the greenery, movement in the simulation to make it more realistic. On the other side of the water stream, the one-way road is located. The greenery changes by the scenario experienced for every participant.

Figure 27 – Model 1 location of momentary subjective well-being questionnaire 3

Location 4: The fourth location is at the south side of the Stationsplein where most of the greenery is present in the original plans of the KnoopXL development. The location is near the walking bridge that goes over the small water stream of the area and some terrace places are nearby that are also modeled according to the KnoopXL plans.

Figure 28 – Model 1 location of momentary subjective well-being questionnaire 4

Location 5: The last location is on the north side of the Stationsplein close to the station itself. At this spot, the high-rise towers are shown in the distance of District E and the green dependent square is in front of the participant. The variation in models shows the different interpretations of the square according to the experienced scenario. The surrounding areas, besides the considered Stationsplein and District E of KnoopXL are modeled too according to the original plans. This all to make the experience as complete and realistic as possible.

Figure 29 – Model 1 location of momentary subjective well-being questionnaire 5

3.3 Evaluating Well-being After Each iVR Scenario

After each iVR scenario, participants are asked to reflect on their experience before moving on to the next virtual environment. This moment of reflection captures the post-VR scenario well-being and aims to measure how each specific scenario influenced participants' perception and emotional response in a more reflective, slightly delayed way compared to the in-scenario momentary feedback. This is done immediately following each scenario to minimize recall bias and maintain contextual relevance.

The same five well-being indicators that are used in the momentary subjective well-being questionnaire are presented again: safety, stress, comfort, engagement, and pleasure. Now the focus lies on the participant's overall experience of the entire scenario. These indicators are again measured on a 5-point Likert scale, ranging from very negative to very positive, and the format of the questionnaire is kept identical to the version described in section 3.2 and shown in Appendix IV. To maintain a clear and consistent measurement approach, the questionnaire is handed out in paper format directly after each scenario, supervised by the researcher to ensure completion. All responses are later digitalized and processed in SPSS to allow for structured analysis and comparison.

In addition to the five well-being indicators, the post-scenario survey also included four extra questions aimed at understanding participants' behavioral intentions and project perception. These questions cover the likelihood of living in the area, the hypothetical frequency of visits, and the clarity of the KnoopXL project vision as perceived through the given scenario. Answer options for these questions are categorical and standardized to allow meaningful comparison across all participants and scenarios.

This approach integrates elements of stated choice methodology, where participants are not only asked to evaluate how their well-being is, but also how they would hypothetically behave in these environments. These insights provide an indirect and valuable indication of their preferences and priorities when it comes to greenery in dense urban areas. It also offers a way to test whether different configurations of greenery (amount, clustering, seasonal state) have an impact not only on emotional well-being, but also on perceived livability and usability of a place.

Every participant completed this survey four times after each of the four out of eight scenarios they experienced. This repeated measurement design supports within-subject comparison, allowing for more detailed analyses of shifts in perception based on environmental variation.

The results of these analyses will be presented in Chapter 4. The full post-VR scenario questionnaire can be found in Appendix IV

3.4 Evaluating the Overall Well-being of the Experiment

After participants complete all four iVR scenarios, they are invited to reflect on their overall well-being and the experiment as a whole. This final questionnaire aims to capture more generalized emotional responses, offering insight into the long-term impact of the experience. Unlike the scenario-specific post-VR scenario questions, which focus on immediate reactions to each individual environment, the overall well-being responses reflect a broader evaluation of how the entire iVR experiment affects participants' subjective state.

To ensure consistency, the same five well-being indicators (safety, stress, comfort, engagement, and pleasure) are used again. These are measured using the same 5-point Likert scale as in the momentary subjective and post-VR scenario questionnaires. By maintaining this uniform structure across all phases of the experiment, it becomes possible to compare changes and trends in well-being responses over time.

In addition to overall well-being, participants also evaluate the quality of the immersive experience itself. Questions include their perceived sense of presence, clarity of the simulation, and ease of navigation. This information is crucial to understanding how technological factors may influence the effectiveness of the experiment. The outcomes of these questions are further discussed in Chapter 5.

Participants are also invited to provide open-ended feedback. These questions invite comments on the strengths and weaknesses of the experiment, suggestions for improvement, and any other thoughts participants wish to share. This feedback helps to identify potential limitations in the experimental design and offers useful input for future applications of immersive VR in similar research contexts. The open responses are later coded by the researcher for inclusion in qualitative analysis.

All feedback and general experience questions are structured as multiple-choice questions with five predefined categories, along with a "rather not say" option to ensure participant comfort and privacy. The results from this final survey provide valuable input for both the data analysis presented in Chapter 4 and the broader interpretation and implications discussed in Chapter 5. The complete overall questionnaire appears in Appendix V.

3.5 Research Methods Used

In this study, linear regression and fixed-effects panel regression is applied to analyze the influence of varying greenery attributes on human subjective well-being during the immersive Virtual Reality (iVR) simulations. These statistical models are chosen for their ability to quantify the impact of independent variables, such as the amount of greenery, clustering of trees, and seasonal changes, on the dependent variables, which in this case are the momentary subjective, post-VR scenario, and overall well-being scores.

The linear regression model is used to establish the relationship between the greenery attributes and the well-being measures across the different scenarios. This model provided insight into the direct effects of specific greenery attributes such as tree density, clustering, and the presence of leaves on participants' momentary subjective well-being scores as well as their post-VR scenario evaluations. Later, the linear regression model also was used to control for the effect of the personal characteristics on all different well-being outcomes

measured. This analysis provides insight into the relationship between participants' personal characteristics and their different well-being captured measurements.

Given the repeated measures design of the study, with each participant exposed to multiple scenarios, fixed-effects panel regression was implemented. This method connected the personal characteristics with the help of dummy coding to the participants' different measurements due to the four iVR scenarios visited. This helped in creating a better and more accurate understanding of how changes in greenery attributes impacted subjective well-being directly. This approach ensured that the analysis captured the unique responses of each individual to the varying greenery conditions in the iVR simulations with their personal characteristics kept constant and connected to the right participant.

Both regression methods were instrumental in identifying and quantifying the relationships between greenery characteristics and well-being outcomes. The results of these analyses, detailed in Chapter 4, offer important insights into the role of urban greenery in creating more enhanced well-being in high-rise urban environments.

3.6 Data Collection

The data collection took place between February 17th and April 3th, 2025. The experiment took place in the EAISI Digital Twin Lab on the campus of the Eindhoven University of Technology. Due to this location boundary, the aim was to recruit at least 40 participants to create valuable and reliable outcomes. These participants all went through the experiment process of Figure 6, which took +/- 40 min.

Every participant visited 4 of the 8 models while connected to the immersive VR technology. The reason for not visiting all models is the negative impact this could have on the well-being and mood output of participants due to the time all 8 scenario visits would take and the decrease in excitement this could trigger. The allocation of the models and order is randomly generated and attached in Appendix VI. The output is logged in an Excel file and the information about personal characteristics is added and anonymized by the researcher. The order of the experiment follows the questionnaires as mentioned in this Chapter. The use of multiple scenarios varying in specific greenery attributes allows for inference of attribute effects on well-being outcomes measured and the behavioral intentions. The differences and similarities between the momentary subjective well-being during the iVR experiment and the post-VR scenario well-being is analyzed on these varying greenery attributes in the scenarios.

3.7 Ethics and Data Management

The information required for the experiments consists of human participants and their justification for choices made and feelings perceived. This makes it important to conduct the experiments ethical and safe and to keep the perceived data safely stored. Besides safe data management, it is also important to execute the performed research with integrity, since the outcomes need to be reliable and truly based on the participants' input. The general principles of the Dutch code of conduct are: Honesty, Scrupulousness, Transparency, Independence, and Responsibility. This code of conduct together with the ethical board review on the TU/e forms the base of secure, ethical, and integer data management (NWO, 2018). The ERB approval number is ERB-229.

To secure the transparent approach, the participant needs to be well informed and consent to the experiment beforehand (research purpose, their role, right to withdraw, risks e.g. motion sickness). This includes sufficient written information to be able to decide whether or not they

want to perform the experiment and also approval to use the given information during the experiment. This will be signed with the help of a form before the experiment starts.

The names of the participants will not be needed, so instead a participant number will be assigned to the data perceived. Any other personal data such as gender, age, living area, etc. will be used to analyze possible relations between these personal characteristics and the user experience. The data gathered will be listed beforehand. The participant number will secure safety and make the person anonymized for others. By not providing the persons collected data per participant, but only summarized data in the relation analyses the participant will never be recognizable for readers of the report.

After the experiment, participants will be debriefed to explain the study's goals and ensure their well-being.

3.8 Conclusion

In conclusion, this chapter provides a detailed research methodology that will be used to explore the effects of changing greenery attributes on human well-being in a high-rise urban environment. During this research, immersive virtual reality (iVR) will be used as a tool to analyze the momentary subjective well-being effect in a controlled environment. By simulating the future project called KnoopXL in Eindhoven, the research enables participants to evaluate and experience different greenery scenarios in a realistic and immersive environment before any physical implementation takes place.

Advanced gaming and modeling software such as Twinmotion and Unreal Engine are used to create eight detailed iVR scenarios, which will vary in season (having leaves/not), tree amount, and tree clustering. With the help of immersive pop-up questionnaires on five strategically chosen spots in the iVR scenarios, the momentary subjective well-being of the participants is measured on safety, stress, comfort, excitement, and pleasure across the different greenery setups of the KnoopXL project. To ensure full immersion during the sessions, features such as teleportation movement, animated greenery, and natural hand representations were added to the simulations.

There are different methods used during this research. The stated choice and factorial design play a role in the experiment. Firstly, this experiment does not utilize a formal stated choice model, elements of stated choice are present in the post-scenario questionnaires, where participants express their intended usage, residential interest, and changed perspectives based on systematically varied hypothetical environments. These stated intentions provide indirect insight into participant preferences and the perceived value of different greenery configurations. The factorial design is used to allow each participant to explore four of the eight scenarios. This decision is made to avoid fatigue and so maintain data reliability on excitement and other well-being factors. The use of a factorial design (8 scenarios based on 3 binary

greenery attributes) allows for inference of greenery attribute effects on well-being outcomes and behavioral intentions.

Both linear regression and fixed-effects panel regression significantly contributed to the depth and reliability of the analysis. These methods enabled a nuanced understanding of how specific greenery attributes (amount, clustering, and season) affect human subjective well-being in immersive virtual environments. By controlling for personal characteristics and accounting for repeated measures, the analysis provided robust evidence of the psychological value of urban greenery in high-rise urban environments.

The ethical practices are taken into concern through informed consent, anonymized data storage, and alignment with the Dutch Code of Conduct for Scientific Integrity. Furthermore, specific measures were implemented to minimize the risk of occurring cybersickness. The participants are limited exposed to the models by entering four of the in total eight scenarios, teleportation is used instead of free movement, and a clear structural briefing with explanation of stopping the simulation if any discomfort occurs is provided before the session. These precautions helped to maintain the comfort and safety of the participants.

Altogether, this robust methodology bridges technology, urban design, and psychological research, providing a reliable framework to assess the influence of green space design on human well-being (short- and long-term) in unbuilt urban projects. The insights gained can directly be used in planning decisions and contribute to healthier, human-centered city development of high-rise green areas.

4 Results

This section will discuss the results of the experiments and evaluate the gathered dataset with the findings of the studied literature. Research sub-questions 3,4, and 6 will be answered with the results of the experiment. First, the sample characteristics will be discussed, followed by the momentary subjective feedback of the participants on the tested greenery attributes which are: trees having leaves or not, amount of trees, and clustering of trees. The post-VR scenario well-being will be analyzed, and connections will be made with the momentary subjective well-being and the well-being after all scenarios. The processes of data coding and open-question handling will be discussed. At the end of the chapter, the main question about the influence of the tested greenery attributes on human well-being and the role of momentary subjective well-being feedback will be answered with the help of the analyzed data.

4.1 Sample Characteristics

During a period of 7 weeks, with 4 weeks delay due to a hardware failure, 40 participants are gathered in the Digital Twin Lab of the TUe. The data collection took place between February 17th and April 3th, 2025. It took approximately 40 minutes for every participant to complete the total process of surveys and virtual tours in the 4 scenarios assigned as shown in Appendix VI and described in Figure 6. Of the 40 participants 29 identify as male and 11 as female. All participants answered all questions and completed 4 iVR scenarios, thus there are no missing values or “rather not saying” answers.

The age of the participants is collected into categories. To have a sufficient distribution and reliable group size the original categories of the questionnaire are reduced to the age of the participants between 18-24 years and >24. In this way, both categories have a sufficient group size to use in the analysis of the research. In Table 4 all original data and frequencies together with the restructured categories used for the analysis is provided.

Other data, besides age, that is collected and processed in the same way before the experiment started is: current living environment, amounts of visits to a high-density city center, amounts of visits to a high-density environment with noticeable greenery, personal importance of greenery to enjoyment of an area, the subjective importance of greenery to individual's well-being, familiarity with urban design or architecture, familiarity with KnoopXL project, and previous experience with iVR technology or simulation.

