Solid walls in urban environments and their effect on women's perceived safety in virtual reality

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Abstract

Women's perceived safety in urban environments are impacted by the streets' urban design. One design intervention that increases people's perception of safety is the presence of windows (Navarrete Hernandes, 2021). Navarrete-Hernandes' study was conducted by showing men and women pictures of different streets with and without solid walls and grading their safety. In our study, we tested women's perceived safety of solid walls in a virtual reality (VR). Six different street environments were created and evaluated with a within-subject experiment. The women had to make a choice between two streets in regards to perception of safety; one street with solid walls and one with windowed walls. Aspects changed between the scenes were the amount of cars, greenery and height of buildings. The results indicate that solid walls have an impact on women's perceived safety in urban environments. However, methodological flaws may have influenced the results, making them uncertain.

Keywords

Perceived Safety; VR; Urban Design; Solid Walls

1. Introduction

Perceived safety in public areas has been a major point of interest as it may have many positive effects on its citizens (Anderson et. al., 2017). Anderson explains that the use of public space helps to build a sense of community by facilitating encounters and shared interactions, and promotes mental and physical health. However, these benefits are not equally shared among the different social groups of a society, where groups to different extents are explicitly excluded from public space due to factors such as gender, age or ethnicity (Cattell et. al., 2007).

Literature shows that the designing and planning of public space do not take into account women's experiences in public spaces (Burgess, 2008). Cavanagh (1998) even presents arguments that women and their concern for their personal safety shapes their lives and "largely determine when and where women will go".

One safety intervention in public space that has an impact on women's perceived safety is visibility. A theory by Jane Jacobs suggests that adding more "eyes on the street", i.e. windows and doors, serves as witnesses which can increase the

perception of safety and even reduce crime (Jacobs, 1993). This was confirmed by a Navarrete-Hernandez (2021), showing that women would perceive streets with windows as more safe compared to streets with solid walls. However, as this study used manipulated photographs as stimuli to the participants, an opportunity to a similar study but with a more immersive stimuli such as VR arises. Virtual Reality (VR) may provide a higher level of immersion and presence compared to traditional methods (Schrom-Feiertag et. al., 2020), thus leading to a different result or perhaps a more decisive one.

In this study, we aim to investigate whether VR can be an alternative to more traditional evaluation methods by studying women's perception of safety. We will examine whether streets with solid walls compared to streets with windowed walls have an effect on women's perceived safety in VR. Our scientific question is phrased as follows:

Do solid walls have an effect on women's perceived safety in an urban environment experienced in virtual reality?

Our hypothesis is that solid walls will have a negative effect on women's perceived safety and therefore the streets with windowed walls will be preferred more frequently. This hypothesis is based on the results of Navarrete-Hernandez's (2021) study.

1.1 Limitations

Only female university students in the age of 20-26 will be considered in this study. Cultural differences of the perception of safety will not be explored or taken into consideration. The study only focuses on comparing safety in urban environments, not rating the environments in terms of safety themselves.

2. Background

In this section previous research on the perceived safety in urban environments and how it differs between genders are presented in 2.1, followed by how visibility can affect safety in 2.2. Lastly, VR and its potential in urban designing is presented in 2.3.

2.1 Perceived safety in public spaces

Perceived safety in public areas differ between men and women, with women feeling less safe partly due to social and physical vulnerability (Navarrete-Hernandez, 2021). The study claims that women more often than men avoid walking in e.g. poorly lit or isolated spaces and that their movement is formed from fear of violence. Furthermore, Navarrete-Hernandez explains that urban planning is generally designed for a daily schedule of "home-work-home" which favors men since women are overrepresented in part-time work resulting in more complex travelling patterns. Having a gender perspective approach when planning urban environments can better women's perceived safety in urban environments. This can strengthen social inclusion, reinforce feelings of belonging and improve mental health (Anderson et. al., 2017).

2.2 Visibility in public spaces

Visibility in public spaces is a frequently used strategy to promote safety. Reducing solid walls and designing for the informal surveillance of "eyes on the street" (Jacobs,

1993) by e.g. strategic placement of doors and windows builds safer urban environments for women. Navarrete-Hernandez et al. provides results showing that removing solid walls greatly increases women's perception of safety. In their study, photostimuli were used where the participants would rate different pictures with solid walls and pictures with windows respectively (see figure 1), where the pictures with windowed walls were perceived as feeling more safe. However, there are other methods available to investigate perception of safety that are more immersive compared to photographs, such as VR (Schrom-Feiertag et. al., 2020).