Table 4 – Restructured data categories and frequencies

Subject	Original categories	Number of Participants	Percentage of Sample	Restructured categories	Number of Participants	Percentage of Sample
Gender	Male	29	72,5%	Male	29	72,5%
	Female	11	27,5%	Female	11	27,5%
Age	<18	-	-	18-24	25	62,5%
	18-21	3	7,5%	>24	15	37,5%
	22-24	22	55%			
	25-27	8	20%			
	28-30	3	7,5%			
	31-40	1	2,5%			
	41-50	-	-			
	50-65	2	5%			
	>65	1	2,5%			
Living Environment	Urban	15	37,5%	Urban	15	37,5%
	Suburban	3	7,5%	Sub Urban Area	25	62,5%
	Small Town	22	55%			
	Rural	-	-			
High-Density City Visits	Daily	11	27,5%	Daily	11	27,5%
	Multiple times a week	11	27,5%	Multiple times a week	11	27,5%
	Once a month	14	35%	Once a month or less	18	45%
	Once every 3 months	3	7,5%			
	Once a year	1	2,5%			
	Other	-	-			
High-Density City with Noticeable Greenery Visits	Daily	10	25%	Daily	10	25%
	Multiple times a week	9	22,5%	Multiple times a week	9	22,5%
	Once a month	16	40%	Once a month or less	21	52,5%
	Once every 3 months	4	10%			
	Once a year	1	2,5%			
	Other	-	-			
Greenery Importance to enjoyment in area	Not important	-	-	Important, but no priority	20	50%
	Slightly	-	-	Priority	20	50%
	Somewhat	1	2,5%			
	Important	19	47,5%			
	Very Important	20	50%			
Greenery Importance on Well-being	Not at all	-	-	Not extremely important	20	50%
	Slightly	-	-	Extremely important	20	50%
	Moderately	3	7,5%			
	Very much	17	42,5%			
	Extremely	20	50%			
	Not familiar	25	62,5%	Not familiar	25	62,5%
	Slightly	4	10%	Familiar	15	37,5%

Familiarity with Urban Design	Moderately	3	7,5%			
	Very familiar	8	20%			
Familiarity with KnoopXL project	No	24	60%	Not familiar	24	60%
	Yes seen announcements	7	17,5%	Familiar	16	40%
	Yes aware of project	9	22,5%			
Previous iVR experience	No	30	75%	No	30	75%
	Yes	10	25%	Yes	10	25%

The sample's living environment consisted mainly of individuals living in small towns in suburban areas or urban environment inhabitants. The suburban category is represented the most in the sample (62,5%), which consists mostly of people living around Eindhoven just outside the city or students who travel to Eindhoven from their parental home.

Furthermore, the frequency of visits to a high-rise environment and the amount of noticeable green in these areas are collected. There are 3 categories used in the restructured data, ranging from daily to once a month or less. As visible in the table, most of the time the amount of visits to the high-density city is almost equal to the visits with noticeable green, but sometimes the noticeable green was less visited than a high-density city. This could mean that not all high-density cities are experienced with noticeable green by the participants.

The importance of greenery is categorized into two groups: “priority” and “important, but not a priority.” Both categories were selected 20 times, resulting in an even 50/50 split across the sample. This indicates that while greenery is widely acknowledged as relevant, there is a clear divide in the degree to which participants prioritize it. Half of the respondents view greenery as a top priority, while the other half recognize its value but do not describe it as a priority.

The data structure of the subjective outcome of greenery for human well-being is in the same composition as the one of greenery importance above. This means that the sample values the greenery as important and a significant contribution to their well-being. Just as the greenery importance to enjoyment in the area, 2 restructured categories are provided labeled as “extremely important” and “not extremely important”. These are also chosen 20 times each.

Since the experiment took place on the TU/e campus, it was expected that some participants might have a background in architecture or urban planning and thus be familiar with ongoing developments in Eindhoven. For this reason, questions were included regarding participants’ familiarity with urban design and with the KnoopXL case study. Most respondents indicated that they were unfamiliar with both urban design and the KnoopXL project. This suggests that the sample consisted largely of individuals without a specific academic or professional link to the built environment, contributing a more general public perspective to the results.

Not only were participants asked about their familiarity with the urban design and the specific project used in the simulation, but their previous experience with immersive virtual reality (iVR) technology was also taken into account. This was done to better understand how prior exposure to immersive environments might influence participants' responses during the experiment. Out of the total participant group, 30 individuals reported having no prior experience with iVR, indicating that for the majority, this experiment was their first encounter with immersive technology. The remaining 10 participants indicated some level of familiarity, primarily through gaming applications. However, only a few of them had ever interacted with iVR in the context of built environment simulations.

4.2 Momentary Subjective Well-being Analysis

4.2.1 Descriptive Analysis of the Effect of Greenery Attributes on Momentary Subjective Well-being

To start the analysis of the greenery attributes of the experiment (having leaves or not, amount of trees, clustering of trees) and their effect to the momentary subjective well-being scores, Cronbach's Alpha is computed. Cronbach's Alpha shows good internal consistency with a score of 0,853. The composite score that will be used for this scenario in further analytical research is calculated to replace all values provided to the 5 inputs in every scenario and spot. This is done with the formula: $(Q_{safety} + Q_{comfort} + Q_{pleased} + Q_{stress} + Q_{excited}) / 5$. These 5 questions are asked after every scenario visited by the participants and answered on a 5-point Likert Scale, with 1 related to the most negative output of the question and 5 as the most positive. These outputs are the values used in the formula. The calculation provided in SPSS is shown below with its reliability included.

After obtaining a reliable Cronbach's Alpha score, confirming internal consistency among the well-being indicators, further analysis was conducted to explore how different combinations of scenarios and spatial settings influenced participants' momentary subjective well-being. This enabled a comparison across all experimental conditions to determine which specific scenario and location pairing resulted in the highest overall well-being outcomes. In this analysis, momentary subjective well-being is treated as the dependent variable, while the various scenarios and spatial positions serve as independent factors. By comparing the mean momentary subjective well-being scores across these different combinations, insights can be gained into which environmental configurations, such as tree density, clustering, or seasonal effects, are perceived most positively by participants. The corresponding results of this comparative analysis are presented in Tables 7 and 8. As a reminder the scenarios and spots with their greenery and locational attributes are shortly shown again in Tables 5 and 6, just as they were elaborated and described in Chapter 3.2.

Table 5 – Overview of scenario variation with greenery attributes attached

Model:	*Aspect 1: leaves*	*Aspect 2: amount of trees*	*Aspect 3: clustering*
1	Having leaves	Many trees (30)	Clustered
2	Having leaves	Many trees (30)	Not clustered
3	Having leaves	Low amount trees (15)	Clustered
4	Having leaves	Low amount trees (15)	Not clustered
5	Not having leaves	Many trees (30)	Clustered
6	Not having leaves	Many trees (30)	Not clustered
7	Not having leaves	Low amount trees (15)	Clustered
8	Not having leaves	Low amount trees (15)	Not clustered

Table 6 – Spot locational characteristics

Spot:	*Locational characteristics*
1	Between 3 high-rise buildings with a small green park nearby
2	Near a car road. Spot is dominated by lower greenery bushes
3	Near one of the high-rise buildings and next to a water stream
4	South side of the Stationsplein near a walking bridge with a lot of trees nearby
5	North side of the Stationsplein close to the station building itself with a lot of trees nearby

The spot Table 7 shows which one of the 5 spots measured in every scenario is contributing the most to momentary subjective well-being scores. The highest momentary subjective well-being score is on spot 3, where the participant is standing close to a high-rise building with on the other side a small stream of water. The waterside is covered with some greenery in every scenario with some of the scenarios containing more trees or leaves etc. according to the scenario ID. In all scenarios, this spot was the most favorable to positive momentary subjective well-being possibly due to its greenery and surrounding factors. The mean momentary subjective well-being score here is 4,18 on the 5-point Likert Scale with a standard deviation factor of 0,442. This is the lowest standard deviation score which means that the experiences were not only positive, but also more consistent on this spot.

The lowest momentary subjective well-being score is attached to spot 2, where the surrounding area is a road suitable for cars with greenery that will differ according to every specific scenario. Another important aspect of this location is the bigger amount of low greenery compared to the other spots where the trees are more dominant. This low greenery is changing, just for the scenarios of having leaves or not, and remains the same for the clustering and amount of tree variants also shown in Chapter 3.2.2 Figure 15 and 16.

Table 7 – Momentary subjective well-being score mean of the spots in the scenarios

Spot	Mean	Standard Deviation
1	3,76	0,501
2	3,31	0,501
3	4,18	0,442
4	3,88	0,487
5	3,81	0,496
Total	3,79	0,559

As visible in Table 8, spot 1 showed the highest scores in scenarios 6, 1, and 5, and the lowest in scenarios 8, 4, and 7. Scores varied depending on the scenario, with especially noticeable differences in the amount of trees and seasonal change. Compared to other spots, spot 1 generally scored in the mid-range. Spot 2 received the lowest overall scores across most scenarios. Even in scenarios where other spots scored higher, spot 2 remained low. The highest scores were in scenarios 1, 6, and 2; the lowest in scenarios 4, 8, and 5. When compared to the other locations, spot 2 consistently ranks lowest. Spot 3 showed the highest values across all scenarios. Scenarios 1, 2, and 5 recorded the top scores here. Even the lowest-scoring scenarios at this spot (scenarios 8, 4, and 7) had higher scores than the top scores at other spots. Spot 3 stands out as the most positively experienced location in every scenario. Looking at spot 4, the scores were highest in scenarios 6, 1, and 2, and lowest in scenarios 8, 7, and 4. The differences between scenarios were moderate. Compared to spot 1 and spot 5, spot 4 followed a similar pattern, with slightly lower values overall than spot 3, and higher values than spot 2. Lastly, spot 5 showed the highest scores in scenarios 6, 1, and 2, and the lowest in scenarios 4, 8, and 7. The range of scores between scenarios was limited, showing relatively stable values. Spot 5 scored consistently above spot 2, slightly below spot 3, and similarly to spot 1 and spot 4.

Table 8 – Momentary subjective well-being score comparison between scenarios and mean of spots in the scenario

	Spot 1	*Spot 2*	*Spot 3*	*Spot 4*	*Spot 5*
Scenario 1	3,90	3,60	4,37	3,97	3,90
Scenario 2	3,82	3,39	4,25	3,94	3,89
Scenario 3	3,77	3,25	4,15	3,93	3,82

Scenario 4	3,62	3,14	4,09	3,83	3,65
Scenario 5	3,83	3,23	4,20	3,92	3,89
Scenario 6	3,92	3,46	4,21	4,06	3,96
Scenario 7	3,67	3,25	4,12	3,74	3,72
Scenario 8	3,57	3,19	4,03	3,64	3,68

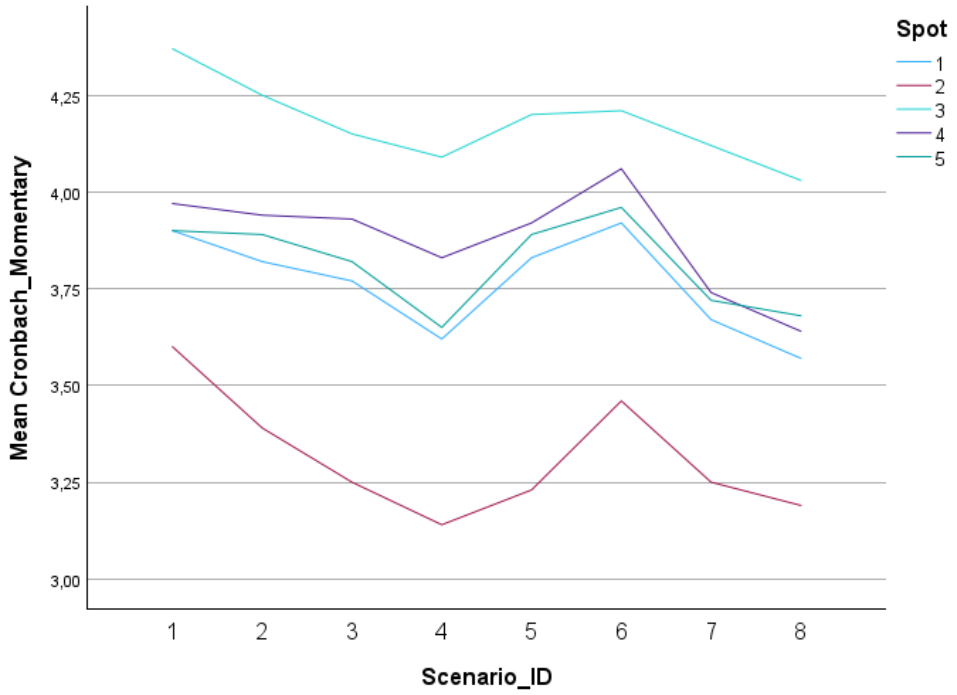

Figure 30 – Momentary subjective well-being scores for each scenario and spot

To see if scenarios 1 to 4 are more favorable than scenarios 5 to 8 for this spot a specific graph is made that compares all scenarios and spots combined just as in Table 8. As visible in this graph of Figure 30 the most ideal interaction between spot and scenario is: scenario 1 spot 3. Here the highest mean momentary subjective well-being among the participants is measured with a score of 4,37. What can also be seen in the graph is that the measured momentary subjective well-being scores at each spot are lower in scenario 4 compared to the other scenarios. This means that this scenario with less trees, not clustered, and having leaves is experienced less positive for the momentary subjective well-being than the other scenarios. It is also seen that momentary subjective well-being scores are lower at spot 2 compared to other spots and that occurs in every scenario, which means that the environment around this spot is less favored to create positive experiences.

4.2.2 Linear Regression Analysis of Greenery Attributes Effects on Momentary Subjective Well-being

To find the statistical significance of the greenery attributes' effect on the momentary subjective well-being, a linear regression is performed. The goal of this analysis is to see which greenery attributes have a significant effect on the momentary subjective well-being of a participant, who visits 4 different scenarios with each of 5 spots where only the greenery attributes change between the scenarios. The outcome must explain how every participant's momentary subjective well-being changes significantly due to the changing greenery attributes. In this way, the influence of the greenery attributes is analyzed on the participant's momentary subjective well-being. The momentary subjective well-being scores are the dependent variable, and the greenery attributes are added as predictors to the model. The outcomes are

checked on the p-value for the significance and the estimated addition positive or negative to the momentary subjective well-being for each greenery attribute.