Figure 1: Photos used in Navarrete-Hernandez et al. study to investigate perception of safety in streets with windows or streets with no windows.

2.3 Urban design and VR

Urban design is the process of shaping a city, district or a public space and connecting it with people or nature. In the past decades, citizens participating in urban design has become more important and is considered one of the key factors in making successful urban design and development projects (Faliu, 2019). Faliu further describes how an extensive amount of different methodologies and toolkits have been developed lately which can be used for urban design projects. One of these methodologies is Virtual Reality (VR), which can provide a higher level of immersion and presence compared to traditional methods (Schrom-Feiertag et. al., 2020). Schrom-Feiertag explains that this completely changes participation as citizens no longer look passively at a screen or other digital content but now become immersed in a virtual world which people can interact and feel connected to. As such, VR can be used to simulate urban settings, providing interactive environments for citizens to evaluate designs.

3. Method

The perceived safety of streets with windowed walls compared to streets with solid walls was examined using a within-subject experiment. This was done in order to gather as much data as possible from each participant. In the experiment, each participant was presented with different intersections in virtual reality, and asked which street they would prefer to take in terms of safety. The intersections consisted of two streets, one to the right and one to the left (see figure 2). The innermost wall on each street (Wall #1 and Wall #2) worked as the examined stimulus and one of them had windows while the other one was a solid wall. Apart from the stimulus the two streets were made to look identical in order to minimise the risk that

other factors could affect the participant's perceived safety.

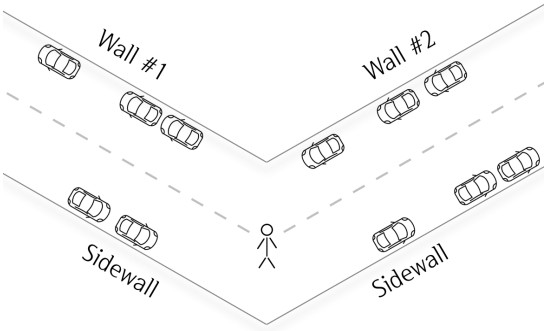

Figure 2: Birdseye view sketch of the intersection, showing the setup of the experiment.

3.1 Scenes

The experiment consisted of six different scenes that were shown to the participant one at a time, each scene containing one intersection. The scenes were created in *Unity 3D* and were inspired by Navarrete-Hernandez photographic simulation (see figure 1). To create the scenes, we used pre-existing assets from *UrbanEyes*, an urban walkthrough project created by KTH-students provided by our supervisor, as well as assets from the *Unity Asset Store*. The plugin *SteamVR* was used to implement VR in the Unity project. The six intersections varied in appearance based on four different variables; the direction of the street containing the solid wall, the height of the building, how much greenery there was on the streets and how many cars were parked along it (see figure 3). The sidewalls (see figure 2) remained the same throughout the scenes.