Table 9 – Model summary of linear regression analysis momentary subjective well-being

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Linear regression model	0,182[a]	0,033	0,030	0,55053

Predictors: Tree_Clustering, Tree_Amount, Season; Dependent variable: momentary subjective well-being

The R Square value equals 0.033, as can be seen in the model summary in Table 9, which means that only 3.3% of the momentary subjective well-being can be explained by the greenery attributes.

Table 10 – ANOVA model momentary subjective well-being with greenery attributes as predictors

Model		Sum of Squares	df	Mean Square	F	Sig.
ANOVA	Regression	8,297	3	2,766	9,126	<0,001[b]
	Residual	241,250	796	0,303		
	Total	249,548	799			

a. Dependent Variable: Momentary subjective well-being Cronbach's Alpha score

b. Predictors:Tree_Clustering, Tree_Amount, Season

The ANOVA test was conducted to evaluate whether the combined greenery attributes significantly contribute to explaining the variance in momentary subjective well-being across all scenarios. Table 10 revealed a statistically significant result with a p-value < 0.001, indicating that the regression model including these predictors explains significantly more variance than a model without them.

This outcome confirms that the combination of greenery attributes tested in this study has a meaningful overall impact on how participants experienced momentary subjective well-being in immersive VR environments. While the ANOVA result does not specify which individual attribute drives this effect, it establishes that at least one or more of the greenery attributes plays a statistically significant role in shaping well-being responses. The specific contribution of each variable will be further examined in the regression coefficient analysis.

Table 11 – Coefficients table of a linear regression model with dependent variable momentary subjective well-being and greenery attributes as predictors

		Unstandardized Coefficients		Standardized Coefficients		
Model	Greenery attribute	B	Std. Error	Beta	t	Sig.
Regression coefficients	(Constant)	4,219	0,103		40,964	<0,001
	Having leaves	0,049	0,039	0,044	1,272	0,204
	Without leaves	0				

	Many Trees	0,193	0,039	0,172	4,945	<0,001
	Less Trees	0				
	Clustered	0,044	0,039	0,040	1,143	0,253
	Not Clustered	0				

a. Dependent Variable: Momentary subjective well-being Cronbach's Alpha score

As visible in Table 11 the constant value of the model explains the mean score of the momentary subjective well-being. This score is 4.219 for the momentary subjective well-being. The tree amount, with a p-value of <0.001, is the only significant greenery attribute contributing to the participants' momentary subjective well-being. The estimated value for the amount of trees is 0.172. This means that more trees in a scenario had a significant positive effect on the momentary subjective well-being of participants compared to a scenario with the greenery attribute level of less trees.

Having leaves or not turns out as not significant, which is quite surprising, since the descriptive analysis of Chapter 4.2.1 showed a big difference in the mean score between scenarios with leaves compared to scenarios without leaves (1.1 point on the 5-point Likert Scale). Possible reasons for the not significant score are that the amount of trees is more important for the momentary subjective well-being or that the spread between the scenarios is too big to be sure that the difference is significant. The sample size needs to be expanded to prove a statistical difference that having leaves is affecting momentary subjective well-being.

Since the scenarios are built up out of different greenery attributes it would be valuable to see which greenery attribute had a significant influence on a certain spot. These interactions are included in the linear regression model:

- spot * having leaves or not
- spot * amount of trees
- spot * clustering of trees

The outcome will show if the interactions are significant, which shows that a specific spot could have more influence on a different greenery attribute of momentary subjective well-being and which of the greenery attributes is the most influential. The result is compared to the baseline, which is the opposite of the tested interaction of the greenery attributes. For example, the spots and the scenarios with leaves are positive or negative compared to the scenarios with an interaction between spots and environments without leaves. That is why the scenarios without leaves are shown as zero in the table. The results are summarized in Table 12. The R^2 value of this regression was 0.062, which means that the model explains 6,2% of the variance in the dependent variable (Crohnbach's Alpha score of momentary subjective well-being).

Table 12 – Estimates of Linear Regression with Interactions added to Momentary Subjective Well-being and greenery attributes

Parameter	Estimate	*Significance (p-value)*
Intercept	*4.091*	*<0.001*
Having leaves	*0.064*	*0.353*
Without leaves	*0*	*-*
Many Trees	*0.159*	*0.020*
Less Trees	*0*	*-*
Clustered Trees	*0.003*	*0.969*
No Clustered Trees	*0*	*-*
Spot 1	*-0.085*	*0.374*

Spot 2	*-0.540*	*<0.001*
Spot 3	*0.330*	*<0.001*
Spot 4	*0.037*	*0.695*
Spot 5 (baseline)	*0*	-
Having leaves * Spot 1	*0.028*	*0.774*
Having leaves * Spot 2	*0.060*	*0.530*
Having leaves * Spot 3	*0.073*	*0.448*
Having leaves * Spot 4	*0.075*	*0.433*
Having leaves * Spot 5	*0.068*	*0.497*
(Baseline Without leaves * Spot X)	*0*	-
Many Trees * Spot 1	*0.018*	*0.855*
Many Trees * Spot 2	*0.020*	*0.834*
Many Trees * Spot 3	*-0.032*	*0.734*
Many Trees * Spot 4	*-0.005*	*0.958*
Many Trees * Spot 5	*-0.024*	*0.812*
(Baseline Less Trees * Spot X)	*0*	-
Clustered * Spot 1	*0.023*	*0.814*
Clustered * Spot 2	*9.944E-14*	*1.000*
Clustered * Spot 3	*0.028*	*0.774*
Clustered * Spot 4	*-0.015*	*0.875*
Clustered * Spot 5	*0.021*	*0.832*
(Baseline Not Clustered * Spot X)	*0*	-

The intercept estimate of 4.091 ($p < 0.001$) represents the baseline momentary well-being score. This score is statistically significant and serves as the reference point for interpreting all other effects in the model. The analyses showed that only the amount of trees had a significant positive effect on momentary subjective well-being (β = 0.159, p = .020). The other two greenery attributes (having leaves or not, clustering) were not significant. The effect of tree amount was consistent across spots within scenarios. There were no significant interactions found between greenery attributes and spots. This means that the different greenery attributes affect momentary subjective well-being approximately the same in every spot. However, some spots were found to be significantly more pleasant (Spot 3) or less pleasant (Spot 2) independently of tree characteristics. This could be explained by external factors such as the road with cars located near spot 2 and the water stream located near spot 3.

4.2.3 Fixed Effects Panel Regression: Momentary Subjective Well-being

The personal characteristics of the participants need to be fixed during the analysis to prevent individual biases. If the fixed effects panel regression is not considered the analysis will be about the 160 rows seen as 160 individuals instead of 40 rows of individuals who each visit 4 scenarios but have the same personal characteristics. (Brüderl & Ludwig, 2015).

To perform this fixed effects panel regression in SPSS the Least Squares Dummy Variable (LSDV) approach can be used. This is done by creating a dummy variable that sets the personal characteristics of every person to his/her participant ID. In total for the 40 participants, 39 dummy variables were created for their IDs, with ID=1.0 used as a reference to avoid multicollinearity. In this way, the personal characteristics are fixed to the participant's dummy ID for all four models visited by the same participant. After this dummy creation and addition to the first regression model, a second regression model is added to the analysis where the greenery attributes are included. In this way, a comparison and contribution of the greenery attributes can be analyzed without interference of the personal characteristics due to the fixed effect panel regression method. This is summarized in Table 13.

Table 13 - Variables entered to perform a fixed effect panel regression with dependent variable momentary subjective well-being

Regression model	Variables entered to model
1	ID=2.0 till ID=40.0
2	ID=2.0 till ID=40.0, Seasonal effect, Tree Amount, Tree Clustering

The model summary in Table 14, shows that 19,2% of the variation in momentary subjective well-being scores occurs between participants, since the R square value of the first regression model equals 0.192. Looking at the R square of the second regression model, which equals 0.209, this model explains 20,9% of the variation in momentary subjective well-being between participants. The R square value change from model 1 to model 2 is 0.017, which means that the addition of the greenery attributes accounts for 1,7% of the variation. Model 1 included the dummy categories to make the personal characteristics a fixed value to the right participant ID and the second model had the addition of greenery attributes compared to model 1. This result is also significant as visible in Table 14 by the significant F change score below 0.05.

Table 14 – Model summaries of fixed effect panel regression

	R	R Square	Std. Error of the Estimate	R square change	F change	Significance F change
Model 1	0,438	0,192	0,51515	0,192	9,126	<0,001
Model 2	0,457	0,209	0,51060	0,017	4,766	<0,001

Table 15 – ANOVA of panel regression with momentary subjective well-being as dependent variable

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	47,862	39	1,227	4,624	<0,001
	Residual	201,686	760	0,265		
	Total	249,548	799			
2	Regression	52,185	42	1,243	4,766	<0,001
	Residual	197,362	757	0,261		
	Total	249,548	799			

The entire coefficients table is shown in Appendix VIII, but the most important aspects and outcomes are shown in Table 16 together with the main conclusions and interpretations. All values to the ID dummies are left out to spot the differences between regression model 1 and regression model 2 where the greenery aspects are included. These ID dummies were the only outcome of model 1 since the greenery attributes are the addition in model 2 to make a comparison possible and analyze the contribution of the greenery attributes. In this way, the effect and significance could be explained, while the personal characteristics are attached to the dummy ID's of each participant.

Table 16 – Effect of greenery attributes on momentary well-being in a fixed effect panel regression

		Unstandardized B	Standardized Beta	Std. Error	Sig.
Model 1	(Constant)	3,590		0,115	<0,001
Model 2	(Constant)	3,764		0,153	<0,001
	Having leaves	0,031	0,028	0,039	0,423
	Without leaves	0		-	-
	Many Trees	0,152	0,136	0,038	<0,001
	Less Trees	0		-	-
	Clustered	0,004	0,004	0,039	0,909
	Not Clustered	0		-	-

As visible in Table 16 the constant values of 3.590 (Model 1) and 3.764 (Model 2) represent the baseline well-being score when the base greenery attributes (no leaves, low amount of trees, not clustered) are included in the model. The slight difference between these constants indicates that Model 2 may include other unmeasured factors or characteristics (potentially captured by the model) that positively influence momentary subjective well-being compared to Model 1.

Furthermore, the greenery attributes analyzed from Table 16 indicate that scenarios with more trees have a positive coefficient compared to scenarios with less trees, suggesting that an increase in the number of trees increases momentary subjective well-being by 0,136. This implies that participants may prefer environments with more dense tree coverage. The greenery attribute of clustered trees shows a non-significant effect, with a Standardized Beta coefficient close to zero (B = 0.004). This suggests that tree clustering does not meaningfully affect momentary subjective well-being. Whether trees are clustered or evenly spread does not appear to significantly alter the momentary subjective well-being in the immersive virtual environments used in this study. The seasonal greenery aspect also has a small positive Standardized Beta coefficient (0.028) and is not statistically significant (p = 0.423). This indicates that the presence or absence of leaves does not have a significant effect on participants' momentary subjective well-being, suggesting that seasonal variation in greenery does not substantially influence momentary subjective well-being responses in high-rise urban environments.

4.3 Post-VR Scenario Well-being Analysis

4.3.1 Descriptive Analysis of the Effect of Greenery Attributes on Post-VR Scenario Well-being

To analyze post-VR well-being after every scenario visit, Cronbach's Alpha is calculated just as performed for the momentary subjective well-being in Chapter 4.2.1.

Table 17 – Cronbach's Alpha output SPSS post-VR scenario well-being

Cronbach's Alpha	*N of Items*
0,931	*5*

The Cronbach's Alpha is very strongly reliable with a score above 0,9. The composite score that will be used for this scenario in further analytical research is calculated to replace all values provided to the 5 inputs in every scenario.

To analyze if the tested greenery attributes of having leaves or not, the amount of trees, and the clustering of trees are affecting the participants' post-VR scenario well-being a linear regression analysis is performed. The input is Cronbach's Alpha of the participants' post-VR scenario well-being as a dependent variable and the changing greenery attributes out of the different scenarios as predictors.

Firstly, the mean and standard deviation of post-VR scenario well-being are analyzed in the scenarios. Where the momentary subjective well-being analyses the mean of the spots too, the post-VR scenario well-being takes just the scenarios into account since the score is about the well-being experienced during the entire scenario and not the influence of the spots in particular. The mean and standard deviation are analyzed to see if there is a difference in post-VR well-being in certain scenarios after they are experienced. The results are shown in Table 18.

Table 18 – Post-VR scenario well-being score mean of the scenarios

Scenario	Mean	Standard Deviation
1	4,65	0,394
2	4,52	0,423
3	4,01	0,381
4	3,77	0,391
5	3,50	0,488
6	3,51	0,418
7	3,12	0,333
8	2,71	0,438
Total	3,72	0,748

There is a trend visible in the mean scores, which shows that the scenarios with a higher number have a decreasing mean post-VR scenario well-being score. This suggests that scenarios having leaves (1 to 4) result in a more positive score than scenarios without leaves (5 to 8). Also, a bigger tree amount (scenarios 1,2,5, and 6) provided a higher score than the scenarios with the same greenery attributes but less trees (3,4,7, and 8). The effect of the clustering of trees in scenarios 1,3,5, and 7 seems to be not that large compared to the scenarios with the same greenery attributes but non-clustered trees 2,4,6, and 8. In scenario 5 the clustering of trees resulted in a less positive post-VR scenario well-being score, compared to scenario 6 with the same greenery attributes but non-clustered trees.