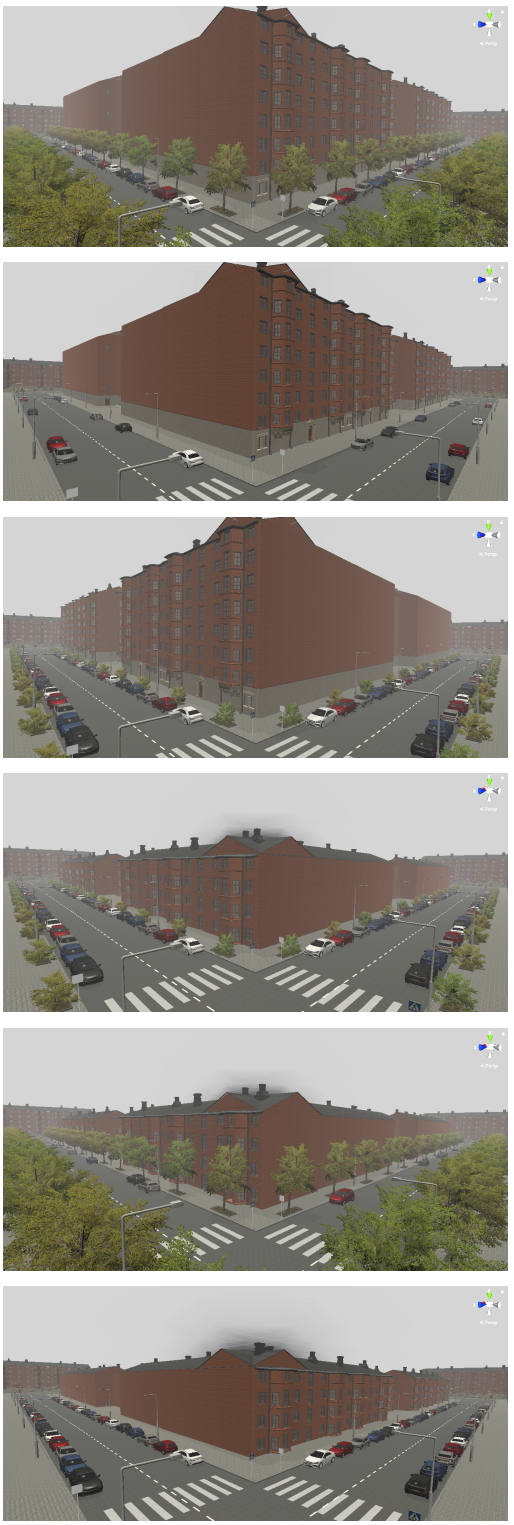

Figure 3: Scene 1-6, in descending order.

The buildings were either four or seven stories tall. The sidewalks either had no greenery, trees or bushes and the streets either had few cars parked on it or were full of cars. Each scene is described in table 1

Scene	Solid wall	Building	Greenery	Cars
1	Left	Tall	Trees	Many
2	Left	Tall	No	Few
3	Right	Tall	Bushes	Many
4	Right	Short	Bushes	Many
5	Right	Short	Trees	Few
6	Left	Short	No	Many

Table 1: The six different scenes and what they contain

3.2 Setup of the experiment

Prior to the study, all participants signed a consent form agreeing for their data to be used. The participants were presented each of the six scenes in a manually randomised order to prevent ordering effects. The experiment was done using a HTC Vive Pro 2.0 headset. They were instructed that both streets lead to the same place and were asked to choose their preferred street in regards to perceived safety while thinking out loud. When each scene started the participant was placed as if they would be walking on the street towards an intersection. To avoid ordering effects they were placed so that they initially faced the corner of the intersection so that equal parts of the street with the solid wall and the street with windowed walls would be visible. They were able to move around partly in the environment using the 4x4 meter empty room that the experiment took place in to explore details closer and perceive a feel of realism of walking on the streets. While keeping their VR headset on the participants were asked to state which street they would pick. After choosing, the participant was presented the next scene and the procedure was repeated until all six intersections had been evaluated. When all six scenes had been shown the participant removed the VR headset and an interview was conducted (see Appendix 1). During the interview the participants were presented a picture of all the scenes printed on paper together with an arrow showing the direction chosen by the participant for each one. They then had to answer questions regarding their choices and what they based their choices on for each scene. The participants were also asked if they noticed any differences in their reasoning depending on which scene they were shown.

In order to minimise other factors that may interfere with the results the participants all received the same set of instructions, all did the test in the same room and used the same equipment.

3.3 Pilot study

A pilot study was conducted prior to the real testing. Here the participant was asked questions between each scene, but this made the participant look for patterns and “correct answers” which we wanted to avoid. Therefore, in the final setup of the experiment we decided to instruct the participants to think aloud while making their choices and conduct the interview afterwards using printouts of each scene and arrows to mark their decisions.

3.4 Subjects

The participants were ten female university students at KTH Royal Institute of Technology between the ages of 20-26 (average of 22.9). All participants lived in Stockholm.

4. Results

In this section we will present the total amount of preferred directions, the choices for each scene individually and the qualitative data obtained from the interview.

4.1 Empirical results

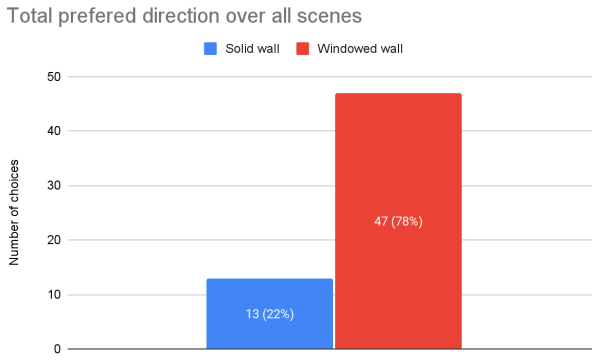

Figure 4: prefered direction over all scenes.

The participants made six choices each, resulting in a total of 60 choices. As seen in figure 4, the direction with the windowed wall was chosen 47 (78%) times, and the direction with a solid wall was chosen 13 (22%) times.