Besides the mean score difference, there are also some interaction effects visible. For instance, tree clustering seems more important in certain conditions. During scenarios with leaves and many trees, the clustering seems not that important with a score of 4,65 for the clustered variants and 4,52 for the non-clustered variants. But looking at the scenarios without leaves and less trees, the clustered variants have a mean post-VR scenario well-being score of 3,12 while the non-clustered variants have a score of 2,71. This is a large difference between the different conditions. The tree clustering seems to have the biggest effect on the scenarios with less trees during the winter season.

4.3.2 Linear Regression Analysis of Greenery Attributes Effects on Post-VR Scenario Well-being

To investigate the impact of greenery attributes on post-VR scenario well-being, a linear regression analysis was performed. The goal of this analysis is to assess which greenery attributes have a significant effect on the post-VR scenario well-being of participants after experiencing one of the four scenarios. As with the analysis for momentary subjective well-being, this model aims to explain how each participant's post-VR scenario well-being changes significantly based on the different greenery attributes. The dependent variable is post-VR scenario well-being, while the greenery attributes are treated as predictors in the regression model. The statistical significance of the predictors is assessed via the p-value, and their estimated effect (positive or negative) on post-VR well-being is also determined.

Table 19 – Model summary of linear regression analysis on post-VR scenario well-being

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Linear regression model	0,833	0,695	0,689	0,41204

Predictors: Tree_Clustering, Tree_Amount, Season; Dependent variable: momentary subjective well-being

The Model Summary in Table 19 shows an R value of 0.833, indicating a strong positive correlation between the greenery attributes and post-VR scenario well-being. The R^2 value of 0.695 means that 69.5% of the variance in post-VR scenario well-being is explained by the predictors in the model. This suggests a relatively high explanatory power of the greenery attributes in relation to post-VR scenario well-being. The Adjusted R^2 of 0.689 adjusts for the number of predictors and confirms that the model remains robust despite the inclusion of multiple predictors. The Standard Error of the Estimate is 0.41204, indicating a moderate level of error in predicting post-VR well-being.

Table 20 – ANOVA model post-VR scenario well-being with greenery attributes as predictors

Model		Sum of Squares	df	Mean Square	F	Sig.
ANOVA	Regression	60,225	3	20,075	118,224	<0,001[b]
	Residual	26,485	156	0,170		
	Total	86,710	159			

a. Dependent Variable: Post-VR well-being Cronbach's Alpha score

b. Predictors:Tree_Clustering, Tree_Amount, Season

The ANOVA test (Table 20) was conducted to determine whether the greenery attributes significantly contribute to explaining the variance in post-VR scenario well-being. The F-value of 118.224 and the p-value of < 0.001 indicate that the regression model is statistically significant. This means that the combination of greenery attributes tested in this study significantly improves the outcomes of post-VR scenario well-being when compared to a model with no predictors. While the ANOVA does not specify which individual greenery attribute is most significant, it confirms that at least one of the greenery attributes plays a meaningful role in shaping participants' well-being in virtual environments.

Table 21 – Coefficients table of a linear regression model with dependent variable post-VR scenario well-being and greenery attributes as predictors

		Unstandardized Coefficients		Standardized Coefficients		
Model	Greenery attribute	B	Std. Error	Beta	t	Sig.
Regression coefficients	(Constant)	3,518	0,172		37,812	<0,001
	Having leaves	1,027	0,065	0,698	15,772	<0,001
	Without leaves	0				
	Many Trees	0,642	0,065	0,436	9,862	<0,001
	Less Trees	0				
	Clustered	0,193	0,065	0,131	2,955	0,004
	Not Clustered	0				

a. Dependent Variable: Post-VR scenario well-being Cronbach's Alpha score

The regression analysis results are summarized in the Coefficients Table (Table 21), which presents the individual contributions of the greenery attributes having leaves, tree amount, and tree clustering on post-VR scenario well-being. The coefficients for each predictor provide valuable insight into the direction and strength of their effects on the dependent variable post-VR scenario well-being.

The coefficient for having leaves is positive ($B = 0.698$) and statistically significant ($p < 0.001$), suggesting that the presence of leaves on trees leads to a 0.698-point increase in post-VR scenario well-being. This finding emphasizes the importance of seasonal variation in greenery, highlighting that participants in scenarios with trees that have leaves report significantly better well-being compared to scenarios with trees that have no leaves.

Tree amount is also a significant predictor of post-VR scenario well-being, with a positive coefficient of 0.436 ($p < 0.001$). This indicates that environments with more trees are associated with a 0.436-point increase in post-VR scenario well-being. This result suggests that participants respond positively to environments with more trees and greenery present. More trees, therefore, contribute to better post-VR scenario well-being for participants after each of these simulated environments.

The coefficient for tree clustering is also positive and statistically significant ($B = 0.131$, $p = 0.004$), indicating that clustered trees have a positive effect on post-VR scenario well-being. However, the impact is less pronounced compared to the tree amount and having leaves. The positive but smaller coefficient suggests that tree clustering slightly enhances well-being, but its effect is smaller in comparison to the other greenery attributes. Nonetheless, it still contributes positively to the overall user experience in the virtual environments, highlighting the value of tree arrangement in green space design.

4.3.3 Fixed Effects Panel Regression: Post-VR Scenario Well-being

The personal characteristics of the participants need to be fixed during the analysis to prevent individual biases just like the analysis performed on the momentary subjective well-being of Chapter 4.2.3. The same LSDV approach is used to perform this fixed effects panel regression in SPSS.

Table 22 - Variables entered to perform a fixed effect panel regression with dependent variable post-VR scenario well-being

Regression model	Variables entered to model
1	ID_dummy=2.0 till ID_dummy=40.0
2	ID_dummy=2.0 till ID_dummy=40.0, Seasonal effect, Tree Amount, Tree Clustering

The model summary in Table 23, shows that 26% of the variation in momentary subjective well-being scores occurs between participants, since the R square value of the first regression model equals 0.260. Looking at the R square of the second regression model, which equals 0.877, this model explains 87,7% of the variation in momentary subjective well-being between participants. The R square value change from model 1 to model 2 is 0.617, which means that the addition of the greenery attributes accounts for 61,7% of the variation. However, model 1 was not statistically significant due to the F change significance score of 0.364. Model 2 significantly improves the model's explanatory power, as evidenced by both the substantial increase in R^2 and the statistical significance of the F-change.

Table 23 – Model summaries of fixed effect panel regression

	R	R Square	Std. Error of the Estimate	R square change	F change	Significance F change
Model 1	0,510	0,260	0,73115	0,260	1,082	0,364
Model 2	0,937	0,877	0,30146	0,617	19,931	<0,001

Table 24 – ANOVA of fixed effect model with post-VR scenario well-being as dependent variable

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22,560	39	0,578	1,082	0,364
	Residual	64,150	120	0,535		
	Total	86,710	159			
2	Regression	76,077	42	1,811	19,931	<0,001
	Residual	10,633	117	0,091		
	Total	86,710	159			

The entire coefficients table is shown in Appendix IX, but the most important aspects and outcomes are shown in Table 25 together with the main conclusions and interpretations. All values to the ID dummies are left out to spot the differences between regression model 1 and regression model 2 where the greenery aspects are included. In this way, the effect and significance could be explained, while the personal characteristics are again attached to the dummy ID's of each participant just as in Chapter 4.2.3.

Table 25 – Effect of greenery attributes on post-VR scenario well-being in a fixed effect panel regression

		Unstandardized B	Standardized Beta	Std. Error	Sig.
Model 1	(Constant)	2,500		0,366	<0,001
Model 2	(Constant)	3,381		0,202	<0,001
	Having leaves	1,056	0,717	0,052	<0,001
	Without leaves	0		-	-

	Many Trees	0,666	0,453	0,051	<0,001
	Less Trees	0		-	-
	Clustered	0,198	0,135	0,051	<0,001
	Not Clustered	0		-	-

As visible in Table 25 the constant values of 2.500 (Model 1) and 3.381 (Model 2) represent the well-being score when baseline greenery attributes (leaves, trees, clustering) are included in the model. The difference between these constants is likely due to the inclusion of additional predictors (the greenery attributes). These attributes provide more specific information, which adjusts the baseline estimate of post-VR scenario well-being in Model 2. The constant in Model 2 is now higher because the model accounts for more variance and influences the interpretation of the dependent variable.

The coefficients Table 25 shows that trees with leaves have a significant positive effect on the post-VR scenario well-being of participants. The same holds for many trees and the clustering of trees. The standardized coefficients show how big the effect of each variable is on the total score. For trees with leaves, this value is the largest, so the influence of having trees with leaves or not is the most influential on the post-VR scenario well-being that is measured just after a scenario is experienced by a participant. Having trees in clusters or spread is the least influential on the post-VR scenario well-being of participants.

The significance of the greenery attributes tested is significant for all of them with a score of <0.001. The results of the standardized Beta suggest that leaves, tree amount, and clustering each play a meaningful role in shaping post-VR scenario well-being outcomes in virtual green environments. The presence of leaves showed the strongest effect ($\beta = 0.717$, $p < .001$), followed by tree amount, with many trees leading to higher post-VR scenario well-being outcomes compared to fewer trees ($\beta = 0.453$, $p < .001$). Tree clustering had the weakest but still statistically significant effect ($\beta = 0.135$, $p < .001$).

4.4 Effect of Personal Characteristics on Momentary Subjective, Post-VR Scenario, and Overall Well-being

To see the effect of different personal characteristics on well-being a linear regression analysis will be performed on the momentary, post-VR scenario, and overall well-being of the experiment. The results will explain which personal characteristics are significant and how big the effect on the well-being will be. In the end, a comparison between all well-being analyses could be made to see differences and equivalences.

4.4.1 Momentary Subjective Well-being

To begin, the momentary subjective well-being of participants is analyzed, which captures the immediate subjective well-being responses to each scenario during the experiment. The linear regression model evaluates how personal characteristics influence participants' momentary subjective well-being during the iVR experience. The model provided an R^2 value of 0.027, indicating that only 2,7% of the variance in momentary subjective well-being is explained by personal characteristics.

Table 26 – Estimate effects of personal characteristics on momentary well-being

Parameter	Unstandardized B	Standardized Coefficients Beta	*Significance (p-value)*	*Positive or negative effect on well-being*
Constant	*3.772*		*<0.001*	
Male	*-0.021*	*-0.017*	*0.718*	-
Female		*0*	-	
18-24 year	*-0.024*	*-0.021*	*0.606*	-
>24 year		*0*	-	
Urban	*0.127*	*0.110*	*0.038*	+
Outer Urban Area		*0*	-	
Daily visits to high-density city	*0.041*	*0.061*	*0.045*	+
Multiple times a week visits to high-density city	*0.089*	*0.122*	*0.003*	+
Once a month or less visits to high-density city		*0*	-	
Daily visits to high-density city with Greenery	*0.048*	*0.073*	*0.010*	+
Multiple times a week visits to high-density city with Greenery	*0.036*	*0.105*	*0.008*	+
Once a month or less visits to high-density city with Greenery		*0*	-	
Greenery is Important to the enjoyment area	*-0.065*	*-0.058*	*0.184*	-
Greenery is Priority in the enjoyment area		*0*	-	
Greenery not extremely important on well-being	*0.022*	*0.020*	*0.664*	+
Greenery extremely important on well-being		*0*	-	
Not familiar with urban design	*0.044*	*0.038*	*0.774*	+
Familiar with urban design		*0*	-	
Not familiar with KnoopXL	*-0.081*	*-0.071*	*0.548*	-
Familiar with KnoopXL		*0*	-	
No previous iVR experience	*0.052*	*0.041*	*0.329*	+
Have previous iVR experience		*0*	-	

The model's intercept is 3.772. This value represents the predicted momentary subjective well-being score for a participant in the reference categories of all predictors. In this case, this is a person that got all personal characteristics indicated with 0 (reference) in Table 26. Also visible in Table 26, some of the personal characteristics are significant and others are not. All personal characteristics are compared to the last personal characteristic attribute in the category as the baseline. For example, the effect of daily and multiple times-a-week visits to a high-density city center are compared to once-a-month or less visits to a high-density city center. The table shows the positive or negative effects of the personal characteristics and the size of the effect (standardized beta column). The linear regression showed that the current living environment type was significantly associated with momentary subjective well-being (p=0.038), with participants from the residential environment type 'urban' scoring higher. Frequent visits to green space (p=0.010 & p=0.008, positive influence) and frequent visits to the city (p=0.045 & p=0.003, positive) were also associated with higher momentary subjective well-being. Characteristics such as gender, age, subjective importance of greenery to enjoyment, previous experience with iVR, and familiarity with the design had no significant effect on momentary subjective well-being.

4.4.2 Post-VR Scenario Well-being

In this section, the post-VR scenario well-being of participants is analyzed, which measures the responses after completing each iVR scenario. This analysis helps identify which personal characteristics influence well-being after each immersive experience. The same table and positive or negative effect is provided as in Chapter 4.4.1. The model provided an R^2 value of 0.084, indicating that 8,4% of the variance in post-VR scenario well-being is explained by personal characteristics.

Table 27 – Estimate effects of personal characteristics on post-VR scenario well-being

Parameter	Unstandardized B	Standardized Coefficients Beta	*Significance (p-value)*	*Positive or negative effect on well-being*
Constant	*4.508*		*<0.001*	
Male	*-0.031*	*-0.019*	*0.860*	-
Female		*0*	-	
18-24 year	*-0.033*	*-0.022*	*0.814*	-
>24 year		*0*	-	
Urban	*0.529*	*0.348*	*0.004*	+
Outer Urban Area		*0*	-	
Daily visits to high-density city	*0.161*	*0.159*	*0.778*	+
Multiple times a week visits to high-density city	*0.076*	*-0.069*	*0.898*	-
Once a month or less visits to high-density city		*0*	-	
Daily visits to high-density city with Greenery	*0.223*	*0.209*	*0.333*	+
Multiple times a week visits to high-density city with Greenery	*0.184*	*0.129*	*0.574*	+
Once a month or less visits to high-density city with Greenery		*0*	-	
Greenery is Important to the enjoyment area	*-0.077*	*-0.052*	*0.593*	-
Greenery is Priority in the enjoyment area		*0*	-	
Greenery not extremely important on well-being	*0.161*	*0.109*	*0.283*	+
Greenery extremely important on well-being		*0*	-	
Not familiar with urban design	*0.215*	*0.141*	*0.592*	+
Familiar with urban design		*0*	-	
Not familiar with KnoopXL	*-0.065*	*-0.043*	*0.872*	-
Familiar with KnoopXL		*0*	-	
No previous iVR experience	*-0.064*	*-0.038*	*0.684*	-
Have previous iVR experience		*0*	-	

The model's intercept is 4.508. This value represents the predicted post-VR scenario well-being score for a participant in the reference categories of all predictors. This would be a person with the same characteristics as in Chapter 4.4.1 since the personal characteristics are constant. As visible in Table 27, just the current living environment is significant in the effect on post-VR scenario well-being (p=0.004). The other personal characteristics are not significant to post-VR scenario well-being. Participants with an urban living environment got a significantly higher post-VR scenario well-being score of 1,339 compared to participants whose current living environment is outer urban.

4.4.3 Overall Well-being

After the total experiment, the well-being of all scenarios visited is measured for each participant. For analysis, this score is also computed to a sufficient Cronbach Alpha score of 0,78 and just as the momentary and post-VR scenario well-being compared to the personal characteristics of every participant. The results are shown in Table 28. The model provided an R^2 value of 0.252, indicating that 25,2% of the variance in overall well-being is explained by personal characteristics. Compared to the momentary subjective and post-VR scenario well-being this contribution is larger.

Table 28 – Estimate effects of personal characteristics on overall well-being

Parameter	Unstandardized B	Standardized Coefficients Beta	*Significance (p-value)*	*Positive or negative effect on well-being*
Constant	*4.635*		*<0.001*	
Male	*0.113*	*0.145*	*0.130*	+
Female		*0*	-	
18-24 year	*-0.146*	*-0.203*	*0.016*	-
>24 year		*0*	-	
Urban	*0.159*	*0.220*	*0.042*	+
Outer Urban Area		*0*	-	
Daily visits to high-density city	*-0.004*	*-0.010*	*0.476*	-
Multiple times a week visits to high-density city	*0.086*	*0.035*	*0.963*	+
Once a month or less visits to high-density city		*0*	-	
Daily visits to high-density city with Greenery	*0.157*	*0.206*	*0.509*	+
Multiple times a week visits to high-density city with Greenery	*0.288*	*0.374*	*0.291*	+
Once a month or less visits to high-density city with Greenery		*0*	-	
Greenery is Important to the enjoyment area	*-0.086*	*-0.276*	*0.002*	-
Greenery is Priority in the enjoyment area		*0*	-	
Greenery not extremely important on well-being	*0.193*	*0.136*	*0.140*	+
Greenery extremely important on well-being		*0*	-	
Not familiar with urban design	*0.095*	*0.767*	*0.002*	+
Familiar with urban design		*0*	-	
Not familiar with KnoopXL	*-0.358*	*-0.503*	*0.038*	-
Familiar with KnoopXL		*0*	-	
No previous iVR experience	*-0.067*	*-0.083*	*0.321*	-
Have previous iVR experience		*0*	-	

The model's intercept is 4.635. This value represents the predicted overall well-being score for a participant in the reference categories of all predictors. This would be a person with the same characteristics as in Chapter 4.4.1 and 4.4.2 since the personal characteristics are constant. Furthermore, the results of the analysis showed that participants of the age category 18-24 scored significantly lower on the overall well-being than participants in the category 24 and above (standardized Beta = -0.146, p = 0.016). The current living environment (standardized Beta = 0.159, p = 0.042), greenery importance to enjoyment area (standardized

Beta = -0.086, p = 0.002), familiarity with urban design (standardized Beta = 0.095, p = 0.002) and KnoopXL familiarity (standardized Beta = -0.358, p = 0.038) were significant predictors of the overall experience. Familiar with design and higher ratings of greenery were associated with a more positive experience. In contrast, familiarity with the location (KnoopXL) led to a slightly more negative experience on overall well-being scores. Gender, frequency of visits to city/green space, and previous iVR experience did not significantly affect overall well-being.

4.4.4 All Significant Well-being Outcomes Compared

Finally, in Table 29, a comparison of the significant effects across all three types of well-being (momentary subjective, post-VR scenario, and overall well-being) is presented. This comparison provides insight into which personal characteristics have consistent effects across different measures of well-being, and which only affect some of these well-being measurements or provide no significant effect at all.

Table 29 – Significant Standardized Beta outcomes of personal characteristics on momentary subjective, post-VR scenario, and overall well-being

Parameter	Momentary	*Post-VR*	*Overall*
Male			
Female			
18-24 year			*(B =-0.203, p = 0.016)*
>24 year			
Urban	*(B = 0.110, p = 0.038)*	*(B =0.348, p = 0.004)*	*(B =0.220, p = 0.042)*
Outer Urban Area	*0*	*0*	*0*
Daily visits to high-density city	*(B = 0.061, p = 0.045)*		
Multiple times a week visits to high-density city	*(B = 0.122, p = 0.003)*		
Once a month or less visits to high-density city	*0*		
Daily visits to high-density city with Greenery	*(B = 0.073, p = 0.010)*		
Multiple times a week visits to high-density city with Greenery	*(B = 0.105, p = 0.008)*		
Once a month or less visits to high-density city with Greenery	*0*		
Greenery is Important to the enjoyment area			*(B = -0.276, p = 0.002)*
Greenery is Priority in the enjoyment area			*0*
Greenery not extremely important on well-being			
Greenery extremely important on well-being			
Not familiar with urban design			*(B = 0.767, p = 0.002)*
Familiar with urban design			*0*
Not familiar with KnoopXL			*(B = -0.503, p = 0.038)*
Familiar with KnoopXL			*0*
No previous iVR experience			
Have previous iVR experience			

All significant effects on well-being by personal characteristics are shown in Table 29. Participants living currently in an urban environment have a positive effect on the well-being score in all measurements compared to participants living in outer urban areas. The biggest effect was on overall well-being with a standardized Beta of 0.767 as a result on the mean of a 5-point Likert Scale. The age group was only significantly affecting the overall well-being. The visits to a high-density city center and a high-density city center with greenery are only

significant for the momentary subjective well-being. The importance of greenery on well-being is for both the momentary and the overall well-being negative. The overall well-being was significantly affected by familiarity with urban design and the KnoopXL project. These personal characteristics were not significant for the momentary subjective and post-VR scenario measured well-being.

4.5 Conclusion & Discussion

This chapter presented an extensive analysis of the experimental results and their connection to the literature review on urban greenery and human well-being. A variety of statistical techniques is used, including Cronbach's Alpha, linear regression model, and fixed effects panel regression. These techniques revealed insightful patterns about the influence of specific greenery attributes, locational attributes, and personal characteristics on both momentary- and post-VR scenario well-being.

Firstly, the data sample's characteristics are analyzed and restructured into categories, and their frequency is attached. These categories were later used in the results to spot different patterns of characteristics that are linked to certain greenery attribute preferences. After a general inventory of the sample, a Cronbach's Alpha score is calculated to replace the different well-being scores with one composite score which is more convenient to use for further analysis. These scores revealed that the presence of leaves and more trees had a significant positive effect on the participants' post-VR scenario well-being. The other greenery attribute, clustering of trees, also had a significant positive effect but a smaller impact on participants' post-VR scenario well-being.

When focusing on momentary subjective well-being experienced during each scenario, the amount of trees was the only greenery attribute that had a significant score across all different spots and scenarios measured. Surprisingly, the presence of leaves and tree clustering, which were impactful in post-VR scenario well-being, did not provide a significant score on momentary subjective well-being. This suggests that participants were more immediately influenced by the volume of greenery rather than its detailed structure.

The spots among themselves differ in their momentary subjective well-being score, which could be caused by locational attributes. For instance, spot 3 is located near water and got a significantly higher score on momentary subjective well-being in all different scenarios tested. The same holds for spot 2, which is located near a road. Here the momentary subjective well-being scores are continuously lower across all scenarios, which could be due to the safety feeling of participants close to the road. These spatial contexts could be a determinant of differences among momentary subjective well-being across spots. This was confirmed with the help of a linear regression model, which had a significant outcome for spot 2 with a less positive generated momentary subjective well-being compared to spot 1 (B=-0.540). Spot 3 on the other hand resulted in generating a more positive momentary subjective well-being with a standardized beta score of 0.330 compared to spot 1.

The fixed-effects panel regression was applied to account for the repeated-measures nature of the study, where each participant experienced four different iVR scenarios out of eight in total. This method allowed the analysis to control for individual-level characteristics by treating the personal characteristics as constant connected to a dummy for the participant. Instead of interpreting each of the four visits as separate observations, the fixed-effects model recognized them as nested within the same person. This approach helped isolate the impact of greenery attributes on subjective well-being. By controlling for unobserved personal traits, the model ensured that the differences in well-being outcomes were attributed more accurately to the greenery attributes rather than individual variance. This enhanced the validity of the

findings and offered a more reliable understanding of how specific greenery attributes and spatial contexts shape momentary subjective and post-VR scenario well-being within immersive virtual environments.

An in-depth look at the personal characteristics showed that participants with a current living environment in an urban area, frequent visits to green and dense city areas, and high priority for greenery are associated with higher well-being outcomes. Especially the momentary- and overall well-being measured after all scenarios had been run through scored a significant positive effect. Participants who were already familiar with urban design scored lower on the well-being measurements, while familiarity with the KnoopXL project provided a slightly higher score. These familiarities were only significant for the overall well-being measured after all scenarios were seen by the participant and not on the post-VR scenario and momentary subjective well-being.

In summary, this chapter shows that the influence of greenery on human well-being is dependent on multiple aspects and affected by contextual aspects too. The momentary subjective well-being is mostly affected by the amount of greenery, but the location-specific attributes such as water presence or cars nearby are influential too. Post-VR scenario well-being after the scenario are mostly affected by the greenery attributes of having leaves or not and the amount of trees. The findings of this study underline the importance of sufficient macro-level management (overall tree presence and spread) as well as micro-level management (location-specific attributes and direct exposure to greenery) to create human well-being-stimulated urban environments. The use of immersive VR allowed for precise measurement of these influences, reinforcing the importance of integrated urban planning that considers not only the amount of greenery but also its spatial placement and interaction with human perception and well-being.

5 Conclusions and Recommendations

5.1 Conclusions

This thesis explores how the amount, clustering, and seasonal variation (having leaves or not) of greenery in high-rise urban environments affects subjective human well-being. The experiment makes use of immersive virtual reality (iVR) technology, considering the case of the future KnoopXL project in Eindhoven. During the experiment, multiple controlled virtual scenarios were developed to evaluate the momentary subjective, post-VR scenario, and overall well-being during the entire experiment. The study successfully integrates theoretical insights, innovative digital tools, and empirical research to contribute to a more human-centered approach in future urban design.

In the first chapter, the research context and societal relevance were introduced. The more cities grow and urbanization increase, the more vertical expansion become more common and green space becomes increasingly scarce. This is especially in the areas dominated by high-rise buildings. The existing literature and urban planning practices often emphasize the ecological and aesthetical functions of greenery but overlook its psychological and well-being impact. From this gap, the main research question was formulated: *How do the clustering, seasonal changes, and amount of greenery in high-rise-built environments influence human subjective well-being, as measured using an immersive virtual reality setting?* The immersive VR technology was identified as a key strength for this experiment, allowing controlled measurements of participant experience in future built projects.

The literature review chapter provides support for the research gap noted and answers already some of the sub-questions of this thesis. Sub-question 1 "*Which well-being states are most relevant when assessing human subjective well-being in relation to greenery in high-rise-built environments?*" was answered in the literature study by defining the basic emotions anger, joy, fear, disgust, sadness, and surprise. These emotions resulted eventually in the five most relevant measurements of well-being for this study: safety, stress, comfort, engagement, and pleasure. Also, sub-question 2 *"How can iVR technology serve as a tool to measure the effect of greenery on human subjective well-being?"*, was answered in the literature review. Multiple other case studies and sources about iVR technology usage in practice nowadays showed that immersive VR would be the most suitable tool to use to measure the momentary subjective well-being in a controlled way with an immersive questionnaire integrated into the scenarios. iVR is used instead of AR or MR for its unique aspects of immersing a participant into a created virtual world without traveling toward the area. Also, future projects can be visualized in this way without even being realized yet. Furthermore, iVR offers a unique solution to measure the understudied momentary subjective well-being by the creation of an immersive questionnaire for this momentary subjective well-being. This makes it able to measure the effect of the tested greenery attributes on momentary subjective well-being as well as on overall well-being. The literature review also noted that personal characteristics like gender, age, familiarity with urban design, etc. were found to mediate individual's well-being. These were taken into account during this experiment to provide insights to the existing gap in experimental research about measuring momentary subjective well-being and linking it to the specific environmental changes, but also to the personal characteristics.

The third chapter outlined the research methodology. The entire experiment is shown in a chronological way including the creation of the eight immersive VR scenarios, varying systematically in tree amount, clustering, and seasonal state. Furthermore, the KnoopXL project and is explained and the context scenario link is made. The interactivity features in the scenarios that are coded with the help of Unreal Engine are explained together with the creation of the questionnaire. Participants will enter four of the eight randomized scenarios,

during which they were asked to rate their momentary subjective well-being at five strategic chosen fixed locations. Post-scenario and after the entire experiment, surveys are provided to the participants to capture more reflective and generalized responses. In this way the analysis could be made about the difference in short term experience feedback and the overall long-term feedback on well-being. Ethical approval and data anonymization ensured the integrity and reliability of the data collection process.