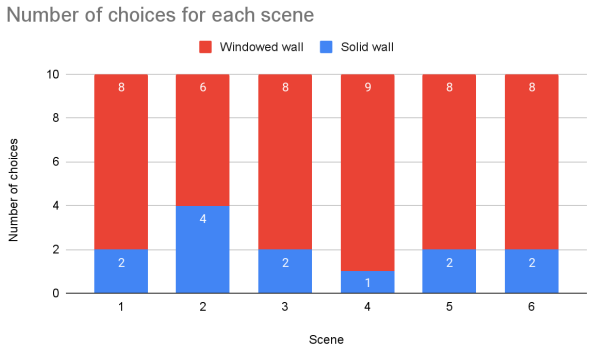

Figure 5: number of choices for each scene.

Scene 1, 3, 5 and 6 had the windowed wall chosen eight times. In scene 2 the windowed wall was chosen six times, and scene 4 had the windowed street chosen nine times.

4.1.1 Analysis of empirical results

A total of seven chi-squared tests were done in order to investigate whether the participants' choices for streets with solid vs windowed walls showed statistical significance. The first of the seven tests were for the total choices across all scenes, and the rest of the tests were for each scene individually. The null hypothesis H_0 was stated as "proportion of choices for solid vs non-solid walls will be the same", and H_1 as "proportion of choices for solid versus windowed walls will not be the same". The tests were done with an alpha level of 0.05 and with a degree of freedom of 1.

The results of the tests can be seen in table 2. For the total prefered directions over all scenes, the result from the chi-square test was 0.000011 which is < 0.05, thus rejecting the null hypothesis H_0 and accepting H_1. This shows that the participants' preferred direction of streets with windowed walls are therefore statistically significant. For the individual scenes, only scene 4 showed statistical significance as $p = 0.012$. The rest of the scenes showed no statistical significance (see table 2).

Chi-square tests	Result
All scenes	0.00001
Scene 1	0.058
Scene 2	0.053
Scene 3	0.058
Scene 4	0.012
Scene 5	0.058
Scene 6	0.058

Table 2: Table of all the chi-tests done for the results

4.3 Qualitative results

4.3.1 Solid walls

Eight of the participants did not mention the lack of windows on one of the walls for the *first* scene that they were presented. They expressed that they thought the streets looked very similar and that it was hard to choose, resulting in half of these choosing the street with the solid wall. However, when the second scene was presented, 9 out of 10 participants chose the street with windows, with six of them explicitly mentioning that the decision was based on which wall had windows.

After all scenes had been presented, one of the participants had not mentioned nor detected the solid walls throughout the whole experiment. The other nine said that they based their decision making on the walls and that the windows made them feel more safe since people could see them. Six of the participants said that the first corner was the hardest to make a decision on since they could not spot any differences. Two of these expressed that all scenes from scene two and onwards were easy to make a decision on since they had detected the difference by then.

4.3.2 Greenery

The participants had different opinions regarding the greenery of the scenes. Four of the participants answered that it was easier to make their decision in the scenes that did not have greenery, since this made it clear which street lacked windows. Four others expressed that the trees and bushes made them feel more safe since it made the neighbourhood feel more taken care of. Two others said that the greenery concealed their sight and that they were unaware if people could be lurking behind the bushes, affecting their perception of safety negatively.

4.3.3 Cars

The lack of cars or direction of them were mentioned by some participants. Two participants mentioned that they preferred if there were more cars since this indicated that people were home. Meanwhile, two others prefered the opposite, with one arguing that more cars was threatening and increased the possibility of someone dragging her into a car. One participant mentioned that she prefered to walk facing the opposite direction of the parked cars so that she could see if someone was inside the vehicle, while another wanted to stay unaware of this and therefore wanted to walk in the same direction as the parked cars.

4.3.4 Area and buildings

Some of the participants' pointed out that the height of the buildings affected their choices of path. High walls on the path solid-walls made the environment feel like an industrial area according to two

participants, which made it feel less safe. Additionally, two participants thought it felt like the high walls made the area feel cramped and intrusive. One participant mentioned that the placement of the windows in the lower buildings made it feel like they are more easily seen, which made it feel safer. Some participants brought up that the lower buildings with low placed windows made the path feel more like a residential area, making it feel safer.