Chapter 4 presented the results and SPSS analysis provided. The statistical analysis revealed clear and significant differences between momentary subjective well-being across the greenery attributes tested. Scenarios with more trees, clustered greenery, and having leaves on the trees consistently scored positive on perceived safety, comfort, engagement, pleasure, and stress. Conversely, trees without leaves often resulted in a less positive momentary well-being score. The personal characteristics had an effect on all tested well-being moments too, showing for example that prior familiarity with urban green areas did not enhance positive outcomes of overall well-being after the experiment. The questionnaire after all scenarios confirmed that the majority of the participants experienced a high level of presence (60%) and immersion (70%) in the iVR environment, indicating that the in-scenario measurements were generally accepted as representative by the participants.

The remaining sub-questions are answered in Chapter 4 too. Sub-question 3 *"To what extent do people's momentary subjective well-being vary based on the changing attributes of greenery in high-rise-built environments?"* is answered by providing a fixed panel regression analysis. Out of this analysis came forward that when focusing on momentary subjective well-being experienced during each scenario, the amount of trees was the only greenery attribute that had a significant score. Surprisingly, the presence of leaves and tree clustering did not provide a significant score on momentary subjective well-being. This suggests that participants were more immediately influenced by the volume of greenery rather than its detailed structure.

Sub-question 4 *"To what extent do people's post-VR scenario well-being vary based on the changing attributes of greenery in high-rise-built environments?"* is answered with this same analysis method as sub-question 3. These scores revealed that the presence of leaves and more trees had a significant positive effect on the participants' post-VR scenario well-being. The other greenery attribute, clustering of trees, also had a significant positive effect but a smaller impact on participants' post-VR scenario well-being.

The 5th sub-question *"To what extent do technological features of iVR (e.g., resolution, mobility, interactivity) affect users' subjective well-being in virtual green environments?"* was partly discussed in the literature review where stated that the higher the quality of the iVR model, the more immersed an individual can become. The technological features of the iVR system such as smooth teleportation navigation and integrated immersive interaction played a supportive, but essential role in capturing momentary subjective responses. The mobility integrated with Unreal Engine (Chapter 3) could prevented cybersickness, ensuring that participants remain focused and comfortable. The overall questionnaire shows that just 2,5% of the participants experienced significant discomfort due to this cybersickness and 90% of the participants indicated that the navigation was easy to use. This, together with the high quality of the model due to the collaboration with the development company in creating a realistic KnoopXL model, ensures that the technological features would result in realistic outcomes.

Beyond answering the research questions, this study holds both societal and scientific relevance. From a societal perspective, the findings mark the value of greenery in dense urban environments not just for visual or ecological purposes, but as a key contributor to psychological subjective well-being. The demonstrated impact of tree amount and seasonal variation on users' subjective well-being responses provides a clear direction for future urban

development, specifically in high-rise areas where green space is limited. The distinction between momentary subjective well-being and post-VR scenario well-being reveals differences in how environments are experienced in real-time versus in reflection afterward. Spot 2 consistently showed the lowest momentary subjective well-being ratings across scenarios, while the post-VR scenario scores were generally higher. In contrast, spot 3 scored the highest in every scenario, aligning with more favorable post-VR scenario ratings. This indicates that spatial variation within environments plays a role in shaping both immediate and reflective well-being evaluations. Urban planners and policymakers can use these insights to create more livable, inclusive, and health-supportive environments in a broad context and spot-specific.

From a scientific perspective, the study contributes to the growing body of research on subjective well-being in urban environments by combining momentary, post-VR scenario, and overall well-being measures within immersive virtual reality (iVR). By integrating momentary subjective in-scenario responses with post-VR scenario reflections, the study offers a layered understanding of how participants experience and evaluate urban green spaces over time and afterward. The use of iVR provides a reliable and controlled method to assess the spatial effects of greenery attributes such as tree amount, clustering, and seasonal variation on different types of well-being. In addition, the inclusion of personal characteristics enables a more nuanced interpretation of individual differences in environmental perception. This methodological framework can be applied in future research to explore other urban design variables or tested across different demographic and geographic contexts.

Collectively, these findings demonstrate that the design of green areas has a measurable effect on human well-being in high-rise urban spaces. With this entire experiment and research study the main research question can be answered. The seasonal effect and amount of trees emerge as the most crucial determinants in the well-being state of participants. Moreover, this thesis confirms the potential of immersive VR as a robust research method that enables urban planners to test and refine green spaces before any brick is built. In an era of rapid urban densification, such insights are valuable for shaping livable, health, and positive well-being generating urban spaces.

5.2 Limitations and Future Research

Although the study provided valuable insights to the effect of greenery attributes on short- and long-term well-being in high-rise environments using immersive virtual reality, some limitations should be acknowledged and opportunities for further research need to be discussed.

First of all, the participant sample was limited in diversity and amount to represent the entire population. Most of the respondents were university students with a similar age and living environment. This homogeneity may have caused some limitations to generalize these findings for a broader population, particularly older adults or individuals with disabilities could have another perception of green spaces and the use of them.

Secondly, the immersive VR proved to be an effective tool to simulate spatial and visual characteristics of the built environment with greenery involved. Nonetheless, other sensory stimuli, such as sound and smell, were excluded from the experiment to focus on the visual appearance of greenery attributes. Other studies show that multisensory stimuli (birdsong or the smell of grass) had a significant contribution to emotional responses in the built environment. Future research could extend the scenarios by integrating auditory and olfactory cues to create a complete multisensory stimuli environment.

Thirdly, the self-reported immersive questionnaire could be expanded with behavioral measurements like heart rate or skin conductance. In this way, a broader and non-biased

output can be generated to measure the stress or excitement for instance. People could perhaps feel physically different then they think and self-report during the experiment.

Lastly, the experiment was limited to four randomized visits out of eight scenarios to avoid fatigue and reduce the chance of cybersickness occurring. This pragmatic choice resulted in incomplete within-subject exposure to experience all experimental conditions. A full factorial design with a greater sample size could allow participants to experience all of the conditions in the different scenarios to increase the robustness of the statistical comparisons.

From a methodological perspective, this study used linear regression and fixed effects to examine the effect of greenery attributes on subjective well-being, while using dummy coding to assign multiple scenario inputs to the same participant. This approach did not estimate the direct effects of personal characteristics, such as gender or age group, together with the effect of greenery attributes on subjective well-being. This was done with a separate analysis in Chapter 4.4. To simultaneously examine both the influence of greenery attributes and the role of personal characteristics, future research should consider using a mixed-effects regression model. This method can account for the multiple observations per participant by including random effects for participants or scenarios, while still estimating the impact of stable personal characteristics through fixed effects.

In conclusion, for future research it is recommended to include more diverse participant profiles to increase the validity and uncover potential differences between user groups that could have a different perception of greenery in high-rise environments. Furthermore, the iVR simulation could be expanded with multisensory stimuli to replicate the real environment more accurately. Also, the addition of behavioral measurements could be used to gather more valid and non-biased data about the physical stress or excitement during the simulations. Lastly, the design could be made full factorial to avoid within-subject exposure. This could be done, perhaps with different stages taken into the approach over multiple sessions, to avoid fatigue and improve the internal validity of the experiment. The iVR experiment of this research could be a real addition to other planned high-rise projects to measure future inhabitants' effect on well-being in different greenery attribute scenarios.

5.3 Recommendations

Based on the results of this study, several practical recommendations can be made to support more human-centered decision-making in future high-rise urban developments. These recommendations focus on the implementation of greenery attributes that showed the strongest effects on subjective well-being, as well as on the use of immersive VR as a design and evaluation tool. These recommendations also provide an answer to the last sub-question *"What strategic advice can be given to urban planners and policymakers on the use of immersive VR to evaluate and implement greenery in high-rise urban environments affecting human subjective well-being?".*

Firstly, the amount of trees appeared as the most consistent and significant predictor of improved subjective well-being during and after the immersive VR experience. This finding suggests that current urban policies should go beyond general green space requirements and provide more specific guidance on the visual presence and density of trees in high-rise areas. Even in compact environments, design decisions should prioritize maximizing the amount of trees, as it has a direct effect on comfort, safety, engagement, stress, and pleasure.

Secondly, the seasonal state of greenery also influenced well-being outcomes, especially in the post-VR scenario well-being measurements. Trees with visible leaves were perceived more positively compared to leafless trees. Urban greening developments should therefore take seasonal variation into account by including both evergreen species and planting

schemes that maintain visual richness across all seasons. This allows green spaces to contribute to psychological well-being throughout the entire year.

Thirdly, this study confirms the potential of immersive VR as a valuable tool in urban design processes. The use of iVR enabled controlled, repeatable simulations of future urban spaces, which allowed participants to evaluate scenarios in a realistic and well-being-affected way. The designed immersive questionnaire made it possible to capture the momentary subjective well-being, which was an understudied subject. Policymakers and urban planners are encouraged to adopt immersive technology to test design alternatives before implementation. This can support more evidence-based decisions and reduce design errors that would otherwise only be noticed after construction.

In addition, immersive VR can serve as an effective method to engage non-expert stakeholders and future users in the design process. The interactive nature of iVR makes it accessible to a broad audience, including residents, community groups, and citizens who would normally not be involved in early planning stages. By including these groups in immersive simulations, cities and developers can gather valuable feedback and improve the social acceptance of new developments.

Lastly, this research shows the importance of considering not only ecological or functional design indicators, but also psychological and experiential outcomes. The integration of well-being measurements through immersive VR allows urban planning to evolve into a more inclusive and human-centered discipline. Especially in vertical urban environments, where traditional green spaces are limited, the focus must be prioritized on how environments are perceived and experienced and their contribution to more livable and stimulating human subjective well-being cities.

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6 Appendices

Appendix I – Information form experiment

Introduction

Eindhoven University of Technology (TU/e) invites you to take part in this research project which aim is to analyze user-experience due to environmental aspects during an immersed VR-simulation with a comparison to the overall experience.

Joining this research project is your choice. Your participation is completely voluntary and does not pose any physical, legal or economic risks. You are not obliged to answer questions you are uncomfortable with, and you can withdraw from the research at any time without explaining why. Declining or withdrawing will not have negative impact for you.

Before you decide, please read the following information to understand what the project is about, what we expect from you and how we handle your personal data. After reading, you can sign up by completing the attached form.

If you have questions, feel free to contact me (r.onderdijk@student.tue.nl). You can also discuss this information with people you trust.

1. Who are we?

This research project is conducted by:

Technische Universiteit Eindhoven (TU/e) De Groene Loper 3 5612 AE Eindhoven	Data controller (Ruud Onderdijk)

2. What will taking part in the research project involve?

In the research project we will collect your personal data using a discrete method:

- Asking you to fill in various questionnaires during a period of +/- 30 minutes, 5 times about user experience in the iVR-simulation.
- Visiting location KnoopXL 2 times (2 different models) so we can ask questionnaires about the user-experience.
- Presenting you a questionnaire after the experiment about your total experience, which you can fill in writing.

3. What personal data from you do we gather and process?

We collect and process the following personal data which is necessary for the project purpose:

Category and type	**Personal data**	**Purpose**	**Retention period**
Personal characteristics	*Gender, age, current living environment, familiar with project, feelings before project, experience*	*To compare with feelings afterward and make anonymous links with other participants in demographical information*	*6 months after data collection*
Momentary experience	*Feelings of safety, comfort, stress, excitement, annoyance*	*Analyze data concerning your user-experience and feeling in the iVR session*	*10 years after research is complete*
Overall experience	*Feelings of safety, comfort, stress, excitement, annoyance*	*Analyze data concerning your user-experience and feeling in the iVR session*	*10 years after data collection*
Connected to iVR environment	*Immersiveness, detail of world*	*Immersiveness of the iVR-environment*	*10 years after data collection*
Project opinion	*Positive/negative about KnoopXL,*	*If the simulation let you understand the project better and changed your opinion.*	*10 years after data collection*

Your data is retained only for the time period as specified in the table. Keeping your data for this period helps us to comply with scientific principles, such as producibility and verification.

After this period, your personal data will be deleted or anonymized to ensure it can no longer be linked to you. Unless you explicitly agree to the use of your identifiable information in publications (for example your quotes or your name).

4. Stopping your participation and your rights

If you end your participation in the research we will not use your data anymore from that moment on.

For questions, ending your participation or complaints, please contact the researcher via the contact details as provided in the table under section 1.

For concerns or questions about the handling of personal data, you can e-mail the data protection officer as indicated in section 1. You can also file a complaint with the Dutch data protection authority: the Autoriteit Persoonsgegevens.

You have the right to request access, rectification, objection, erasure or adaptation of your data. Submit your request via the contact details as provided in section 1.

5. Legal basis for processing your personal data

The TU/e processes your personal data to conduct scientific research, which is the university's public task as stated in article 1.3 of the Dutch Wet Hoger onderwijs en Wetenschappelijk onderzoek. The TU/e always follows the applicable codes of conduct for research integrity and the scientific standards when conducting research.

6. Who has access to your personal data?

Only authorized employees involved in the research have access to your personal data if this is necessary for their tasks. The authorized employees will keep your personal data confidential.

TU/e has a suitable agreement with these parties to protect your personal data. We will not share your personal data with any other party, unless we are required to do so by law.

TU/e will process your personal data within the European Economic Area (EEA) by storing your data on a server inside the EEA. In addition, TU/e has implemented appropriate technical and organizational measures to protect your personal data. These measures include using centrally managed and verified research- and storage tools.