4.3.5 Own experiences

Regarding the participants' perception of safety when walking alone in the real world, all except one answered that they experience feeling unsafe. The participant that did not feel unsafe said that it was because she knew that someone always knew where she was. Seven of these said that it was mainly at night time when it was dark. When walking alone, the majority of the participants said that they prefered large, trafficked and uplit roads with lots of people, in city centres or well inhabited areas. However, some participants mentioned that drunk or suspicious people could make the experience very uncomfortable. A few also mentioned that they would never walk alone in a forest or take a shortcut through a trail, as that would feel unsafe.

5. Discussion

In this section we discuss the empirical and qualitative data to draw conclusions about women's percepted safety in urban environments. Criticism of our methods and future development for studies within the field is also raised.

5.1 Women's perception of safety

Our analysis of the empirical results indicates that our hypothesis was correct; solid walls tend to have a negative effect on women's perceived safety. This is in line with the results from Navarrete-Hernandez (2021), further strengthening the evidence for the phenomenon.

Furthermore, when answering our first interview question regarding what they based their answers on, nine out of the ten participants mentioned the windows. One partic said "The total windowless wall. I felt safer if there were windows so that someone could see me if I were to be attacked or similar. If you see that the light is on in someone's home then I would rather walk there." Similar comments were made that when windows exist, there is a chance for someone to be inside to witness or help out in other ways. This indicates that the presence of windows does have an affect on women's perceived safety. However, how much it affects and to what extent is difficult to conclude.

5.1.1 Detecting patterns

During the experiment, most participants said that the two streets in their first presented scene looked identical, making their choice based on gut feeling or without motivation. After scene number two and three, all participants except for one commented on the windows and that this was changing through the different scenes. It is difficult to know if their answers after discovering the solid wall affected their answers or if the streets with windows really made the participants feel safer.

When asked if there were any scenes where it was easier to make a decision, one

participant answered “Scene 3 and 6 because there were no trees so it was easy to see where there were no windows”. Three other participants had similar comments on the topic. Another participant commented during the first presented scene that they observed the solid wall but that this would not make a difference for them. In the interview conducted right afterwards she said that the height of the buildings together with the solid walls gave an industrial and abandoned feeling which could indicate that she did not appreciate these streets. Whether these participants answered from what made them feel safer , or what they believed the study wanted them to answer because they had detected the pattern of the scenes, is difficult to draw conclusions regarding.

5.1.2 Perception of safety in different environments

It is hard to say whether greenery made the area feel more or less safe, as both views were represented by the participants. Previous studies have highlighted that greenery that obstructs the view may make women feel unsafe (Jiang, 2017). This was also mentioned in our study by two of the participants. However, four participants thought that the greenery made the area feel more taken care of, and therefore more safe. Because of this, it was hard to draw any conclusion about a clear threshold of what is considered *too much* greenery, as it seems to be individual.

Something that was mentioned by four participants was that the lack of greenery made it more obvious that some of the walls were solid. According to the participants, this made it easier to make a decision of choosing the windowed wall since it was easier to detect whether the walls were solid or not. However, even though this sounds reasonable, it does not correlate well with the results. Scene two, the scene with no trees and tall buildings, were in fact the most frequently chosen solid-wall of all scenes. Therefore, it is difficult to draw conclusions on the participants' perception of greenery as their words didn’t match their actions.

5.1.3 Measuring perception with virtual reality

It is debatable whether the use of virtual reality is better than relying on photos as a tool for measuring perception in urban environments. As there are many senses contributing to people's perception, one could argue that using VR would be beneficial as it provides a more immersive experience and is therefore more accurate. However, the 3D rendered scenes in VR are so far not able to be produced to look very realistic compared to a manipulated photo of a real urban environment, due to limitations in computational power. Furthermore, time consumption plays a large part in testing the environment. As a detailed and realistic looking VR scene can require extensive amounts of work and expensive assets, photo stimuli is probably a more efficient and affordable way of testing. Therefore, the best tool of measurement could differ depending on the amount of details being measured in the experiment. For simple changes of urban design, photo stimuli may be adequate, while for high fidelity testing, VR may be a more suitable alternative.

5.2 Methodological critique

5.2.1 Direction of cars

The streets of each scene were created identical in order to minimize the effect of

surrounding stimuli. Our cars were always parked according to traffic direction, which resulted in the streets being not entirely identical. This turned out to have a big effect on some of the participants. One participant preferred walking by the cars directed towards her so she would know if the cars were empty or not while another preferred the opposite as she wanted to remain unknown of others presence. This made it hard to draw conclusions on the cars' presence and in order to evaluate their effect we could instead have switched their directions in some scenes or change so that the side walls also were solid sometimes.

5.2.2 Deficient pilot study

No pilot study was conducted after the change of asking all interview questions after the test. This was due to lack of time which resulted in mistakes that could have been avoided.

The printouts showed the street from the point of view that the participant initially was placed. We mostly wanted to record if they picked solid or windowed walls and to use the pictures as aid for the interview when they had removed the VR-headset. Due to the printouts being from the initial point of view, they were quite zoomed in and didn't show much of the street environment, which was troublesome since the amount of cars were not shown. Some participants that based their choices on the cars therefore had trouble recalling why they made their choices which easily could have been avoided if the pictures showed more of the street environment.

5.2.3 Use of VR equipment

Some participants were not used to using VR equipment and therefore we first let them try out a scene with a different setting to introduce them to the wearing the headset and show the VR grid. However, when presented with the intersections, the majority remained still and some started talking about their VR experience which was unrelated to the study. Perhaps the first presented scene could have been a test scene where we didn't collect data to give the participants a feel of what the upcoming scenes would look and feel like.

Discussions on whether the participants should be able to teleport themselves down the streets using remote hand controls emerged when designing our environment. A decision was made to not implement this since it may have taken focus away from observing the sight. However, this would have given the participants an opportunity to see more of the street and receive a better feeling of walking on each street rather than looking at the two. The placement of the participants was, as previously mentioned, made to reduce ordering effects but this made the sighting obscured which could have been avoided if teleportation was implemented.

5.2.4 Interviews

Our decision to ask the questions after all choices were made may have impacted the results and should also have been tested beforehand. As the participants were interviewed and shown their choices at the end of the test, there could be eventual mismatches in memory versus what they experienced in each scene. However, our interview questions were focused around finding a pattern in the scenes. By interviewing the participants after each scene, the participants could have been incited to find a pattern rather than to choose based on their instinct. Therefore

we still chose to do the interviews after all of the scenes.

5.3 Future work

The study showed that windowed walls made women feel more safe, however, certain places do not allow many windows for different reasons. Therefore the threshold of the amount of windows on a wall needed in order to feel safe could be interesting to measure.

When using VR you have the possibility to put people right into vastly different situations. In this project we used a neutral weather and light setting to only focus on the design of the streets. Dark conditions were expressed by participants as being the situation where they feel the most vulnerable which therefore could be studied further. With a dark setting, the participants would be placed in a more real life situation where they tend to feel unsafe which could give new perspectives on the greenery, cars, height of buildings and lack of windows since all of these would have an effect on light and eyesight conditions.

Furthermore, the use of virtual reality to measure perception is mainly based on the assumption that the immersive experience may contribute to more realistic results. In order to make the experiment more immersive and realistic, other aspects such as ambient noise, dirt, trash, better textures and 3D models, lights in some of the windows or a few people walking could have influenced the resultss.

6. Conclusion

The empirical data indicated that our hypothesis was correct. As with previous studies in the field of perception of safety (Navarrete-Hernandez, 2021), solid walls tend to have a negative effect on women's perceived safety. However, the qualitative data suggests that our results could be based on pattern recognition, and therefore it is difficult to draw conclusions about the validity of the empirical data. Furthermore, our study indicated that other stimuli such as cars, greenery and height of buildings may have both positive and negative impact on the perceived safety. Due to scattered results and personal preferences of the participants, conclusions can not be drawn from this study, but may be relevant to examine in future research. Lastly, VR should be considered a useful tool for testing urban designs in future studies.

7. Acknowledgements

We would like to thank our supervisor Christopher Peters for his useful support and advice. We would also like to thank the VIC studio at KTH and their employees for lending us their VR equipment and answering our questions.

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Image source

Figure 1: Navarrete-Hernandez, P, Vetro, A & Concha, P. (2021). “Building safer public spaces: Exploring gender difference in the perception of safety in public space through urban design interventions”. Landscape and Urban Planning, Volume 214, 2021, 104180, ISSN 0169-2046, https://doi.org/10.1016/j.landurbplan.2021.104180.

Appendix 1

Interview questions

1. How did you experience each corner?
2. Did you see any patterns regarding your choices?
3. Was there any particular corner that felt more safe?
4. Was there any particular corner that felt more unsafe?
5. Was there any corner where it was hard to make a choice?
6. Was there any corner where it was easier to make a choice?
7. Do you ever feel unsafe while walking alone?
8. What type of street or attributes on streets would you prefer when walking alone?