7. Future research

During the research project, your personal data may also prove useful for new, socially important research. In such case, we would like to reuse your data for the new research. This will only happen if (1) your personal data is truly necessary, (2) the recognized ethical standards for scientific research are followed, and (3) the new research objectives align with the current research objectives. If your personal data is used in future research, we will take all reasonable steps to inform you about this. You can object to the use of your personal data for new research.

We might use anonymized data for new purposes such as research or education. We will ensure the data cannot be linked to you and we will not disclose anything that makes you identifiable.

This research has been assessed and approved by the ethical committee of Eindhoven University of Technology.

***** Scroll down for the form *****

Consent form for participation by an adult

By signing this form, I confirm:

1. I have enough information about the research project from the separate information sheet. I have read it and I had the chance to ask questions, which have been answered to my satisfaction.

2. I take part in this research project voluntarily. There is no explicit or implicit pressure for me to take part in this research project and I understand I can stop my participation at any moment, without explaining why. I do not have to answer any question I do not want to answer.

3. I know my personal data will be collected and used for the research, as explained to me in the information sheet.

Furthermore, I consent to the following parts of the research project:

4. I consent to my personal data, [such as footage taken of me, audio taken of me, answers or quotes I gave during the research, to be used by the researcher in publications and/or in presentations – without including my name.

YES ☐ NO ☐

5.

Name of participant:
Signature:

Name of researcher: Ruud Onderdijk
Signature:

Date:

Date:

Appendix II – Pre-Experiment Questionnaire

Survey pre-experiment

This first part of the questionnaire will focus on some personal characteristics and your current well-being. These will be used in general analysis, which will keep your information anonymous.

1. What is your gender?
   - ☐ Man
   - ☐ Woman
   - ☐ Other
   - ☐ I'd rather not say

2. What is your age?
   - ☐ <18
   - ☐ 18-21
   - ☐ 22-24
   - ☐ 25-27
   - ☐ 28-30
   - ☐ 31-40
   - ☐ 41-50

□ 50-65
□ >65
□ I'd rather not say

3. Where is your current living environment located?
   □ Urban
   □ Suburban
   □ (small) Town
   □ Rural
   □ I'd rather not say

4. How often do you visit a high-density city center? (>100.000 inhabitants)
   □ Daily
   □ Multiple times a week
   □ Approximately once a month
   □ Approximately once every 3 months
   □ Approximately once a year
   □ Other: _____
   □ I'd rather not say

5. How often do you visit a high-density environment with noticeable greenery present?
   □ Daily
   □ Multiple times a week
   □ Approximately once a month
   □ Approximately once every 3 months
   □ Approximately once a year
   □ Other: _____
   □ I'd rather not say

6. How important is greenery (parks, trees, gardens) to your overall enjoyment of an area?
   □ Not important at all. I don't care about greenery in the area.
   □ Slightly important, but I wouldn't notice if it was gone.
   □ Somewhat important. I like having greenery, but it's not a big factor for me.
   □ Important. Green spaces make the area much more enjoyable.
   □ Very important. Greenery is essential for my happiness and well-being.
   □ I'd rather not say

7. To what extent does greenery (parks, trees, gardens) contribute to your personal well-being?
   □ Not at all. Greenery has no impact on my well-being.
   □ Slightly. I notice it, but it doesn't make much difference to me.
   □ Moderately. Greenery has some positive effect on my well-being.
   □ Very much. It significantly improves my mood and overall well-being.
   □ Extremely. Greenery is essential for my mental and physical well-being.
   □ I'd rather not say

8. How familiar are you with the profession of urban design or architecture?
   □ Not familiar at all
   □ Slightly familiar
   □ Moderately familiar
   □ Very familiar

□ I'd rather not say

9. Are you familiar with the redevelopment plans of KnoopXL?
   □ Yes, I am familiar with the redevelopment project.
   □ Yes, I have seen some announcements.
   □ No, I was not aware of the redevelopment plan.
   □ I'd rather not say

10. If you are familiar with the redevelopment plan, what is your perspective/opinion about the area?

□ I'd rather not say

11. Do you have any previous experience with iVR technology and simulation already?
   □ I'd rather not say
   □ No
   □ Yes, namely

_____
_____
_____
_____

Appendix III – Momentary Experience Questionnaire

Scenario

Imagine this scenario:

You've planned to meet a friend at the station. You arrive a bit earlier than expected, and now you have about 15 minutes to spare before your friend arrives. You decide to wait outside the station, enjoying the time on your own.

While you're waiting, you observe the surroundings. The area is busy with people coming and going. In this moment, you're just passing time, but you start noticing how the space around you makes you feel. Are you comfortable and relaxed, or do you feel distracted and stressed by any objects in the environment? How does the greenery or lack of it impact your overall mood while you wait?

Now, we're going to simulate this scene in iVR. You'll be placed in a virtual environment that resembles this situation. As you wait for your friend in the virtual world, you can explore your surroundings as time passes. Throughout the experience, pay attention to how you feel, how the space around you impacts your mood and your overall perception of the environment.

After the simulation, you'll be asked about your emotions and thoughts. Did the environment make you feel calm and comfortable? Did the greenery, or lack of it, influence how you felt? Did the space feel realistic? Let's see how different environments affect your well-being and perception of space as you wait for your friend.

The survey below will be administered at specific "spots" within the iVR environment to capture immediate reactions. Each question should be rated on a **5-point Likert scale**, where **1** represents the lowest value (e.g., "Not at all" or "Very unpleasant") and **5** represents the highest value (e.g., "Very much" or "Very pleasant"). This survey will be held on 5 strategic spots within each iVR environment to capture real-time feedback.

Momentary Experience Survey Questions

Answer the following statements about your feelings on this location:

	1	*2*	*3*	*4*	*5*
How safe do you feel right now?	Very unsafe	Unsafe	Neither unsafe nor safe	Safe	Very safe
How comfortable do you feel right now?	Very uncomfortable	Uncomfortable	Neither uncomfortable nor comfortable	Comfortable	Very Comfortable
How annoyed do you feel right now?	Very annoyed	Annoyed	Neither pleased nor annoyed	Pleased	Very pleased
How stressed do you feel right now?	Overwhelmed, unable to cope with current demands	Moderate stress, mildly struggling with demands	Neutral, manageable level of stress	Calm, with few stressors	Completely relaxed, free from stress, mentally at peace
How excited / engaged do you feel right now?	Bored, disinterested or apathetic	Mild disinterest, not engaged	Neither bored nor excited	Engaged, curious, and interested	Highly excited, deeply immersed in and enjoying current activities

Appendix IV – Post-VR Scenario Experience

Post-VR Scenario Experience

After each iVR experience, the mood and perception of the participant is asked with the help of the following questions. These answers help to identify the influence of every variant in greenery on the participants.

Post-VR Experience Survey Questions

Answer to the following statements about the simulation you just experienced:

	1	*2*	*3*	*4*	*5*
How safe do you feel now compared to before the experiment?	Very unsafe	Unsafe	Neither unsafe nor safe	Safe	Very safe
How comfortable do you feel now compared to before the experiment?	Very uncomfortable	Uncomfortable	Neither uncomfortable nor comfortable	Comfortable	Very Comfortable
How pleased do you feel now compared to before the experiment?	Very unpleased	Unpleased	Neither pleased nor unpleased	Pleased	Very pleased
How stressed do you feel now compared to before the experiment?	Overwhelmed, unable to cope	Moderate stress, mildly	Neutral, manageable level of stress	Calm, with few stressors	Completely relaxed, free from stress,

	with current demands	struggling with demands			mentally at peace
How excited and engaged do you feel now compared to before the experiment?	Bored, disinterested or apathetic	Mild disinterest, not engaged	Neither bored nor excited	Engaged, curious, and interested	Highly excited, deeply immersed in and enjoying current activities

1. Did this scenario help you better understand the KnoopXL project?
   - □ Not at all
   - □ Slightly
   - □ Moderately
   - □ Mostly
   - □ Completely
   - □ I'd rather not say

2. Did this scenario change your perspective on the KnoopXL project?
   - □ Not at all
   - □ Slightly
   - □ Moderately
   - □ Mostly
   - □ Completely
   - □ I'd rather not say

3. How often would you use this area if the KnoopXL was designed as in this iVR simulation?
   - □ Never
   - □ Rarely
   - □ Sometimes
   - □ Often
   - □ Always
   - □ I'd rather not say

4. Is this a place you would like to live (this surrounding area, greenery, traffic, city spot) if one of the buildings located in the area could include an apartment for you?
   - □ Not at all, this spot is nothing to live in for me.
   - □ Unlikely, I think there are better areas to live in.
   - □ Neutral, I could live here but it's not my first choice.
   - □ Likely, I like multiple aspects of this area.
   - □ Definitely, I enjoy this area completely.
   - □ I'd rather not say

Appendix V – Overall Experience Questionnaire

Post-Experiment Survey

After participants complete all iVR scenes, this survey will help capture their overall perceptions of how each attractiveness factor contributed to their experience.

Post-Experiment Survey Questions

Answer to the following statements about the entire simulations you just experienced:

	1	*2*	*3*	*4*	*5*
How safe did you feel during the simulations?	Very unsafe	Unsafe	Neither unsafe nor safe	Safe	Very safe
How comfortable did you feel during the simulations?	Very uncomfortable	Uncomfortable	Neither uncomfortable nor comfortable	Comfortable	Very Comfortable
How annoyed did you feel during the simulations?	Very annoyed	Annoyed	Neither pleased nor annoyed	Pleased	Very pleased
How stressed did you feel during the simulations?	Overwhelmed, unable to cope with current demands	Moderate stress, mildly struggling with demands	Neutral, manageable level of stress	Calm, with few stressors	Completely relaxed, free from stress, mentally at peace

How excited / engaged do you feel after these simulations?	Bored, disinterested, or apathetic	Mild disinterest, not engaged	Neither bored nor excited	Engaged, curious, and interested	Highly excited, deeply immersed in and enjoying current activities
How immersive did the simulations feel?	Not immersive at all	Not immersive	Neutral	Immersive	Very immersive

1. Do you live in or near a city similar to the one modeled in the iVR experience?
   - □ Not at all
   - □ Slightly similar
   - □ Somewhat similar
   - □ Mostly similar
   - □ Completely similar
   - □ I'd rather not say

2. Did you feel present in the virtual world? Why or why not?
   - □ Not at all
   - □ Slightly
   - □ Moderately
   - □ Mostly
   - □ Completely
   - □ I'd rather not say

3. Were there moments were you forgot it wasn't real?
   - □ Not at all
   - □ Rarely
   - □ Occasionally
   - □ Frequently
   - □ Always
   - □ I'd rather not say

4. Was it easy to navigate and interact with the environment?
   - □ Very difficult to navigate
   - □ Somewhat difficult
   - □ Neutral, neither easy nor difficult
   - □ Somewhat easy
   - □ Very easy to navigate
   - □ I'd rather not say

5. Did you experience any discomfort, such as dizziness or nausea?
   - □ Not at all
   - □ Slightly unpleasant, but no discomfort
   - □ Neutral, I didn't experience discomfort
   - □ I experienced mild discomfort
   - □ I experienced significant discomfort (e.g. dizziness, nausea)
   - □ I'd rather not say

6. Did your feelings change over time?
   - □ Not at all
   - □ Slightly
   - □ Moderately

□ Significantly
□ Completely
□ I'd rather not say

7. Was there anything that felt unrealistic or disconnected?
   □ Everything felt unrealistic or disconnected
   □ Mostly unrealistic or disconnected
   □ Some parts felt unrealistic or disconnected
   □ Mostly realistic and connected
   □ Everything felt completely realistic and connected
   □ I'd rather not say

8. Were the changes in your well-being fundamental to the changes in the greenery around you or were there different aspects involved?
   □ Completely due to factors other than greenery changes
   □ Mostly due to factors other than greenery changes
   □ Neutral, both greenery and other factors influenced well-being
   □ Mostly due to the greenery changes
   □ Completely due to the greenery changes
   □ I'd rather not say

Other factors besides greenery changes (if applicable):…….

9. What could be improved to enhance the experience?
   □ Many things could be improved
   □ A few things could be improved
   □ Neutral, neither good nor bad experience
   □ Very few things could be improved
   □ Nothing could be improved
   □ I'd rather not say

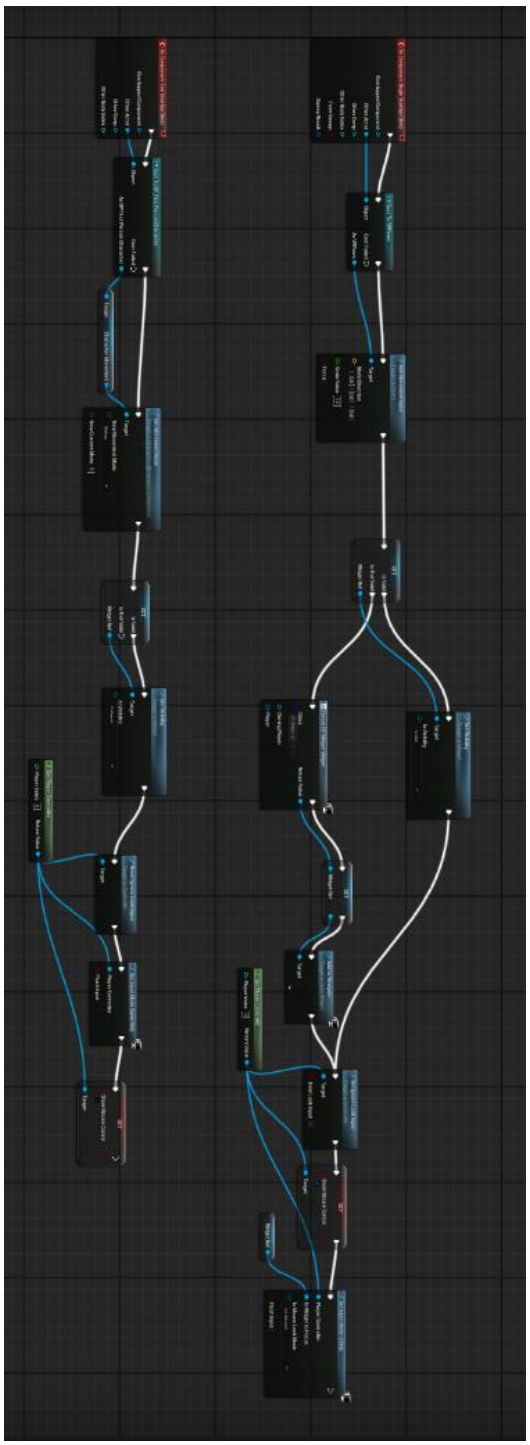
   Suggested improvements:

Appendix VI – Random variation and order of participant's to the models

PARTICIPANT	1	2	3	4
1	Model 1	Model 4	Model 5	Model 8
2	Model 6	Model 5	Model 1	Model 2
3	Model 7	Model 8	Model 1	Model 2
4	Model 7	Model 3	Model 5	Model 1
5	Model 6	Model 8	Model 1	Model 3
6	Model 3	Model 1	Model 4	Model 2
7	Model 6	Model 7	Model 4	Model 1
8	Model 5	Model 3	Model 2	Model 8
9	Model 7	Model 2	Model 6	Model 3
10	Model 5	Model 4	Model 2	Model 7
11	Model 6	Model 4	Model 2	Model 8
12	Model 3	Model 4	Model 5	Model 6
13	Model 8	Model 3	Model 4	Model 7
14	Model 5	Model 3	Model 6	Model 8
15	Model 8	Model 7	Model 3	Model 5
16	Model 5	Model 4	Model 7	Model 6
17	Model 8	Model 4	Model 7	Model 5
18	Model 6	Model 4	Model 8	Model 7
19	Model 8	Model 5	Model 7	Model 6
20	Model 1	Model 2	Model 7	Model 3
21	Model 8	Model 2	Model 1	Model 4

22	Model 3	Model 5	Model 6	Model 1
23	Model 6	Model 1	Model 4	Model 7
24	Model 5	Model 3	Model 6	Model 2
25	Model 5	Model 4	Model 7	Model 2
26	Model 6	Model 2	Model 4	Model 8
27	Model 8	Model 4	Model 5	Model 3
28	Model 6	Model 8	Model 3	Model 7
29	Model 4	Model 6	Model 7	Model 5
30	Model 2	Model 1	Model 8	Model 7
31	Model 1	Model 2	Model 3	Model 4
32	Model 2	Model 1	Model 7	Model 4
33	Model 3	Model 8	Model 1	Model 5
34	Model 4	Model 2	Model 8	Model 1
35	Model 1	Model 3	Model 6	Model 8
36	Model 2	Model 1	Model 7	Model 6
37	Model 5	Model 2	Model 4	Model 8
38	Model 3	Model 2	Model 1	Model 7
39	Model 6	Model 5	Model 2	Model 3
40	Model 3	Model 6	Model 5	Model 1

Appendix VII – Blueprint of the momentary subjective well-being questionnnaire used in iVR



Appendix VIII – Coefficients tables of panel regression momentary subjective well-being both models

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	3,590	,115		31,166	<,001
	ID=2.0	,370	,163	,103	2,271	,023
	ID=3.0	,340	,163	,095	2,087	,037
	ID=4.0	,740	,163	,207	4,543	<,001
	ID=5.0	,380	,163	,106	2,333	,020
	ID=6.0	,110	,163	,031	,675	,500
	ID=7.0	,690	,163	,193	4,236	<,001
	ID=8.0	,150	,163	,042	,921	,357
	ID=9.0	-,130	,163	-,036	-,798	,425
	ID=10.0	,090	,163	,025	,552	,581
	ID=11.0	-,150	,163	-,042	-,921	,357
	ID=12.0	,020	,163	,006	,123	,902
	ID=13.0	,080	,163	,022	,491	,624
	ID=14.0	,240	,163	,067	1,473	,141
	ID=15.0	,070	,163	,020	,430	,668
	ID=16.0	,040	,163	,011	,246	,806
	ID=17.0	-,260	,163	-,073	-1,596	,111
	ID=18.0	-,270	,163	-,075	-1,657	,098
	ID=19.0	-,110	,163	-,031	-,675	,500
	ID=20.0	,470	,163	,131	2,885	,004
	ID=21.0	,410	,163	,115	2,517	,012
	ID=22.0	,330	,163	,092	2,026	,043
	ID=23.0	,370	,163	,103	2,271	,023
	ID=24.0	,260	,163	,073	1,596	,111
	ID=25.0	,240	,163	,067	1,473	,141

	ID=26.0	,180	,163	,050	1,105	,270
	ID=27.0	-,160	,163	-,045	-,982	,326
	ID=28.0	,330	,163	,092	2,026	,043
	ID=29.0	,290	,163	,081	1,780	,075
	ID=30.0	,390	,163	,109	2,394	,017
	ID=31.0	,590	,163	,165	3,622	<,001
	ID=32.0	,440	,163	,123	2,701	,007
	ID=33.0	-,230	,163	-,064	-1,412	,158
	ID=34.0	,390	,163	,109	2,394	,017
	ID=35.0	1,876E-13	,163	,000	,000	1,000
	ID=36.0	,290	,163	,081	1,780	,075
	ID=37.0	,150	,163	,042	,921	,357
	ID=38.0	,310	,163	,087	1,903	,057
	ID=39.0	,200	,163	,056	1,228	,220
	ID=40.0	,320	,163	,089	1,964	,050

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
2	(Constant)	3,764	,153		24,559	<,001
	ID=2.0	,294	,163	,082	1,808	,071
	ID=3.0	,340	,161	,095	2,106	,036
	ID=4.0	,742	,163	,207	4,564	<,001
	ID=5.0	,380	,161	,106	2,353	,019
	ID=6.0	,126	,163	,035	,773	,440
	ID=7.0	,690	,161	,193	4,273	<,001
	ID=8.0	,150	,161	,042	,929	,353
	ID=9.0	-,130	,161	-,036	-,805	,421
	ID=10.0	,090	,161	,025	,557	,577
	ID=11.0	-,152	,163	-,043	-,936	,350
	ID=12.0	,020	,161	,006	,124	,901

ID=13.0	,156	,163	,044	,959	,338
ID=14.0	,232	,162	,065	1,435	,152
ID=15.0	,101	,162	,028	,624	,533
ID=16.0	,032	,162	,009	,199	,843
ID=17.0	-,230	,162	-,064	-1,418	,157
ID=18.0	-,241	,162	-,067	-1,484	,138
ID=19.0	-,126	,163	-,035	-,773	,440
ID=20.0	,479	,162	,134	2,956	,003
ID=21.0	,417	,162	,116	2,572	,010
ID=22.0	,293	,162	,082	1,809	,071
ID=23.0	,370	,161	,103	2,291	,022
ID=24.0	,222	,162	,062	1,372	,170
ID=25.0	,240	,161	,067	1,486	,138
ID=26.0	,178	,163	,050	1,093	,275
ID=27.0	-,122	,162	-,034	-,754	,451
ID=28.0	,360	,162	,101	2,222	,027
ID=29.0	,282	,162	,079	1,744	,082
ID=30.0	,390	,161	,109	2,415	,016
ID=31.0	,606	,163	,169	3,724	<,001
ID=32.0	,448	,162	,125	2,769	,006
ID=33.0	-,229	,162	-,064	-1,415	,157
ID=34.0	,397	,162	,111	2,448	,015
ID=35.0	1,891E-13	,161	,000	,000	1,000
ID=36.0	,252	,162	,070	1,558	,120
ID=37.0	,149	,162	,042	,920	,358
ID=38.0	,319	,162	,089	1,968	,049
ID=39.0	,162	,162	,045	1,002	,317
ID=40.0	,283	,162	,079	1,747	,081
Season	,031	,039	,028	,802	,423
Tree_Amount	,152	,038	,136	3,964	<,001

	Tree_Clustering	,004	,039	,004	,115	,909

Appendix IX – Coefficients tables of panel regression post-VR scenario well-being both models

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	2,500	,366		6,839	<,001
	pID_dummy_2	1,700	,517	,361	3,288	,001
	pID_dummy_3	1,050	,517	,223	2,031	,044
	pID_dummy_4	1,750	,517	,371	3,385	<,001
	pID_dummy_5	1,450	,517	,308	2,805	,006

pID_dummy_6	1,800	,517	,382	3,482	<,001
pID_dummy_7	1,700	,517	,361	3,288	,001
pID_dummy_8	1,300	,517	,276	2,514	,013
pID_dummy_9	,950	,517	,201	1,838	,069
pID_dummy_10	1,200	,517	,254	2,321	,022
pID_dummy_11	1,000	,517	,212	1,934	,055
pID_dummy_12	,750	,517	,159	1,451	,149
pID_dummy_13	,950	,517	,201	1,838	,069
pID_dummy_14	1,500	,517	,318	2,901	,004
pID_dummy_15	1,100	,517	,233	2,128	,035
pID_dummy_16	1,200	,517	,254	2,321	,022
pID_dummy_17	,900	,517	,191	1,741	,084
pID_dummy_18	,750	,517	,159	1,451	,149
pID_dummy_19	,750	,517	,159	1,451	,149
pID_dummy_20	1,400	,517	,297	2,708	,008
pID_dummy_21	1,600	,517	,339	3,095	,002
pID_dummy_22	1,350	,517	,286	2,611	,010
pID_dummy_23	1,400	,517	,297	2,708	,008
pID_dummy_24	1,450	,517	,308	2,805	,006
pID_dummy_25	1,450	,517	,308	2,805	,006
pID_dummy_26	1,350	,517	,286	2,611	,010
pID_dummy_27	,900	,517	,191	1,741	,084
pID_dummy_28	1,100	,517	,233	2,128	,035
pID_dummy_29	1,100	,517	,233	2,128	,035
pID_dummy_30	1,450	,517	,308	2,805	,006
pID_dummy_31	2,150	,517	,456	4,159	<,001
pID_dummy_32	1,400	,517	,297	2,708	,008
pID_dummy_33	,950	,517	,201	1,838	,069
pID_dummy_34	1,400	,517	,297	2,708	,008
pID_dummy_35	,650	,517	,138	1,257	,211
pID_dummy_36	1,400	,517	,297	2,708	,008

	pID_dummy_37	1,100	,517	,233	2,128	,035
	pID_dummy_38	1,300	,517	,276	2,514	,013
	pID_dummy_39	1,100	,517	,233	2,128	,035
	pID_dummy_40	1,150	,517	,244	2,224	,028

a. Dependent Variable: Cronbach_post_VR

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
2	(Constant)	3,381	,202		26,594	<,001
	pID_dummy_2	1,367	,215	,290	6,367	<,001
	pID_dummy_3	1,050	,213	,223	4,926	<,001
	pID_dummy_4	1,651	,215	,350	7,689	<,001
	pID_dummy_5	1,450	,213	,308	6,802	<,001
	pID_dummy_6	1,272	,215	,270	5,923	<,001
	pID_dummy_7	1,700	,213	,361	7,975	<,001
	pID_dummy_8	1,300	,213	,276	6,099	<,001
	pID_dummy_9	,950	,213	,201	4,457	<,001
	pID_dummy_10	1,200	,213	,254	5,629	<,001
	pID_dummy_11	1,099	,215	,233	5,119	<,001
	pID_dummy_12	,750	,213	,159	3,518	<,001
	pID_dummy_13	1,283	,215	,272	5,978	<,001
	pID_dummy_14	1,764	,214	,374	8,260	<,001
	pID_dummy_15	1,481	,214	,314	6,911	<,001
	pID_dummy_16	1,464	,214	,311	6,856	<,001
	pID_dummy_17	1,331	,214	,282	6,219	<,001
	pID_dummy_18	1,230	,214	,261	5,739	<,001
	pID_dummy_19	1,278	,215	,271	5,953	<,001
	pID_dummy_20	1,086	,214	,230	5,078	<,001
	pID_dummy_21	1,385	,214	,294	6,476	<,001
	pID_dummy_22	1,134	,214	,240	5,300	<,001

	pID_dummy_23	1,400	,213	,297	6,568	<,001
	pID_dummy_24	1,283	,214	,272	6,010	<,001
	pID_dummy_25	1,450	,213	,308	6,802	<,001
	pID_dummy_26	1,449	,215	,307	6,749	<,001
	pID_dummy_27	1,067	,214	,226	4,995	<,001
	pID_dummy_28	1,531	,214	,325	7,154	<,001
	pID_dummy_29	1,364	,214	,289	6,387	<,001
	pID_dummy_30	1,450	,213	,308	6,802	<,001
	pID_dummy_31	1,622	,215	,344	7,553	<,001
	pID_dummy_32	1,136	,214	,241	5,319	<,001
	pID_dummy_33	,900	,214	,191	4,217	<,001
	pID_dummy_34	1,185	,214	,251	5,541	<,001
	pID_dummy_35	,650	,213	,138	3,049	,003
	pID_dummy_36	1,233	,214	,262	5,776	<,001
	pID_dummy_37	1,150	,214	,244	5,383	<,001
	pID_dummy_38	,986	,214	,209	4,611	<,001
	pID_dummy_39	,933	,214	,198	4,371	<,001
	pID_dummy_40	,934	,214	,198	4,365	<,001
	Season	-1,056	,052	-,717	-20,424	<,001
	Tree_Amount	-,666	,051	-,453	-13,163	<,001
	Tree_Clustering	-,198	,051	-,135	-3,859	<,001

a. Dependent Variable: Cronbach_post_VR